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Larval Fish Abundance in the Benthic and Surface Drift of the Missouri River

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By

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Knowledge of the larval fish community of the Missouri River is one of the biggest gaps in fisheries research. The Nebraska Game and Parks Commission has sampled the drift of the Missouri River for many years (1983-2015), but these data have not been compiled into a unified assessment. Therefore, the objectives of this study were to: 1) quantify temporal and spatial aspects of larval fish community composition (richness) and structure (abundance) of the surface drift, 2) quantify associations of larval fish communities of the drift to different discharges of the Missouri River, 3) quantify the larval benthic drift community, and 4) document evidence of natural spawning and fertilization success by Pallid Sturgeon *Scaphirhynchus albus* through capture of free embryos entering the drifting phase in the Nebraska portion of the Lower Missouri River.

For the surface drift portion of this thesis, there were nine sites from four segments used for these analysis. The greatest overall abundance occurred in 2000 (2.036 fish/m^3, SE=0.122), with Sciaenidae, (N = 155,400) being the most abundant. There were either no significant trends or declining trends in relative abundance over time for all sites and families except for Clupeidae at St. Helena. When comparing

segments, similar results were noted with only three segment/family combinations yielding a positive trend (Catostomidae (Segment 1), Cyprinidae (Segment 3), and Percidae (Segment 3)). Analysis of similarity (ANOSIM) found Segment 1 was dissimilar from Segment 2, Segment 3, and Segment 4. *Post hoc* similarity percentage (SIMPER) analysis displayed that abundances of Sciaenidae across the segments was the reason for this difference. Annual discharge did not influence fish communities of the surface larval drift.

The benthic fish community was sampled primarily at Nebraska City, NE (rkm 907.6), with limited sampling at Niobrara, NE. The most abundant family sampled in the benthic drift was Sciaenidae from the Nebraska City Site in 2015 (n=88) (0.008 fish/m^3, SE$\pm$0.0027). One wild Pallid Sturgeon free embryo was captured on May 28, 2014

Sampling the larval fish drift provides insights on the overall health and productivity of the system and by assessing trends in the larval fish abundance of the drift annual variations and changes in recruitment can be detected

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THESIS INTRODUCTION AND STUDY OBJECTIVES

The Missouri River is the longest river in North America, extending 3,768 km from southwest Montana to the confluence with the Mississippi River near St. Louis, Missouri (Galat and Lipkin, 2000). The Missouri River basin encompasses 137 million hectares or 1/6 of the continental United States of America (Hesse and Schmulbach, 1991). Jacobson and Heuser (2001) described the Missouri River as a large and complex system, with many reservoirs, control structures, and free-flowing reaches. Pegg et al. (2003) stated lotic systems have been altered around the world for flood control, navigation, power generation, and recreational demands. The Missouri River is a prime example of alterations to a lotic system. Channelization began in 1912 from the mouth of the Missouri River near St. Louis, MO (river kilometer (rkm) 0.0) upstream to Kansas City, MO (rkm 591). The first dam, Fort Peck Dam (rkm 2851), was constructed on the Missouri River in 1933 as a means to provide navigation flows throughout the low-water months (Hesse and Schmulbach, 1991). The Missouri River has been affected by anthropogenic activities ever since. The greatest of these human activities was authorized in 1944 by The Flood Control Act or Pick-Sloan Plan. This plan would be the basis for the development of the entire Missouri River basin. Today, one-third of the Missouri River is impounded, one-third is channelized, and one-third is said to have “free-flowing” reaches, but in reality one percent of the river, which is a reach 40 km upstream of Canyon Ferry Reservoir in Montana, is the only area not affected by water releases. The construction of dams has minimized flooding events and floodplain connectivity (Pegg et al., 2003). Dams have disturbed the natural hydrograph, decreased sediment load and organic matter transport, and altered water temperatures (Hesse and Sheets, 1993). All of these human activities had detrimental effects on much of the native fish and wildlife communities (Hesse and Mestl, 1993).

The Missouri River has been greatly changed by development of storage reservoirs, flood-control structures, and channelization (Hay et al. 2008). There has been notable decline in native fish populations since the channelization of the river and the construction of the dams. Hesse and Mestl (1993) noted that Blue Catfish *Ictalurus furcatus,* Flathead Catfish *Pylodictis olivaris,* and Paddlefish *Polyodon spathula* have declined since pre-impoundment conditions. Other native species that have experienced similar declines include Sauger *Sander canadensis*, Shoal Chub *Macrhybopsis hyostoma,* Sturgeon Chub *M. gelida,* Sicklefin Chub *M. meeki,* Silver Chub *M. storeriana,* Flathead Chub *Platygobio gracilis,* Plains Minnow *Hybognathus placitus,* Western Silvery Minnow *H. argyritis,* Brassy Minnow *H. hankinsoni,* and Pallid Sturgeon *Scaphirhynchus albus* (Steffensen et al., 2014abc).

The drift of the larval stage of fishes is important to their life histories (Brown and Armstrong, 1985). However, fates of larval fish for many riverine fishes are a major knowledge gap making studying larval fish essential. The study of the larval fish communities are important because habitat requirements and distribution often differ from juvenile and adult fish, and larval fish respond differently to environmental disturbances (Schlosser, 1985). Recruitment is considered a major source of ambiguity that impedes conservation and management (Quist et al., 2004). If the larval fish abundances are constant over time then the reason for decline is probably elsewhere in the life cycles of these fishes. If it does appear that larval fish are declining then some reasons for this decline should be determined. Gaining knowledge on early life stages of these fishes could help direct fisheries management in the future.

Thesis Objectives:

Little is known about the larval fish community of the drift in the Missouri River. Paradoxically, larval sampling has been conducted for many years (1983-2015, Table 1-1), yet these data have not been put into a cohesive assessment. Thus, the objectives of this study were to:

(1) Quantify temporal and spatial aspects of larval fish community composition (richness) and structure (abundance) of the drift (Chapter 2).

(2) Quantify associations of larval fish communities of the drift to different discharges of the Missouri River (Chapter 2)

(3) Quantify the larval benthic drift community. (Chapter 3)

(4) Document evidence of natural spawning and fertilization success by Pallid Sturgeon through capture of free embryos entering the drifting phase in the Nebraska portion of the Lower Missouri River (Chapter 4).

Study Area:

The Missouri River was split into four distinct segments (excluding Lewis and Clark Lake) from the Nebraska/South Dakota State Line (rkm 1407.3) to the Nebraska/Kansas state line (rkm 796.6). Segment 1 is the upper unchannelized reach of the Nebraska portion of the Missouri River from the state line with South Dakota (rkm 1407.3) to the headwaters of Lewis and Clark Lake (rkm 1334.2). This segment is characterized by a more natural river morphology, but flow is influenced by water releases from Fort Randall Dam and input from the Niobrara River. Segment 2 is the lower unchannelized portion of the Missouri river from Gavins Point Dam (rkm 1305.2) to Ponca State Park (rkm 1212.6) near Ponca, NE and also has a natural river morphology, but flow is influenced by Gavins Point Dam and the James River. Segment 3 is the upper channelized reach from Ponca State Park (rkm 1212.6) to the confluence of the Platte River (rkm 957.6) near Plattsmouth, NE. This reach of river is highly modified with wing dikes located along the inside bend and an outside bend armored with rip-rap. Segment 4 is similar to Segment 3 with wing dikes and armored revetment, but it is located in the lower channelized reach and is highly influenced by flows from the Platte River This segment runs from the confluence of the Platte River (rkm 957.6) to the Nebraska state line (rkm 796.6).

A total of 23 sites have been historically sampled for this project since 1983, but 10 sites were used for this analysis. Larval fish drift net sites used were Boyd/Verdel (rkm 1393.69), Niobrara (rkm 1351.9) in Segment 1; St. Helena (rkm 1285.5), Mulberry

Bend (rkm 1245.6), and Ponca (rkm 1212.6) in Segment 2; South Sioux City (rkm 1178), Decatur (rkm 111.9), and Blair (rkm 1044.5) in Segment 3; and Nebraska City (rkm 907.7) and Brownville (rkm 860.9) in Segment 4 (Figure 1-1).

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Table 1-1. Historic larval fish netting data from 1983 to 1994 by year with 0.50 m (A), 0.75 m (B), and 1.00 m (C) signifying diameter at mouth opening. If cell is occupied larval fish sampling was completed at that Site with that net.

Site	Site Name	Year									
		83	84	85	86	87	88	89	90	91	92
8130	Lower Boyd Co	A, B	B	B	C	C	C	C			
8140	Verdel									C	
8160	Niobrara	A, B	B	B, C	B, C	C	C	C	B, C	C	
8161	Niobrara Town Site										
8210	Gavins Pt. Tailwater	A, B	B	B	C	C	C	C	C	C	
8230	St. Helena	A, B	B	B	C	C	C	C	B, C	C	
8250	Brooky Bottom	A, B	B	B	B, C				C		
8260	Mulberry Bend										
8280	Ponca	A, B	B	B		C	C	C	C	C	
8310	S. Sioux City			B	C	C	C	C	C	C	
8320	Dakota City										
8340	Decatur				C	C	C	C	C	C	
8350	Tekamah				C	C	C	C	C		
8360	Blair				C	C	C	C			
8371	Boyer Chute Refuge										
8390	Bellevue										
8391	Hidden Lake										
8410	Plattsmouth										
8430	Nebraska City					C	C	C			
8435	Nebraska City South										
8460	Brownville					C	C	C			
8480	Rulo					C	C				
8500	Lewis and Clark Lake	A, B	B	B					C		

Table 1-1. Continued.

Site	Year 93	94	95	96	**97**	**98**	**99**	**00**	**01**	**02**
8130						C	B	B	B	
8140								B	B	B
8160	B, C					C	B	B	B	B
8161										
8210										
8230						C	B	B	B	B
8250										
8260								B	B	B
8280	C					C	B	B	B	
8310										
8320										
8340						C	B	B	B	B
8350									B	
8360	C					C	B	B	B	B
8371	B, C		C							
8390					A				B	
8391					A					
8410									B	
8430									B	B
8435										
8460	C					C	B	B	B	B
8480										
8500										

Table 1-1. Continued.

	Year										
Site	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**10**	**11**	**12**	**13**
8130											
8140	B	B		B	B	B	B				
8160	B	B	B	B	B	B	B	B	B	B	B
8161											
8210											
8230	B	B		B	B	B	B				
8250											
8260	B	B	B	B	B	B	B	B	B	B	B
8280											
8310											
8320	B								B		
8340	B	B		B	B	B	B		B		
8350											
8360	B	B	B	B	B	B	B	B	B	B	B
8371											
8390		B	B	B	B	B	B	B	B	B	B
8391											
8410											
8430	B	B	B	B							
8435	B	B									
8460	B	B		B							
8480											
8500											

Figure 1-1. Larval fish sampling locations. Boyd/Verdel and Niobrara are in Segment 1 (rkm 1407.3-1334.4) St. Helena, Mulberry Bend, and Ponca are in Segment 2 (rkm 1305.2-1212.6), South Sioux City, Decatur and Blair are in Segment 3 (rkm 1212.6-957.6), and Nebraska City and Brownville are in Segment 4 (rkm 957.6-796.6).

Chapter 2:

Larval Fish Surface Drift Net Sampling:

Abstract:

Knowledge of larval fish communities is one of the biggest gaps we have in fish research on the Missouri River. The Nebraska Game and Parks Commission sampled the surface drift of the Missouri River since the 1970s, consistently sampling from 1983-2015. These data were analyzed to (1) quantify temporal and spatial aspects of larval fish community composition (richness) and structure (abundance) of the drift of the Missouri River and to (2) correlate the larval fish community of the drift to different annual discharges of the Missouri River. Larval fish were sampled using 560-micron mesh drift nets (1983-2013) or 500-micron nets (post-2013), which were four meters long, with a 0.75-meter diameter opening. Nine sites (4 segments) along Nebraska's border of the Missouri River were sampled and larval fish were identified to family. A total of 18 unique families were captured from 1983-2015 totaling 258,868 fish, but most of the catch (N = 257,988) was comprised of eight families. Sciaenidae, (N = 155,400) was the most abundant followed by Catostomidae (N = 48,877), Clupeidae (N = 17,366), Cyprinidae (N = 28,723), Moronidae (N = 2,803), Percidae (N = 1,967), Hiodontidae (N = 1,638) and Centrarchidae (N = 1,214). The highest overall annual abundance for all fish captured occurred in 2000 (2.036 fish/m^3, SE=0.122). This analysis indicated either no trends or declining trends in relative abundance through time for most sites and taxa, except for the St. Helena Site for Clupeidae, which

exhibited an increasing trend. This same approach was used to analyze segments over time and found similar results with only three segment/family combinations yielding a positive significant trend (Catostomidae (Segment 1), Cyprinidae (Segment 3), and Percidae (Segment 3)).   Analysis of similarity (ANOSIM) found Segment 1 was dissimilar from Segment 2, Segment 3, and Segment 4. *Post hoc* similarity percentage (SIMPER) analysis showed that differences in abundance of Sciaenidae was the reason for this dissimilarity. Annual discharges were categorized as high, moderate, or low discharge years then used as a treatment factor to test if flow conditions altered the drift community. This analysis showed that the fish communities of the surface larval drift did not differ across the range of discharge variability. Sampling the abundance of the larval fish drift provides insights on the overall health and productivity of the system, and by assessing trends in the larval fish abundance of the drift, annual variations and changes in recruitment could be detected.

Introduction:

Development of rivers for energy production, navigation, and flood control has resulted in very few free-flowing river reaches in the United States of America (Benke, 1990). Construction of dams restricts the flow of sediment and water, which can alter the quantity and quality of habitat (Ligon et al., 1995). For example, the Missouri River has been impounded, channelized, narrowed, and deepened to accommodate a navigation channel. This channelization changed the Lower Missouri River into a swift channel with few areas where larval and young-of-year fish can seek refuge. Ultimately, physical alterations to rivers, such as the Missouri River, have affected the diversity and natural production of riverine fish (Scheidegger and Bain, 1995). Most riverine larval fish need free flowing rivers to drift as part of their life cycles, and interruption of these drifts could be detrimental to their survival. This river fragmentation also disrupts the drift patterns of larval fish because of the reduction of free flowing riverine habitat (Braaten et al., 2008). Species with life histories suited to high discharge, habitat heterogeneity, and long-distance migratory corridors that are synonymous with large rivers have shown considerable decline (Pracheil et al., 2013).

The Missouri River has been modified throughout most of its extent, therefore it is important to monitor the larval fish community because changes in larval fish abundance can be addressed by the variation in discharge and geomorphology at the system level (Hesse, 2009). Hesse (2009) also stated that a change in species composition can give insight on success or failure of reproduction at the species level. Drift nets have been used extensively in lotic systems to measure annual reproduction, and drift net sampling has been used to capture larval fish from the Missouri River since the 1970s (Hesse, 2009). Larval drift net sampling on an annual basis can try to help us gauge the reproductive success of fish of the Missouri River and how annual reproduction responds to these river changes.

Little is known about larval fish community dynamics in the Missouri River. Certainly not much is known about how climactic events influence relative abundance, yet there are some data available to begin to flesh out these details. Larval fish data have been collected from the Missouri River for over thirty years, but there has been an overall lack of cohesive assessment of this long term data set. Thus, the objectives of this study were to (1) quantify temporal and spatial aspects of larval fish community composition (richness) and structure (abundance) of the drift and to (2) quantify associations of larval fish communities of the drift to different hydrologic conditions of the Missouri River.

Sampling Methods:

Study Area:

Larval fish communities were assessed at site-specific and segment spatial scales. Ten of the 23 Sites across the four distinct segments of the Missouri River were used because they were consistently sampled across time (Table 1-1), and the Boyd County Site and the Verdel Site were lumped together, in Segment 1, because of close proximity to each other. Larval fish drift nets were deployed at Boyd/Verdel (rkm 1393.69) and Niobrara (rkm 1351.9) in Segment 1; St. Helena (rkm 1285.5), Mulberry Bend (rkm 1245.6), and Ponca (rkm 1212.6) in Segment 2; South Sioux City (rkm 1178), Decatur (rkm 111.9), and Blair (rkm 1044.5) in Segment 3; and Nebraska City (rkm 907.7) and Brownville (rkm 860.9) in Segment 4 (Figure 1-1).

Segment 1 is the upper unchannelized reach of the Nebraska portion of the Missouri River from the state line with South Dakota (river kilometer [rkm] 1407.3) to the headwaters of Lewis and Clarke Lake (rkm 1334.2). Segment 1 is characterized by a more natural river morphology, but is influenced by Fort Randall Dam and the Niobrara River. Segment 2 is the lower unchannelized portion of the Missouri river from Gavins Point Dam (rkm 1305.2) to Ponca State Park (rkm 1212.6) near Ponca, NE and also has a more natural river morphology, but is influenced by Gavins Point dam and the James River. Segment 3 is the upper channelized reach from Ponca State Park (rkm 1212.6) to the confluence of the Platte River (rkm 957.6) near Plattsmouth, NE. This reach of river is highly modified with wing dikes located along the inside bend and an outside bend armored with rip-rap. Segment 4 is similar to Segment 3 with wing dikes and armored revetment, but it is located in the lower channelized reach and is highly influenced by flows from the Platte River and runs from the confluence of the Platte River (rkm 957.6) to the Nebraska state line (rkm 796.6).

Data Collection:

Larval fish sampling by the Nebraska Game and Parks Commission commenced in 1983 (with some preliminary sampling conducted in the 1970s). The drift nets used for this project were 560-micron mesh nets (1983-2013) and 500-micron mesh nets (post-2013), which were four meters long, with a 0.75-m diameter opening for most of the project. However, nets with a 0.5 meter and a one meter diameter mouth opening were used intermittently in the 1980s and early 1990s (Table 1-1). Catches from nets with different diameter mouth openings and mesh sizes could be compared because they were standardized by volume of water sampled. The amount of water filtered was determined by the use of a General Oceanics (Miami, FL) or a Sea Gear (Melbourne, FL) flow meter (Figure 2-1). Nets were deployed in a paired configuration, stationary in the current, and held just below the water's surface (Hesse, 2009). The duration drift nets were deployed depended on the detritus load in the river. Each Site had 3 sampling locations; right bank, mid-river, and left bank. Samples were preserved in a 10% formalin solution to be processed at a later date. Larval fish were identified to Family.

Data Analysis:

Abundance was measured as the number of fish captured per cubic meter of water sampled. The volume of water sampled was obtained by using the following equation (Hesse, 2008):

$$\frac{3.14 \text{ x net diameter (m))}^2}{4} \text{ x distance of water sampled (m)}$$

where distance of water sampled (m) equals the flow meter counts x rotor constant (26,873)/999,999. The amount of water sampled was individually calculated but if one flow meter failed the reading from the opposite side of the boat was used as nets were run in a paired configuration. Abundance through time by segment and family was calculated and linear regression (SAS 9,4; SAS Institute, Cary, North Carolina) was used to determine if trends in the larval fish relative abundance could be identified through time at the site and segment level.

Trends in the fish community structure were also assessed by segment using PRIMER-E (Primer-E 6; Plymouth PL United Kingdom). The data were fourth-root transformed to lessen the influence of extremes in abundances (Pegg and McClelland, 2004). Data were then converted to a Bray-Curtis similarity matrix indicating samples with higher coefficients were more similar (Bray and Curtis, 1957). A two-way crossed, segment and discharge, Analysis of Similarity (ANOSIM) test was conducted to observe if communities were similar between segments or discharge classifications. The ANOSIM is similar to an analysis of variance (ANOVA) but uses permutations to decide on differences among factors (Pegg and McClelland, 2004, Bray and Curtis, 1957, Clarke and Warwick, 2001). The ANOSIM produces a probability (p-value) and a Global-R statistic. We use the Global-R to indicate how strongly similar communities are, where a Global-R value closer to one means the groups are more dissimilar and a value closer to zero indicates they are more similar (Uerling, 2017). Similarity was determined by a Global R-value between 0.0-0.3. If the Global-R value showed dissimilarities (R>0.3), then pairwise tests were performed to determine the similarities or dissimilarities among segments. We ranked annual discharge as low, moderate or high, and these classifications were used as a factor to see if the fish community differed with different discharges. Classifications were determined by the 25th quartile years considered low water years, and the 75th quartile years as high water years for the duration of the project. All of the years in the mid-range were considered moderate discharge years (Table 2-1). The United States Geological Survey (USGS) gauge USGS06486000 from Sioux City, IA (rkm 1178) was used for Segments 1-3 and the gauge at Nebraska City, NE USGS06807000 (rkm 907.7) was used for Segment 4. These two gauges were selected because they had the longest running historical data which encompassed all of the years of the study.

Similarity percentage (SIMPER) analysis was also conducted to determine which families contributed the most to differences among communities across segments. The SIMPER procedure compares two groups of samples, identifying which is more influential in each comparison (Clarke and Warwick, 2001). The relationships between the communities were then visualized using a multi-dimensional scaling (MDS) plot.

Results:

A total of 258,868 larval fish were collected from the ten sites on the Missouri River (Table 2-2). Sciaenidae was the most prevalent family collected (N = 155,400) followed by Catostomidae (N = 48,877), Cyprinidae (N = 28,723) Clupeidae (N = 17,366), Moronidae (N = 2,803), Percidae (N = 1,967), Hiodontidae (N = 1,638) and Centrarchidae (N = 1,214; Table 2-2). The highest overall annual abundance for all fish captured was in 2000 (2.036 fish/m^3, SE±0.122; Figure 2-2).

Individual linear regression models showed that 19 of the 78 site/family combinations were significant (alpha = 0.05), but all had very low R^2 values (Table 2-3). Clupeidae at the St. Helena Site displayed the only positive slope (R^2 = 0.019, (slope = 0.002; Figure 2-3). The remaining 18 significant site/family combinations exhibited negative trends (Table 2-3). The highest abundance for Segment 1 was in 1987 (0.234 fish/m^3, SE ± 0.022), Segment 2 was in 1986 (1.277 fish/m^3, SE ± 0.087), Segment 3 was in 1986 (3.689 fish/m^3, SE ± 0.0.290), and Segment 4 was in 2000 (7.419 fish/m^3, SE ± 0.471; Figure 2-4). Abundances by family and segment through time can be found in Appendix A (Figures A-1-A-18).

The linear regression models analyzing segments through time displayed 12 of the 32 segment/family combinations had alpha $\leq$ 0.05, but all had very low R^2 values (Table 2-4). Three of the segment/family combinations exhibited a positive slope (Catostomidae (Segment 1, R^2 = 0.0130, m = 0.0015), Cyprinidae (Segment 3 R^2 = 0.0113, m = 0.0024), and Percidae (Segment 3, R^2 = 0.0051, m = 0.0004). All of the remaining regression figures can be seen in Appendix A (Figures A-19-A-44).

Segment and discharge conditions (high, moderate, and low) showed no dissimilarities in fish community structure (Global R = 0.067, p = 0.079) when flow was used as the factor. When Segment was used as the factor the Global R value was slightly lower than the 0.3 threshold (Global R = 0.267), but the p-value was significant (p = 0.001), therefore the pairwise comparisons between the segments were examined for additional details. Pairwise tests revealed Segment 1 was dissimilar to Segments 2, 3, and 4, but all other segments were not dissimilar to each other (Table 2-5). Sciaenidae contributed most to the differences among community structure in Segments 1 and 2 (Table 2-6), between Segments 1 and 3 (Table2- 7), and between Segments 1 and 4 (Table 2-8). When Sciaenidae was removed from the analysis there were no dissimilarities between the segments (Global R = 0.184). The MDS plot can be seen in Figure 2-5 where Segment 1 is removed from the other Segments.

Discussion:

Sciaenidae larvae were very prevalent throughout the system, so it was not surprising that it was the most abundant family. Conversely, it was unexpected to find that they made up nearly 61% of the total larval fish collected. Holland (1986) found that eggs and larvae of Sciaenidae dominate collections made in the main channel, whereas other larval fishes were more abundant in backwater habitats. With the decline in backwater and floodplain areas along the altered river, this lack of rearing habitat for other fishes could be one of the reasons that Sciaenidae catches were so much higher.

Adult catches of many native species have been declining over the last several years (Steffensen et al. 2014abc), and these trends were expected in the larval drift as well. Though our analysis displayed negative trends in some of the families, our results were somewhat inconclusive. Identifying larval fish to a lower taxonomic level might show more definitive results. For example, researchers have noticed an increase of Silver Carp *Hypophthalmichthys molitrix* and Bighead Carp *H. nobilis* in the Missouri River. Schrank et al. (2001) found that Bighead Carp spawned in mid to late June and early July which is also when samples were collected for this project, so these species might be inflating the numbers of Cyprinidae larvae, making it appear that they are remaining relatively steady, when quite possibly native Cyprinid larvae abundances are declining.

An ANOSIM comparing the high, moderate, and low flow categories did not show dissimilarities, and with there being major high water events during the time of this project (i.e., 1993 and 2011) it was somewhat surprising that this did not show differences in the larval fish communities of the drift. With connectivity to the floodplain and backwater areas, an increase in abundance of certain families or quite possibly a decrease in others would seem appropriate, because of the different families that utilize these different habitats. However, this was not the case, and these discharge events did not have much effect at least at the family level.

Pairwise tests comparing segments showed that Segment 1 was dissimilar from the other segments. The SIMPER analysis shows that Sciaenidae numbers carried the most weight when discerning these differences. With the high numbers of Sciaenidae collected in Segments 2 - 4 and low numbers collected in Segment 1 over the years of this project, it is not surprising that these fish are driving the differences in the fish communities. Cada and Hergenrader (1980), suggested that the conditions in the unchannelized river were more favorable to Sciaenidae populations as opposed to those in the channelized river, but this contradicted what we observed. However, Walburg (1971) found that a maximum of up to 10 million larval Sciaenidae are entrained through Gavins Point Dam daily. This leads to the conclusion that Lewis and Clark Lake could be more responsible for the higher production of Sciaenidae throughout the downstream reaches of the river. The high number of young-of-year Sciaenidae captured by the Nebraska Game and Parks Commission’s lake trawls on Lewis and Clark Lake solidifies these views (Mestl, 2017). Segment 1 differs as the hypo-limnetic releases of water out of Ft. Randall Dam in South Dakota slow the rise in water temperatures and this likely affects the production of Sciaenidae. Also, because of these near bottom releases, very few drifting small fish are lost from Lake Francis Case through Ft. Randall Dam (Walburg, 1971). This could be another reason Sciaenidae, which have a buoyant yolk-sac larval stage (Holland, 1986), have lower numbers in Segment 1. Releases from Big Bend Dam in South Dakota are similar to Gavins Point with higher summer temperatures (USACE, 2008), and Smith and Brown (2002) found similar results with Sciaenidae being the second most abundant species entrained through Big Bend Dam. A post hoc analysis where Sciaenidae data were removed from the results showed that the segments were not dissimilar (Global R = 0.184). This adds more validity to the case that the dissimilarities were caused by the lack of Sciaenidae in Segment 1.

