Community Assessment of Zooplankton, Larval Gizzard Shad, Productivity, and Physicochemical Attributes in Harlan County Reservoir

Job No. 1 Document spatial and temporal changes in zooplankton, larval gizzard shad, chlorophyll *a*, and physicochemical parameters in Harlan County Reservoir between April and October.

Five-Year Segment Performance Report

Project No. F-160-R

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Job 1 Objective

Document spatial and temporal changes in zooplankton, larval gizzard shad, chlorophyll *a* and physicochemical parameters in Harlan County Reservoir between April and October.

Introduction

The U.S. Army Corps of Engineers constructed Harlan County Reservoir between 1947 and 1952. At conservation pool (1946msl) this reservoir covers more than 5,200 ha. The primary purpose for constructing Harlan County Reservoir was flood control, but it is also operated for irrigation. Irrigation withdrawals from the reservoir often exceed 10 vertical feet each year and reservoir filling is dependent on Republican River inflows.

Reservoirs typically have larger watershed to surface area ratios than lakes, which leads to high but irregularly pulsed nutrient and sediment inputs (Wetzel 1990). Also, typical of reservoirs are higher turbidity and greater water-level fluctuations, which lead to reduced macrophytes compared to natural lakes (Wetzel 1990). Consequently most of the primary production in reservoirs comes from phytoplankton (Kimmel et al. 1990). Operations of irrigation reservoirs represent the extreme usage of these systems and thus may be more prone to variable physical, chemical and biotic communities, which potentially can impact fish recruitment, growth and survival.

Nebraska Game and Parks Commission (NGPC) is responsible for fisheries management of Harlan County Reservoir. The fish community in this reservoir has undergone some dramatic changes in the past 20 years. Results from standardized surveys indicate a 653% increase in gizzard shad (*Dorosoma cepedianum*) captured per gill net night during 1994-2001 as compared with surveys conducted from 1980-1991. During the same timeframe gill net captures of walleye (*Stizostedion vitreum*) have decreased 36%. Surveys conducted in 2002-2005 have shown a reversal of this trend as gizzard shad numbers decreased over 550%, but during 2008, catch rates have again increased 800%. During this same timeframe walleye catch rates continue to decline.

The recent increase in gizzard shad at Harlan County Reservoir may indirectly or directly be linked to diminishing walleye recruitment. Stein et al. (1995) proposed that gizzard shad are capable of regulating the food-web in reservoir communities. In part this is possible because of their high fecundity (Bodola 1966; Parrish and Vondracek 1989) and ability to utilize multiple trophic levels (Kutkuhn 1957; Drenner et al. 1986; Mundahl 1988). Gizzard shad are quite capable of producing large year-classes that can create strong predation pressure on zooplankton (Todd and Willis 1985; DeVries and Stein 1992), which is an important food item in the diets of young-of-the-year walleyes (Smith and Pycha 1960; Li and Mathias 1982; Thomas 1989). Any alteration in the abundance or impacts to the productivity of this system may be detrimental to the development of these young walleye. Benthic macroinvertebrates are also a seasonally important prey item for walleye in Harlan County Reservoir (Olson et al. 2007).

In addition to recent changes in the biotic community a variety of abiotic factors may be influencing walleye recruitment. A high correlation between recruitment success and water

temperature has been documented in several systems (Koonce et al. 1977; Serns 1982; Hansen et al. 1988; Quist 2002). Quist (2002) suggested that a combination of abiotic and biotic factors most likely was responsible for the highly variable walleye recruitment observed in Kansas reservoirs.

The ability of NGPC staff to determine what factors have caused the recent decrease in walleye recruitment and explosion of gizzard shad is hampered by lack of specific knowledge concerning Harlan County Reservoir. An accumulation of baseline data surrounding the lower trophic levels and documentation of several key physicochemical attributes would greatly enhance our understanding and predictive capabilities in these systems. The objective of this study is to document spatial and temporal changes in zooplankton, larval gizzard shad, chlorophyll *a* and physicochemical parameters in Harlan County Reservoir between April and October.

Procedures

Harlan County Reservoir was divided into three separate zones with 5 sampling stations in each zone for zooplankton and water quality sampling. Twenty-four stations (including the 15 water quality stations) were established for larval gizzard shad sampling conducted weekly in June and July, and an additional twenty four stations for one sampling in early June (Figure 1). Data from each zone was treated separately, unless no significant differences in results were found between zones. In that case data was pooled to increase sample size for statistical comparisons.

Zooplankton samples were collected semi-weekly in April – May and August – October and weekly in June – July. Zooplankton were collected with an 80-μm Wisconsin plankton net (0.5 m^2 opening) towed vertically from the substrate to the surface and preserved in sucrose and 4% formalin to prevent osmotic distortion (Haney and Hall 1973). During analysis, each sample was diluted to a known volume and stirred to assume homogeneity. A 1-mL aliquot was removed separately from each sample with a Hensen-Stempel pipette and placed in a Ward counting wheel. All zooplankton were identified to lowest possible taxon under a compound microscope and counted by taxon group. This procedure was repeated four times for each sample and the results averaged. When possible at least 25 zooplankton of each taxa were measured to the nearest 0.1 mm for the 15 water quality stations.

Larval gizzard shad were collected weekly in late May – July for each year in this segment. Samples were collected by pushing two plankton nets for 5 minutes at a speed of 0.5 m/s (similar to Sammons et al. 2001). Each plankton net was circular with the larger net having a diameter of 1.0 m (1.8 mm mesh) and the smaller net having a diameter of 0.5 m (0.75 mm mesh). Flow meters were placed at the mouth of each net to determine total cubic meters of water sampled. Weekly samples were collected from 24 sampling stations per zone and one sampling period incorporated a more intense 48 sampling stations. Collected fish were preserved in 70% ethyl alcohol and returned to lab for identification to lowest possible taxon, counted and measured.

Assessment of chlorophyll *a* occurred semi-weekly during April – May and August – November and weekly in June – July, in conjunction with the collection of Secchi disk readings and turbidity samples. Integrated water column samples for chlorophyll *a* and turbidity was taken by collecting water samples every 3m starting at 1m with a Van Dorn bottle sampler. All water

samples from each site were pooled in a bucket and stirred to assume homogeneity. A random sample was collected and processed with an Aquafluor(tm) Handheld Fluorometer and Turbidimeter. Digital readings were recorded on-site.

Temperature and dissolved oxygen was collected semi-weekly from April – May and August – October and weekly in June – July with a YSI meter for each meter of the water column. Digital readings were recorded on site.

Descriptive statistics in Excel was used to provide means and 95% confidence intervals. Statistical comparisons were assessed with a one-way ANOVA. Significance was set at $p \leq 0.05$. No procedures were taken to correct for multiple comparisons. Specific methods for ancillary study components reported within this report can be found in the methods sections of Olds (2007), Maline (2008), and Sullivan (In review).

Results

Nine genera of zooplankton were identified in Harlan County Reservoir from 2002 to 2009 (Table 1). Mean lengths of zooplankton taxa were consistent among years (Table 2). Spatial distribution of zooplankton collected 1 m subsurface did not differ between littoral and pelagic areas in Harlan County Reservoir (Table 3). Similarly, zooplankton density was not significantly different among the three zones of the reservoir due to high sampling variability (Table 4). The greatest zooplankton density was in Zone 3 during June (Table 4). Interestingly, during June and July, there was an increase in the number of zooplankton from east to west across the reservoir (Table 4). Zone 1 (closest to the dam) had the lowest density with Zone 2 being slightly higher and Zone 3 having the highest zooplankton density. Density of zooplankton in April and May was examined by station to provide an indication of spatial heterogeneity. Density of zooplankton varied by sampling station (creating the high variability seen among zones) and distinct patterns persisted in distribution as displayed in the data from April 16, 2007 (Figure 2).

Fish species identified in push net samples from 2002 to 2009 included larval: gizzard shad, freshwater drum (*Aplodinotus grunniens*), white bass (*Morone chrysops*), common carp (*Cyprinus carpio*), channel catfish (*Ictalurus punctatus*), bluegill (*Lepomis macrochirus*), and adult shiners spp. (*Notropis spp.*). The highest densities of larval shad were observed in 2005 and 2006 (Table 5). Several factors could have accounted for these observations including abundant forage, fluctuating water levels between years, or other abiotic and biotic factors. Larval gizzard shad prey on zooplankton when they are abundant (Yako et al. 1996), and high zooplankton densities have been linked to better survival of larval gizzard shad in many systems (Dettmers and Stein 1996; Michaletz, 1997). Because total zooplankton were most abundant in 2005 and 2006 (Table 5), it is possible that this led to better survival and therefore higher densities of larval shad in the same years.

Another factor which could explain the differences in shad abundance is the persistent drought which caused reservoir water levels to be near 40% of full pool in 2005 and 2006. Above average precipitation raised water levels to near full capacity in 2007-2009. It is possible that gizzard shad had dispersed throughout the reservoir in recent years, and the greater area occupied (due to greater reservoir water volume) reduced the overall density of larval gizzard shad.

Equally plausible is the possibility that high densities of shad were located in the extreme upper west end of the reservoir in 2007-2009, an area which was not sampled during this study. To replicate stations across all years, sample locations did not change when the reservoir area expanded, and this led to areas in the west end which were not investigated.

Gizzard shad can become highly abundant in many systems and reduce zooplankton populations through predation. Although research exists on shad food habits in some systems, results have been mixed. Therefore, gizzard shad food habits were investigated weekly from June through October at three stations in Harlan County Reservoir during 2008-2009. Gizzard shad were dissected, and all stomach contents were identified, measured, and enumerated. Gizzard shad < 30 mm showed significant positive correlation between total length and the number and size of zooplankton consumed (Figure 3 and 4). As in other studies, gizzard shad > 30 mm consumed few zooplankton (Figure 5). Prey electivity varied between years and by size class (Figure 6). Small shad (0-14 mm) preferred cyclopoid copepods in 2008 and nauplii in 2009, and selected against calanoid copepods in both years (Figure 6). Medium shad (15-30 mm) showed positive electivity for cyclopoid copepods in 2008 and 2009, positive selection for *Daphnia* spp. in 2008, but negative selection in 2009. From these results, gizzard shad consume zooplankton as larvae; however, the low densities of shad in Harlan Reservoir during this study likely have little impact on zooplankton populations. This is important because unlike other systems where shad have been shown to significantly reduce zooplankton, shad in Harlan County Reservoir have not produced this effect. This allows them to act as forage, while posing a minimal threat to the survival of sport fish during the larval stage through competition.

Gizzard shad consume zooplankton during the larval stage and have the potential to reduce zooplankton populations. Describing the spatial relationship between gizzard shad and zooplankton is important for understanding the interactions between these species. Conventional and geostatistical analysis techniques provide a means of evaluating these relationships. Gizzard shad and zooplankton communities were sampled weekly for 8 weeks in June and July at 24 stations in Harlan County Reservoir from 2005-2009. Zooplankton and gizzard shad densities were correlated during portions of all 5 years (Table 6). Gizzard shad were positively correlated with copepod nauplii most frequently and *Daphnia* spp. least frequently (Table 6). The highest densities of gizzard shad and zooplankton occurred in 2005 and 2006 when the reservoir was under drought conditions. When the reservoir rose to full pool in 2007-2009, gizzard shad and zooplankton density dropped significantly, suggesting the fish and zooplankton were less aggregated, or conditions became unfavorable. In all 5 years, zooplankton and gizzard shad were autocorrelated and showed clustered distributions (Figures 7-11). Densities were especially high in the mid- and upper-reservoir, while low production occurred near the dam. In 2007-2009 the reservoir expanded well beyond the previously established sampling points, leading to increased error on the prediction layers in the upper-reservoir (Figure 12-13). Sampling these locations in the future could lead to a better understanding of the zooplankton and gizzard shad population structure in the upper-reservoir, and would provide better spatial resolution for the prediction layers.

We have found larval gizzard shad and zooplankton are often correlated and show spatial overlap in Harlan Reservoir and copepod nauplii appear to be an especially important group. The inconsistencies observed in the density of shad in different zones of the reservoir are likely a result of changing water levels and dispersed shad populations. Further research aimed at

learning about shad and zooplankton production in the upper reservoir would help to answer these questions. It is possible that the greatest shad production has shifted to the unsampled areas in the west end of the reservoir, and densities in these areas are as high as those found in the low water years of 2005 and 2006.

We have found that gizzard shad and zooplankton distributions in Harlan County Reservoir are predictable at times. As primary forage for other larval and juvenile fish, predicting the abundance and location of zooplankton and gizzard shad would be useful for fisheries managers looking to maximize stocking efforts. Knowledge of the distribution and concentration of the forage base, i.e. gizzard shad and zooplankton, could lead to stocking in areas with high forage, thus minimizing the initial mortality of newly stocked fish caused by starvation.

Each abiotic parameter collected has provided a unique trend within and among the sample years. Results for 2009 were still being collected at the time this report was prepared and are not included in discussion and analysis, but will be reported in the annual report submitted in January 2010.

Readings for standardized chlorophyll *a* indicate that significantly higher quantities were present in Zone 3 as compared to Zone 1 in 6 of the 7 sampling years (Table 7). Annual mean readings of chlorophyll *a* were fairly consistent except for 2008 (Table 8), which was significantly lower than previous readings. The lower chlorophyll *a* readings in 2008 are thought to be a product of using a new Fluorometer. These meters provide standardized readings, which show differences in available chlorophyll *a* and not true chlorophyll *a* measures. The new meter was standardized to produce lower readings. Chlorophyll *a* measurements are most variable during the middle of June to middle of August (Table 9). The number of sample sites necessary to be within 10% of the true mean for the entire sampling season has varied between 15-38 (Table 9).

Secchi disk readings have consistently been significantly greater in Zone 1 than Zone 3 (Table 7). Annual means for secchi disk readings have also demonstrated variability with results from 2004 being significantly lower than other years and results from 2008 being significantly greater than other sample years (Table 8). Annual readings appear to be impacted by changes in water levels and amount of wind that is observed during sampling endeavors. Results for Secchi disk readings were consistent with 12-20 sites being needed to be within 10% of the true mean for the entire sampling season (Table 9). The traditional pre-water release period (March 25-June 15) displayed slightly higher variability than other timeframes.

As would be anticipated, results for turbidity readings were the antithesis of results for Secchi disk readings. Turbidity was significantly greater in Zone 3 than in Zone 1 in 6 of the 7 sampling years (Table 7). The only exception was in 2008, which was almost deemed significant with a p-value of 0.07. The annual mean readings of turbidity were also variable with significantly higher readings in 2004 and 2005 and significantly lower readings in 2008 (Table 8). Turbidity readings were fairly consistent throughout the growing season with the exception of readings taken shortly after pulse flow events into the reservoir. In these instances that occurred on multiple occasions in 2008, the variability was greatly enhanced (Table 9). The number of sites required to be within 10% of the true mean for the entire sampling season typically ranged from 24-42, but increased to 242 sites with the inclusion of these pulse flow event readings. It is unknown why Secchi disk readings did not observe similar changes in

readings during the pulse flow events, but is suspected that it may be associated with Secchi readings being influenced more by free floating algae and less by colloidal suspended solids in Harlan County Reservoir.

Mean annual temperature readings have been fairly consistent between years (19.58ºC-21.02ºC), with 2006 and 2008 being significantly cooler and 2005 and 2007 being significantly warmer than other sampling years (Table 8). The mean annual temperature readings from Zone 3 were significantly warmer than other zones in 2007 and 2008 (Table 7). As a general trend, Zone 2 was cooler the first 3 years and was heavily influenced by cooler readings stemming from the Prairie Dog Creek area (station 25 on Figure 1). Starting in 2006, Zone 1 was slightly cooler. The change is believed to be influenced by more water coming in from Prairie Dog Creek. We suspect that a groundwater spring must have some influence on this geographic area that can be detected when water is not flowing in through the creek. This area offers a unique thermal microhabitat and has seen some larger walleye caught by anglers during warmer months. Temperature readings are more consistent than other water quality parameters as 5-11 sampling stations are required to be within 2.5% of the true mean for the entire sampling season (Table 9). The most variability in temperature readings occurs during the traditional pre-water release timeframe (March 25-June 15) when the water is warming. A weak thermocline was observed on two individual sampling occasions, but did not encompass the entire reservoir on those dates. The influence of wind on this system seems to prohibit the development of a strong thermocline.

Dissolved oxygen readings were significantly greater in Zone 3 versus Zone 1 in 4 of the 6 sampling years (Table 7). In 2008 however, Zone 1 had the highest reading. These results again were heavily influenced by readings taken shortly after pulse flow events. These occasional pulse flow events seem to have a dramatic impact on water quality readings throughout the reservoir, especially in Zone 3. The annual mean readings for dissolved oxygen range from 5.87 in 2004 to 9.06 in 2006 and have been significantly different every year (Table 8). In 2004, the entire reservoir was below 4.0 ppm dissolved oxygen for consecutive samples and fish kill events occurred in the spillway below Harlan County dam and in shallow waters on the upper end of the reservoir. Dissolved oxygen displays the greatest variability in readings during the traditional water release time of year. The number of stations needed to be within 2.5% of the true annual mean is 24-70 (Table 9). Toxic algae blooms that exceed public safety standards have been recorded by the Nebraska Department of Environmental Quality and suggest that algae blooms may greatly impact dissolved oxygen availability during the summer months.

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Deviations from Proposal

There were no significant deviations from the original proposal.

Program Plan

The program plan for 2010-2014 is to complete processing of the samples collected in 2009 and continue the sampling regime established in segments 1-7. Objective 1 will remain the same in order to build on the existing database of abiotic and biotic parameters associated with Harlan County Reservoir. Our intent is to develop a long-term database of these variables that can be used to assist in improving the current understanding of ecological relationships associated with a Midwestern irrigation reservoir. Additionally, in the future we anticipate using the ecological database to develop predictive models for specific fish species based on current conditions. Other objectives included in the 2010-2014 plan are to describe the predator-prey interactions between age-0 walleye and other available prey items, as well as to determine how both biotic and abiotic interactions influence age-0 walleye growth and subsequent recruitment in Harlan County Reservoir. It is the goal of this work to develop an in-depth understanding of all trophic levels in a Midwestern irrigation reservoir and use this information to assist with sport fish management in this and other similar reservoirs. This project anticipates using an on-going M.S. degree seeking student at University of Nebraska-Kearney to complete specific project objectives.

Table 1. A list of taxa found in zooplankton samples collected from Harlan County Reservoir from 2002 to 2009.

Classification of Common Species Occurring in Harlan County Reservoir				
Class	**Order**	**Family**	**Genus**	**Species**
Branchiopoda	Cladocera	Daphnidae	***Daphnia***	***lumholtzi***
Branchiopoda	Cladocera	Daphnidae	***Daphnia***	***pulicaria***
Branchiopoda	Cladocera	Daphnidae	***Daphnia***	***retrocurva***
Branchiopoda	Cladocera	Daphnidae	***Daphnia***	**Immature**
Branchiopoda	Cladocera	Daphnidae	***Ceriodaphnia***	
Branchiopoda	Cladocera	Bosminidae	***Bosmina***	
Branchiopoda	Cladocera	Chydoridae	***Alona***	
Branchiopoda	Cladocera	Sididae	***Diaphanosoma***	
Branchiopoda	Cladocera	Leptodoridae	***Leptodora***	***kindti***
Branchiura	Arguloidea	Argulidae	***Argulus***	
Copepoda	**Calanoida**	Diaptomidae	*Diaptomus*	
Copepoda	**Calanoida immature**			
Copepoda	**Cyclopoida**	Cyclopoidae	*Cyclops*	
Copepoda	**Cyclopoida immature**			
Copepoda	**Harpacticoida**			
Copepoda	**Nauplii immature**			
Ostracoda	**Podocopa**			
Arachnida	**Acariformes**	**Aquatic Mite**		

Table 2. Mean zooplankton lengths (mm) and standard error from 2002 to 2008

	Calanoida	Cyclopoida	*Bosmina*	*D. pulicaria*	*D. retrocurva*	*D. lumholtzi*	Napulii
2002	0.96±0.01	0.72±0.01	0.31±0.01	0.93±0.02	1.05±0.01	N/A	0.2±0
2003	0.98±0.01	0.74±0.01	0.34±0.01	TBD	0.92±0.01	1.28±0.05	0.19±0
2004	0.97±0.01	0.78±0.01	0.36±0.01	1.1±0.02	0.91±0.01	0.72±0.11	0.21±0
2005	1.02±0.01	0.78±0.01	0.32±0.01	1.15±0.09	0.88±0.02	1.25±0.06	0.21±0
2006	1.01±0.01	0.8±0.01	0.37±0.01	1.18±0.02	0.94±0.02	1.21±0.04	0.21±0
2007	0.97±0.01	0.82±0.01	0.41±0.01	1.14±0.02	0.91±0.02	N/A	0.21±0
2008	1.05±0.02	0.86±0.02	0.38±0.01	1.16±0.02	1.01±0.02	N/A	0.2±0

Table 3. The mean (± 1 standard error) number of zooplankton per liter collected at one meter in zone 1 of Harlan Reservoir (2007). Littoral samples were collected where the reservoir was less than four meters deep. Pelagic samples were collected where the reservoir was at least seven meters deep.