Long term data-sets such as this one are important when monitoring an ever changing system such as the Missouri River. Even though the results were not as definitive as expected, it did show many of the family abundances stayed somewhat constant throughout the years. This is important because it provides a good baseline to look back on if this project would be continued in the future. This demonstrated how resilient these fish are that with as many changes as the Missouri River has endured over the years, the larval fish abundances in the drift stayed somewhat constant. Assuming the adult fish are declining and the larval fish abundances are remaining somewhat constant, the limiting factor might be habitat or flow interruption that could be impacting other aspects of their life history. By having many years of data, researchers are able to analyze if there are changes in abundance or richness of certain organisms.

Sampling the larval fish drift community is essential in maintaining a grasp on the spawning success of certain fishes. Although larval drift sampling is important, it is just one step in understanding the life cycle of these fishes and by no means suggests that sufficient growth and survival through the larval stage occurred to successfully recruit to juvenile or adult life stages (Braaten and Guy, 2004). Therefore, all life stages need to be captured to adequately assess the diversity of the system, including larval fish.

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Table 2-1. Missouri River discharge classifications from Nebraska City, Nebraska (rkm 907.7) and Sioux City, Iowa (rkm 1178). Classifications were determined by the 25th quartile years being considered low water years, and the 75th quartile years being considered high water years. All of the years in the mid-range were considered moderate discharge years.

Year	Sioux City Gage USGS 06486000	NE City Gage USGS 06807000
1983	High	Moderate
1984	High	Moderate
1985	Moderate	Moderate
1986	Moderate	Moderate
1987	Moderate	Moderate
1988	Moderate	Moderate
1989	Moderate	Low
1990	Low	Low
1991	Low	Low
1992	Low	Low
1993	Moderate	Moderate
1994	Moderate	Moderate
1995	High	Moderate
1996	High	Moderate
1997	High	High
1998	High	Moderate
1999	High	Moderate
2000	Moderate	Moderate
2001	Moderate	Moderate
2002	Moderate	Low
2003	Moderate	Low
2004	Moderate	Moderate
2005	Low	Low
2006	Low	Low
2007	Low	Moderate
2008	Low	Moderate
2009	Moderate	Moderate
2010	High	Moderate
2011	High	High
2012	High	Moderate
2013	Moderate	Moderate
2014	Moderate	Moderate
2015	Moderate	Moderate

Table 2-2. Total larval fish by family, collected using surface larval drift nets from ten sites on the Missouri River from 1983 to 2015. The asterisk denotes the eight Families with the highest overall catches.

	Segment 1	Segment 1	Segment 2	Segment 2	Segment 2
	Boyd/Verdel	Niobrara	St. Helena	Mulberry	Ponca
Sciaenidae*	63	494	22947	9709	11734
Catostomidae*	2516	5054	5757	1724	2385
Cyprinidae*	75	1070	3911	505	1624
Clupeidae*	16	32	4229	2546	6426
Moronidae*	9	29	1114	294	888
Percidae*	56	175	363	311	88
Hiodontidae*	0	5	3	53	0
Centrarchidae*	7	114	187	122	481
Unidentified	0	15	0	28	0
Polyodontidae	34	67	1	4	2
Uni. Strg/pdlf	0	23	0	10	0
Acipenseridae	0	2	1	2	0
Amiidae	0	0	28	0	0
Ictaluridae	0	0	2	0	0
Lepisosteidae	0	0	1	0	3
Esocidae	0	6	0	0	0
Gasterosteidae	0	0	0	0	0
Gadidae	0	0	2	0	0
Osmeridae	0	0	0	0	0
Atherinopsidae	0	0	0	0	0
Total	2776	7086	38546	15308	23631

Table 2-2. Continued.

	Segment 3	Segment 3	Segment 3	Segment 4	Segment 4	
	S. Sioux City	Decatur	Blair	NE City	Brownville	Total
Sciaenidae*	19884	28702	40302	11676	9889	155400
Catostomidae*	2220	7108	10208	2163	9742	48877
Cyprinidae*	392	779	1714	3423	12230	28723
Clupeidae*	1109	1955	864	94	95	17366
Moronidae*	88	183	108	34	56	2803
Percidae*	41	291	479	60	103	1967
Hiodontidae*	2	53	186	745	591	1638
Centrarchidae*	69	141	3053	13	27	1214
					Subtotal	257988
Unidentified	0	0	47	184	288	562
Polyodontidae	0	17	17	8	20	170
Uni. Strg/pdlf	0	0	4	3	2	42
Acipenseridae	0	4	4	10	6	29
Amiidae	0	0	0	0	0	28
Ictaluridae	0	1	4	1	9	17
Lepisosteidae	0	0	1	1	10	16
Esocidae	0	0	0	0	0	6
Gasterosteidae	0	1	3	0	1	5
Gadidae	0	0	0	0	0	2
Osmeridae	0	2	0	0	0	2
Atherinopsidae	0	0	0	0	1	1
Total	23805	39237	56994	18415	33070	258868

Table 2-3. Results of regression analysis including R2, slope (m) and p-value for the eight most abundant families by each site, as well as all eight families together by each site from surface larval drift net sampling in the Missouri River from 1983 to 2015. All significant sight/family combinations show a negative regression slope except for clupeidae at St. Helena (light grey). Bold values show a significant p-value (alpha = 0.05)

	Boyd/Verdel (8135)	Niobrara (8160)	St. Helena (8230)	Mulberry Bend(8260)	Ponca (8280)
Catostomidae	R^2=0.0001 m=0.0001 p=0.9166	R^2=0.0043 m=0.0007 p=0.0982	R^2=0.0001 m=0.0001 p=0.8586	R^2=0.0041 m=0.0009 p=0.2869	R^2=0.0011 m=0.0007 p=0.6438
Centrarchidae	**R^2=0.0360** **m=-0.00002** **p=0.0063**	R^2=0.0016 m=0.00001 p=0.3113	R^2=0.0004 m=0.00002 p=0.7001	R^2=0.0008 m=-0.00005 p=0.6427	**R^2=0.0467** **m=-0.0014** **p=0.0019**
Clupeidae	R^2=0.0016 m=0.000009 p=0.5727	R^2=0.0016 m=-0.000004 p=0.3184	**R^2=0.0190** **m=0.0015** **p=0.0077**	**R^2=0.0376** **m=-0.0063** **p=0.0011**	R^2=0.0044 m=-0.0118 p=0.3424
Cyprinidae	R^2=0.0003 m=-0.000009 p=0.8160	R^2=0.0017 m=0.0002 p=0.2943	**R^2=0.0199** **m=-0.0015** **p=0.0064**	R^2=0.0006 m=0.0001 p=0.6899	**R^2=0.0200** **m=-0.0024** **p=0.0432**
Hiodontidae	N/A	R^2=0.0042 m=0.000007 p=0.1002	R^2=0.0003 m=-0.000002 p=0.7582	R^2=0.0068 m=0.00006 p=0.1673	N/A
Moronidae	**R^2=0.0217** **m=-0.00001** **p=0.0348**	R^2=0.0024 m=-0.000005 p=0.2124	R^2=0.0014 m=-0.0001 p=0.4754	R^2=0.0029 m=0.0004 p=0.3656	**R^2=0.0442** **m=-0.0068** **p=0.0025**
Percidae	R^2=0.0021 m=-0.00003 p=0.5105	R^2=0.0002 m=-0.000007 p=.07553	R^2=0.0081 m=-0.0001 p=0.0826	R^2=0.0017 m=0.00009 p=0.4877	R^2=0.0093 m=0.0001 p=0.1689
Scianidae	R^2=0.0006 m=-0.00002 p=0.7176	R^2=0.0008 m=-0.00008 p=0.4752	**R^2=0.0420** **m=-0.0191** **p=<.001**	R^2=0.0071 m=-0.0061 p=0.1607	R^2=0.0058 m=-0.0060 p=0.2774
All Fish	R^2=0.0002 m=-0.00002 p=0.8015	R^2=0.0030 m=-0.0001 p=0.2044	R^2=0.0043 m=-0.0006 p=0.2011	R^2=0.0029 m=-0.0005 p=0.3553	R^2=0.0017 m=-0.0006 p=0.4958

Table 2-3 Continued.

	South Sioux City (8310)	Decatur (8340)	Blair (8360)	NE City (8430)	Brownville (8460)
Catostomidae	**R^2=0.0613**	R^2=0.0000	R^2=0.0030	R^2=0.0008	R^2=0.0046
	m=-0.0215	m=-0.0001	m=0.0043	m=-0.0003	m=-0.0259
	p=0.0019	p=0.9613	p=0.2763	p=0.7141	p=0.2821
Centrarchidae	**R^2=0.1009**	R^2=0.0036	**R^2=0.0118**	R^2=0.0043	R^2=0.0004
	m=-0.0010	m=-0.00001	**m=-0.00004**	m=0.00002	m=0.000009
	p=<.0001	p=0.2792	**p=0.0295**	p=0.3887	p=0.7460
Clupeidae	R^2=0.0157	R^2=0.0004	R^2=0.0052	**R^2=0.0261**	R^2=0.0086
	m=0.0277	m=-0.0005	m=0.0011	**m=-0.0002**	m=-0.0001
	p=0.1199	p=0.7006	p=0.1490	**p=0.0336**	p=0.1398
Cyprinidae	R^2=0.0062	R^2=0.0074	R^2=0.0021	R^2=0.0159	R^2=0.0047
	m=-0.0018	m=0.0009	p=0.0014	m=-0.0104	m=-0.0322
	p=0.3316	p=0.1189	p=0.3576	p=0.0986	p=0.2768
Hiodontidae	R^2=0.0014	R^2=0.0089	R^2=0.0028	**R^2=0.0983**	R^2=0.0129
	m=0.00002	m=0.0001	m=-0.00005	**m=-0.0033**	m=-0.0014
	p=0.6472	p=0.0860	p=0.2954	**p=<.0001**	p=0.0701
Moronidae	R^2=0.0212	R^2=0.0027	R^2=0.0032	**R^2=0.0374**	**R^2=0.0223**
	m=-0.0011	m=-0.00009	m=-0.00004	**m=-0.00009**	**m=-0.0001**
	p=0.0704	p=0.3451	p=0.2576	**p=0.0107**	**p=0.0169**
Percidae	**R^2=0.0722**	R^2=0.0078	R^2=0.0030	R^2=0.0001	R^2=0.0117
	m=-0.0009	m=0.0002	m=0.0006	m=-0.000008	m=0.0002
	p=0.0007	p=0.1089	p=0.2718	p=0.8827	p=0.0837
Scianidae	R^2=0.0244	**R^2=0.0182**	R^2=0.0021	R^2=0.0047	R^2=0.0055
	m=-0.2127	**m=-0.0262**	m=0.0078	m=-0.0084	m=-0.0047
	p=0.0525	**p=0.0140**	p=0.3660	p=0.3720	p=0.2366
All Fish	R^2=0.0025	**R^2=0.0123**	R^2=0.0012	R^2=0.0000	R^2=0.0000
	m=-0.0092	**m=-0.0034**	m=0.0005	m=0.00005	m=-0.00009
	p=0.5461	**p=0.0424**	p=0.4668	p=0.9548	p=0.9661

Table 2-4. Results of regression analysis including R^2, slope, and p-value for the eight most abundance Families by segment for surface larval drift net sampling in the Missouri River from 1983 to 2015. All significant segment and family combinations exhibited a negative regression slope except for the Catostomidae (Segment 1), Cyprinidae (Segment 3), and Percidae (Segment 3) (shaded light grey). Values in bold have a significant p-value (alpha=.05).

	Segment 1	Segment 2	Segment 3	Segment 4
Catostomidae	**R^2=0.0130**	**R^2=0.0172**	R^2=0.0036	R^2=0.0052
	m=0.0015	**m=-0.0025**	m=0.0028	m=-0.02140
	p=0.0061	**p=<0.0001**	p=0.0542	p=0.1435
Centrarchidae	R^2=0.0005	R^2=0.0106	R^2=0.0001	R^2=0.0003
	m=<0.0001	m=-0.0002	m=<0.0001	m=-<0.0001
	p=0.5789	p=0.0011	p=0.8081	p=0.7466
Clupeidae	R^2=0.0063	R^2=0.0030	R^2=0.0010	**R^2=0.0171**
	m=-0.0001	m=--0.0028	m=-0.0005	**m=-0.0001**
	p=0.0556	p=0.0839	p=0.3017	**p=0.0077**
Cyprinidae	R^2=0.0050	**R^2=0.0367**	**R^2=0.0113**	R^2=0.0062
	m=0.0004	**m=-0.0019**	**m=0.0024**	m=-0.0290
	p=0.0878	**p=<0.0001**	**p=0.0006**	p=0.1096
Hiodontidae	R^2=0.0065	**R^2=0.0068**	R^2=0.0003	**R^2=0.0332**
	m=<0.0001	**m=-0.0001**	m=<0.0001	**m=-0.0021**
	p=0.0517	**p=0.0092**	p=0.0638	**p=0.0.0002**
Moronidae	R^2=0.0050	**R^2=0.0103**	**R^2=0.00078**	**R^2=0.0269**
	m=-0.00001	**m=-0.0011**	**m=-0.0001**	**m=-0.0001**
	p=0.0877	**p=0.0013**	**p=0.0048**	**p=0.0008**
Percidae	R^2=0.0003	R^2=0.0000	**R^2=0.0051**	R^2=0.0042
	m=-<0.0001	m=-0.00003	**m=0.0004**	m=0.0001
	p=0.6733	p=0.9358	**p=0.0222**	p=0.1890
Scianidae	R^2=0.0007	**R^2=0.0154**	**R^2=0.0084**	R^2=0.0054
	m=-0.00008	**m=-0.0095**	**m=-0.0140**	m=-0.0067
	p=0.5296	**p=<0.0001**	**p=0.0033**	p=0.1344

Table 2-5. Results of the pairwise year and segment ANOSIM comparing the larval fish communities of the drift in the Missouri River by segment for all years (1983 to 2015). Significant dissimilarities (R>3, p<0.05) are denoted by an asterisk.

Segments	R-Statistic	p-value
1 vs 2*	0.475	0.001
1 vs 3*	0.410	0.001
1 vs 4*	0.415	0.01
2 vs 3	0.064	0.004
2 vs 4	0.250	0.001
3 vs 4	0.044	0.220

Table 2-6. SIMPER analysis of Segment 1 vs. Segment 2 larval fish communities of the drift in the Missouri River to determine which families contribute the most weight toward the dissimilarities of the 2 segments.

	Segment 1	Segment 2	
Family	Average Abundance	Average Abundance	Contributing %
Sciaenidae	0.10	0.57	29
Clupeidae	0.05	0.26	12
Catostomidae	0.34	0.41	12
Cyprinidae	0.21	0.33	11
Moronidae	0.04	0.19	10
Percidae	0.13	0.18	8
Centrarchidae	0.08	0.16	7

Table 2-7. SIMPER analysis of Segment 1 vs. Segment 3 larval fish communities of the drift in the Missouri River to determine which families contribute the most weight toward the dissimilarities of the two segments.

	Segment 1	Segment 3	
Family	Average Abundance	Average Abundance	Contributing %
Sciaenidae	0.10	0.66	30
Catostomidae	0.34	0.54	14
Cyprinidae	0.21	0.34	12
Clupeidae	0.04	0.22	10
Percidae	0.13	0.21	8
Centrarchidae	0.08	0.13	7
Moronidae	0.04	0.13	7
Polyodontidae	0.07	0.04	5

Table 2-8. SIMPER analysis of Segment 1 vs. Segment 4 larval fish communities of the drift in the Missouri River to determine which families contribute the most weight toward the dissimilarities of the two segments.

	Segment 1	Segment 4	
Family	Average Abundance	Average Abundance	Contributing %
Sciaenidae	0.10	0.60	26
Cyprinidae	0.21	0.48	14
Catostomidae	0.34	0.55	13
Hiodontidae	0.01	0.24	10
Clupeidae	0.04	0.16	7
Moronidae	0.04	0.12	7
Percidae	0.13	0.17	6
Polyodontidae	0.07	0.07	5
Centrarchidae	0.08	0.08	5

Figure 2-1. Drift net used for larval fish sampling. Net is equipped with a flow meter and 45 kg bomb weight to hold it in the current.

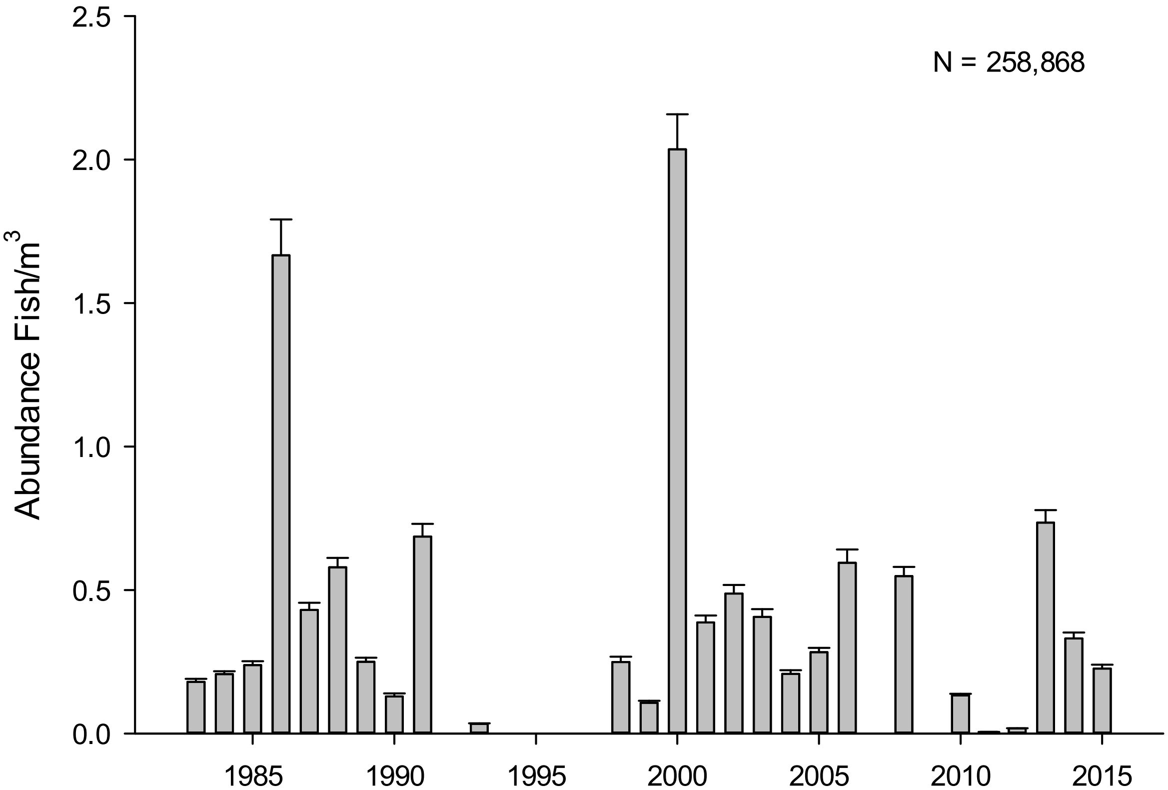

Figure 2-2. Annual abundance of larval fish collected by surface larval drift nets in the Missouri river from 1983 to 2015 for all sites and segments combined. Segments 1 and 2 have no data from the years 1992, 1994 to 1997, 2007, and 2009. Segment 3 has no data from the years 1983 to 1984, 1992, 1994 to 1997, 2007, and 2009. Segment 4 has no data from the years 1983 to 1986, 1990 to 1992, 1994 to 1997, 2007 to 2013.

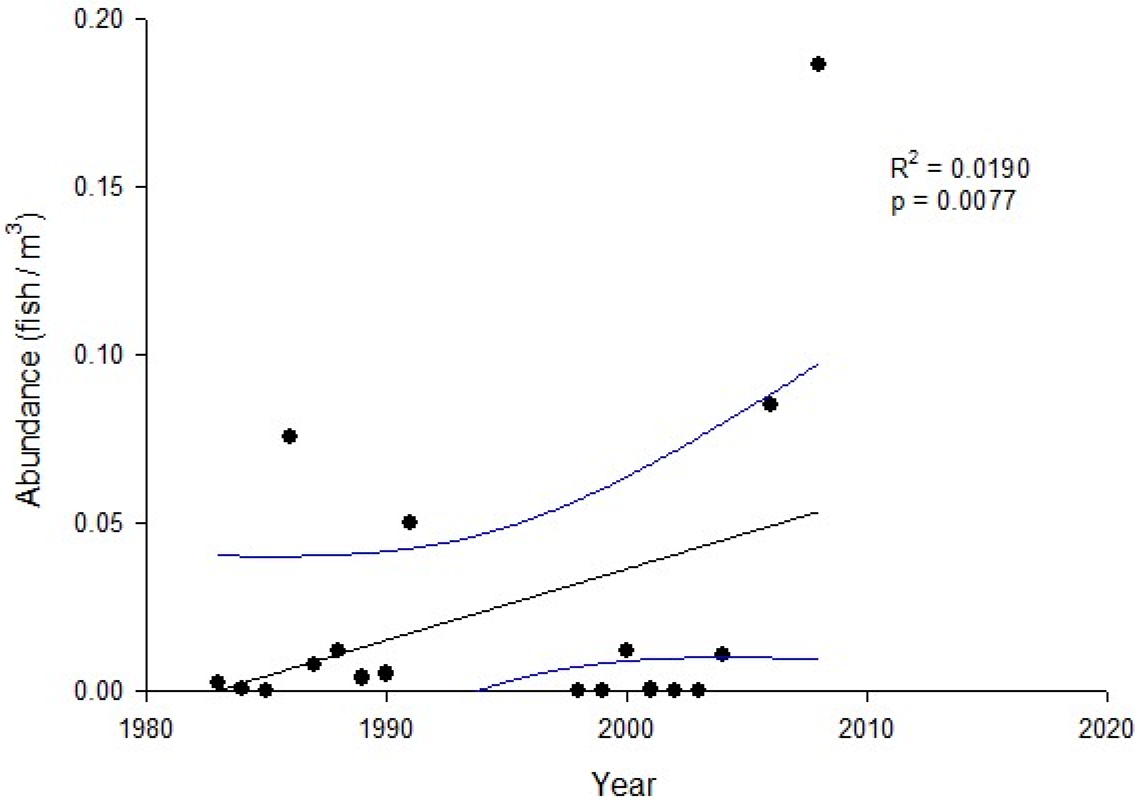

Figure 2-3. Regression analysis for Clupeidae at the St. Helena Site from drift net sampling on the Missouri River. Bands indicate 95% confidence intervals.

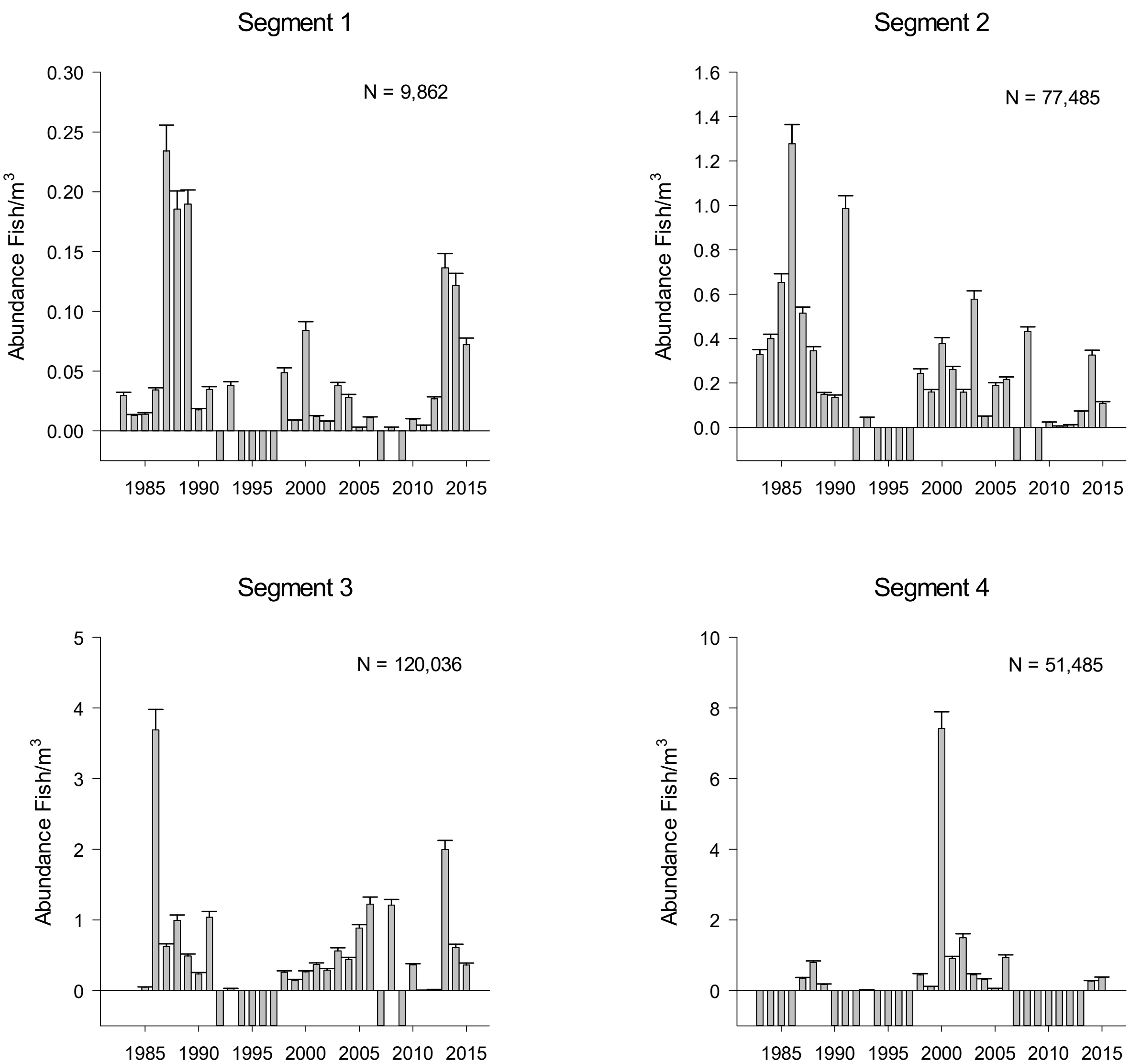

Figure 2-4. Segments 1-4 larval fish annual abundance from 1983 to 2015 from surface larval drift net sampling in the Missouri River. Negative values indicate years with no data. Values on the y-axis are variable.