Month	**Littoral**	**Pelagic**
April	96.02 ± 11.20	78.18 ± 11.34
May	114.21 ± 23.44	115.46 ± 17.30
June	39.55 ± 4.42	68.77 ± 16.06
July	50.00 ± 10.70	52.05 ± 8.65

Table 4. The mean (± 1 standard error) number of zooplankton per liter collected at 1 meter in zones 1, 2, and 3 of Harlan Reservoir from April to July of 2007.

Zone	April	May	June	July
1	83.98 ± 10.44	111.36 ± 10.74	61.14 ± 19.00	63.64 ± 1.86
2	84.32 ± 11.38	96.82 ± 18.22	83.98 ± 7.79	65.68 ± 13.00
3	108.41 ± 30.66	87.61 ± 10.50	139.66 ± 32.92	67.61 ± 41.11

ANOVA, *$p<0.05$

Table 5. Mean densities and standard errors for total gizzard shad, shad size groups, total zooplankton, and individual zooplankton groups collected at Harlan County Reservoir from 2005-2009. Significantly similar values are denoted by the same letter following the standard error.

Organism	2005	2006	2007	2008	2009
Total Gizzard Shad	2.86 ± 0.60[a]	4.32 ± 0.76[a]	0.69 ± 0.10[b]	0.54 ± 0.11[c]	0.97 ± 0.16[b]
Shad 0-14 mm	0.27 ± 0.06[a]	0.36 ± 0.08[a]	0.06 ± 0.01[b]	0.44 ± 0.09[a]	0.29 ± 0.04[a]
Shad 15-30 mm	2.43 ± 0.55[a]	3.63 ± 0.72[a]	0.56 ± 0.08[b]	0.11 ± 0.03[c]	0.69 ± 0.15[b]
Total Zooplankton	69.17 ± 2.51[a]	120.36 ± 8.49[b]	47.48 ± 3.02[c]	35.35 ± 2.35[d]	44.37 ± 1.71[cd]
Total Copepods	20.98 ± 0.97[a]	45.91 ± 3.10[b]	39.63 ± 2.56[b]	28.35 ± 1.99[a]	36.55 ± 1.48[b]
Copepod Nauplii	28.57 ± 1.23[a]	63.11 ± 5.82[b]	16.25 ± 0.91[c]	12.56 ± 1.07[d]	13.74 ± 0.76[cd]
Calanoid Copepod	14.38 ± 0.68[a]	37.64 ± 2.78[b]	13.18 ± 1.33[ac]	10.73 ± 0.91[c]	19.70 ± 0.79[d]
Cyclopoid Copepod	6.59 ± 0.53[a]	8.28 ± 1.66[a]	5.87 ± 0.81[a]	2.83 ± 0.17[b]	3.11 ± 0.23[b]
Total Cladocerans	19.55 ± 1.05[a]	8.38 ± 0.96[b]	7.84 ± 0.87[b]	7.00 ± 0.47[b]	7.82 ± 0.37[b]
Daphnia pulicaria	18.12 ± 1.01[a]	3.73 ± 0.72[b]	4.92 ± 0.62[c]	4.24 ± 0.36[c]	2.68 ± 0.17[bc]
Daphnia retrocurva	0.64 ± 0.07[a]	3.77 ± 0.49[b]	2.69 ± 0.39[b]	2.76 ± 0.30[b]	5.14 ± 0.28[c]

Table 6. Correlations between total gizzard shad density, shad size groups, and total zooplankton density, zooplankton groups, and copepod nauplii. Total Daphnia includes *D. pulicaria* and *D. retrocurva*, and total copepods include the orders *Calanoida* and *Copepoda*. Significance was determined at P<0.10 (*), P<0.05 (**), P<0.01 (***), and P<0.001 (****).

Date	Shad	Total Zooplankton	*Daphnia* spp.	Total Copepods	Nauplii
6/6/2005	Total Shad	0.1266	-0.0444	-0.1027	0.3188
6/6/2005	0-14 mm	0.1049	-0.0544	-0.0527	0.0896
6/6/2005	15-29 mm	0.1148	0.0304	-0.1722	0.3643
6/14/2005	Total Shad	0.0414	-0.1153	0.1467	0.0249
6/14/2005	0-14 mm	0.1349	0.0144	0.1688	0.1296
6/14/2005	15-29 mm	0.0278	-0.1082	0.1186	0.0165
6/21/2005	Total Shad	0.4640**	-0.2835	0.4205**	0.6362****
6/21/2005	0-14 mm	0.3853	0.0758	0.2892	0.3386
6/21/2005	15-29 mm	0.1332	-0.2891	0.064	0.3909*
6/6/2006	Total Shad	0.2478	0.2335	0.1557	0.3470*
6/6/2006	0-14 mm	0.0914	0.1317	-0.0052	0.2507
6/6/2006	15-29 mm	0.2965	0.3162	0.2235	0.3600*
6/12/2006	Total Shad	0.2536*	0.0408	0.1264	0.3012**
6/12/2006	0-14 mm	0.1604	-0.2069	0.1288	0.2813*
6/12/2006	15-29 mm	0.2331	0.0867	0.105	0.2636*
6/19/2006	Total Shad	0.4609**	0.0555	0.5670***	0.2939
6/19/2006	0-14 mm	-0.4071**	-0.0766	-0.3682*	-0.3877*
6/19/2006	15-29 mm	0.6875****	0.0448	0.7858****	0.5240***
6/4/2007	Total Shad	-0.0802	-0.2402	-0.0763	-0.2509
6/4/2007	0-14 mm	-0.2909	-0.2609	-0.3408	-0.3980*
6/4/2007	15-29 mm	-0.0198	-0.1983	-0.0096	-0.1876
6/13/2007	Total Shad	0.1364	0.096	0.1442	-0.1816
6/13/2007	0-14 mm	0.0193	0.0667	-0.0143	-0.1111
6/13/2007	15-29 mm	-0.0287	0.0271	-0.0253	-0.2552*
6/18/2007	Total Shad	0.3748*	0.3248	0.2109	-0.0926
6/18/2007	0-14 mm	0.0455	0.2701	-0.1019	-0.1674
6/18/2007	15-29 mm	0.4233**	0.3693*	0.2369	0.1517
6/3/2008	Total Shad	0.7361****	0.5085***	0.6900****	0.7303****
6/3/2008	0-14 mm	0.7619****	0.5313***	0.7165****	0.7465****
6/3/2008	15-29 mm	-0.1455	-0.2739	-0.1251	-0.0353
6/9/2008	Total Shad	0.2243	-0.0343	0.2896**	0.2689*
6/9/2008	0-14 mm	0.1851	-0.0804	0.2524*	0.2342
6/9/2008	15-29 mm	0.3074**	0.161	0.3519**	0.3161**
6/18/2008	Total Shad	-0.2675	-0.5176***	-0.229	-0.1903
6/18/2008	0-14 mm	-0.2409	-0.4491**	-0.2072	-0.1836
6/18/2008	15-29 mm	-0.2676	-0.5370***	-0.2184	-0.128
6/3/2009	Total Shad	0.5640***	0.5093***	0.5486***	0.6044***
6/3/2009	0-14 mm	0.5464***	0.4991***	0.5430***	0.5924***
6/3/2009	15-29 mm	0.2907	0.276	0.2406	0.2042
6/8/2009	Total Shad	-0.01368	0.0384	-0.0202	-0.043
6/8/2009	0-14 mm	-0.0182	0.033	-0.0328	-0.0514
6/8/2009	15-29 mm	-0.0303	0.0098	-0.0275	-0.0595
6/16/2009	Total Shad	0.5731***	0.2981	0.5738***	0.6487****
6/16/2009	0-14 mm	0.6464****	0.4286**	0.6347****	0.7531****
6/16/2009	15-29 mm	0.4675**	0.2157	0.4716**	0.5363***

Table 7. Longitudinal variation in water quality parameters taken from annual means recorded at 15 separate stations from 3/25/03 – 11/06/03, 4/01/04 – 11/06/04, 4/7/05 – 11/01/05, 4/04/06 – 10/24/06, 4/02/07 – 10/24/07 and 4/01/08 – 10/29/08 in Harlan County Reservoir.

Water Quality Parameter	Year	Zone 1 Mean	Zone 2 Mean	Zone 3 Mean	Difference Between Zone Means Signified by p-value
Chlorophyll *a* (μg/L)	2003	105.92[a]	121.48[b]	131.45[b]	<0.001
	2004	92.19[a]	116.80[b]	122.80[b]	<0.001
	2005	75.15[a]	80.13[a]	110.55[b]	0.005
	2006	96.77[a]	106.54[b]	106.72[b]	0.002
	2007	104.83[a]	107.33[a]	119.78[b]	0.017
	2008	64.14	67.21	68.3	0.182
Secchi depths (cm)	2003	71.73[a]	59.08[b]	47.87[c]	<0.001
	2004	60.27[a]	51.40[b]	46.63[b]	<0.001
	2005	63.83[a]	58.86[a]	48.84[b]	<0.001
	2006	73.04[a]	60.57[b]	51.42[b]	<0.001
	2007	75.22[a]	61.00[b]	56.52[b]	<0.001
	2008	104.89[a]	88.22[b]	85.95[b]	0.005
Turbidity (FTU)	2003	24.53[a]	32.90[b]	39.49[b]	<0.001
	2004	30.86[a]	40.68[b]	46.30[b]	<0.001
	2005	31.94[a]	35.71[a]	41.19[b]	0.008
	2006	26.15[a]	30.84[b]	36.64[c]	<0.001
	2007	20.97[a]	24.04[b]	27.15[c]	<0.001
	2008	13.81	14.43	20.76	0.072
Temperature (C)	2003	18.25	18.12	18.26	0.164
	2004	19.16	19.08	19.28	0.232
	2005	20.51	20.40	20.67	0.203
	2006	18.73	18.79	18.81	0.630
	2007	20.88[a]	20.96[a]	21.24[b]	<0.001
	2008	18.43[a]	18.50[a]	18.72[b]	0.006
Dissolved Oxygen (mg/L)	2003	7.40[a]	7.57[a]	7.69[b]	0.014
	2004	6.93[a]	7.23[b]	7.35[b]	<0.001
	2005	8.57	8.54[a]	8.94[b]	0.009
	2006	8.37[a]	8.66[b]	8.77[b]	0.003
	2007	7.54[a]	7.66[a]	7.81[b]	0.011
	2008	8.35	8.24	8.25	0.630

** superscript letters designate significant difference between zone means at the $p<0.05$ level

Table 8. Comparison of mean annual readings for water quality parameters recorded during similar weeks in 2003, 2004, 2005, 2006, 2007 and 2008 at Harlan County Reservoir.

Water Quality Parameter	Year	Annual Means	95% Confidence Interval for Annual Means
Chlorophyll *a* (μg/L)	2003	114.89	±8.14
	2004	112.25	±8.27
	2005	107.04	±7.96
	2006	110.23	±6.41
	2007	110.65	±9.27
	2008	66.55[a]	±8.40
Secchi depths (cm)	2003	60.96[a]	±3.40
	2004	50.60[b]	±2.69
	2005	58.87	±3.10
	2006	61.65[a]	±4.47
	2007	64.24[a]	±3.28
	2008	92.94[c]	±4.70
Turbidity (FTU)	2003	34.72[a]	±2.57
	2004	39.99[b]	±2.56
	2005	38.86[b]	±2.23
	2006	35.18[a]	±1.66
	2007	24.19[c]	±1.10
	2008	16.65[d]	±3.53
Temperature (C)	2003	20.26	±0.70
	2004	20.37	±0.52
	2005	20.98[a]	±0.59
	2006	19.76[b]	±0.68
	2007	21.02[a]	±0.58
	2008	19.58[b]	±0.74
Dissolved Oxygen (mg/L)	2003	7.16[a]	±0.24
	2004	5.87[b]	±0.28
	2005	8.63[c]	±0.20
	2006	9.06[d]	±0.26
	2007	7.67[e]	±0.20
	2008	8.28[f]	±0.18

* Superscript letters designate a significant difference in annual means for that parameter at a level of $p<0.05$.

** Annual means and associated levels of significance were determined only from samples collected in similar calendar weeks of sampling for all four years of this study.

Table 9. Required sample size to capture a mean that is within 10% of the true mean as determined by annual means collected for various water quality parameters on Harlan County Reservoir during 2003, 2004, 2005, 2006, 2007 and 2008.

Water Quality Parameter	Sampling Year	Traditional Pre-Water Release (3/25-6/15)	Traditional Water Release (6/16-8/16)	Traditional Post-Water Release (8/17-11/06)	Entire Sampling Season
Chlorophyll *a*	2003	10.88	39.65	21.34	23.04
	2004	24.81	47.83	21.68	27.37
	2005	22.00	75.07	20.40	37.98
	2006	26.76	19.28	5.24	17.09
	2007	13.44	18.16	12.73	14.77
	2008	41.61	13.57	4.03	21.18
Secchi depths	2003	19.48	22.93	15.84	19.21
	2004	18.37	14.79	7.59	13.51
	2005	19.33	10.16	26.10	19.01
	2006	21.52	17.68	12.09	17.10
	2007	28.10	14.99	7.00	16.70
	2008	21.08	9.22	5.58	11.96
Turbidity	2003	33.18	47.44	46.83	42.19
	2004	30.77	43.84	26.56	29.09
	2005	42.63	22.89	32.11	32.51
	2006	22.28	32.99	23.11	26.13
	2007	29.24	22.88	19.50	23.87
	2008	188.51	509.98	26.39	241.63

Required sample size to capture a mean that is within 2.5% of the true mean as determined by annual means collected for various water quality parameters on Harlan County Reservoir during 2003, 2004, 2005, 2006, 2007 and 2008.

Water Quality Parameter	Sampling Year	Traditional Pre-Water Release (3/25-6/15)	Traditional Water Release (6/16-8/16)	Traditional Post-Water Release (8/17-11/06)	Entire Sampling Season
Temperature	2003	17.29	2.50	11.49	10.87
	2004	6.32	8.71	2.06	6.26
	2005	7.62	3.16	2.99	4.45
	2006	15.84	1.31	10.90	8.42
	2007	8.13	3.12	1.92	4.65
	2008	11.93	2.35	2.47	5.58
Dissolved Oxygen	2003	6.36	88.41	28.78	39.71
	2004	10.57	172.66	34.62	69.49
	2005	12.72	79.79	40.91	48.00
	2006	30.95	51.43	28.61	38.96
	2007	24.15	44.64	31.48	33.63
	2008	59.54	50.45	43.05	51.42

Figure 1. Location and identification of sampling sites at Harlan County Reservoir.

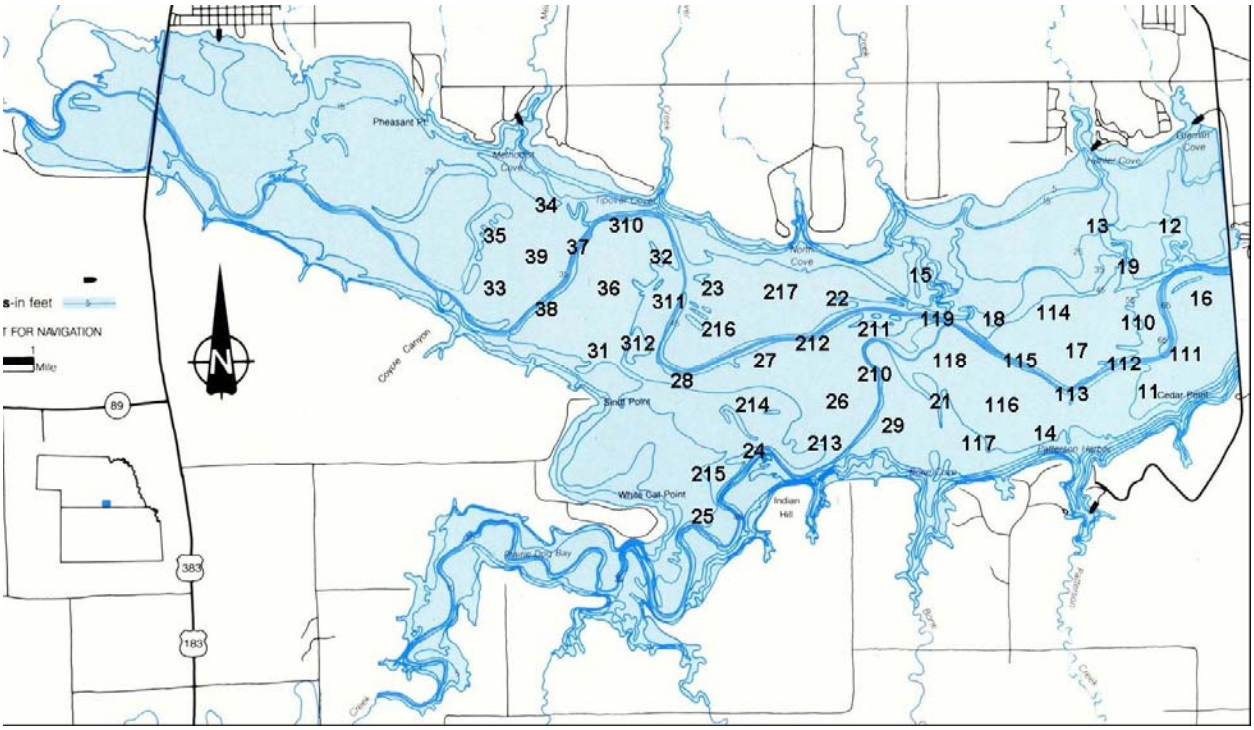

Figure 2. Density of adult zooplankton in Harlan County Reservoir in samples collected on April 16, 2007.