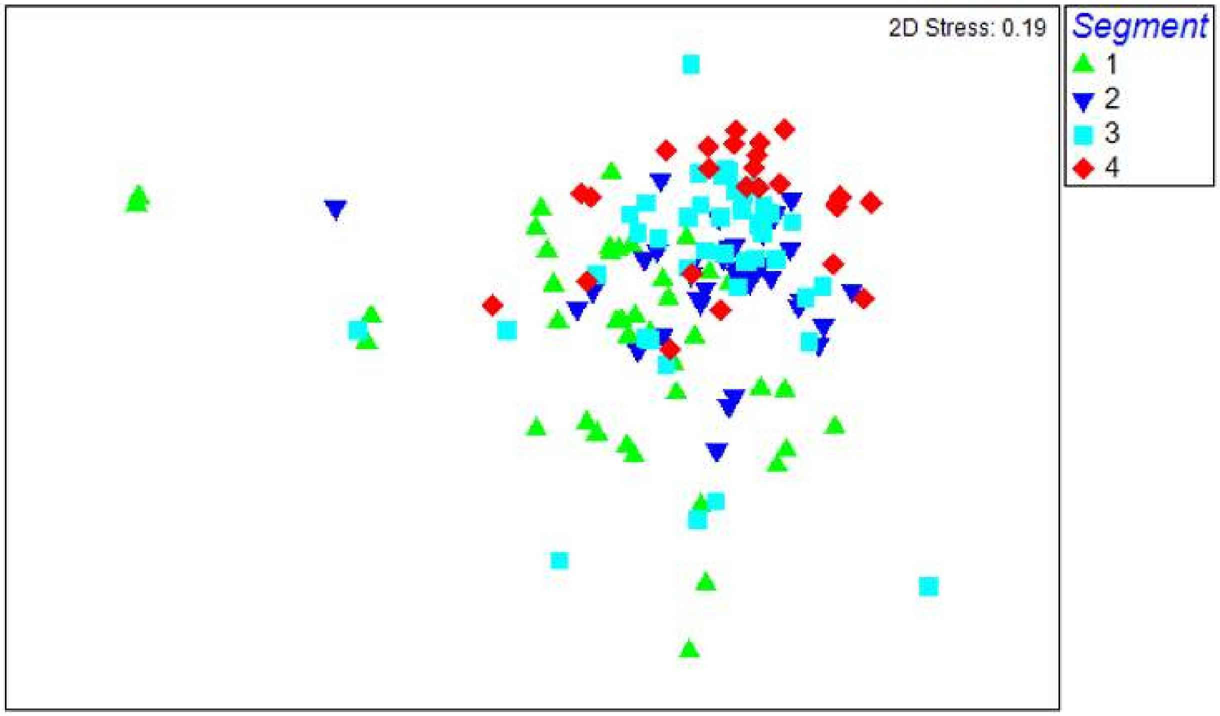

Figure 2-5. Multi-Dimensional Scaling (MDS) plot depicting larval fish communities of the drift on the Missouri River for all segments from 1983 to 2015. The fish community from Segment 1 (green triangles) is dissimilar from the other segments.

Chapter 3:

Quantifying the Benthic Drift of the Lower Missouri River

Abstract:

Many of the native benthic fish species in the Missouri River have been declining over the last several years including the federally endangered Pallid Sturgeon, *Scaphirhynchus albus*, and the Nebraska state listed endangered Sturgeon Chub, *Macrhybopsis* gelida. Sampling the larval benthic fish community has been minimal in the lower Missouri River as this sampling method can be dangerous and generally requires a lot of time and effort, but it is important so that annual reproduction and recruitment can be monitored. Therefore, the objective of this project was to quantify the larval fish benthic drift community, and determine if Pallid Sturgeon reproduction is occurring in the lower Missouri River. Nets were deployed near Nebraska City, NE (rkm 907.6) and near Niobrara, NE (rkm 1351.9) from May to July 2014 and 2015. A total of 175 benthic drift nets were deployed at the Nebraska City Site in 2014 and 2015 yielding 347 fish from nine unique families and 236 unidentified eggs. A total of 20 nets were deployed at the Niobrara Site, capturing 18 total fish from 4 different Families. The most abundant family captured by year and site was Sciaenidae from the Nebraska City Site in 2015 and Cyprinidae in 2014 also from the Nebraska City site. Weekly calculations were completed to see how abundances changed over time at the Nebraska City Site. Cyprinidae from the week of July 8, 2014 had the highest weekly abundance with Sciaenidae from the same week a close second. Notable catches include a free-

embryo Pallid Sturgeon from the Nebraska City Site in 2014 and a Shovelnose Sturgeon *Scaphirhynchus platorynchus* from the Niobrara Site in 2014. Larval Shovelnose Sturgeon recruitment has been lacking in this stretch of the river and this catch could demonstrate the importance of the Niobrara River, a tributary just slightly upstream of the site. With an ever changing system such as the Missouri River it is important to maintain an annual benthic larval drift study to gain an understanding of how abundances differ yearly.

Introduction:

Ichthyofaunal groups in lotic systems have been suffering from human disturbances throughout the United States of America in recent history (Onorato et al., 2000). Many large river systems have been modified and habitat availability and diversity has been lost, spawning sites have been disrupted or eliminated, spawning migrations as well as drift distances have been interrupted, and many nursery habitats have been altered or eliminated due to impoundments, channelization, or other anthropogenic activities (Hesse and Sheets, 1993, Secor et al. 2002). This holds true for the Missouri River, which has experienced many of these anthropogenic actions, causing a decline in native fish populations. Abundances of many benthic species found in the Missouri River such as Blue Catfish *Ictalurus furcatus,* Flathead Catfish *Pylodictis olivaris*, Paddlefish *Polyodon spathula,* Sauger *Sander canadensis*, Shoal Chub *Macrhybopsis hyostoma,* Sturgeon Chub *M. gelida,* Sicklefin Chub *M. meeki,* Silver Chub *M. storeriana,* Flathead Chub *Platygobio gracilis,* Plains Minnow *Hybognathus placitus,* Western Silvery Minnow *H. argyritis,* Brassy Minnow *H. hankinsoni,* and Pallid Sturgeon *Scaphirhynchus albus* have declined following impoundment and channelization (Hesse and Mestl 1993, Steffensen et al. 2014abc). Furthermore, these modifications have disconnected the Missouri River from its historic floodplain, disrupting the natural hydrograph (Steffensen et al., 2014abc).

Young et al. (1997) listed 26 species of fish that were historically present in the benthic fish community of the Lower Missouri River. These include many shiners and minnows (Cyprinidae) as well as suckers (Catostomidae), catfish (Ictaluridae), and Freshwater Drum *Applodinotus grunniens* (Sciaenidae). This list also includes the rarely found Burbot *Lota lota*, (Gadidae) and the endangered Pallid Sturgeon (Acipenseridae). After impoundment and channelization of the Missouri River the Pallid Sturgeon declined and a larval Burbot has not been sampled since 1985. However, Perkin et al. (2015), in a study of fish community changes caused by fragmentation and dewatering showed a shift from more abundant pelagic spawning species to higher abundances of benthic spawning species displaying that the benthic species seemed to cope with these adverse conditions better at least in a smaller stream setting. Conversely, Onorato et al. (2000) found that fish communities changed entirely from historic catches to recent catches after extensive urban development in an Alabama watershed. Similarly, Gandotra and Sharma, (2015) showed that freshwater fish biodiversity loss is a major threat in a stream in India, and the number and types of fish vary with changes in food availability and habitat such as spawning areas, water quality, and flow. Also, in a pasture region in Southeastern Brazil, Casatti et al. (2006) found that areas with less physical habitat disruptions showed higher species richness than more disturbed areas.

With a system such as the Missouri River that continues to be influenced by human actions, it is important to gain an understanding of the benthic larval drift community so that we can document annual reproduction and trends in native and non-native fish abundance. However, there has not been much sampling of the benthic larval fish community as this can be dangerous and very time consuming. Therefore the objective of this project was to quantify the benthic larval drift community, as well as determine if Pallid Sturgeon reproduction is occurring in the lower Missouri River.

Methods:

Study Sites:

The original site for this project was along the outside bend near Nebraska City, NE (rkm 907.6; Figure 3-1) and is where most of the sampling occurred. However, Acipenserformes larvae were detected in the surface samples at the Niobrara Site (rkm 1351.9) during concurrent field work (Figure 3-1). Therefore, a small set of samples were completed at this site in 2014 and 2015.

Sampling methods:

The drift nets used for this study were 750-micron conical nets, 1.75 meters long, with a 0.50 meter opening. Paired nets were deployed from an anchored boat and held stationary on the river bed with the aid of a 45 kg weighted bomb (Figure 3-2). These methods were similar to United States Geological Survey (USGS) project methods (Delonay et al. 2016a) It was deemed unsafe to sample with our boat size and equipment if the river discharge exceeded 1,699 m^3/s (60,000 f^3/s) or if there was too much large, woody debris in the river. We quantified “too much” woody debris by a visual assessment of the river and the debris that was floating on the water surface.

Nets were deployed between 2 and 20 minutes, depending on the sediment or detritus load in the river. The amount of water filtered was measured using a General Oceanics flow meter. Samples were processed immediately following collection and any larval fish resembling Acipenserformes larvae (usually Sturgeon or Paddlefish) were preserved in a 70% ETOH solution. These samples were then further processed for genetic identification by Dr. Ed Heist at Southern Illinois University. The remainder of the bulk samples were preserved in a 10% formalin solution and taken back to the lab where they were sorted and identified to the lowest possible taxa.

Data Analysis:

Abundance was measured as the number of fish captured per cubic meter of water sampled. The volume of water sampled was obtained by using the following equation (Hesse, 2008):

$$\frac{3.14 \times (.50\text{-net diameter (m)})^2}{4} \times \text{distance of water sampled (m)}$$

where distance of water sampled (m) equals the flow meter counts x rotor constant (26,873)/999,999. The amount of water sampled was individually calculated but if one flow meter failed the reading from the opposite side of the boat was used.

Abundance was calculated by family as that was the best resolution to which most larval fish could be identified. Weekly abundances were calculated at the Nebraska City Site by family to see how they changed through time. The Niobrara Site was not included in this analysis due to low numbers of fish captured. Temperature data from the USGS Nebraska City gage (USGS 06807000 Missouri River at Nebraska City) was observed to see if differences in temperature matched changes in abundance over time. A simple correlation analysis was performed to see if there was a relationship between abundance and temperature. Average weekly temperature was calculated and used to see if larval fish abundance correlated with temperature. The four families (Acipenseridae, Catostomidae, Cyprinidae, and Polyodontidae) that had captures throughout most weeks were used for this analysis.

Results:

Sampling occurred from May 13, 2014 through July 8, 2014, and May 13, 2015 through July 7, 2015 in discharges up to 1,699 m^3/s (60,000 f^3/s) and velocities ranging from 0.94 m/s to 1.95 m/s (bottom velocity) and depths up to 7.4 m along the outside bend. Velocities were not measured if the water was too deep and the flow meter could not maintain a perpendicular orientation to the surface when attempting to measure velocity at the bottom of the water column.

A total of 175 benthic larval drift nets were deployed in 2014 (N=87) and 2015 (N=88) resulting in 19,851 m^3 of water being sampled at the Nebraska City Site. A total of 347 fish from nine families and 236 unidentified eggs were captured at this site (Table 3-1). In 2014, 189 fish (0.0216 fish/m^3, SE $\pm$ 0.0034) and 2 unidentified eggs were captured in 87 deployments, while 158 fish (0.0163 fish/m^3, SE$\pm$ 0.00145) and 234 eggs were captured in 88 deployments during 2015.

There were 20 benthic larval drift nets deployed at the Niobrara Site in 2014 (N=12) and 2015 (N=8) for a total of 3,486 m^3 of water being filtered capturing 18 total fish. In 2014, 9 fish (0.0024 fish/m^3, SE$\pm$0.0003) were captured in 12 deployments, while, 8 deployments yielded 9 fish (0.0092 fish/m^3, SE$\pm$0.0010) during 2015 (Figure 3-3; Table 3-1).

The most abundant family sampled was Sciaenidae from the Nebraska City Site in 2015 (n=88) (0.0079 fish/m^3, SE$\pm$0.0026) (Figure 3-4), with Cyprinidae in 2014 from the Nebraska City Site being the second most abundant (n=43) (0.0055 fish/m^3, SE$\pm$0.0029) (Figure 3-4). The most abundant families captured in 2014 from each site were Polyodontidae (n=6) (0.0016 fish/m^3, SE$\pm$0.0012) from the Niobrara Site (Figure 3-5) and Cyprinidae (n=43) (0.0055 fish/m^3, SE$\pm$0.0029) from the Nebraska City Site (Figure 3-4). The most abundant Families sampled in 2015 from each Site were Catostomidae (n=5) (0.0049 fish/m^3, SE$\pm$0.0057) from Niobrara (Figure 3-5) and Sciaenidae (n=88) (0.0079 fish/m^3, SE$\pm$0.0026) from Nebraska City (Figure 3-4). One Pallid Sturgeon free embryo was captured at the Nebraska City Site on May 28, 2014 and was 8mm in length and presumed to be less than 24 hours post hatch due to size.

Cyprinidae had the highest weekly abundance (0.0254 fish/m^3, SE$\pm$0.0099) (Figure 3-6) with Sciaenidae closely behind (0.0246 fish/m^3, SE$\pm$0.0108) (Figure 3-7) both from the week of July 8, 2014. Sciaenidae from the week of June 30, 2015 was ranked third (0.0184 fish/m^3, SE$\pm$0.0092) (Figure 3-7). The Niobrara Site was not included in the weekly abundance analysis due to low numbers of fish captured. The rest of the weekly abundance figures can be found in the appendix (Figure A-45-A-54). The correlation analysis showed that in the benthic larval drift, temperature and abundance were only significantly correlated in 2015 in Polyodontidae (R^2= 0.63, p = 0.018).

Discussion:

This project sought to discover if sampling the outside bend of the Lower Missouri River was feasible and could be achieved efficiently and safely with benthic larval drift nets. When the detritus load was not too heavy (based on how much debris was floating) we could safely sample in discharges up to 1,699 m^3/s (60,000 f^3/s). This project was a preliminary sampling effort of the benthic fish community, and was concurrent with the United States Geological Survey (USGS) efforts in the Nebraska stretch of the Lower Missouri River, but they were only searching for Scaphirhynchus and not quantifying the remainder of the benthic drift. Sampling the benthic fish community was feasible under "normal" water conditions, although it was quite cumbersome at times and much precaution should be taken. Delonay et al. (2016b) found that the majority of the Scaphirhynchus larvae drift along the outside bend in the swiftest current. Sampling safety and effectiveness decline as discharge increases, so caution needs to be taken when high water events are occurring, because a net was lost due to overloading of detritus and swift current as the river discharge increased approximately 566 m^3/s (20,000 f^3/s) very quickly. It was unsafe to sample if the river discharge was over 1,699 m^3/s (60,000f^3/s), but possibly feasible if detritus load was not too heavy. Another factor to consider is the size of the net opening. Gear was lost when using nets with greater than 0.50 m diameter openings. Detritus loads seemed to be less on a falling hydrograph, so if sampling needs to occur, if possible, wait until after the peak of the high water event. Sampling closer to the wing dike tips could be the safer option. However, Delonay et al. (2016b) reported sturgeon catches declined toward the inside bend, but other benthic fish may be captured in these parts of the river.

There were notable catches from this effort. One, free-embryo Pallid Sturgeon was captured from the Nebraska City Site. This fish was 8mm in length and approximately 1 day post hatch (discussed further in chapter 4). One larval Shovelnose Sturgeon was captured in 2014 from the Niobrara Site. Steffensen et al. (2014d) reported there have been no age-0 Shovelnose Sturgeon captured in the unchannelized reaches. However, Steffensen et al. (2014d) also found there was a diverse range of different ages sampled in the area between Fort Randall Dam and Gavins Point Dam.

There must be some recruitment to the adult population in this area possibly because reproduction may be occurring in the Niobrara River, which is just upstream of the site, and could offer suitable spawning habitat.

Temperature data from the USGS gage at Nebraska City, Nebraska (Figure 3-8 and 3-9) exhibited peaks that were similar to the peaks noticed in the weekly larval abundance. Data from four of the families Acipenseridae (Figure 3-10), Catostomidae (Figure 3-11), Cyprinidae (Figure 3-12), and Polyodontidae (Figure 3-13) show similar patterns. However, the only significant correlation between abundance and temperature was for Polyodontidae (R^2= 0.63, p = 0.018). This was surprising because Hay et al. (2008) found temperature and variation in temperature to be a very important predictor of larval Catostomidae densities. This may have been due to a relatively small sample size. Delonay et al. (2016b) found that Pallid Sturgeon from Acipenseridae generally initiate spawning at certain temperatures (16-18 degrees Celsius), but catch of Acipenseridae larvae in the benthic drift was not dependent on temperature.

Sciaenidae was the most abundant family in the benthic drift samples, making up over 30% of the entire benthic catch for the two years sampled. This was somewhat surprising, because Sciaenidae, which have a buoyant yolk-sac larval stage (Holland et al., 1984), was also the most abundant family sampled in the surface drift samples as well. Seven of the most abundant Families found in the surface drift samples were also found in the benthic drift (Table 3-3). The reason there were so many Sciaenidae captured in both of the studies could be because they are very prevalent and easily captured at a young age. Of the eight most abundant families sampled on the surface, Moronidae was the only one not found in the benthic drift. Where the two projects differed was with the remaining less abundant families found in the surface drift. The only other two families found from both projects were Polyodontidae and Acipenseridae. With Ictaluridae, especially Channel Catfish, *Ictalurus punctatus*, being a very prevalent benthic species in juvenile and adult life stages, catching more Channel Catfish larvae in the benthic drift was expected. But, this agrees with Holland et al. (1984) which found that young Channel Catfish are rarely captured in plankton nets. This could be due to the fact that their fins develop quickly and they are able to escape the drift.

It would appear that the surface and benthic drift communities differ less than originally expected. This could be a result of only sampling the fastest part of the river, where the water could be mixing more, and the larvae that started off drifting near the surface eventually mixed in the water column and were captured in the benthic samples. A few more years sampling the benthic drift in multiple stations across the channel could help answer some of these questions and possibly show some separation between the benthic and surface larval drift communities.

Steffensen and Huenemann (2014 and 2015) found Ictaluridae to be their most abundant catch in their benthic otter trawls. This is completely different than what this study found, but as discussed earlier Ictalurids are able to escape the drift at a younger age because of early fin development. Shovelnose Sturgeon from Acipenseridae was the second highest followed by Cyprinidae and Sciaenidae. The catches of

Acipenseridae and Sciaenidae are consistent with this study, but the higher numbers of Cyprinidae (minnows and chubs) which are declining in the Lower Missouri River (Steffensen et al. 2014) were not detected. Results from the 2019 Annual Report from the Pallid Sturgeon Population Assessment (PSPAP) and Habitat Assessment and Monitoring Program (HAMP) (Haas et al. 2020) were compared to the benthic catches of this study. There was a major flood year on the Lower Missouri River in 2019 with many days of floodplain connectivity. The HAMP project conducted push trawl sampling on the floodplain in 2019 and captured many more native age-0 benthic Cyprinids (Sicklefin Chub, Sturgeon Chub, Shoal Chub Silver Chub, and Flathead Chub) than were detected in the benthic larval drift nets in 2014 and 2015. These results from the HAMP floodplain sampling indicate that this floodplain connectivity is very important to the production and age-0 recruitment of these native Cyprinids, and if benthic larval drift sampling could have been conducted in 2019 some of these fish may have been captured.

Channelization of the Lower Missouri River created a harsh benthic drifting environment and Morris et al. (1968) determined that benthic habitat was reduced by 67% after channelization, to mostly chutes and slack water areas. This could be a reason for native benthic fish decline, or it could be the loss to floodplain connectivity, or combination of both of these factors. When characterizing the benthic drift community on the outside bend, Acipenseridae and Polyodontidae are the only families that drift consistently in this fast, deep water. If benthic sampling would be expanded to other parts of the river larvae from other families might be detected. Another factor that was not addressed and could influence the abundance of larvae in the drift is looking at diel differences in the drift. This project only sampled during daylight hours and Nagel et al. (2021) found that the highest percentage of drifting larvae and eggs were collected at dusk and nighttime hours. Sampling at different parts of the day could also help gain a better understanding of what other fish taxa might be in the drift.

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Table 2-1. Missouri River benthic larval drift abundance (fish/m^3) rankings for each family by site and year.

Site	Year	Family	Abundance	Standard Error
Nebraska City	2015	*Sciaenidae*	0.0079	0.0026
Nebraska City	2014	*Cyprinidae*	0.0055	0.0029
Nebraska City	2014	*Polyodontidae*	0.0054	0.0021
Niobrara	2015	*Catostomidae*	0.0049	0.0057
Nebraska City	2014	*Acipenseridae*	0.0047	0.0019
Niobrara	2015	*Polyodontidae*	0.0031	0.0030
Nebraska City	2015	*Cyprinidae*	0.0026	0.0014
Nebraska City	2014	*Sciaenidae*	0.0023	0.0017
Nebraska City	2015	*Catostomidae*	0.0016	0.0012
Niobrara	2014	*Polyodontidae*	0.0016	0.0012
Nebraska City	2015	*Polyodontidae*	0.0012	0.0008
Niobrara	2015	*Cyprinidae*	0.0010	0.0021
Nebraska City	2014	*Catostomidae*	0.0010	0.0006
Nebraska City	2015	*Acipenseridae*	0.0009	0.0006
Nebraska City	2014	*Hiodontidae*	0.0009	0.0007
Nebraska City	2015	Un. Id Larval Fish	0.0008	0.0009
Nebraska City	2014	*Percidae*	0.0006	0.0008
Nebraska City	2014	Un. Id Larval Fish	0.0006	0.0007
Nebraska City	2015	*Hiodontidae*	0.0003	0.0004
Niobrara	2014	*Hiodontidae*	0.0002	0.0005
Niobrara	2014	*Catostomidae*	0.0002	0.0005
Nebraska City	2015	*Percidae*	0.0002	0.0003
Niobrara	2014	*Acipenseridae*	0.0002	0.0004
Nebraska City	2015	*Centrarchidae*	0.0001	0.0002
Nebraska City	2014	*Clupeidae*	< 0.0001	0.0001

Table 3-2. Missouri River benthic larval drift captures from 2014 and 2015 at Niobrara, NE and Nebraska City, NE.

		2014		2015		Total
	Site	Nebraska City	Niobrara	Nebraska City	Niobrara	
Effort	Number of deployments	87	12	88	8	195
	Amount water filtered	9,168 m^3	2,678 m^3	10,683 m^3	808 m^3	23,337 m^3
Family	Species					
Acipenseridae	Pallid Sturgeon	1				1
	Shovelnose Sturgeon	43	1	9		53
Catostomidae	Bigmouth Buffalo			1		1
	Unidentified *Catostomidae*	10	1	13	5	29
Centrarchidae	Unidentified *Centrarchidae*			2		2
Clupeidae	Gizzard Shad	1				1
Cyprinidae	Common Carp	10		8	1	19
	Unidentified *Cyprinidae*	18		16		34
	Unidentified Asian Carp	15				15
Hiodontidae	Goldeye	2	1	2		5
	Unidentified *Hiodontidae*	5				5
Percidae	Unidentified *Percidae*	5		2		7
Polyodontidae	Paddlefish	56	6	11	3	76
Sciaenidae	Freshwater Drum	19		88		107
Unidentified	Unidentified Larval Fish	4		6		10
	Unidentified Egg	2		234		236
	Total	191	9	392	9	601

Table 3-3. A comparison of the families captured from the surface drift sampling project vs the benthic drift sampling project in the Nebraska portion of the Missouri River.

Family	Surface	Benthic
Acipenseridae	X	X
Amiidae	X	
Atherinopsidae	X	
Catostomidae	X	X
Centrarchidae	X	X
Clupeidae	X	X
Cyprinidae	X	X
Esocidae	X	
Gadidae	X	
Gasterosteidae	X	
Hiodontidae	X	X
Ictaluridae	X	
Lepisosteidae	X	
Moronidae	X	
Osmeridae	X	
Percidae	X	X
Polyodontidae	X	X
Sciaenidae	X	X
Total	18	9

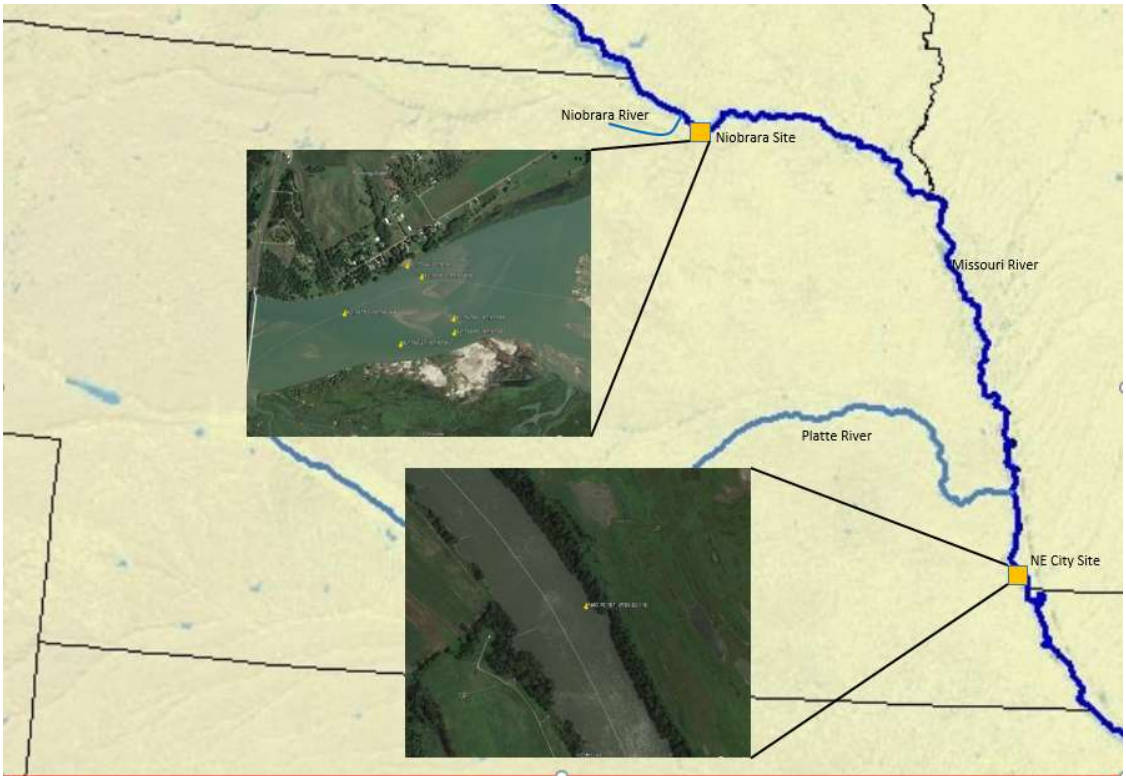

Figure 3-1. The two sites in the Missouri River for the benthic larval fish drift net study. The two sites are near Nebraska City, NE and Niobrara, NE. Actual sampling locations within each site are represented by the yellow pin marks.