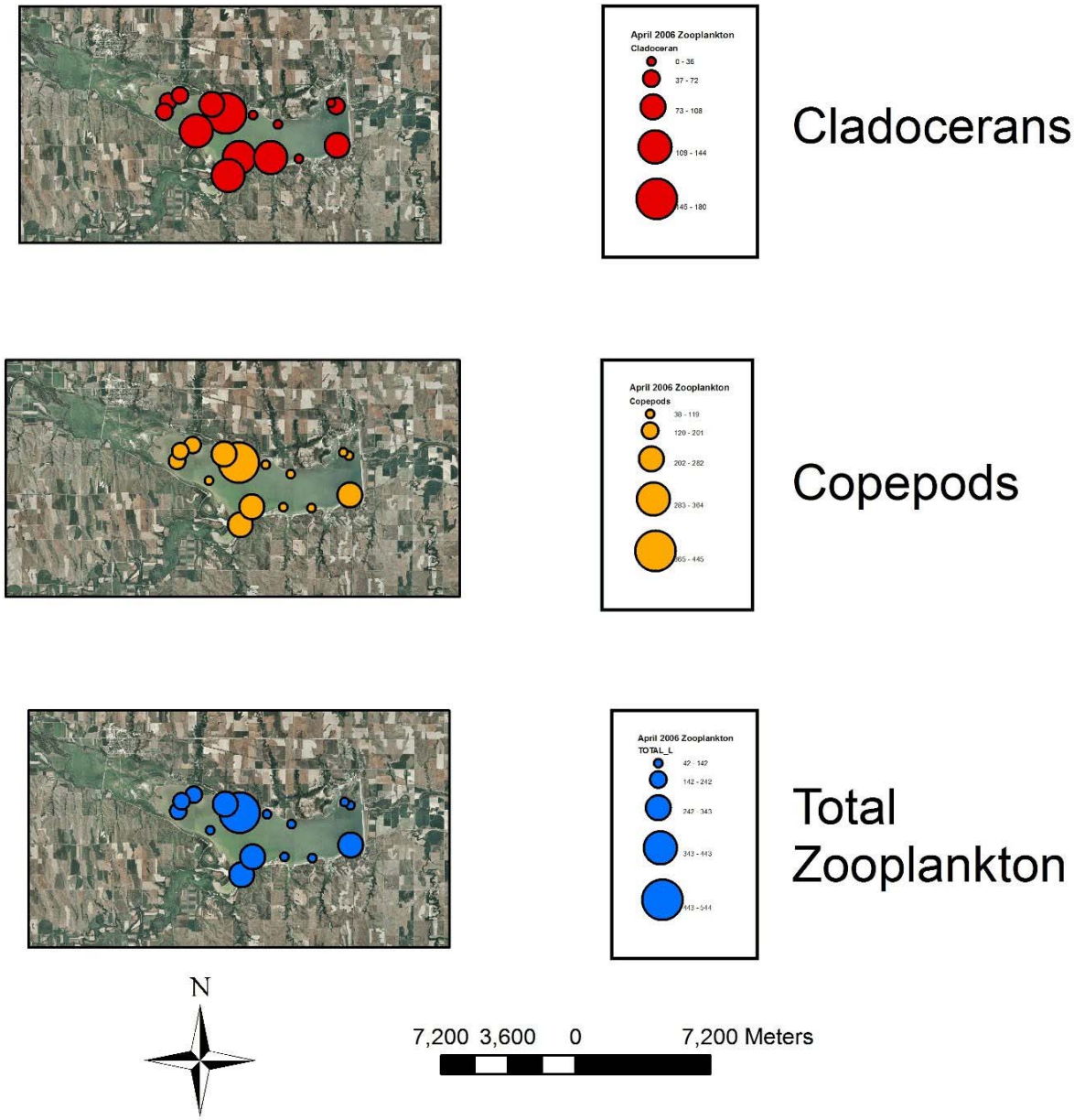

Figure 3. Plot of gizzard shad length (mm) vs. number of zooplankton consumed per fish for gizzard shad collected at Harlan County Reservoir in 2008 (a) and 2009 (b).

Figure 3a.

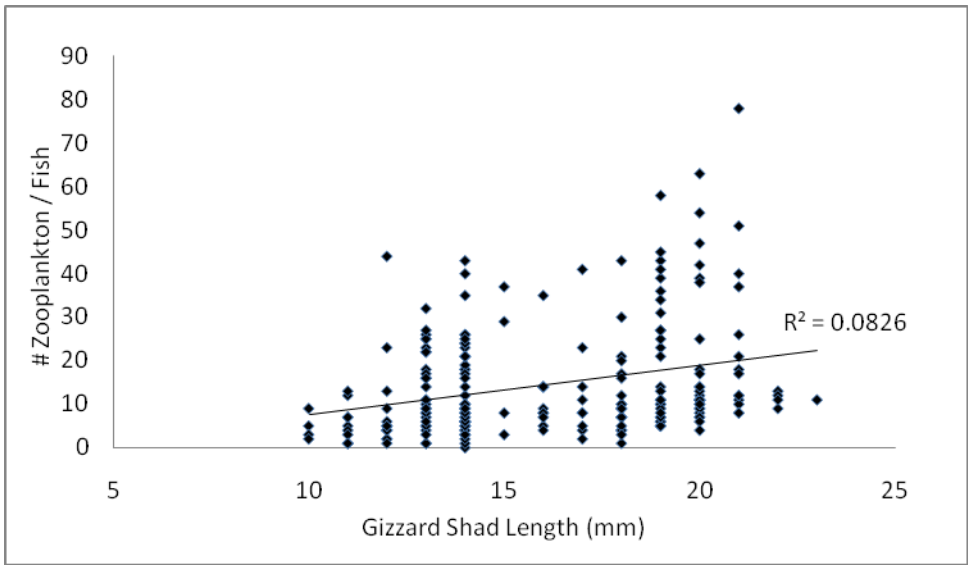

Figure 3b.

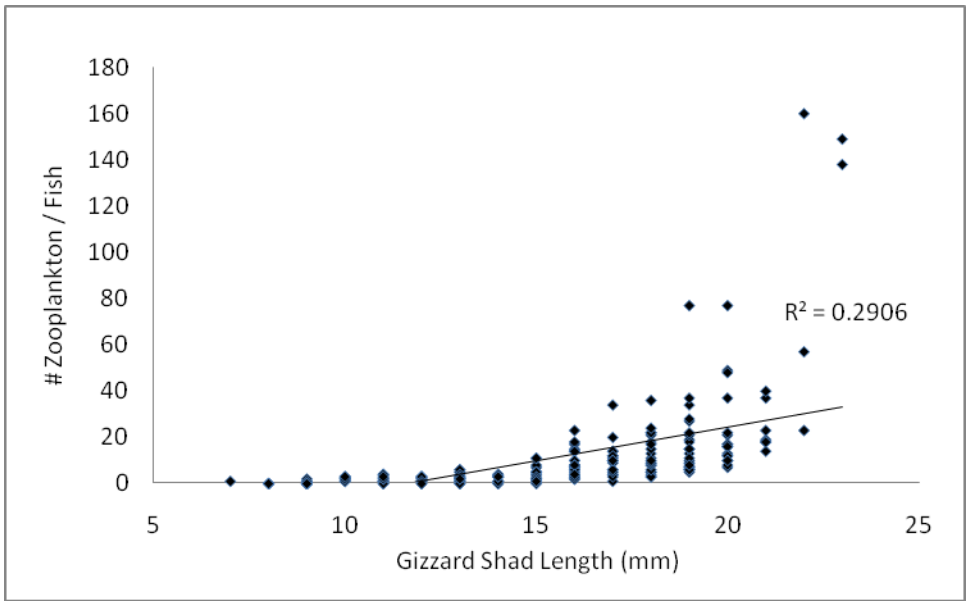

Figure 4. Plot of gizzard shad length (mm) vs. mean prey length (mm) for fish collected at Harlan County Reservoir in 2008 (a) and 2009 (b).

Figure 4a.

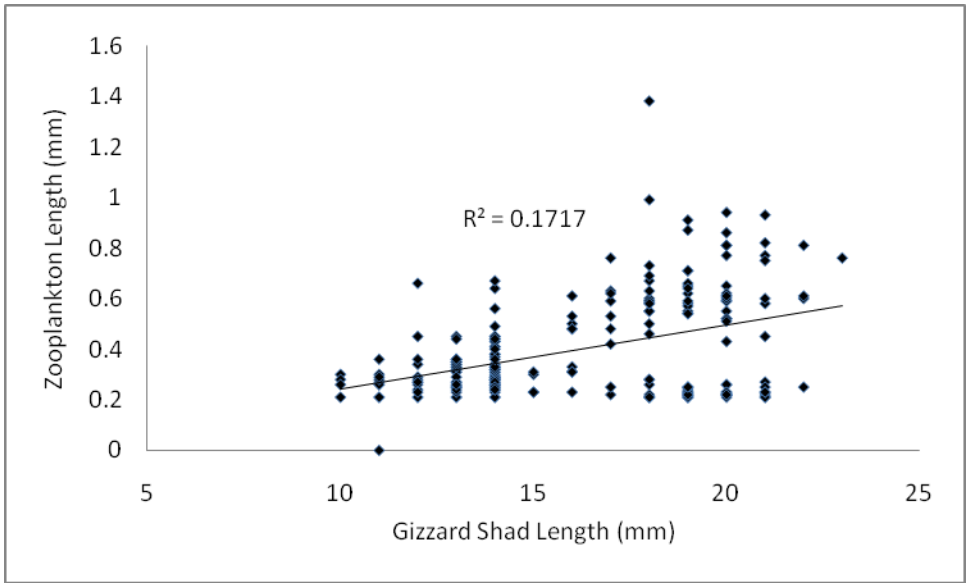

Figure 4b.

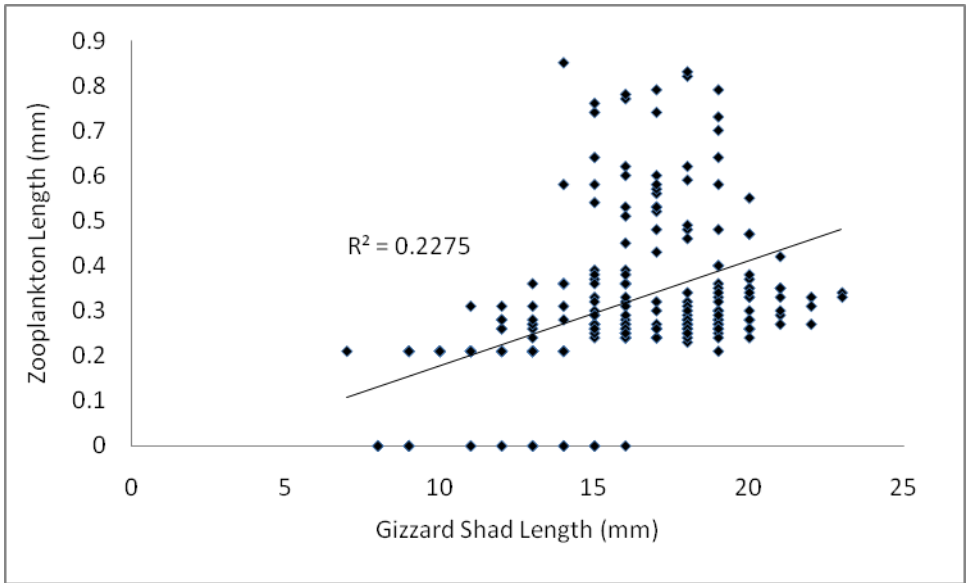

Figure 5. 2008 (a) and 2009 (b) Gizzard shad diet composition expressed as each group's percentage of the total number of zooplankton consumed. Individual pie-charts represent the 3 gizzard shad size classes.

Figure 5a.

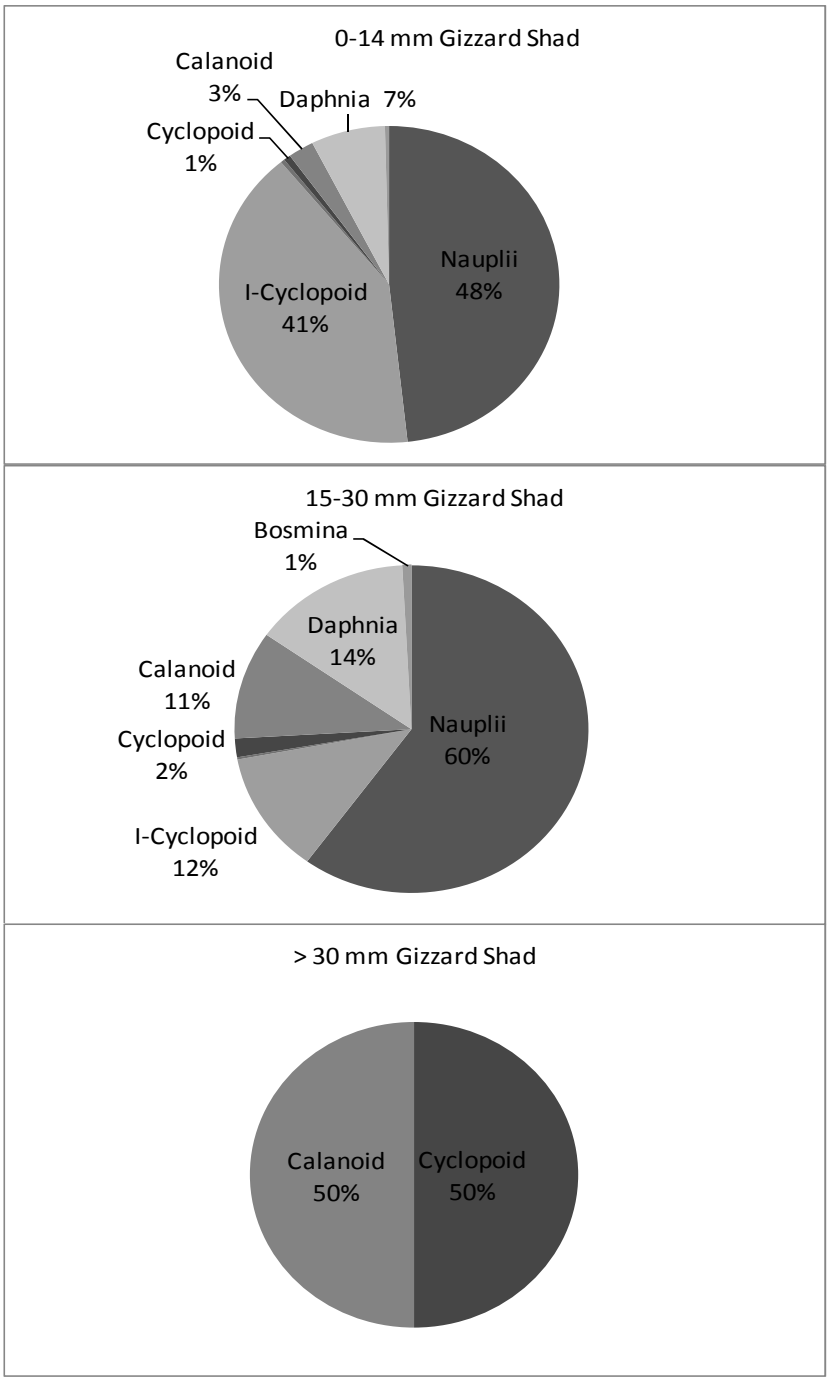

Figure 5b.

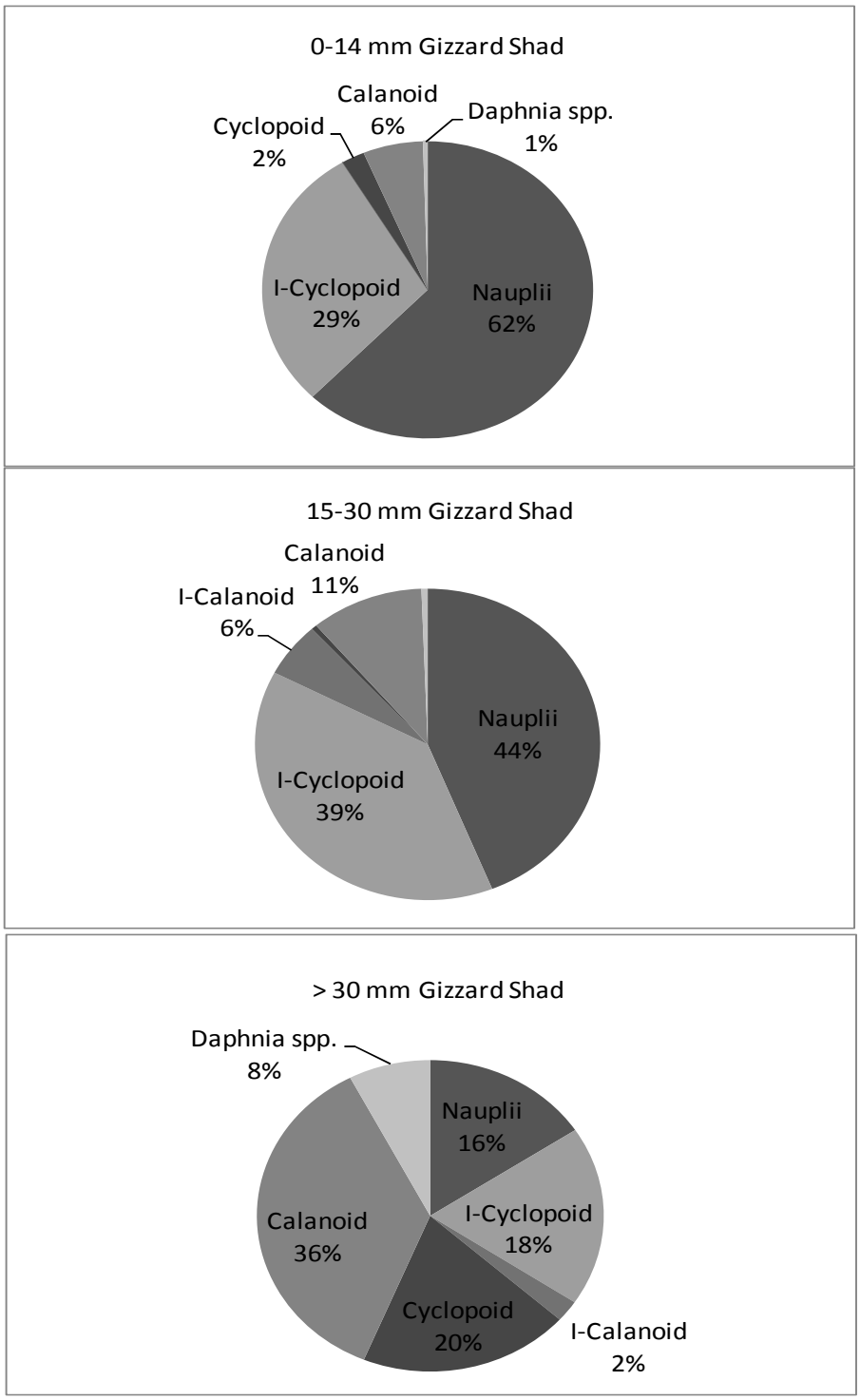
0-14 mm Gizzard Shad
Calanoid 6%
Daphnia spp. 1%
Cyclopoid 2%
I-Cyclopoid 29%
Nauplii 62%
15-30 mm Gizzard Shad
Calanoid 11%
I-Calanoid 6%
Nauplii 44%
I-Cyclopoid 39%
> 30 mm Gizzard Shad
Daphnia spp. 8%
Nauplii 16%
I-Cyclopoid 18%
Calanoid 36%
Cyclopoid 20%
I-Calanoid 2%

Figure 6. Strauss electivity index values from fish collected during 2008 and 2009 at Harlan County Reservoir. Positive and negative values greater or less than ± 0.15 indicate positive and negative selectivity.

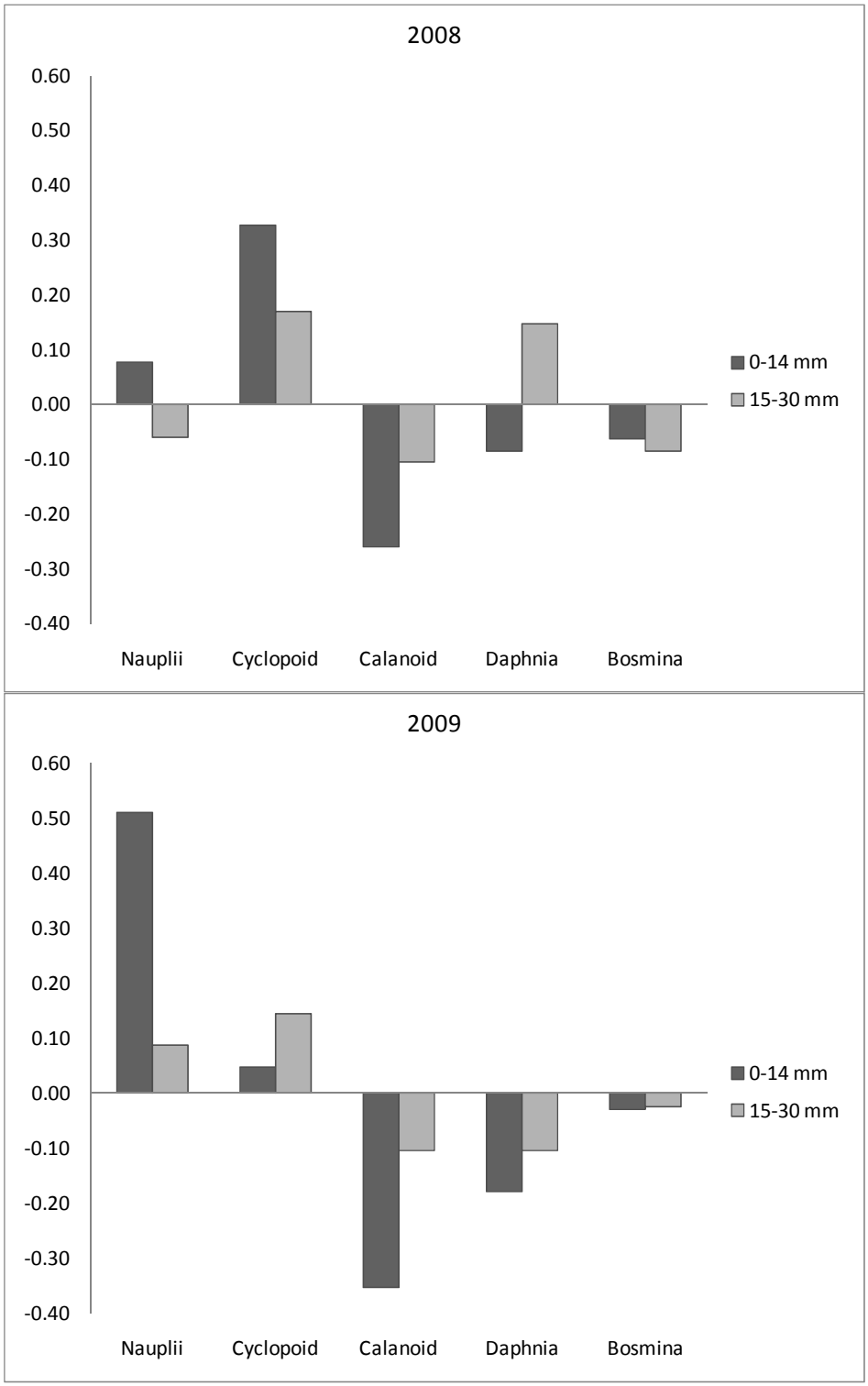

Figure 7. Ordinary prediction map for total gizzard shad and copepod nauplii density on June 21, 2005. Darker shading represents areas with higher densities of larval gizzard shad and copepod nauplii.