Figure 3-2. Drift net used for benthic larval fish sampling. Net is equipped with a flow meter and 45 kg bomb weight to hold it in the current.

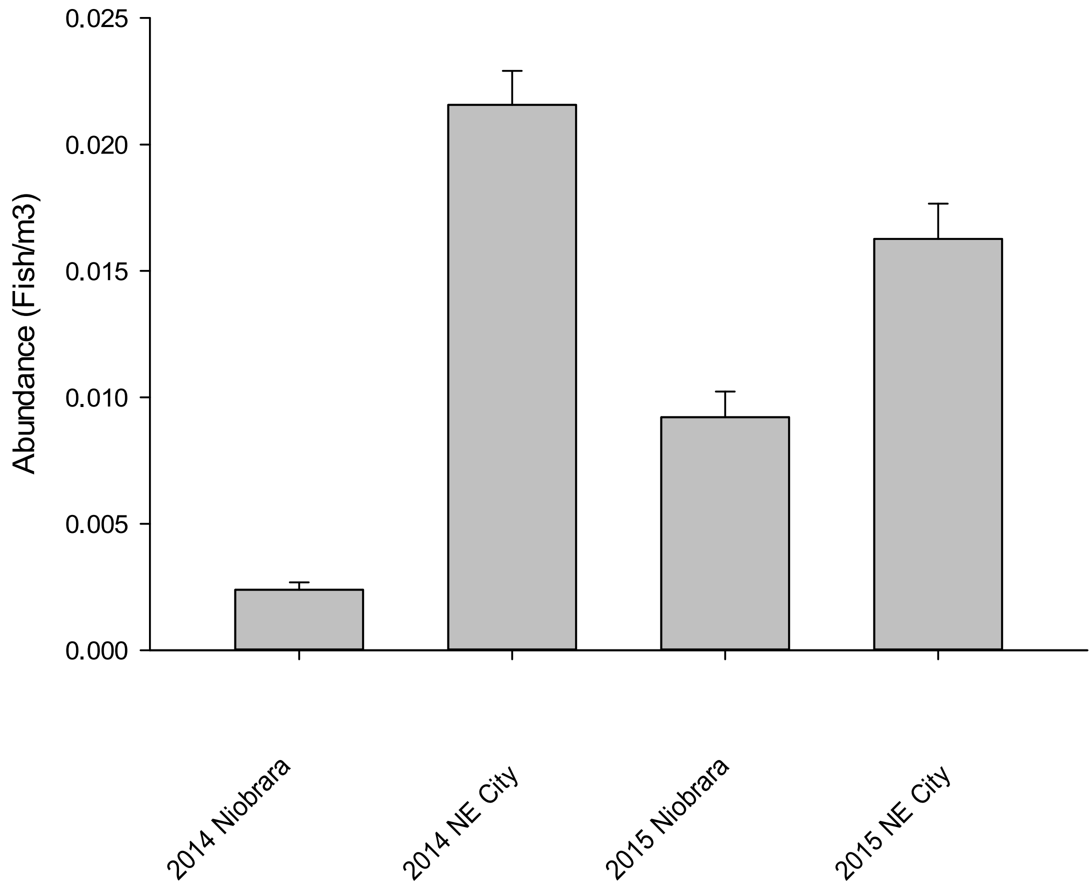

Figure 3-3. Mean benthic larval drift abundance (fish/m^3) by year and site from Niobrara, Nebraska and Nebraska City, Nebraska in 2014 and 2015

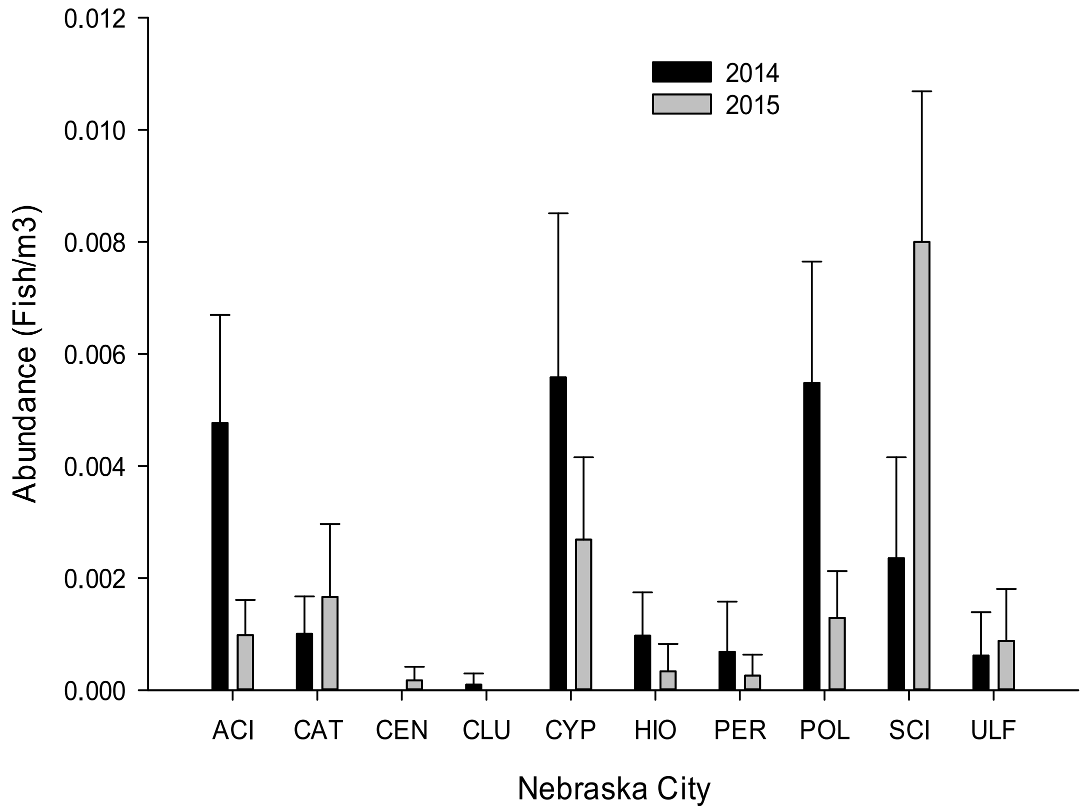

Figure 3-4. Missouri River benthic larval fish abundance (fish/m^3) comparing 2014 and 2015 at the Nebraska City Site for Acipenseridae (ACI), Catostomidae (CAT), Centrarchidae (CEN), Clupeidae (CLU), Cyprinidae (CYP), Hiodontidae (HIO), Percidae (PER), Polyodontidae (POL), Sciaenidae (SCI), Unidentified Larval Fish (ULF).

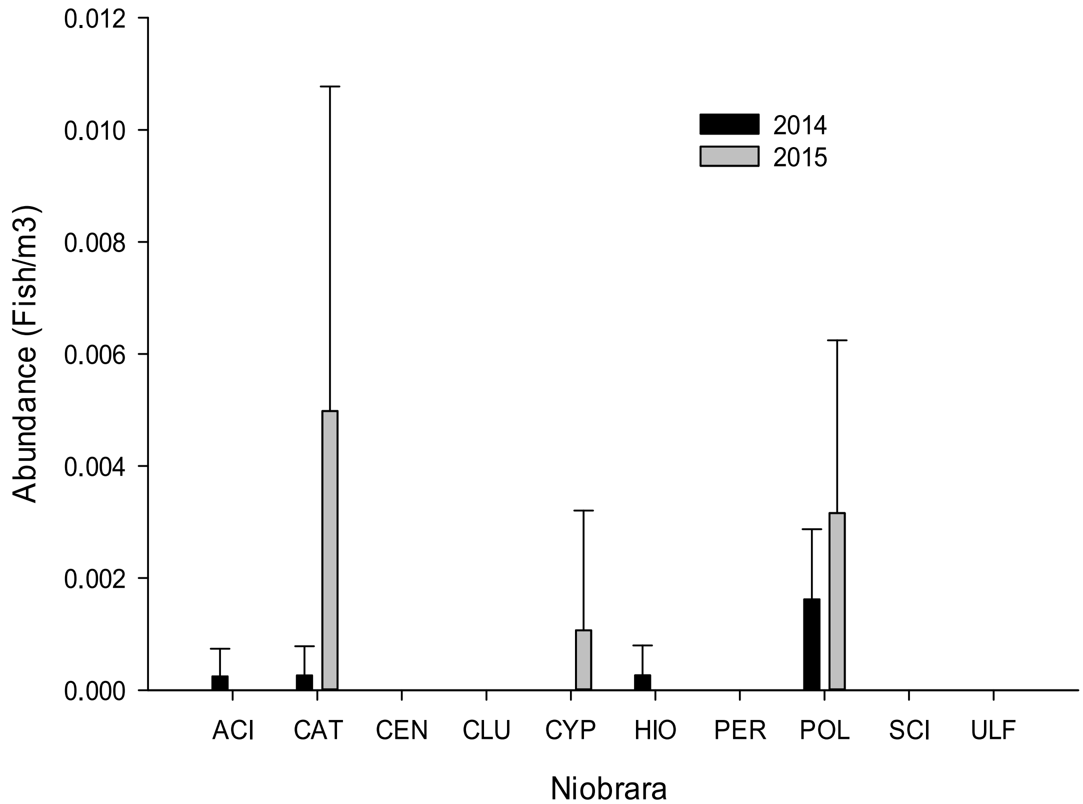

Figure 3-5. Missouri River benthic larval fish abundance (fish/m^3) comparing 2014 and 2015 at the Niobrara Site for Acipenseridae (ACI), Catostomidae (CAT), Centrarchidae (CEN), Clupeidae (CLU), Cyprinidae (CYP), Hiodontidae (HIO), Percidae (PER), Polyodontidae (POL), Sciaenidae (SCI), Unidentified Larval Fish (ULF).

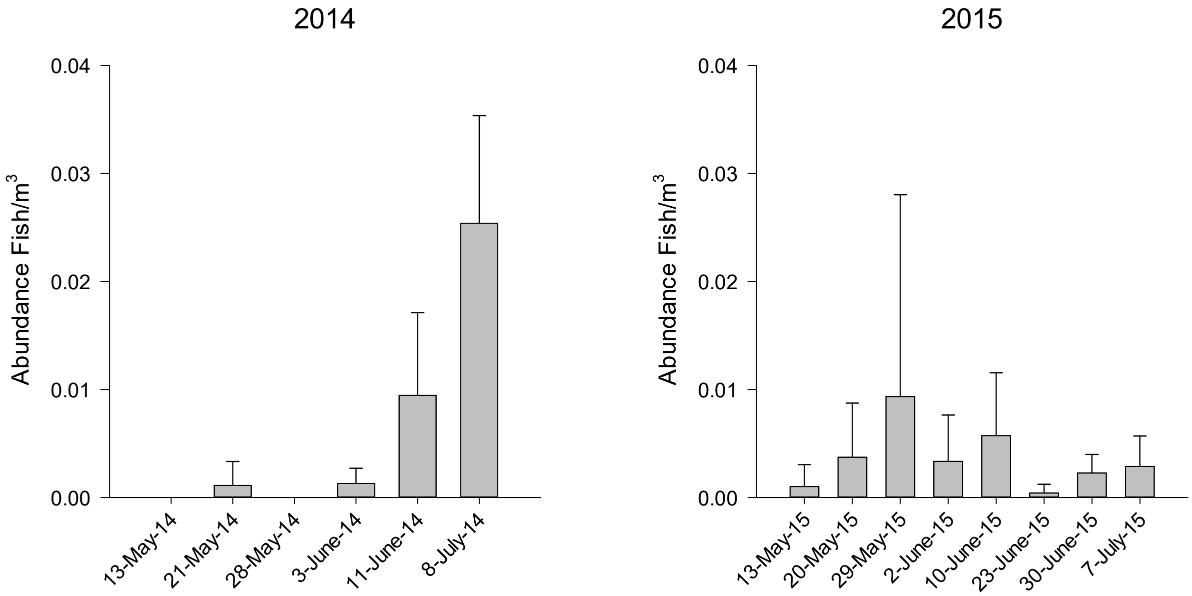

Figure 3-6. Cyprinidae abundances (fish/m^3) by week sampled using benthic larval drift nets at Nebraska City, NE in 2014 and 2015. 2014 has fewer weeks sampled due to high water events that made it unsafe to sample in mid to late June.

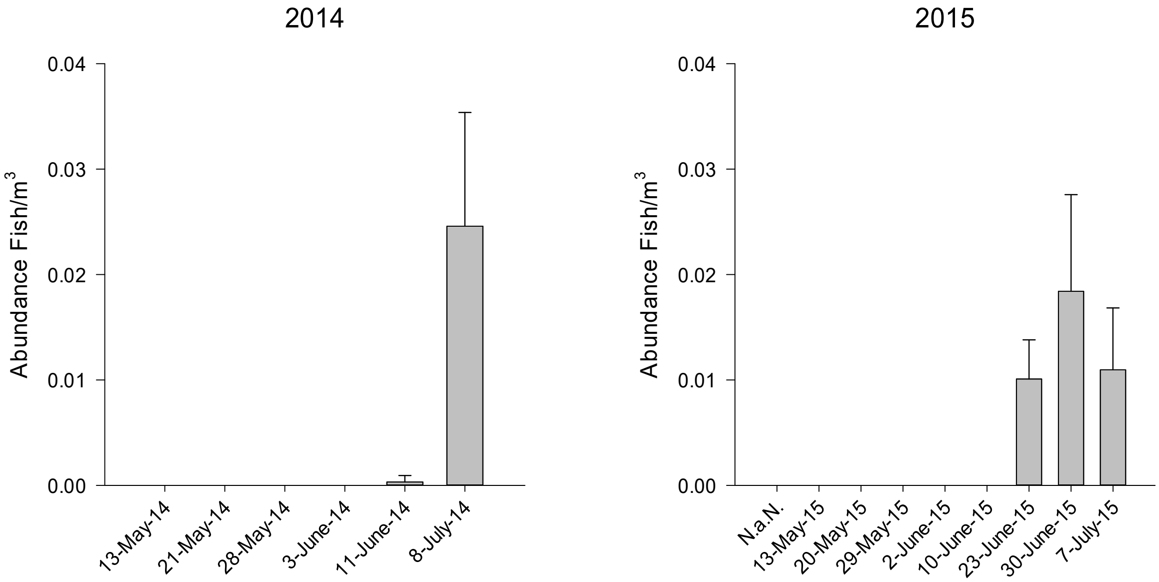

Figure 3-7. Sciaenidae abundances (fish/m^3) by week sampled using benthic larval drift nets at Nebraska City, NE in 2014 and 2015. 2014 has fewer weeks sampled due to high water events that made it unsafe to sample in mid to late June.

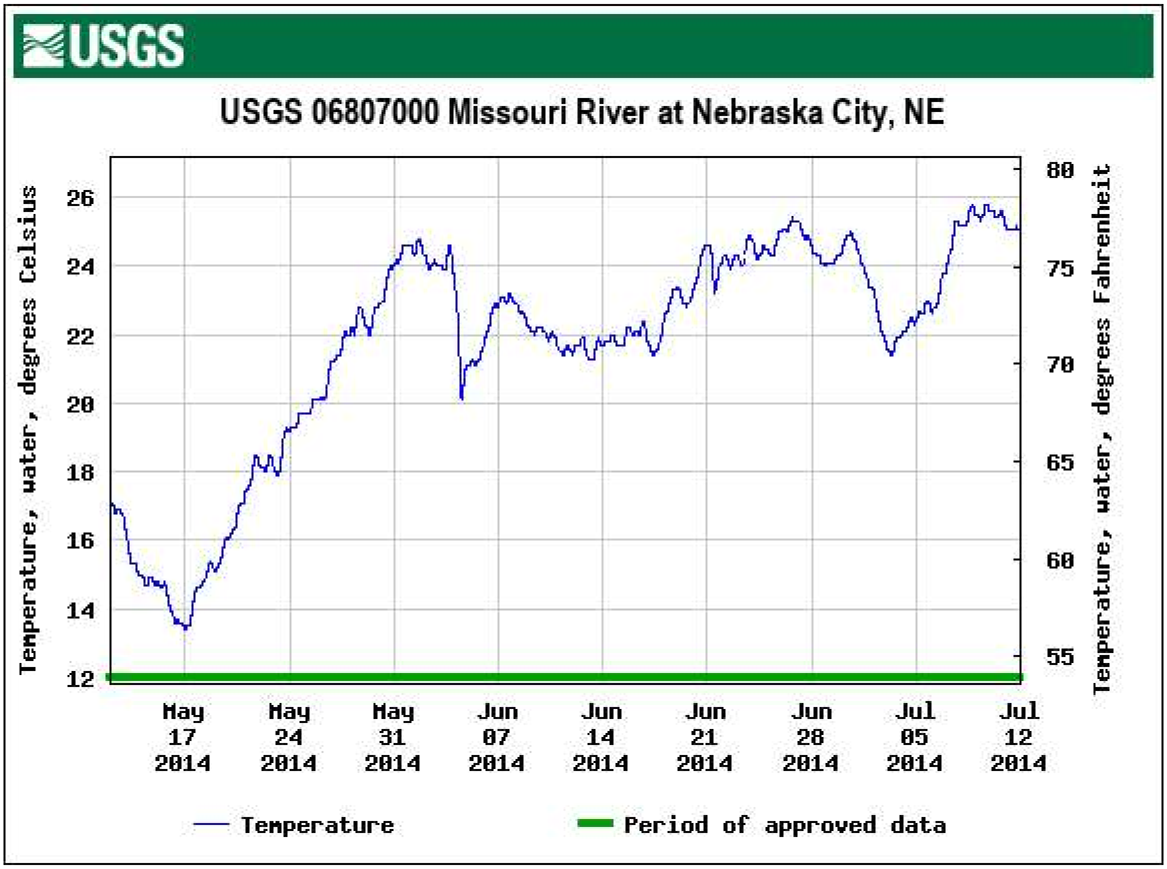

Figure 3-8. Temperature data taken from the USGS gage at Nebraska City, Nebraska (USGS 06807000) in 2014 from the same timeframe that benthic larval drift netting was conducted for this study.

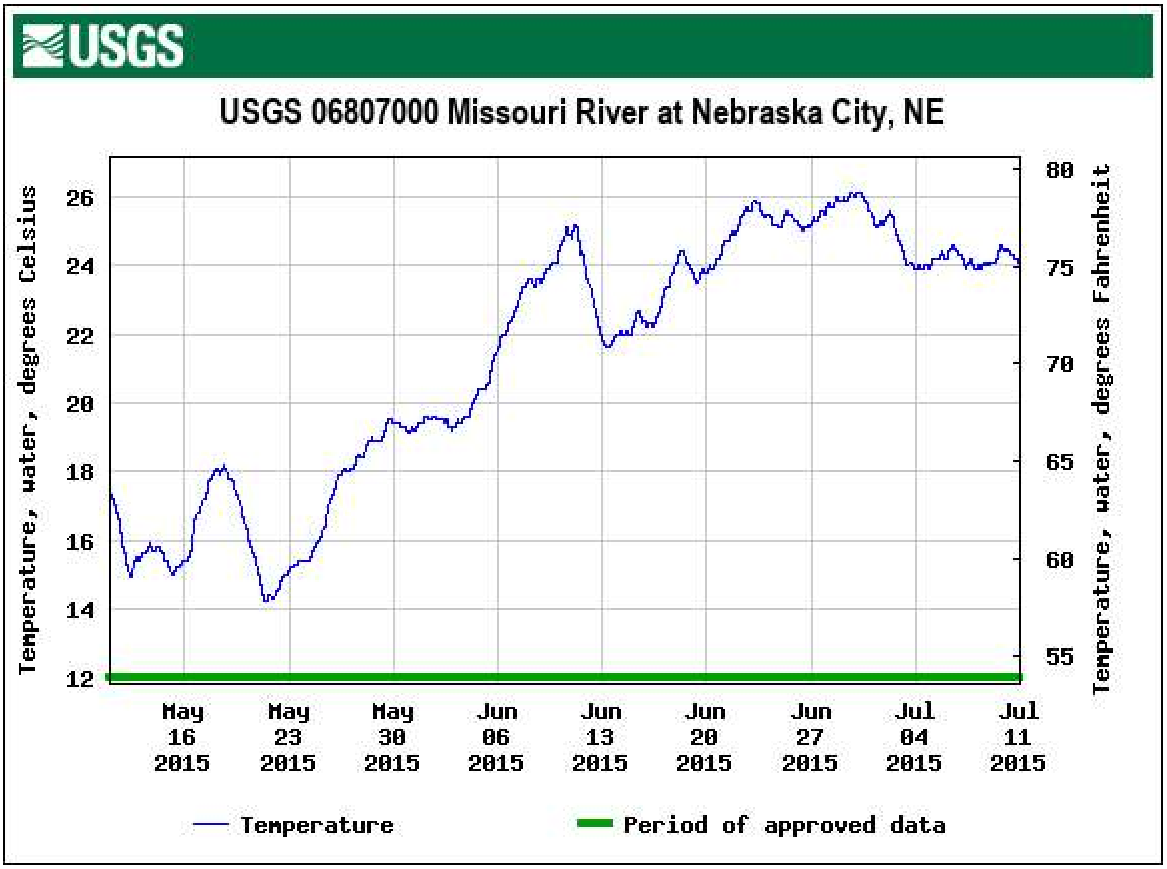

Figure 3-9. Temperature data taken from the USGS gage at Nebraska City, Nebraska (USGS 06807000) in 2015 from the same timeframe that benthic larval drift netting was conducted for this study.

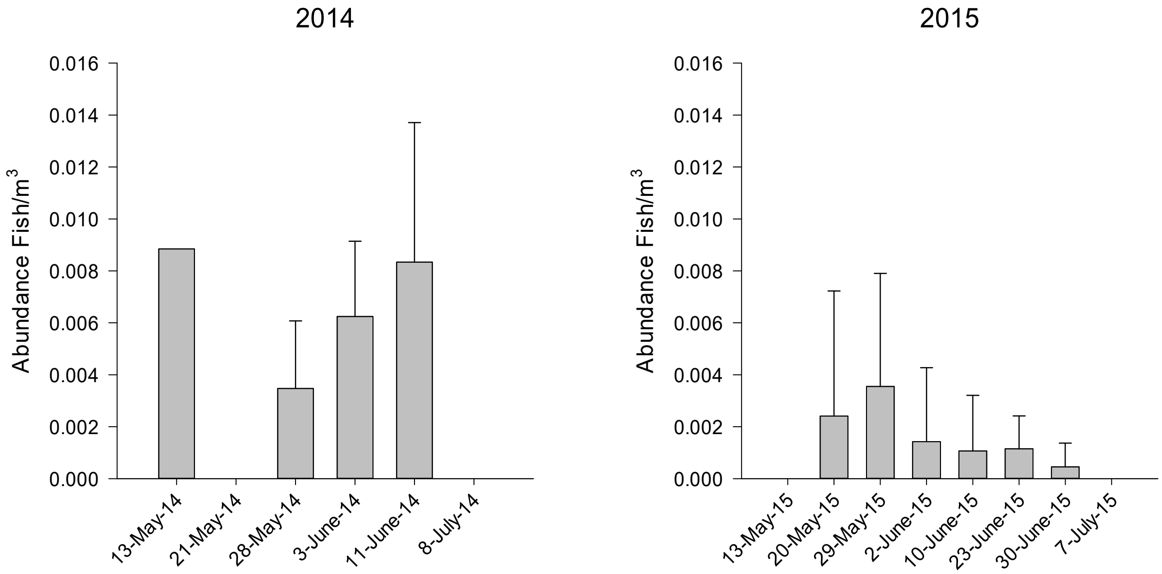

Figure 3-10. Acipenseridae abundances (fish/m^3) by week sampled using benthic larval drift nets at Nebraska City, NE in 2014 and 2015. 2014 has fewer weeks sampled due to high water events that made it unsafe to sample in mid to late June.

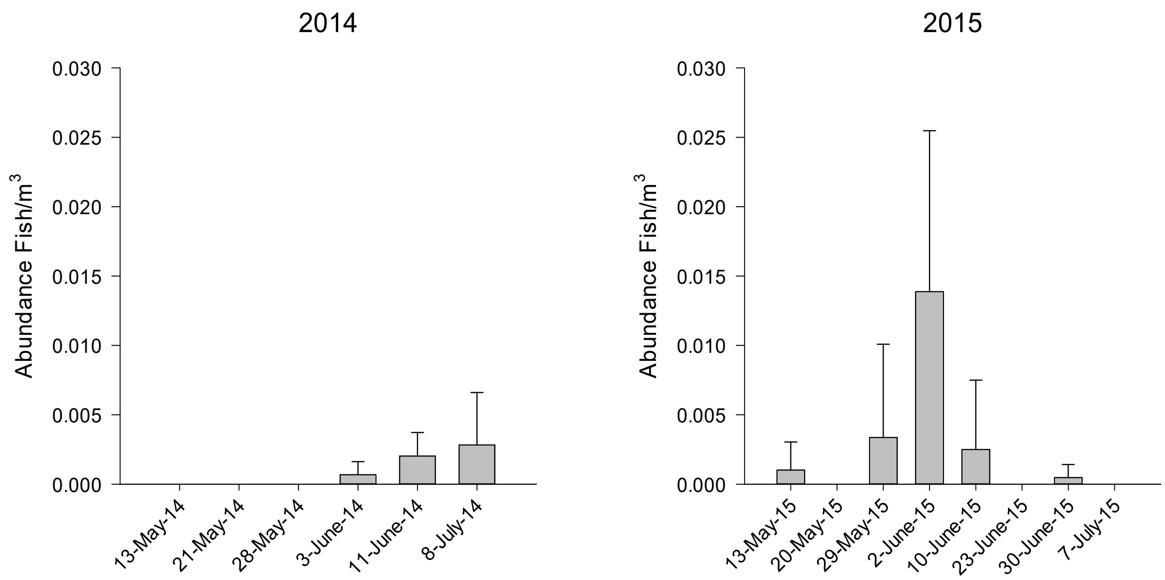

Figure 3-11. Catostomidae abundances (fish/m^3) by week sampled using benthic larval drift nets at Nebraska City, NE in 2014 and 2015. Fewer weeks were sampled in 2014 due to high water events that made it unsafe to sample in mid to late June.