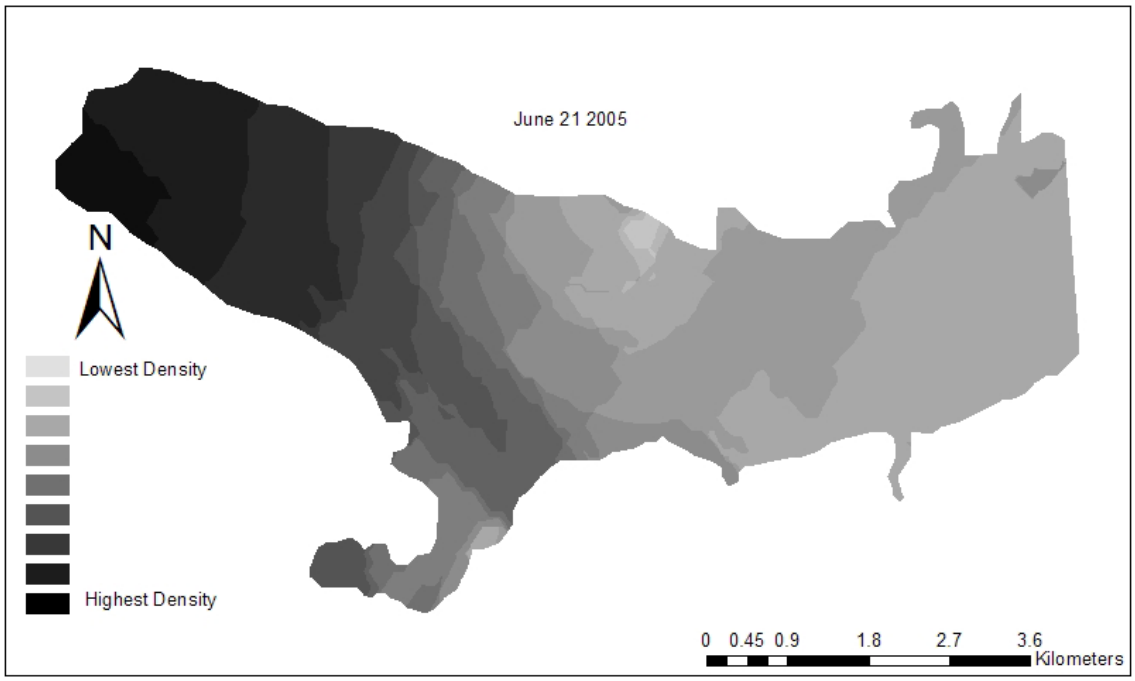

Figure 8. Ordinary prediction map for total gizzard shad and total zooplankton on June 12, 2006. Darker shading represents areas with higher densities of larval gizzard shad and zooplankton.

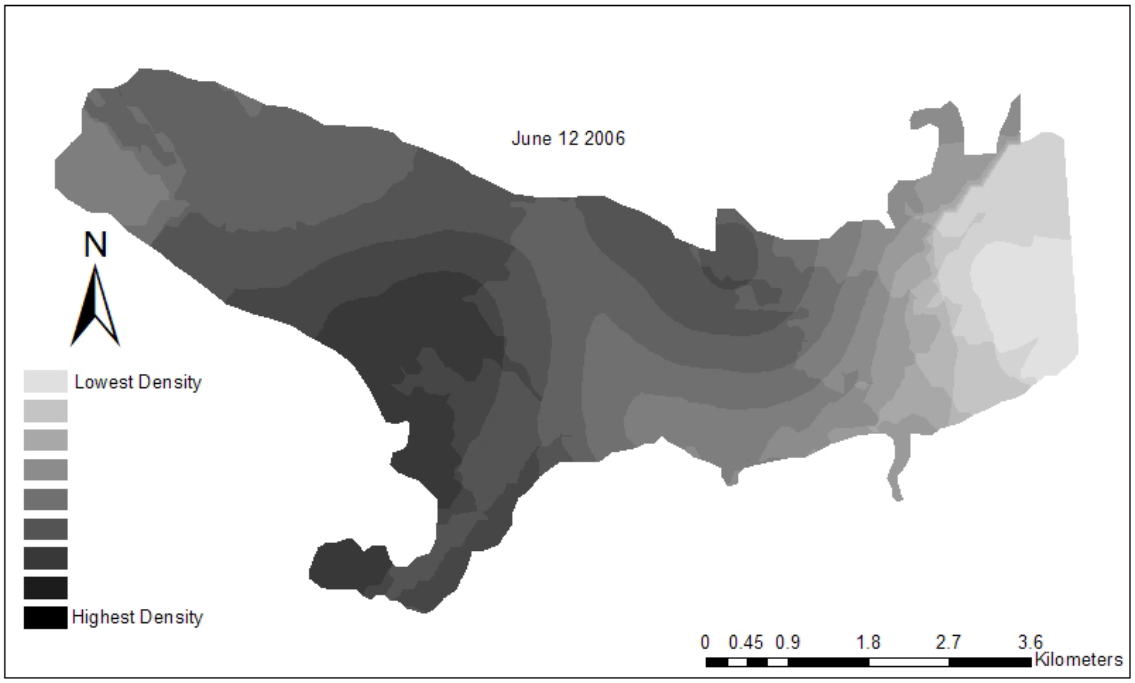

Figure 9. Ordinary prediction map for total gizzard shad and total zooplankton density on June 18, 2007. Darker shading represents areas with higher densities of larval gizzard shad and zooplankton.

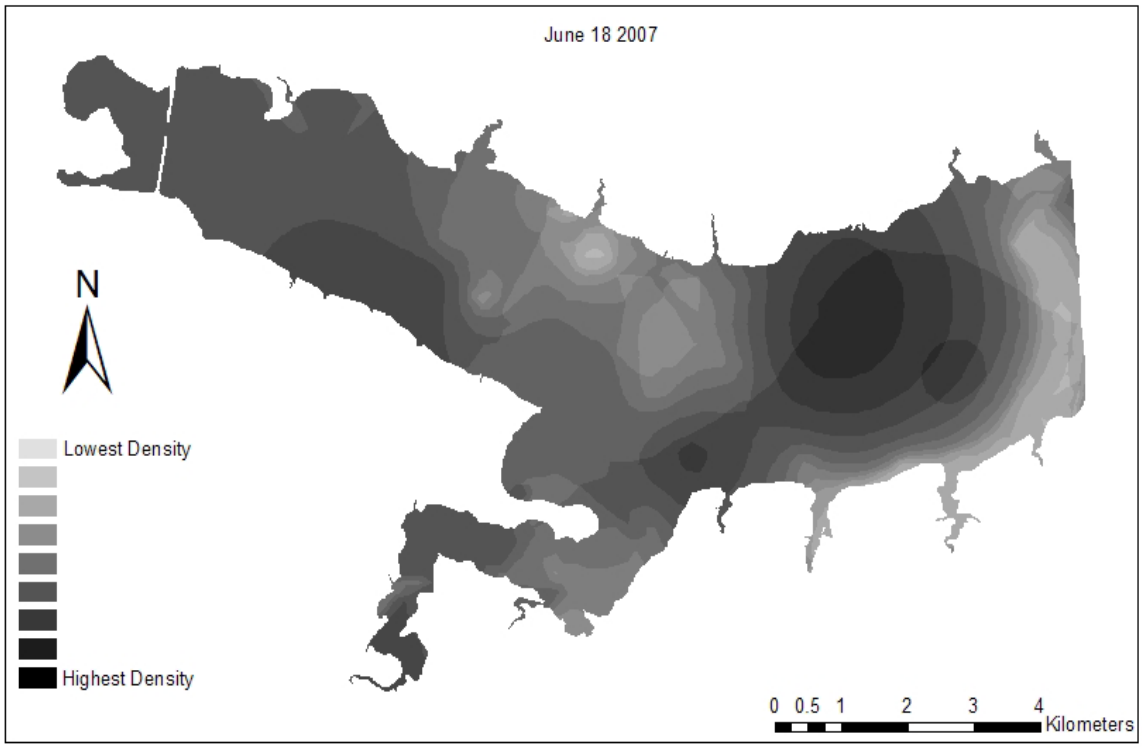

Figure 10. Ordinary prediction map for total gizzard shad and copepod nauplii on June 3, 2008 Darker shading represents areas with higher densities of larval gizzard shad and copepod nauplii.