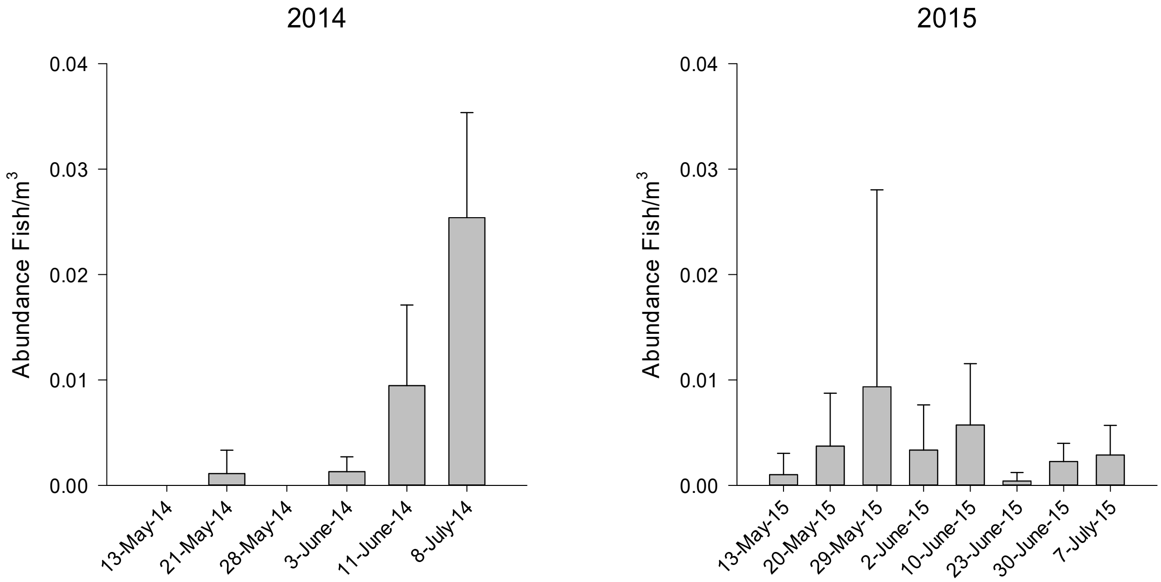

Figure 3-12. Cyprinidae abundances (fish/m^3) by week sampled using benthic larval drift nets at Nebraska City, NE. Fewer weeks were sampled in 2014 due to high water events that made it unsafe to sample in mid to late June.

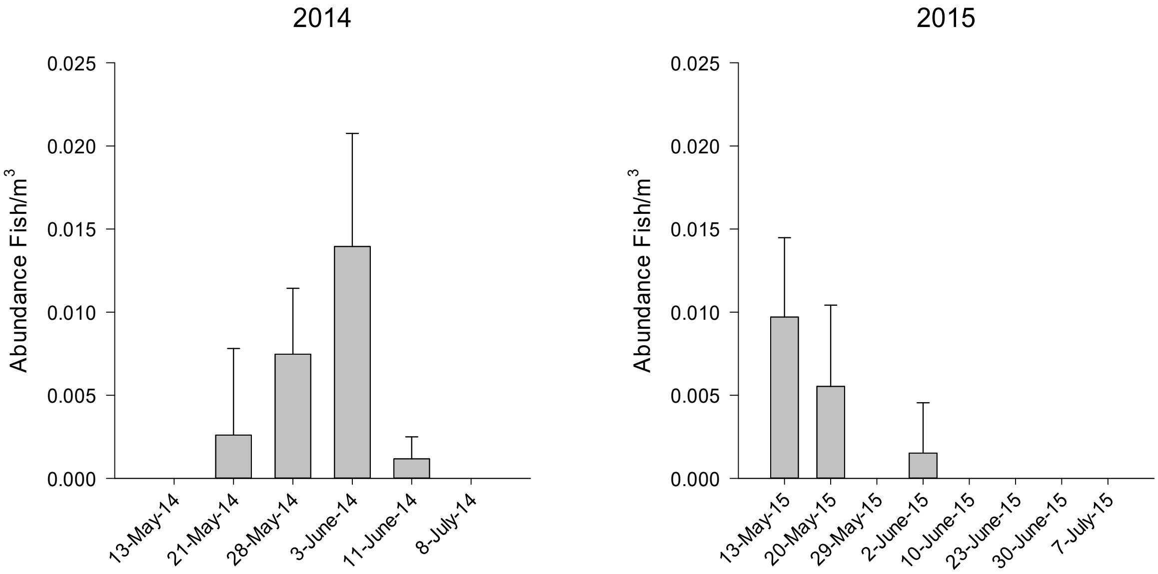

Figure 3-13. Polyodontidae abundances (fish/m^3) by week sampled using benthic larval drift nets at Nebraska City, NE. Fewer weeks were sampled in 2014 due to high water events that made it unsafe to sample in mid to late June.

Chapter 4:

Documented Pallid Sturgeon Reproduction Using Benthic Ichthyoplankton Nets

Abstract:

There are many reasons why Pallid Sturgeon *Scaphirhynchus albus* populations have been in decline. Modifications to the Missouri River altered spawning sites and blocked upstream migrations, which effected natural reproduction and recruitment. Pallid Sturgeon successful reproduction and hatch had not been documented prior to initiation of this project; therefore, the objective for this study was to document Pallid Sturgeon reproduction in the lower Missouri River. Larval fish were sampled in the Missouri River near Nebraska City, Nebraska (rkm 907.6) using benthic drift nets. A total of 86 Acipenser larvae representing Shovelnose Sturgeon *S. platorhynchus* (n=52), Paddlefish *Polyodon spathula* (n=33) and one Pallid Sturgeon that was believed to be one day post-hatch due to its size were captured. These findings suggest Pallid Sturgeon reproduction is possible in the Missouri River, and that detection of these fish is feasible using this gear.

Introduction:

Human modifications to large river systems have altered the availability and diversity of aquatic habitats, disrupted or eliminated spawning sites, blocked spawning migrations, affected drift distance and dispersion, and reduced nursery habitats for many aquatic species (Hesse and Sheets 1993, Secor et al. 2002). The Missouri River has experienced many of these anthropogenic activities, resulting in a notable decline in native fish populations. Hesse and Mestl (1993) and Steffensen et al. (2014abc) have documented precipitous declines in the abundance of many fish species generally associated with large rivers following impoundment and channelization. Furthermore, declines in Pallid Sturgeon abundance warranted an endangered species listing in 1990 (USFWS, 2014).

The current Pallid Sturgeon distribution includes the riverine segment of the Missouri River, the Mississippi River below Alton Dam, and the lower reaches of many larger tributaries (Kallemeyn, 1983) which have all experienced habitat alterations. Pallid Sturgeon have a complex life history that includes being long-lived and late-maturing, further confounding contemporary declines in abundance (Delonay et al., 2016b). Consequently, Pallid Sturgeon in the Lower Missouri River have shown delayed maturation, reduced fecundity, disruptive migration patterns, sometimes exhibit atresia or failure to spawn, and select unnatural, constructed substrates for spawning (Delonay et al., 2016b).

After being successfully fertilized, Pallid Sturgeon embryos develop for 3 to 8 days (Delonay et al., 2016b). The embryos then hatch at approximately 7 to 9 mm and enter a drifting phase. The free embryos will drift 10 to 13 days and will begin exogenous feeding around day 10 depending on water temperature (Delonay et al., 2014; Wildhaber, et al., 2007).

Pallid Sturgeon spawning has been documented in the Lower Missouri River (Gavins Point Dam [river kilometer (rkm) 1305.1] to the confluence with the Mississippi River [rkm 0.0]), but recruitment levels are low (Delonay et al. 2009). Adult spawning behavior has been observed for 33 individual events from 2007-2015 by 27 unique female Pallid Sturgeon (Delonay et al. 2009, 2010, 2012, 2014, 2016abc), but larvae have not been collected to confirm spawning. Therefore, the objective of this study was to document evidence of successful reproduction by Pallid Sturgeon through capture of embryos entering the drifting phase in the Nebraska portion of the Lower Missouri River.

Methods:

Larval fishes were sampled in the channelized reach of the Missouri River near Nebraska City, Nebraska (rkm 907.6) (Figure 4-1). This reach of the Missouri River is highly modified with wing dikes on the inside bend and a revetted outside bend. It is influenced by flows from the Platte River, Nebraska, which is one of the largest tributaries on the Missouri River (Galat et al., 2005), located 50 rkm upstream. All of the samples were taken approximately 15 meters off the revetment just upstream of a revetment scallop in the fastest part of the current.

Two larval drift nets, set in tandem (hereafter termed "paired") for each sampling were deployed from May 13, 2014 to July 8, 2014 and May 13, 2015 to July 7, 2015. Benthic larval drift nets were used because Braaten et al. (2008) found the majority of larval Pallid Sturgeon collected in the upper Missouri River were caught in the lower 0.50 m of the water column. Paired nets (750-micron conical nets, 1.75 m long, with a 0.50 m opening) were deployed for between 2- and 20-minutes, depending on the sediment or detritus load in the river, and held stationary on the river bed with a 45 kg bomb. The volume of water sampled was measured using a General Oceanics flow meter (General Oceanics, Miami, Florida). Fish collected were inspected to determine individual Acipenserformes larvae which were removed and preserved in a 70% ETOH solution for genetic confirmation and sent to Southern Illinois University for genetic confirmation to species. Genetic confirmation is required because the morphometric characteristics of Pallid Sturgeon and Shovelnose Sturgeon are very similar at a young age. Potential Acipenserformes samples were analyzed using a single nucleotide polymorphism (SNP) technique to discern if the larvae were Paddlefish, Shovelnose Sturgeon, Pallid Sturgeon, or possibly a sturgeon hybrid (Heist et al., 2009). This SNP technology identifies about 95% of the Shovelnose Sturgeon and Paddlefish collected. Samples that could not be discerned using the SNP process were further assessed at 16 microsatellite loci (Schrey and Heist 2007) to confirm species identification.

Results:

A total of 175 benthic larval drift nets were deployed in 2014 (N = 87) and 2015 (N = 88) resulting in 19,850 m^3 of water being sampled. Of the 86 potential Acipenserformes larvae identified for genetic confirmation, one larval fish was a non-hybrid, free embryo Pallid Sturgeon; whereas the remaining 85 larval fish were

Shovelnose Sturgeon (n = 52) and Paddlefish (n = 33). The 8-mm long Pallid Sturgeon was captured on May 28, 2014 and presumed to be less than 24 hours post hatch due to size.

Discussion:

The Pallid Sturgeon free embryo captured in 2014 documented the youngest and smallest Pallid Sturgeon collected in the Lower Missouri River, but there have been other recent captures in the lower Missouri River (n=6) (Delonay et al., 2016a; Gosch et al., 2018). Interestingly, all of the larval Pallid Sturgeon were collected in 2014 and were the first age-0 Pallid Sturgeon documented since researchers starting actively seeking Pallid Sturgeon larvae in 2012. Sampling efforts have continued annually, but drifting larval or age-0 Pallid Sturgeon were not further detected until 2018 when four additional larval Pallid Sturgeon were captured (U.S. Corps of Engineers, 2020). There has now been a total of 16 age-0 Pallid Sturgeon collected. Knowledge of Pallid Sturgeon captures is important because documenting successful fertilization and embryos entering the drift phase is rare in the Lower Missouri River. It is also worth noting that the fish was captured downstream of the Platte River, a major tributary to the Missouri River. Discharge from the Nebraska City Gage (USGS 068007000 Missouri River at Nebraska City, NE) was 1,240 cubic meters per second (m^3/s) and temperature was 22.3°C at time of capture. The Platte River had a discharge of 158.6 m^3/s at Louisville (USGS 06805500 Platte River at Louisville, NE). Based on drift rate estimates by Braaten et al. (2011), the larval Pallid Sturgeon was likely spawned between rkms

907.6 - 965.6 in the Lower Missouri River or potentially in the lower 8 rkms of the Lower Platte River (Figure 4-1).

Pallid Sturgeon recruitment to age-1 is a fundamental objective in the Missouri River Recovery Program's (MRRP) Science and Adaptive Management Plan and is the main reason for the construction of interception-rearing complexes (IRCs) (U.S. Corps of Engineers, 2020). U.S. Corps of Engineers (2020) also states that if IRCs are successful and enough of them are constructed, survival of age-0 Pallid Sturgeon in the Lower Missouri River should increase. This makes an annual benthic drift monitoring program important so that successful spawning/fertilization/hatching can be detected. Benthic larval fish sampling should be targeted to give the best chance for successful detection. Knowledge of Pallid Sturgeon reproductive behavior and drift dynamics should be applied to determine where to deploy benthic larval drift nets. The benthic larval drift monitoring program will help gauge if there are larval Pallid Sturgeon in the system for these IRC Sites to retain.

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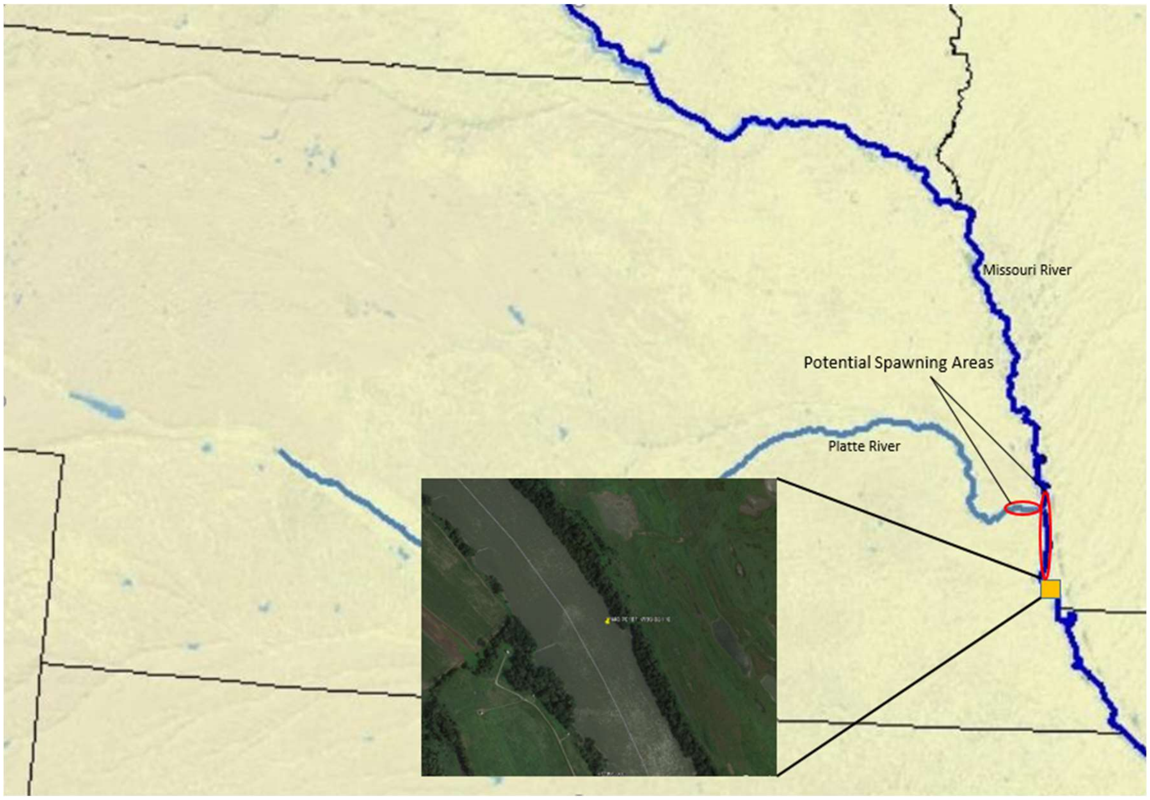

Figure 4-1. Map of benthic larval fish sampling Site location in 2014 and 2015 where age-0 Pallid Sturgeon was captured with potential Pallid Sturgeon spawning areas circled in red.

Chapter 5:

CONCLUSIONS AND MANAGEMENT RECOMMENDATIONS

Larval fish have been sampled by the Nebraska Game and Parks Commission since the 1970's (Hesse, 2009), and there has been a consistent larval fish program since 1983. Even with all of this sampling, knowledge of larval fish communities is one of the major gaps we have as managers on the Missouri River. The drifting stage of a fish is very important to its life history (Brown and Armstrong, 1985), and the study of the larval fish community is necessary because the habitat requirements are often different for juvenile or adult fish (Schlosser, 1985). Larval fish sampling can be very costly and time consuming especially with the large lab component usually associated with this type of project. When sampling the river bed for benthic drifting fish it can even become dangerous. These are all factors that need to be considered when planning a larval drift project.

The overarching objective of my thesis was to use a 30 year larval fish data set and quantify the larval drift of the Missouri River. After evaluating my specific objectives these are the concluded results.

(1) Quantify temporal and spatial aspects of larval fish community composition (richness) and structure (abundance) of the drift (Chapter 2).
   a. A total of 258,868 fish from 18 unique families were captured from ten sites on the Missouri River from 1983-2015. Larval fish abundances did not vary much through time. When analyzing

abundances at the site level only 17 of the 78 site/family combinations showed significance (alpha = 0.05). Those that showed significance exhibited very low R^2 values. Clupeidae at St. Helena was the only site/family combination that had a positive slope (m = 0.0015).

b. When looking at the segment level through time, the results were similar to the site level analysis with only 12 of the 32 family/site relationships showing significance (alpha = 0.05). Once again the R^2 values were very low. Only three of the significant family/segment combinations displayed a positive slope, Catostomidae (Segment 1, m = 0.0015), Cyprinidae (Segment 3, m = 0.0024), and Percidae (Segment 3, m = 0.0004).

c. A two-way crossed analysis of similarity (ANOSIM) was used to compare the larval fish community of the drift. When comparing segments from the entire sampling period the Global R value was slightly lower than the 0.3 threshold (Global-R=0.267), but the p-value was significant (p=0.001). This warranted a closer look at the pairwise comparisons. The pairwise tests revealed that Segment 1 was dissimilar from the rest of the segments but the other segments were not dissimilar from each other. The similarity percentage (SIMPER) analysis showed Sciaenidae contributed the most weight for these results.

(2) Quantify associations of larval fish communities of the drift to different discharges of the Missouri River (Chapter 2).

   a. A two-way crossed ANOSIM with discharge condition (high, moderate, low) as a factor was used to discern if discharged changed the fish communities of the larval drift. This analysis yielded no dissimilarities when discharge was used as a factor (Global-R = 0.067, p = 0.079).

(3) Quantify the benthic larval drift community, and determine if Pallid Sturgeon reproduction is occurring in the lower Missouri River (Chapter 3)

   a. A total of 175 benthic larval drift nets captured 347 fish from nine unique families and 236 unidentified eggs at the Nebraska City Site. In 2014, 189 fish (0.0216 fish/m^3, SE$\pm$0.0034) were captured. In 2015, 158 fish (0.0163 fish/m^3, SE$\pm$0.0014) were captured. At the Niobrara Site, 20 benthic larval drift nets captured 18 total fish from four unique families. In 2014, 9 fish (0.0024 fish/m^3, SE$\pm$0.0003) were captured. In 2015, 9 fish (0.0092 fish/m^3, SE$\pm$0.0010) were captured. Sciaenidae from the Nebraska City Site in 2015 was the most abundant family captured.

   b. Calculated weekly abundances for 2014 and 2015 at the Nebraska City Site showed Cyprinidae had the highest weekly abundance (0.0254 fish/m^3, SE$\pm$0.0099) with Sciaenidae closely behind (0.0246 fish/m^3, SE$\pm$0.0108), both from the week of July 8, 2014. The correlation analysis showed that in the benthic larval drift, temperature and weekly abundance were only significantly correlated in 2015 from Polyodontidae (R^2= 0.63, p = 0.018).

(4) Document evidence of natural spawning and fertilization success by Pallid Sturgeon through capture of embryos entering the drifting phase in the Nebraska portion of the Lower Missouri River (chapter 4).

   a. A total of 86 Acipenserformes larvae representing Shovelnose Sturgeon *Scaphirhynchus platorhynchus* (n=52), Paddlefish *Polyodon spathula* (n=33) and one wild Pallid Sturgeon *Scaphirhynchus albus* were captured. The Pallid Sturgeon was captured on May 28, 2014, was 8mm long, and estimated to be one day post hatch due to size. One larval Shovelnose Sturgeon was captured at the Niobrara Site also.

Management and Research Recommendations

More information needs to be gathered to gain a complete understanding of the larval drift in the Missouri River; therefore, I present these management and research recommendations.

1. The surface larval drift project should be continued to maintain a grasp on larval fish drift abundances. This is important because we need to be able to

determine if abundances are staying the same or trending in a certain direction, so that these circumstances can be addressed in a timely manner. Not only is this important to monitor the health of the system, but it is also important on an agency level. Many people utilize the Missouri River for fishing opportunities, and it is essential to maintain this fishery. Larval fish abundances can be an early indicator of overall adult fish health and condition as well as potential year class strength of many of the sought after species by Missouri River anglers. Larval fish drift net sampling can also help maintain a grasp on invasive species abundances.

A byproduct of the fish sampling is collection of the drifting macroinvertebrates. These organisms are forage for the adult and juvenile fish species in the river and abundances of these macroinvertebrates could give insight on future fish health.

I propose fixed sites that are sampled every time the project reoccurs, and these sites should be selected to represent each segment equally. Sampling results could then be compared over time and to other data collected on the Missouri River such as trawl data. Many of the native species of the Missouri River are declining (Steffensen et al. 2004abc), but our analysis did not detect marked declines in the larval fish drift. We need to identify this disconnect between larval and adult life stages to address things such as mortality or lack of recruitment. This could be accomplished by more sampling for adults to see if they are underrepresented in our samples. If more sampling does not yield any higher abundances of adult fish, then we need to look elsewhere and see if habitat, predation, interrupted flow, etc. could be the limiting factors.

Our data were analyzed at the family level, however, if we could identify our fish to genus or species, we might improve detection of some of these species declines. This would be beneficial because even though the populations are stable at the family level, certain species within in the family could be declining and a higher level of resolution could help to discern these declines.

2. We determined that it was feasible to sample the outside bend with our equipment, but only if sampled under a discharge threshold of 1,699 m^3/s (60,000 f^3/s). It is important to maintain this threshold when doing this type of sampling on the outside bend of the Missouri River due to crew safety. If discharges are over this threshold we have determined it to be unsafe to sample. It is also necessary to maintain using only a 0.5 m diameter net opening so the net does not get too full and heavy with detritus.

   The benthic drift aspect of this project attempted to identify successful Pallid Sturgeon reproduction which is why we chose the site and timeframe in which to sample the outside bend of the river. To better quantify the benthic larval drift community I would design the project similar to the surface larval drift project previously discussed. I would suggest multiple sites with multiple stations on transects across the river channel with sampling occurring on the river bed. I would also suggest starting in early May and sampling through mid to late July and possible August similar to Delonay et al. (2016).

3. Assessing the capabilities of various net diameter, shape, and mesh sizes of nets would be valuable. For example, different shapes of the net mouths (such as rectangle or D-shaped) may maximize detection of drifting Pallid Sturgeon. Braaten et al. (2008) found that the majority of larval Pallid Sturgeon collected were caught in the lower 0.50 m of the water column. Therefore, these different shapes might be able to sample this benthic area more effectively than the round nets that were used for this project.

4. I would sample more at the Niobrara Site. Even though we did not capture a Pallid Sturgeon at this site, we did capture a Shovelnose Sturgeon larvae. Capture of this larvae was very important also because of lack of recruitment of Shovelnose Sturgeon in that stretch of river.

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Steffensen, K. D., Stukel, S., and Shuman, D. A. 2014a. The status of fishes in the Missouri River, Nebraska: Sauger *Sander Canadensis.* Transactions of the Nebraska Academy of Sciences. 34:68-79.

Appendix A:

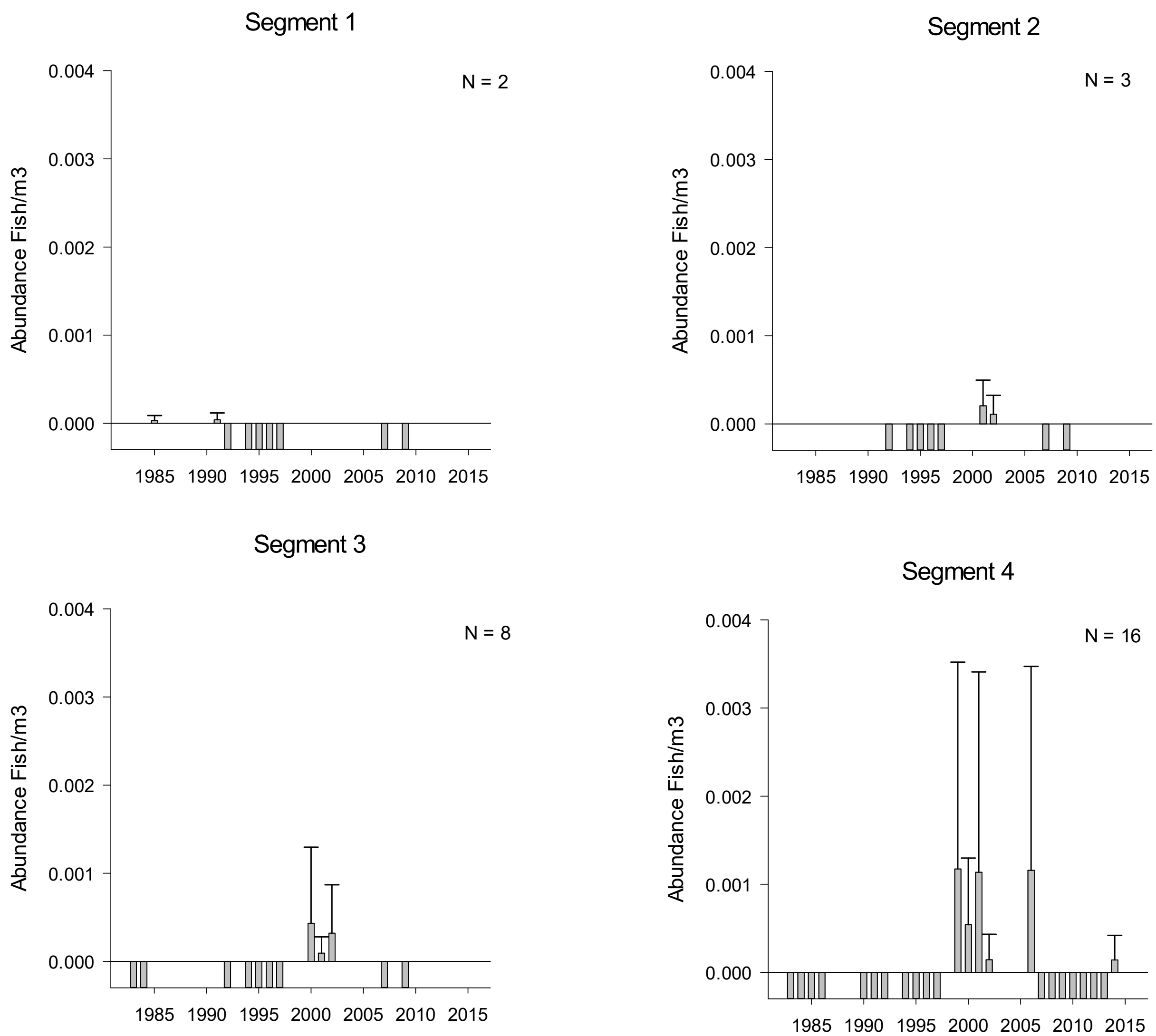


Figure A-1. Abundance (fish/m^3 ± 2 SE) for Acipenseridae from 1983 to 2015 from surface larval drift nets deployed in four segments of the Nebraska portion of the Missouri River. Negative values indicate years with no data.

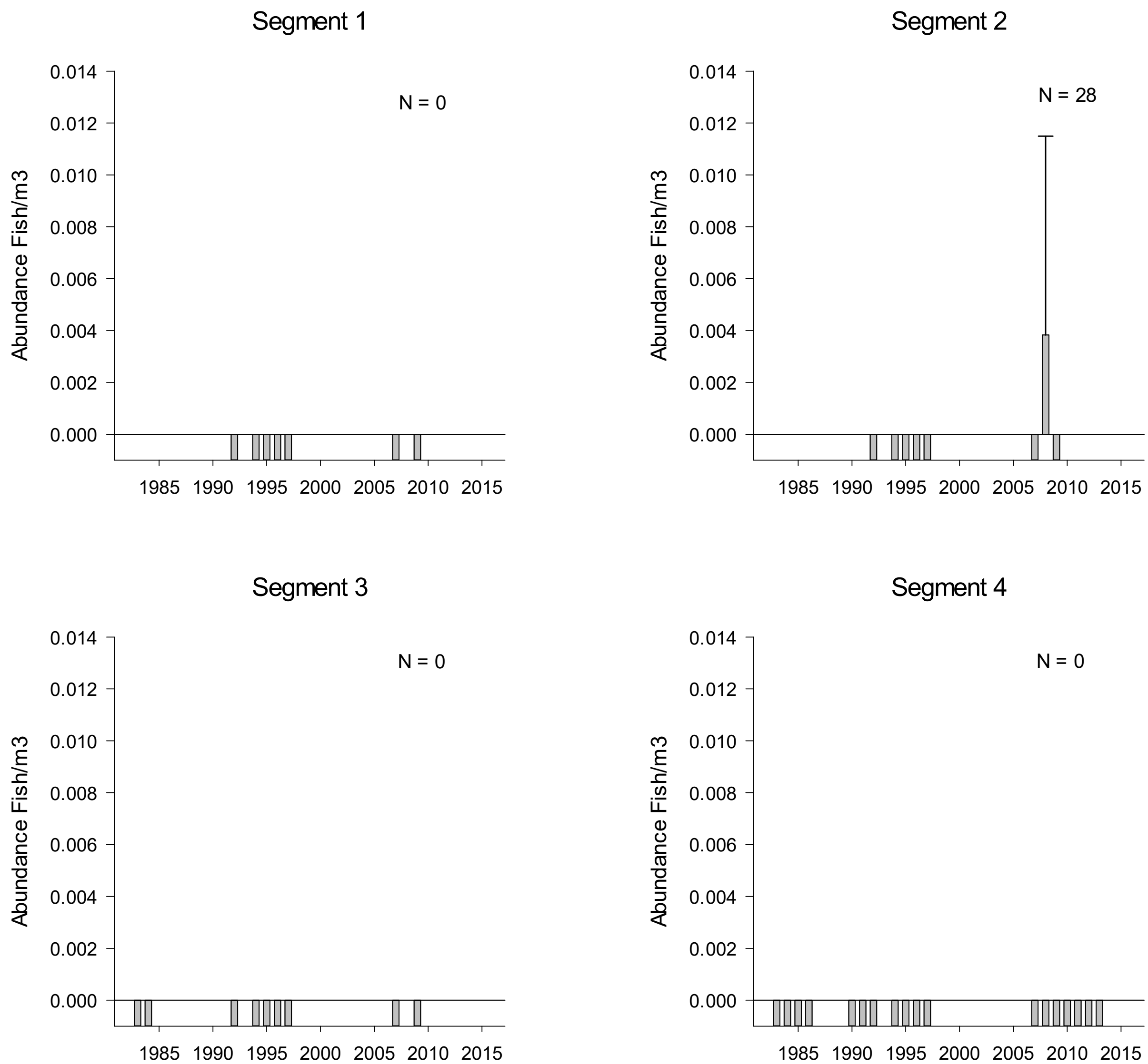


Figure A-2. Abundance (fish/m^3 ± 2 SE) for Amiidae from 1983 to 2015 from surface larval drift nets deployed in four segments of the Nebraska portion of the Missouri River. Negative values indicate years with no data. Amiidae was only sampled in Segment 2 in 2008.

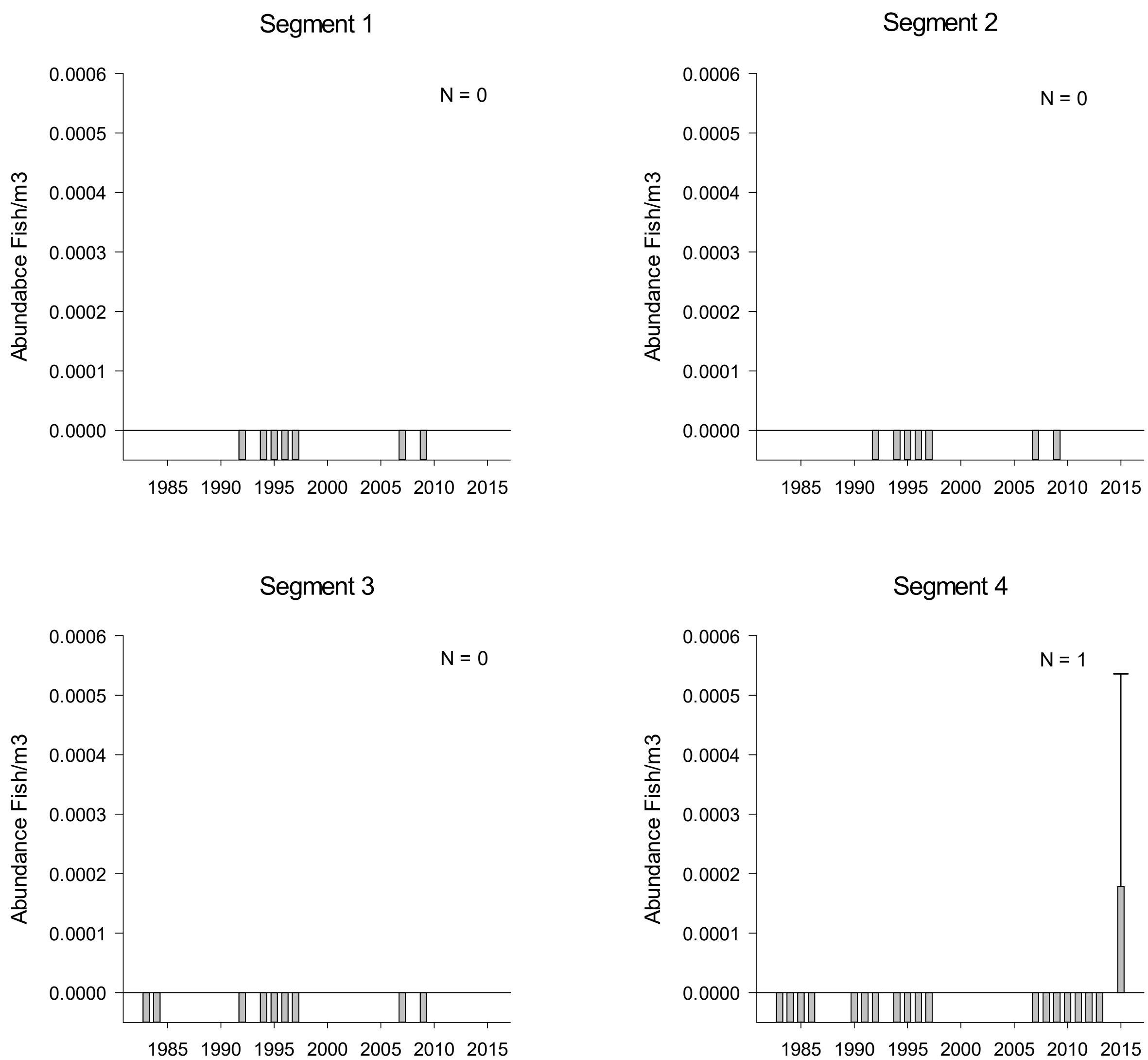


Figure A-3. Abundance (fish/m^3 ± 2 SE) for Atherinopsidae from 1983 to 2015 from surface larval drift nets deployed in four segments of the Nebraska portion of the Missouri River. Negative values indicate years with no data. Atherinopsidae was only sampled in Segment 4 in 2015.

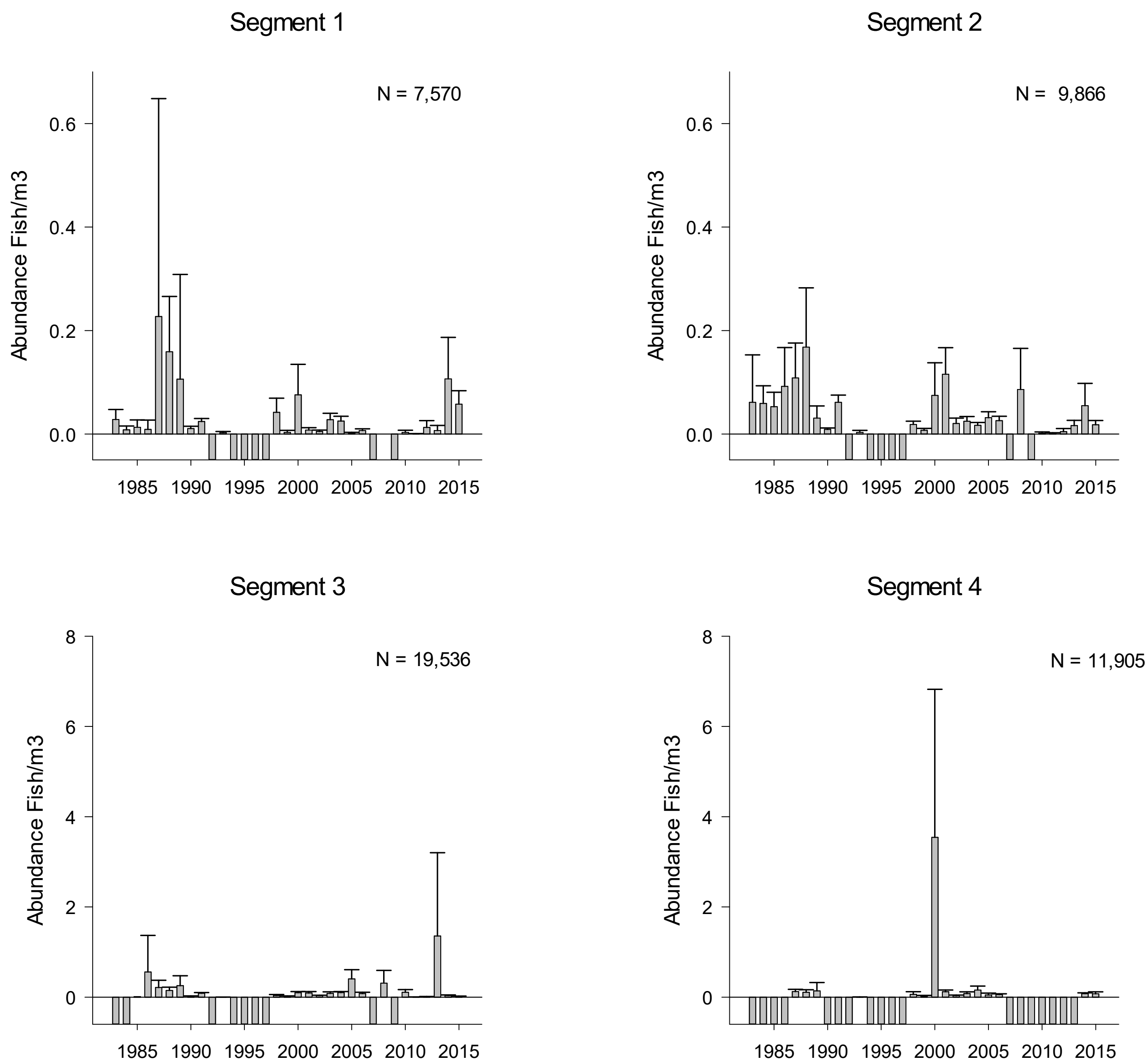


Figure A-4. Abundance (fish/m^3 ± 2 SE) for Catostomidae from 1983 to 2015 from surface larval drift nets deployed in four segments of the Nebraska portion of the Missouri River. Negative values indicate years with no data. Values on the y-axis are variable.

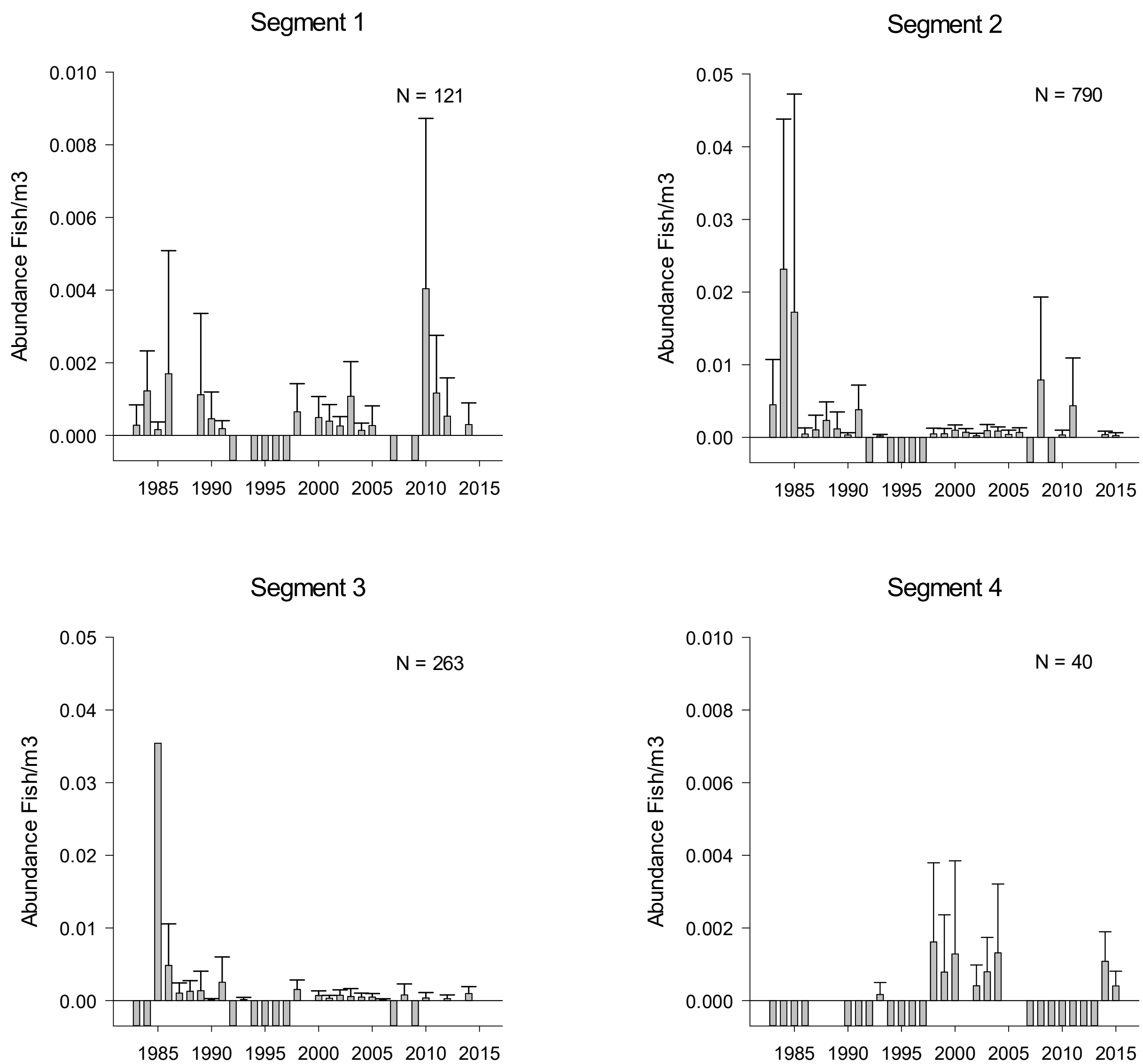


Figure A-5. Abundance (fish/m^3 ± 2 SE) for Centrarchidae from 1983 to 2015 from surface larval drift nets deployed in four segments of the Nebraska portion of the Missouri River. Negative values indicate years with no data. Values on the y-axis are variable.

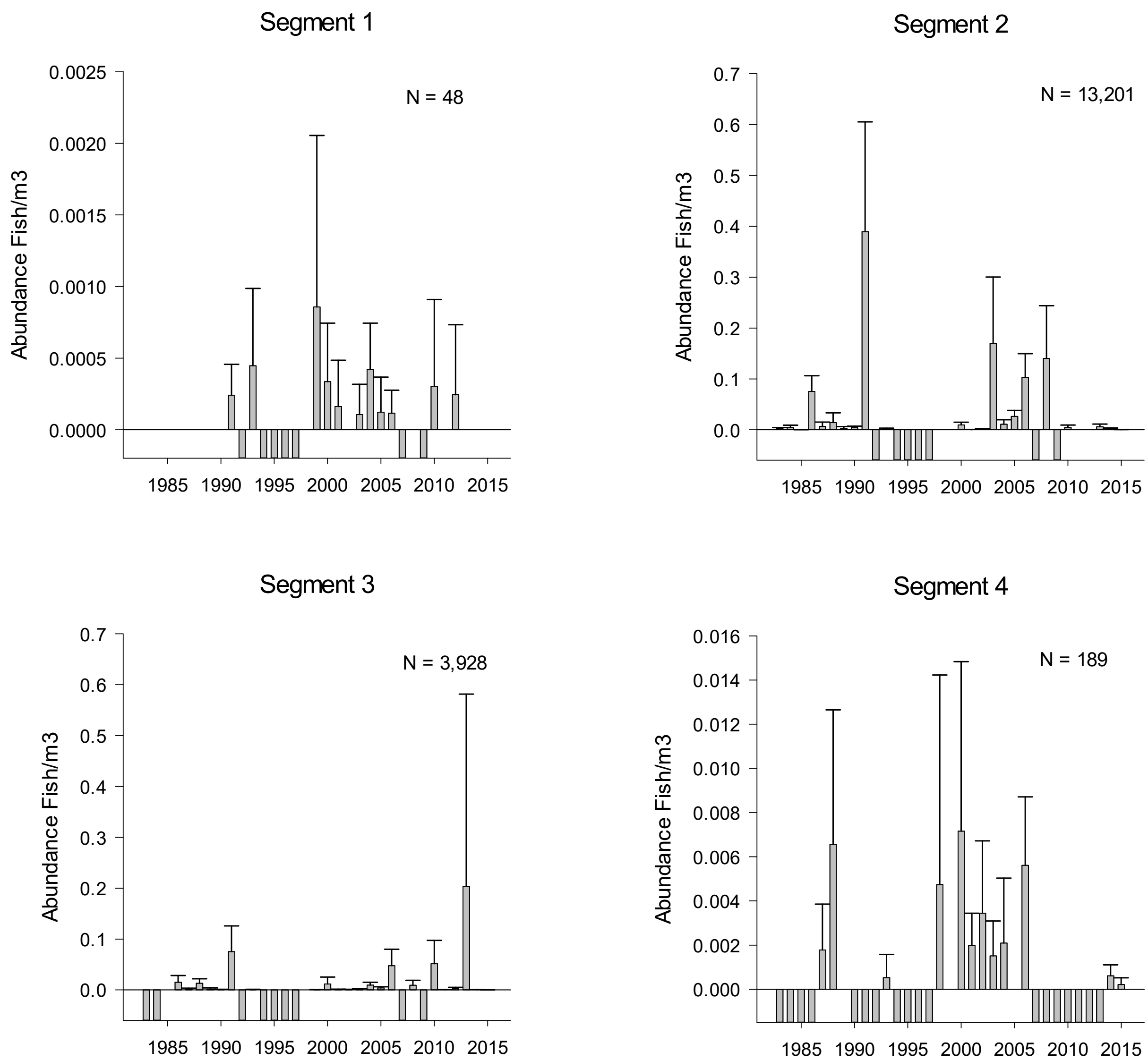


Figure A-6. Abundance (fish/m^3 ± 2 SE) for Clupeidae from 1983 to 2015 from surface larval drift nets deployed in four segments of the Nebraska portion of the Missouri River. Negative values indicate years with no data. Values on the y-axis are variable.

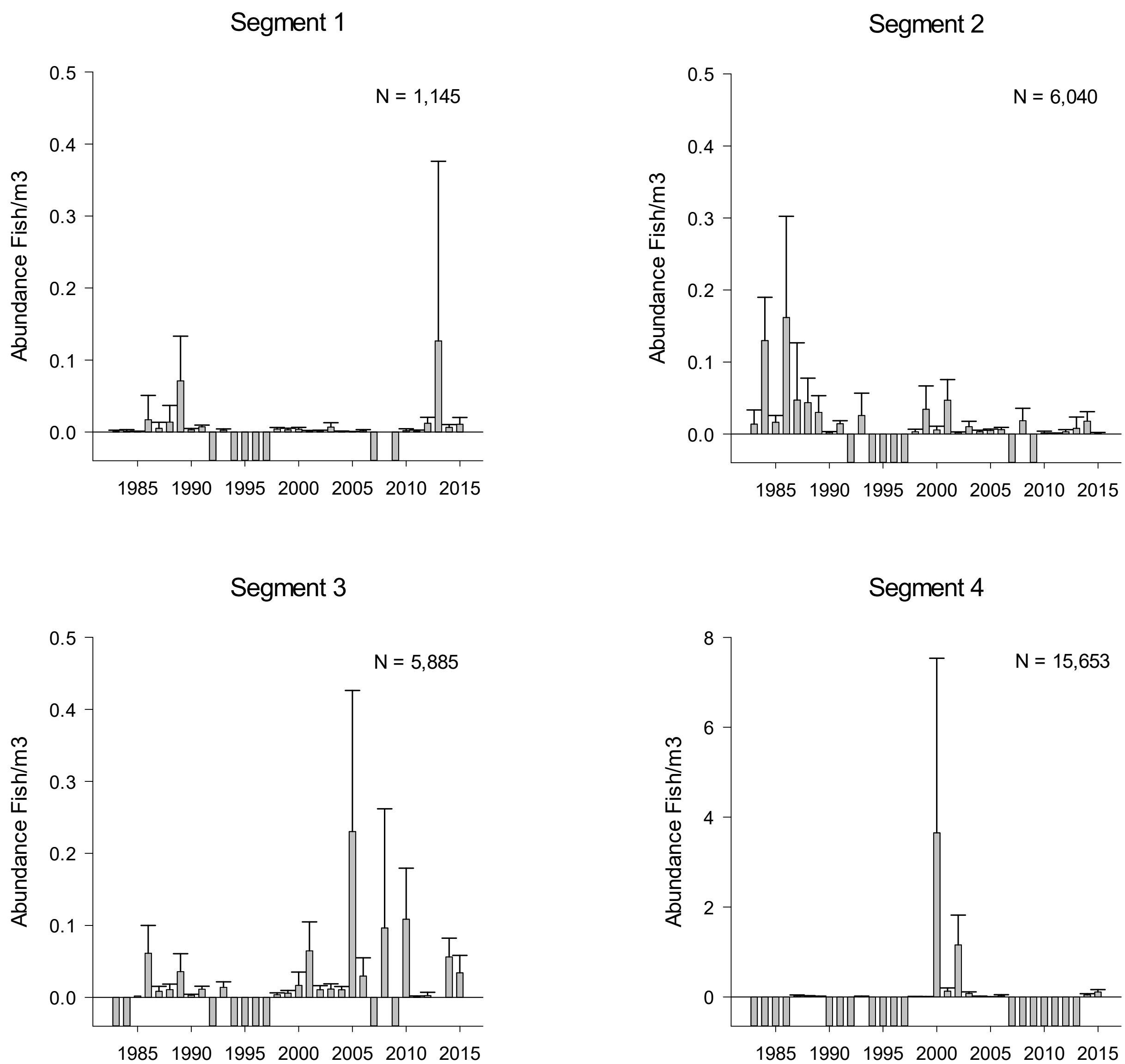


Figure A-7. Abundance (fish/m^3 ± 2 SE) for Cyprinidae from 1983 to 2015 from surface larval drift nets deployed in four segments of the Nebraska portion of the Missouri River. Negative values indicate years with no data. Values on the y-axis are variable.