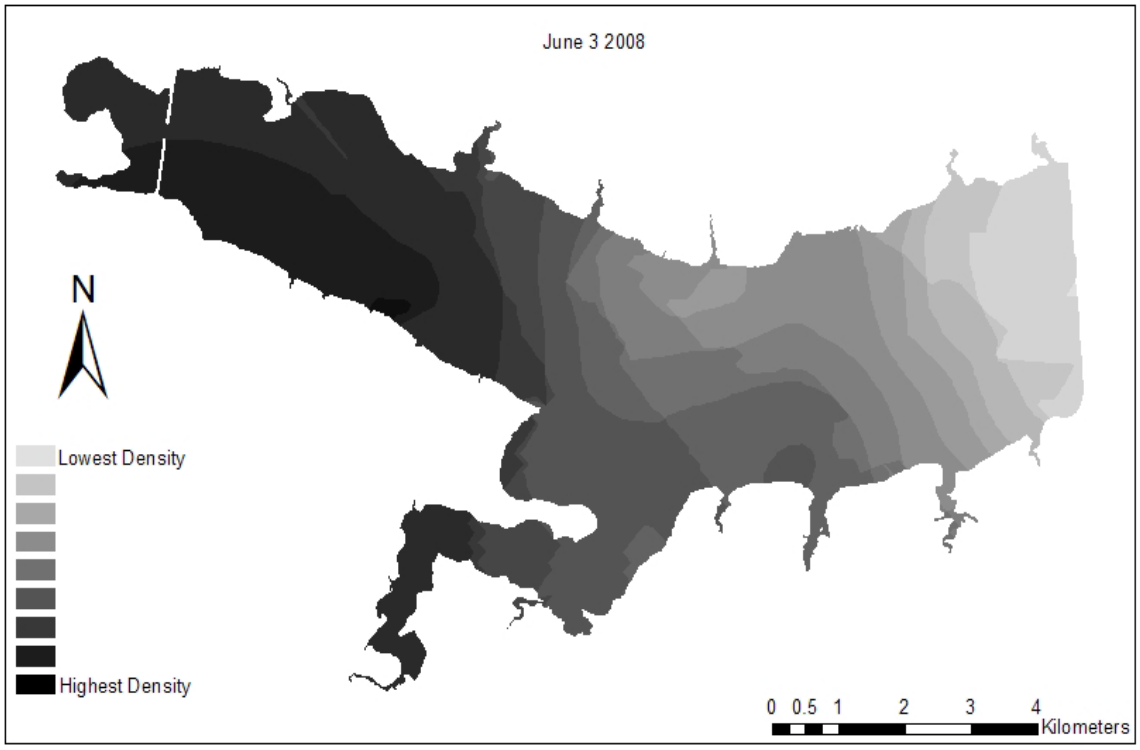

Figure 11. Ordinary prediction map for total gizzard shad and copepod nauplii on June 16, 2009. Darker shading represents areas with higher densities of larval gizzard shad and copepod nauplii.

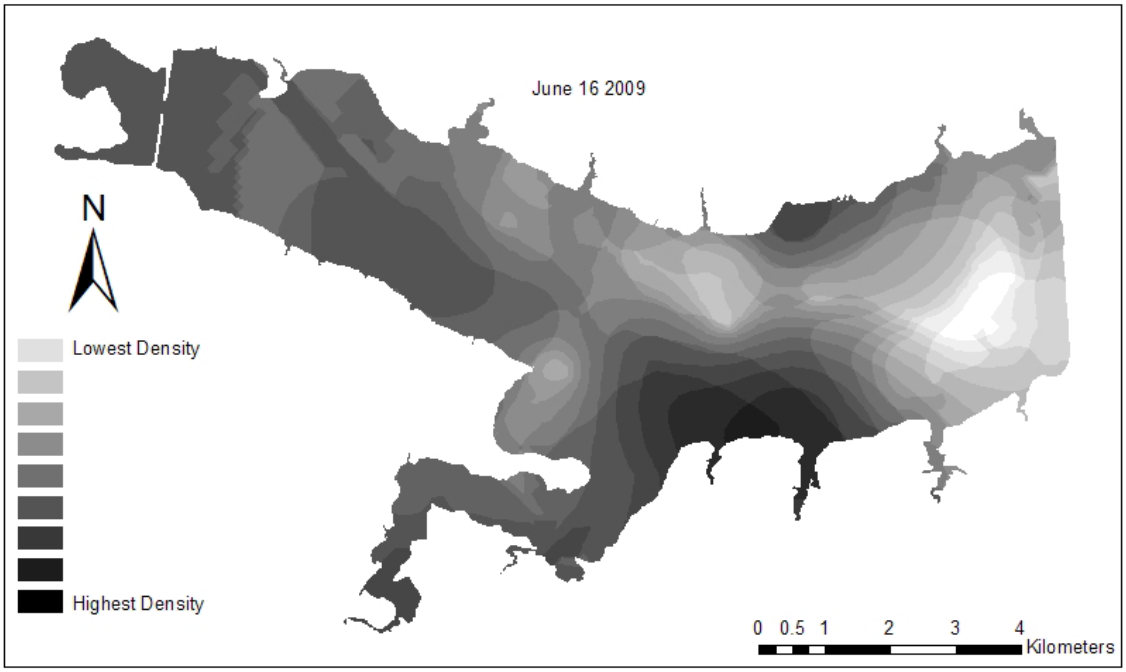

Figure 12. Standard prediction error maps for total gizzard shad density at Harlan County reservoir in 2005 and 2006.

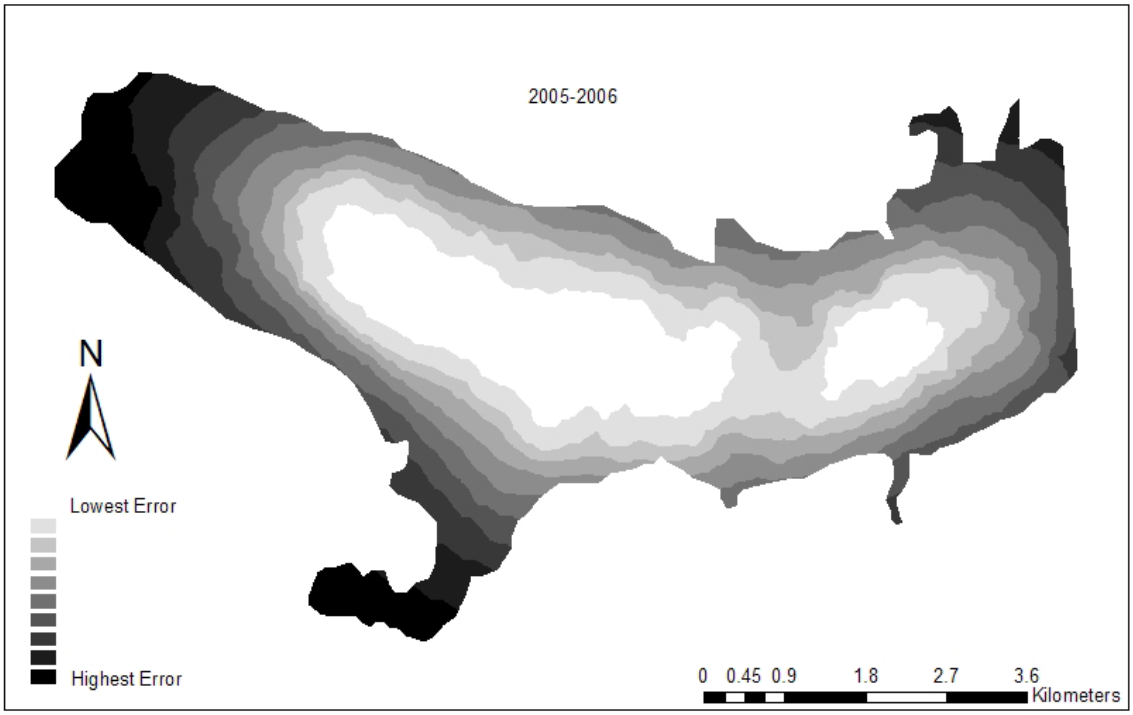
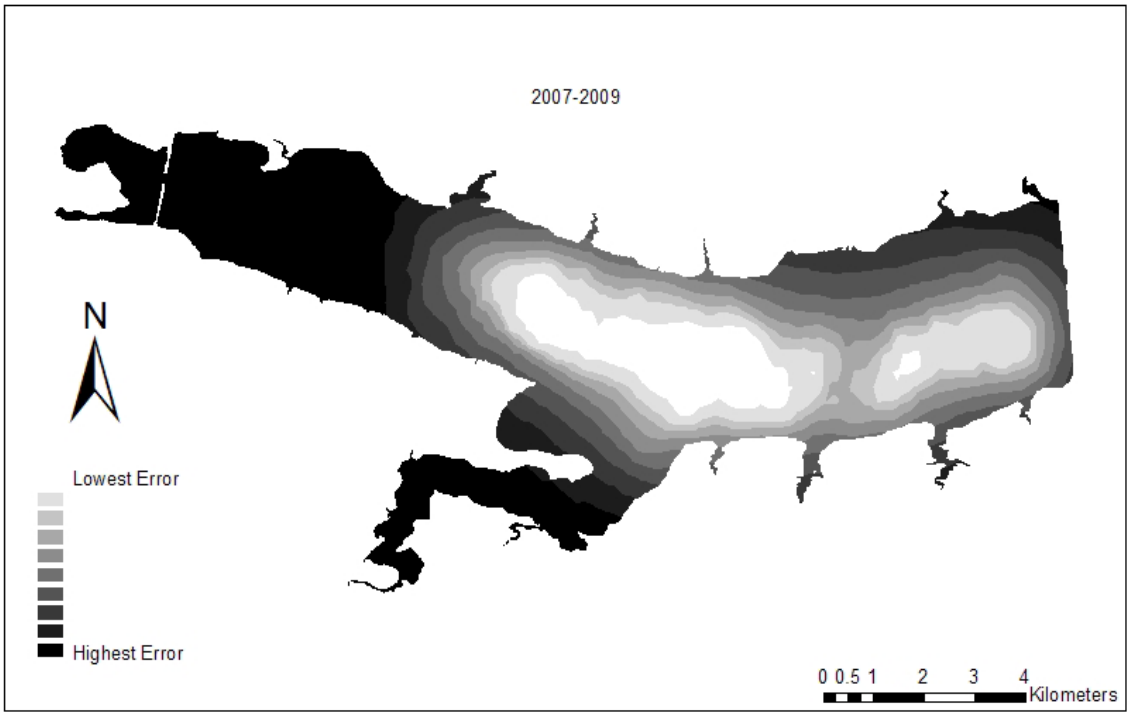
Figure 13. Standard prediction error maps for total gizzard shad density at Harlan County reservoir in 2007-2009.