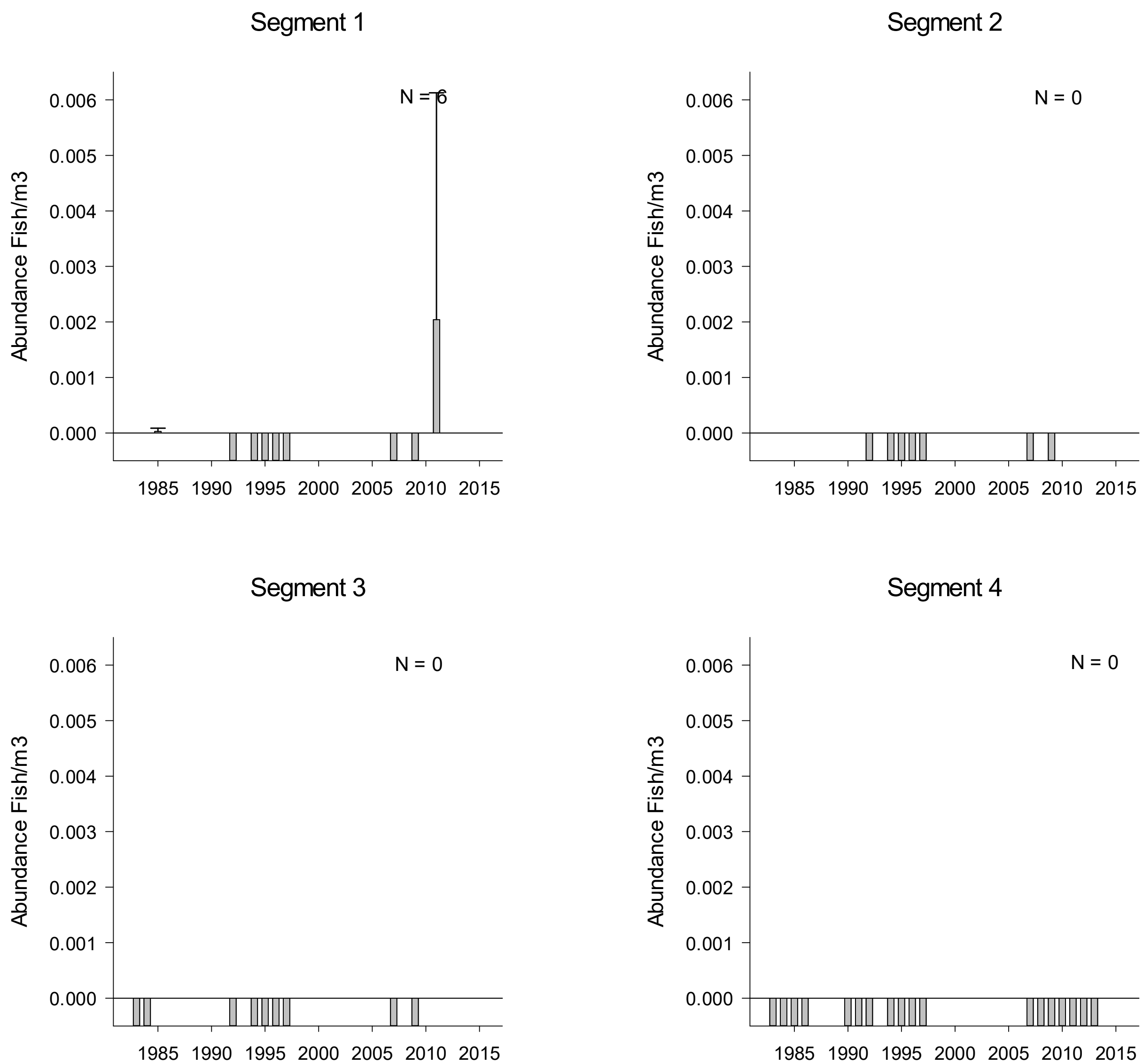


Figure A-8. Abundance (fish/m^3 ± 2 SE) for Esocidae from 1983 to 2015 from surface larval drift nets deployed in four segments of the Nebraska portion of the Missouri River. Negative values indicate years with no data. Esocidae was only sampled in Segment 1 in 2011.

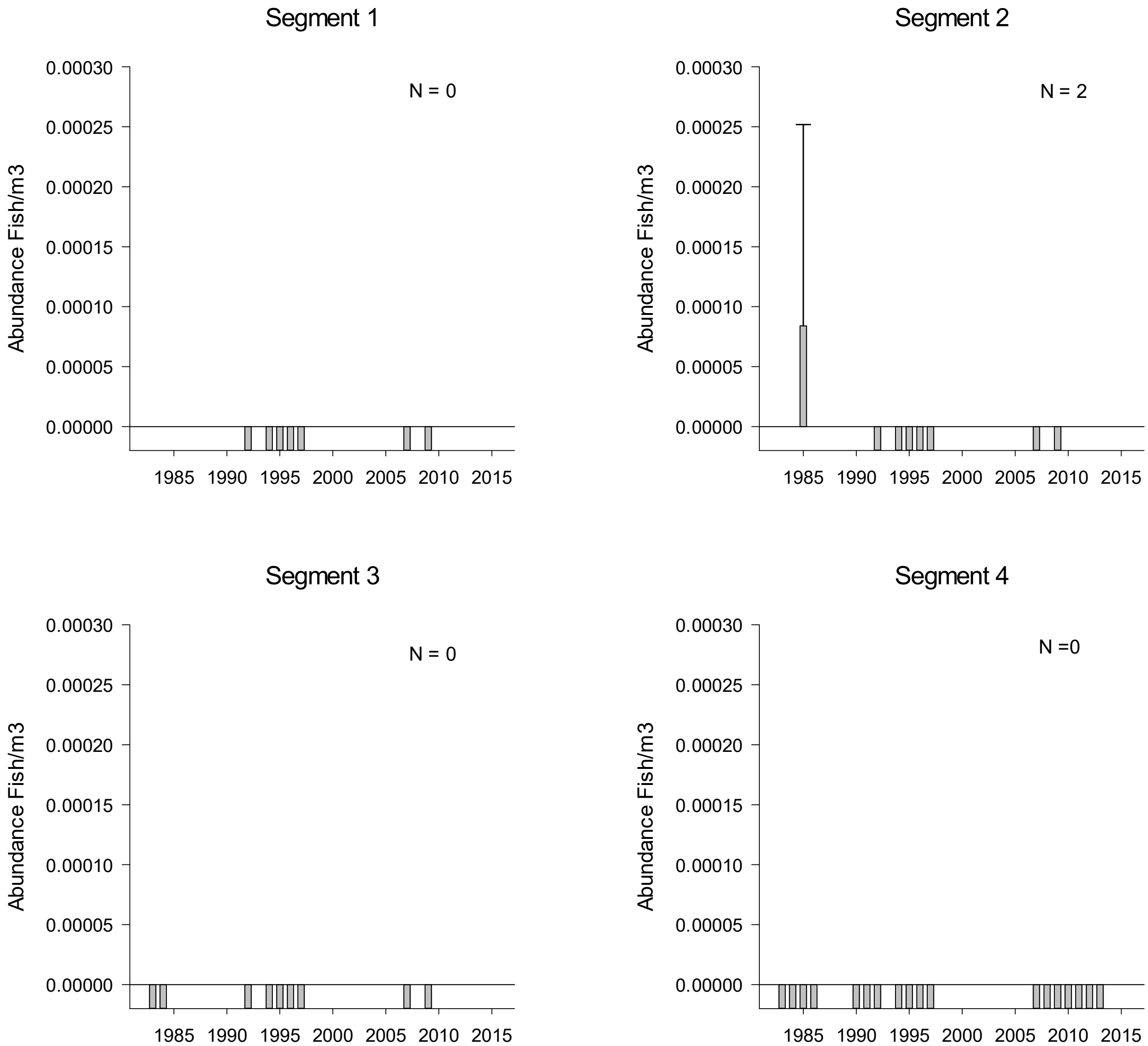


Figure A-9. Abundance (fish/m^3 ± 2 SE) for Gadidae from 1983 to 2015 from surface larval drift nets deployed in four segments of the Nebraska portion of the Missouri River. Negative values indicate years with no data. Gadidae was only sampled in Segment 2 in 1985.

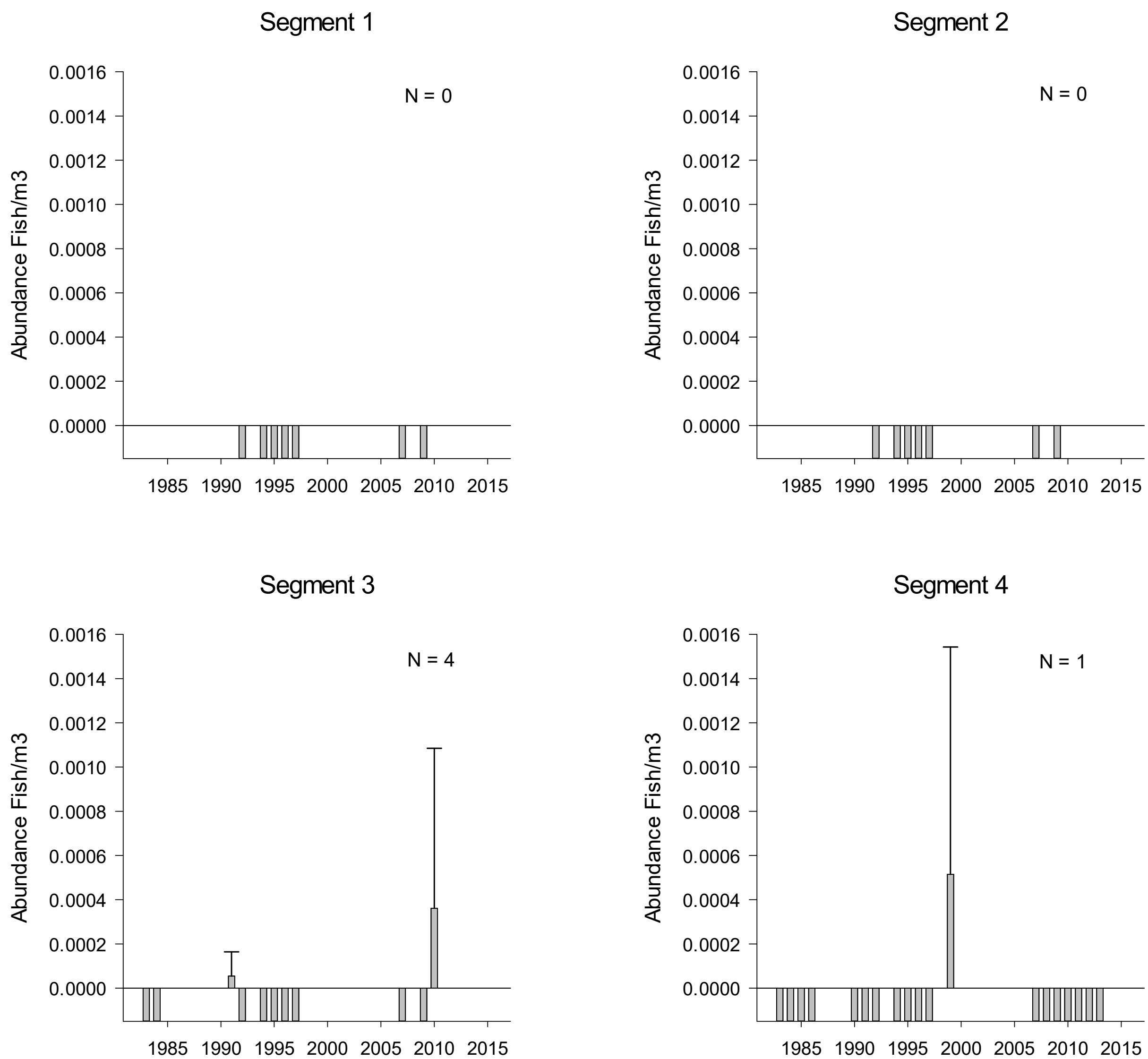


Figure A-10. Abundance (fish/m^3 ± 2 SE) for Gasterosteidae from 1983 to 2015 from surface larval drift nets deployed in four segments of the Nebraska portion of the Missouri River. Negative values indicate years with no data. Gasterosteidae was not found in Segment 1 or Segment 2.

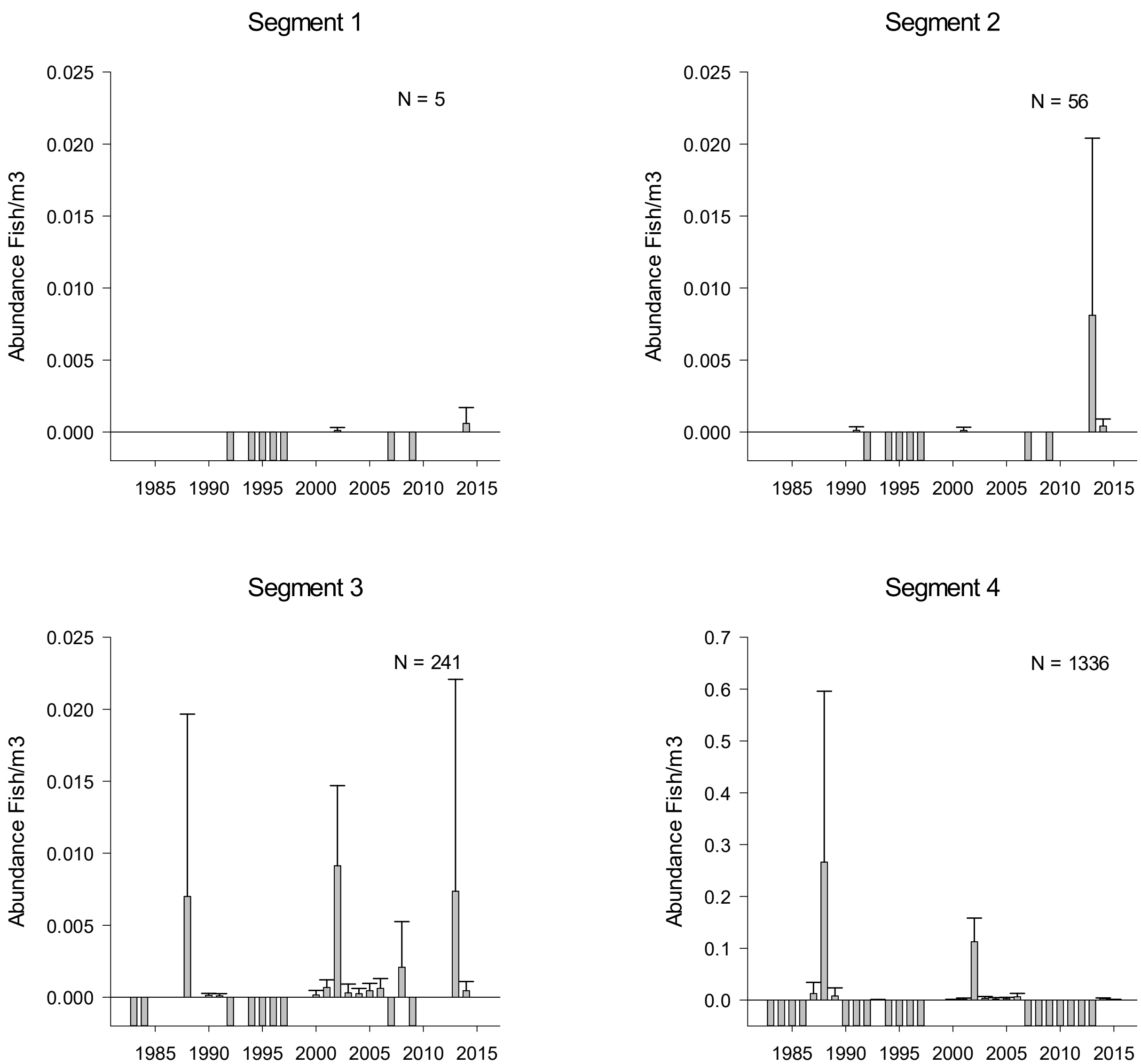


Figure A-11. Abundance (fish/m^3 ± 2 SE) for Hiodontidae from 1983 to 2015 from surface larva drift nets deployed in four segments of the Nebraska portion of the Missouri River. Negative values indicate years with no data. Values on the y-axis are variable.

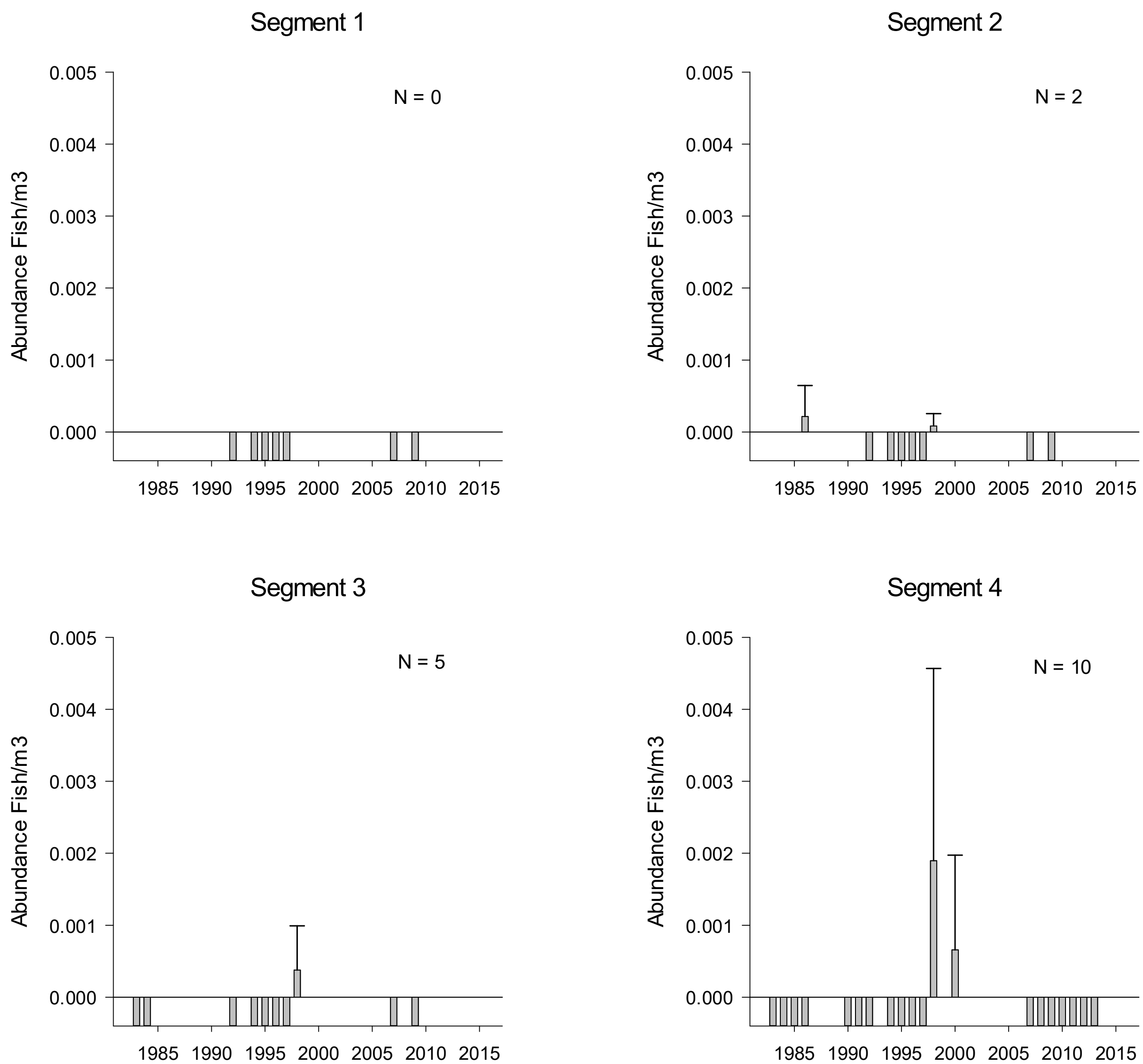


Figure A-12. Abundance (fish/m^3 ± 2 SE) for Ictaluridae from 1983 to 2015 from surface larval drift nets deployed in four segments of the Nebraska portion of the Missouri River. Negative values indicate years with no data. Ictaluridae was not sampled in Segment 1.

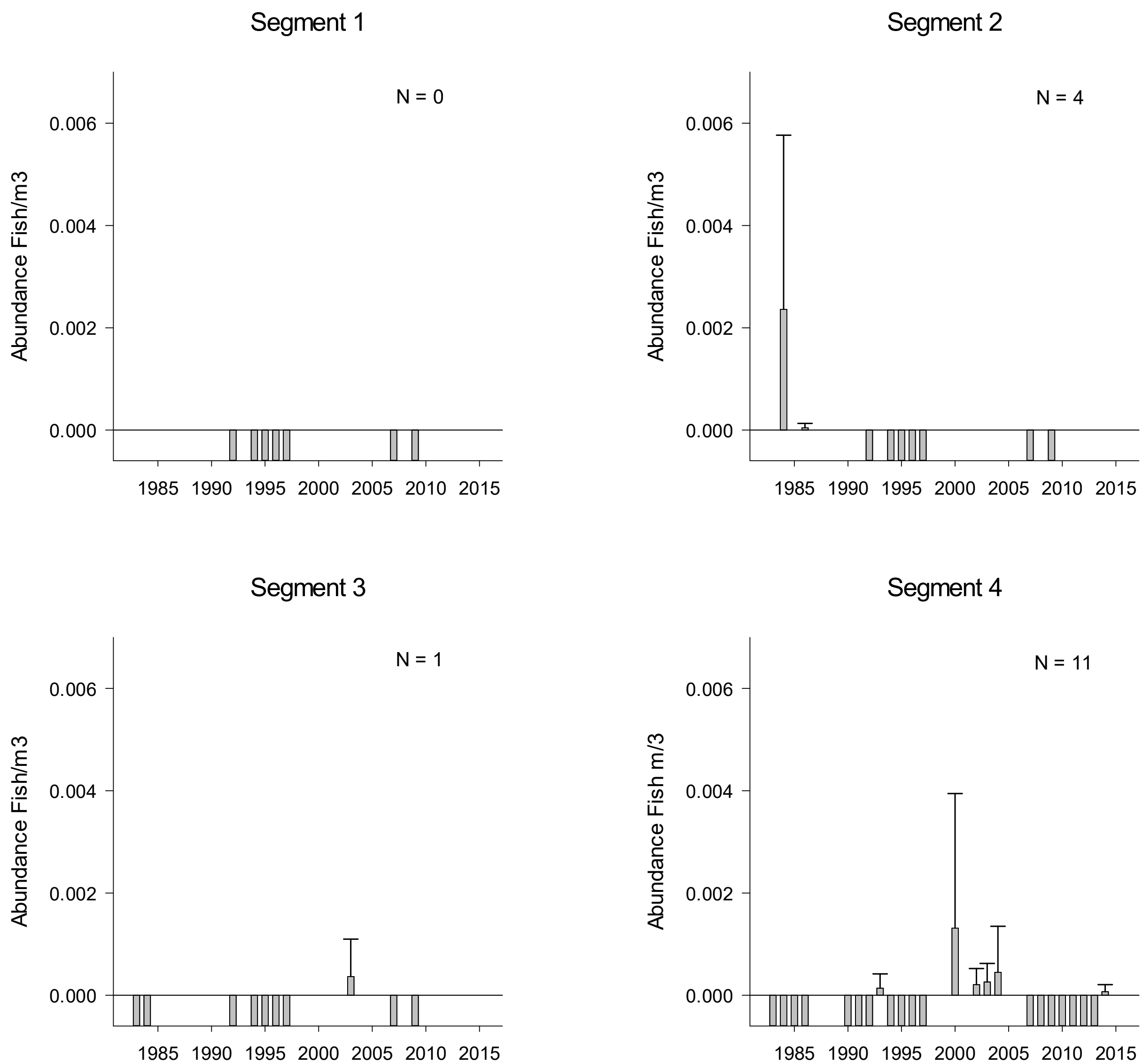


Figure A-13. Abundance (fish/m^3 ± 2 SE) for Lepisosteidae from 1983 to 2015 from surface larval drift nets deployed in four segments of the Nebraska portion of the Missouri River. Negative values indicate years with no data. Lepisosteidae was not sampled in Segment 1.

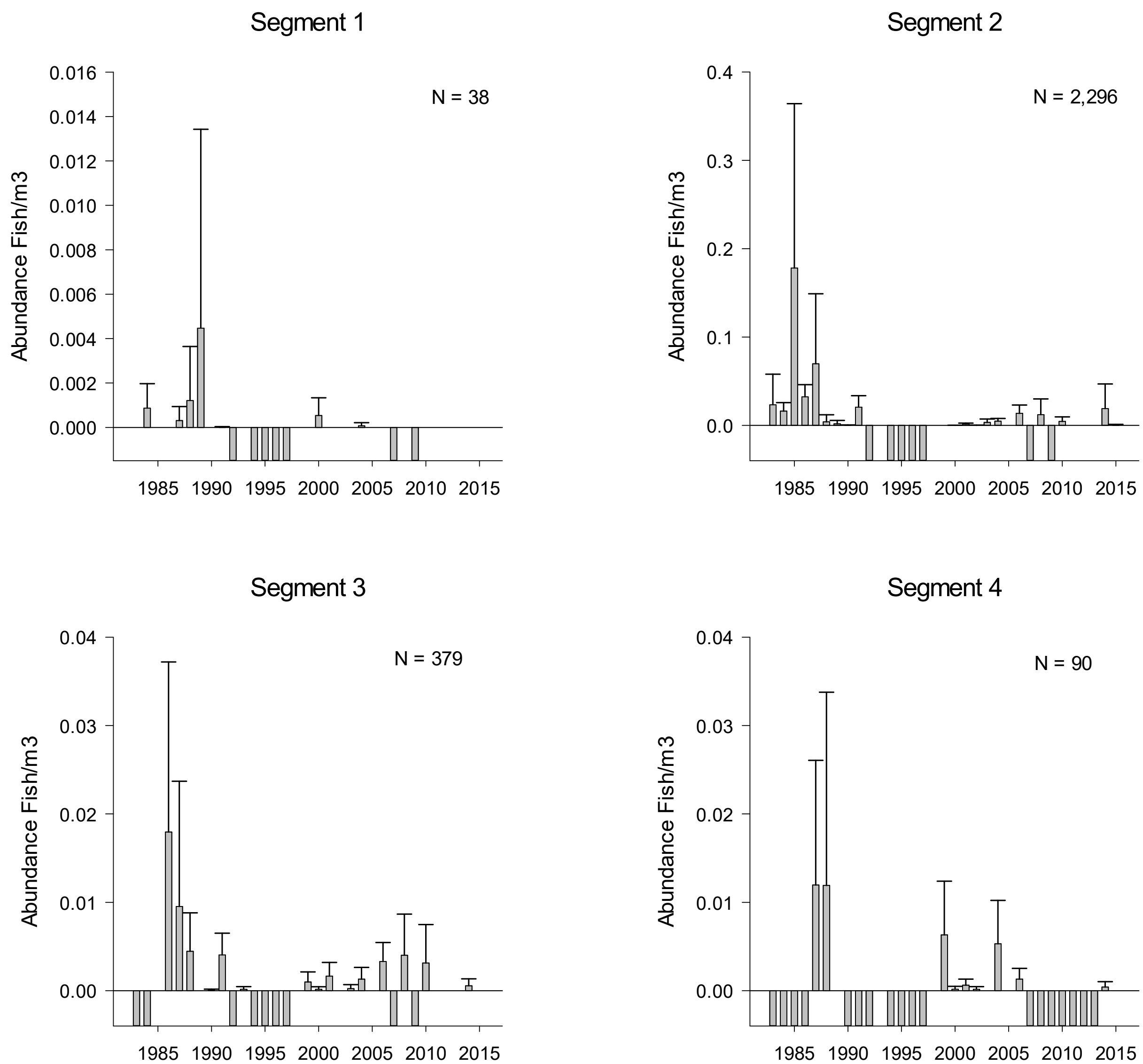


Figure A-14. Abundance (fish/m^3 ± 2 SE) for Moronidae from 1983 to 2015 from surface larval drift nets deployed in four segments of the Nebraska portion of the Missouri River. Negative values indicate years with no data. Values on the y-axis are variable.

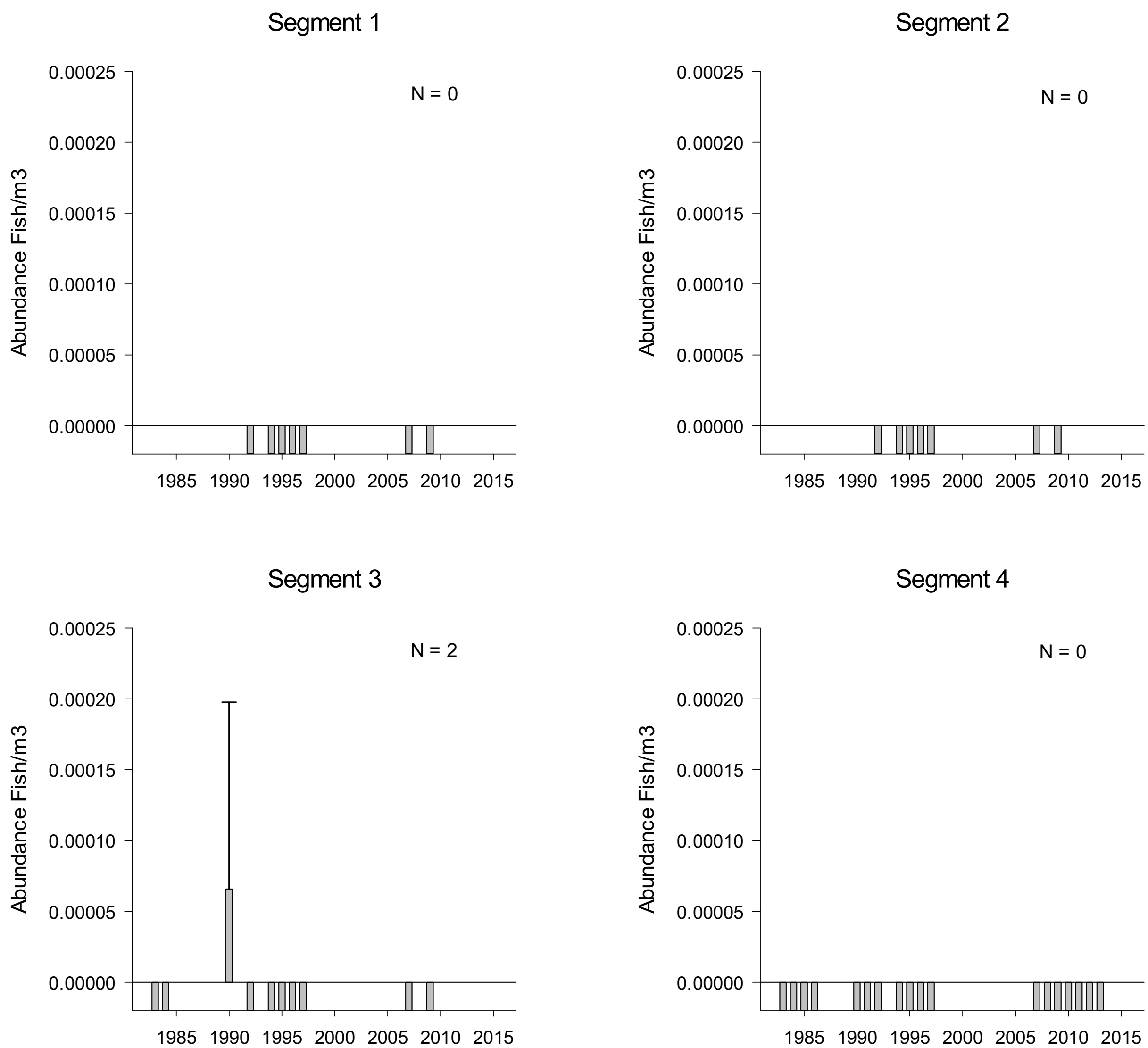


Figure A-15. Abundance (fish/m^3 ± 2 SE) for Osmeridae from 1983 to 2015 from surface larval drift nets deployed in four segments of the Nebraska portion of the Missouri River. Negative values indicate years with no data. Osmeridae was only sampled in Segment 3 in 1990.

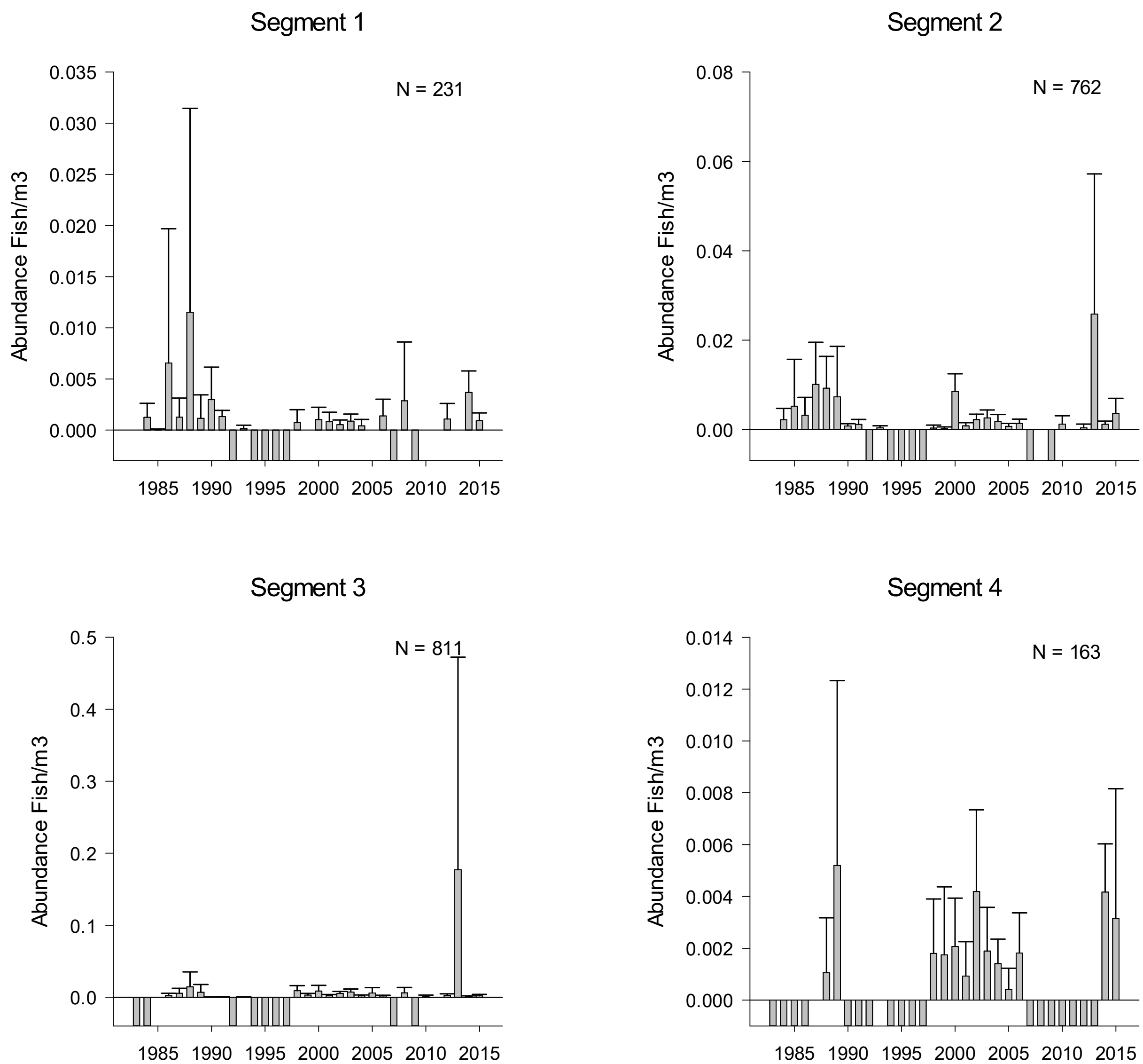


Figure A-16. Abundance (fish/m^3 ± 2 SE) for Percidae from 1983 to 2015 from surface larval drift nets deployed in four segments of the Nebraska portion of the Missouri River. Negative values indicate years with no data. Values on the y-axis are variable.

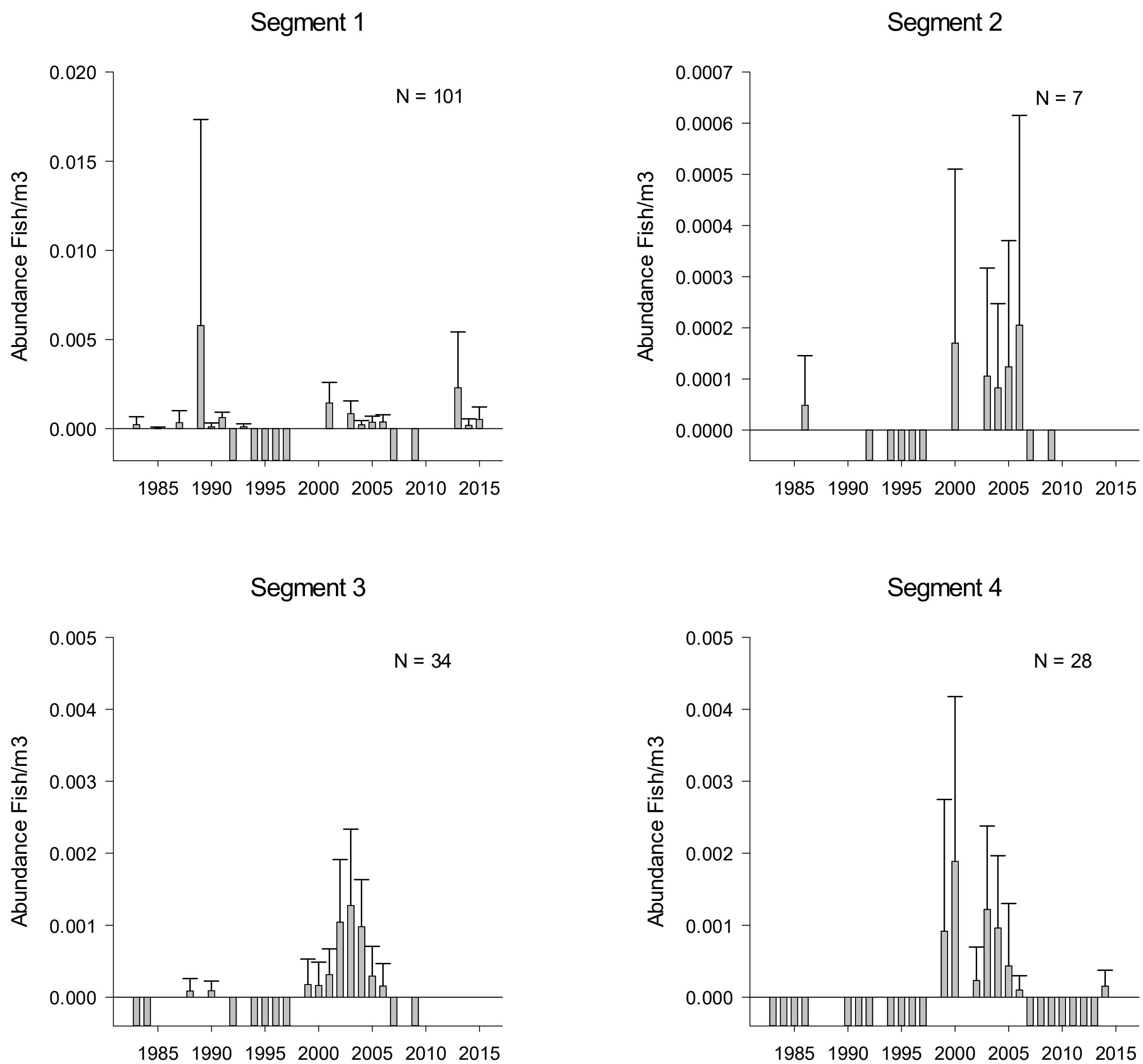


Figure A-17. Abundance (fish/m^3 ± 2 SE) for Polyodontidae from 1983 to 2015 from surface larval drift nets deployed in four segments of the Nebraska portion of the Missouri River. Negative values indicate years with no data. Values on the y-axis are variable.

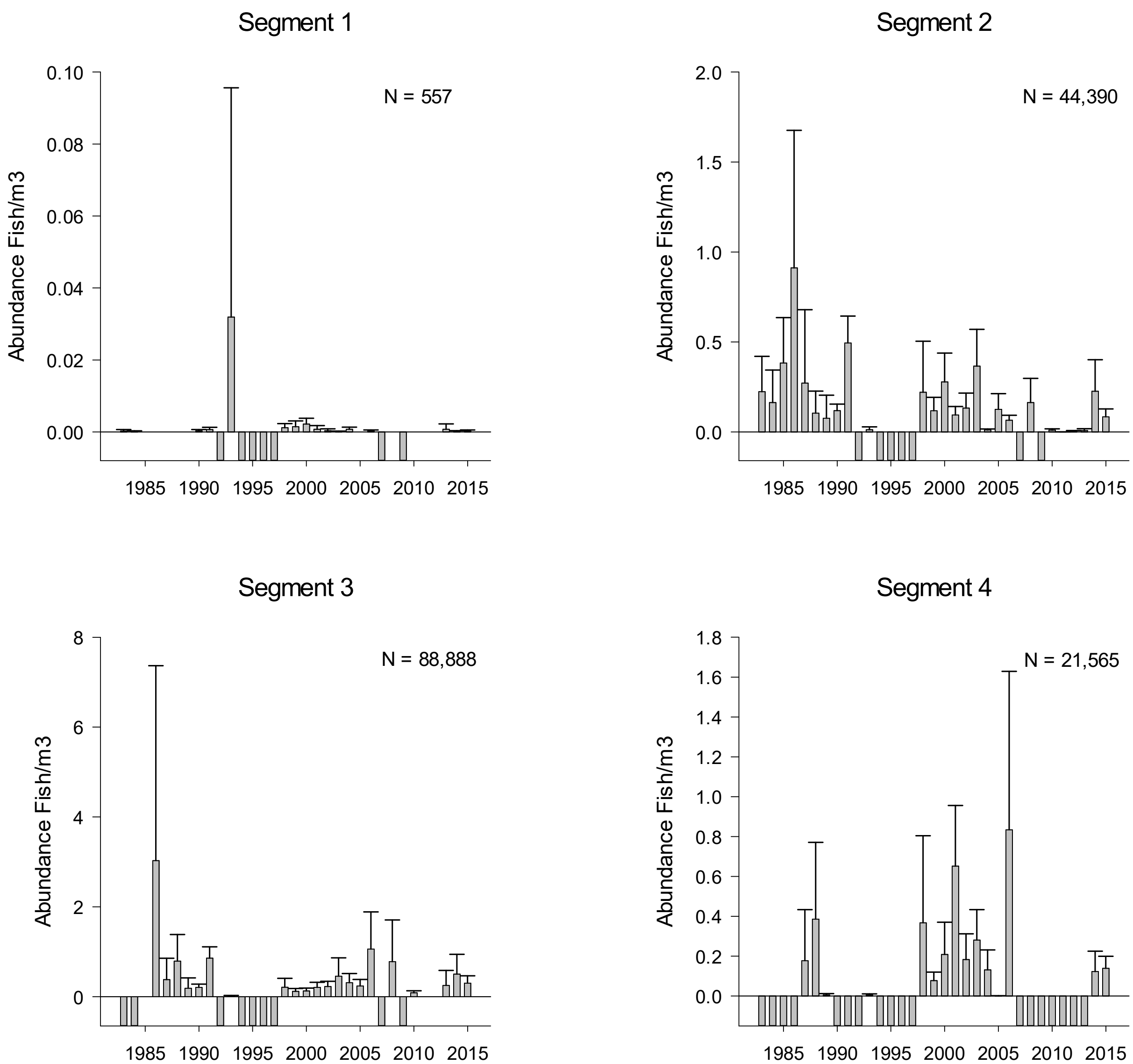


Figure A-18. Abundance (fish/m^3 ± 2 SE) for Sciaenidae from 1983 to 2015 from surface larval drift nets deployed in four segments of the Nebraska portion of the Missouri River. Negative values indicate years with no data. Values on the y-axis are variable.

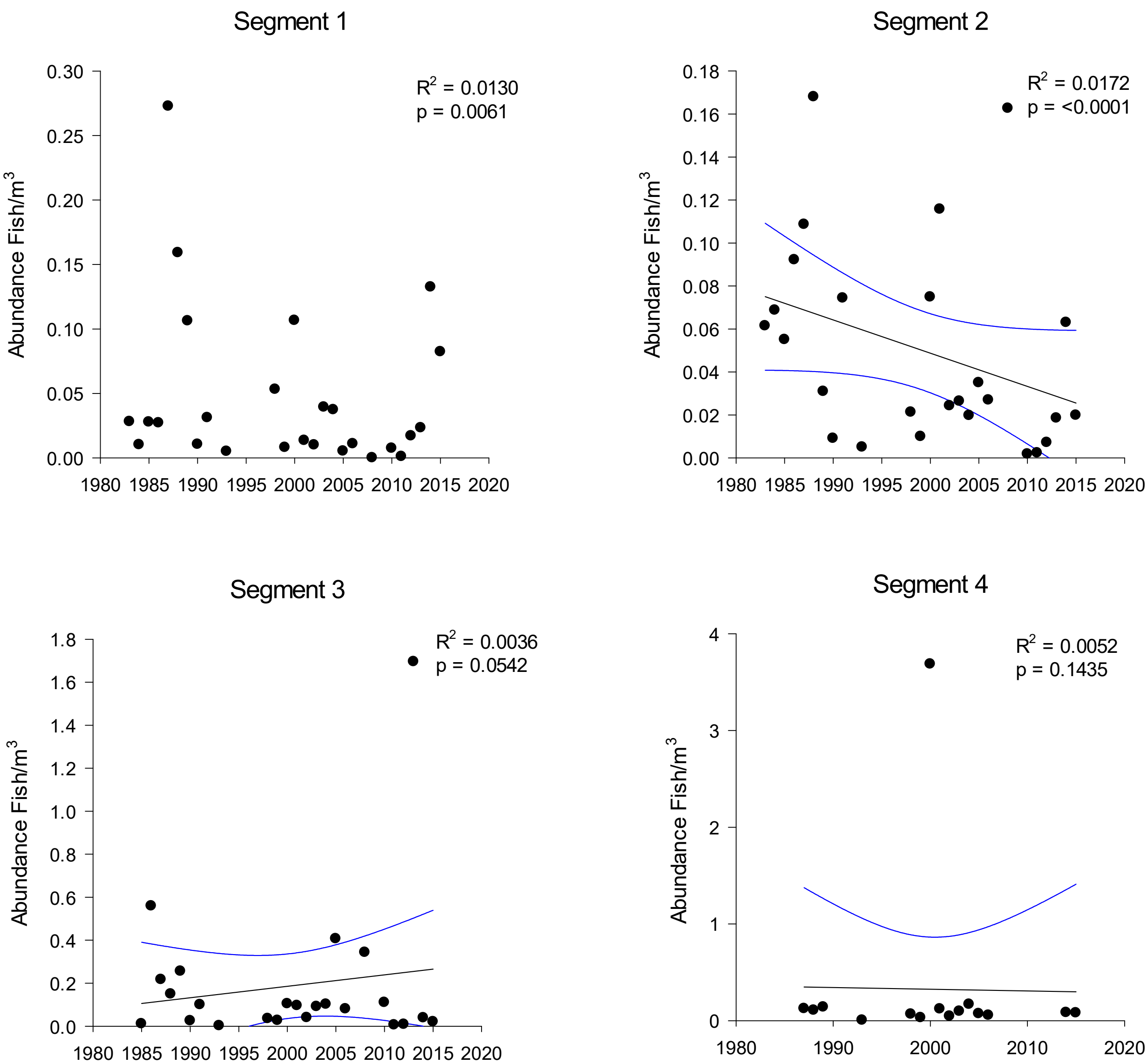


Figure A-19. Regression analysis for Catostomidae from 1983 to 2015 from surface larval drift nets deployed in four Segments of the Nebraska portion of the Missouri River. Bands indicate 95% confidence intervals. Segments 1 and 2 have no data from the years 1992, 1994 to 1997, 2007, and 2009. Segment 3 has no data from the years 1983 to 1984, 1992, 1994 to 1997, 2007, and 2009. Segment 4 has no data from the years 1983 to 1986, 1990 to 1992, 1994 to 1997, 2007 to 2013. Values on the y-axis are variable. Lines were removed from the Segment 1 figure because it was depicted as a negative slope, but it had a positive slope when the raw data were used for the regression analysis.

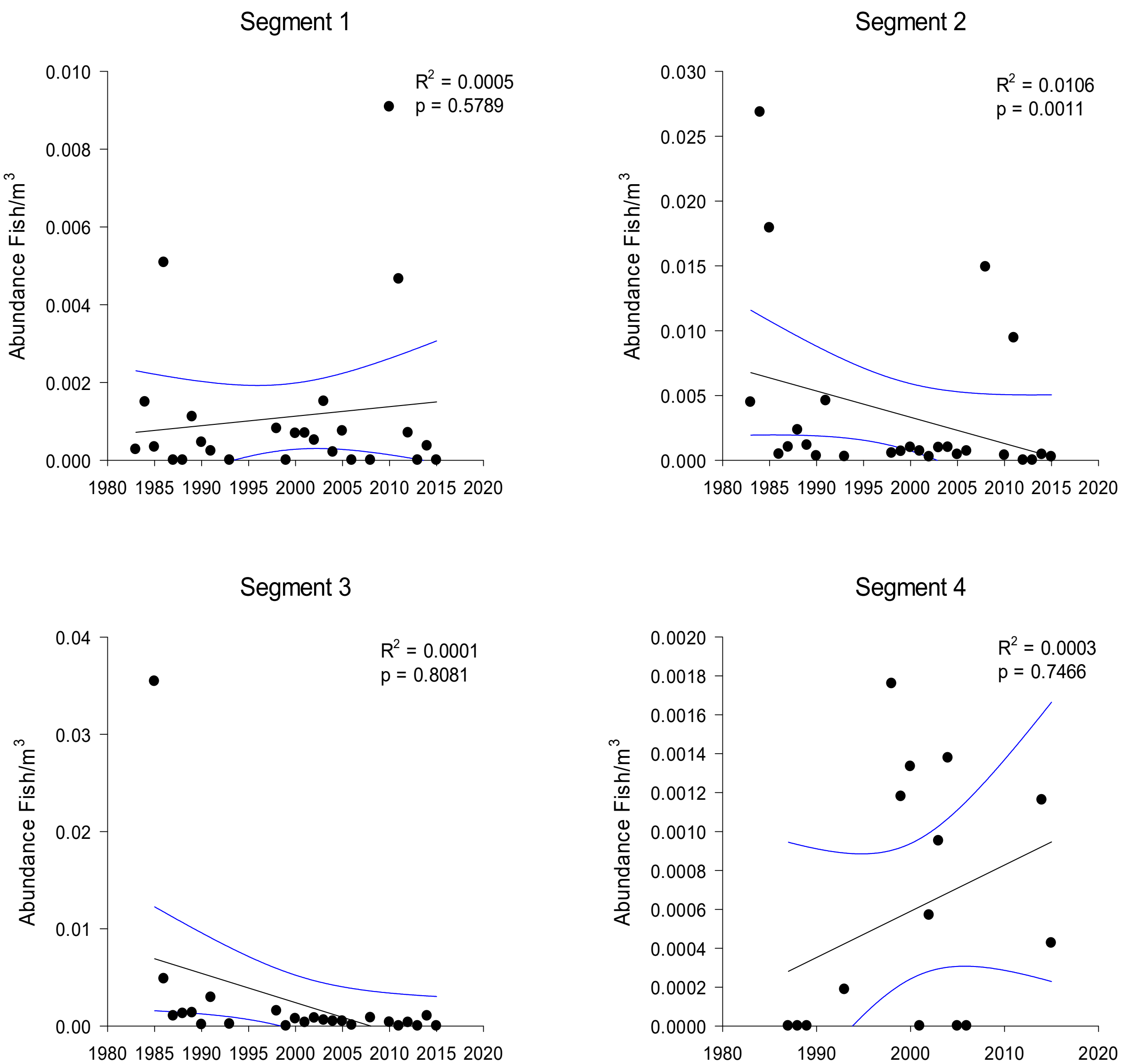


Figure A-20. Regression analysis for Centrarchidae from 1983 to 2015 from surface larval drift nets deployed in four Segments of the Nebraska portion of the Missouri River. Bands indicate 95% confidence intervals. Segments 1 and 2 have no data from the years 1992, 1994 to 1997, 2007, and 2009. Segment 3 has no data from the years 1983 to 1984, 1992, 1994 to 1997, 2007, and 2009. Segment 4 has no data from the years 1983 to 1986, 1990 to 1992, 1994 to 1997, 2007 to 2013. Values on the y-axis are variable.

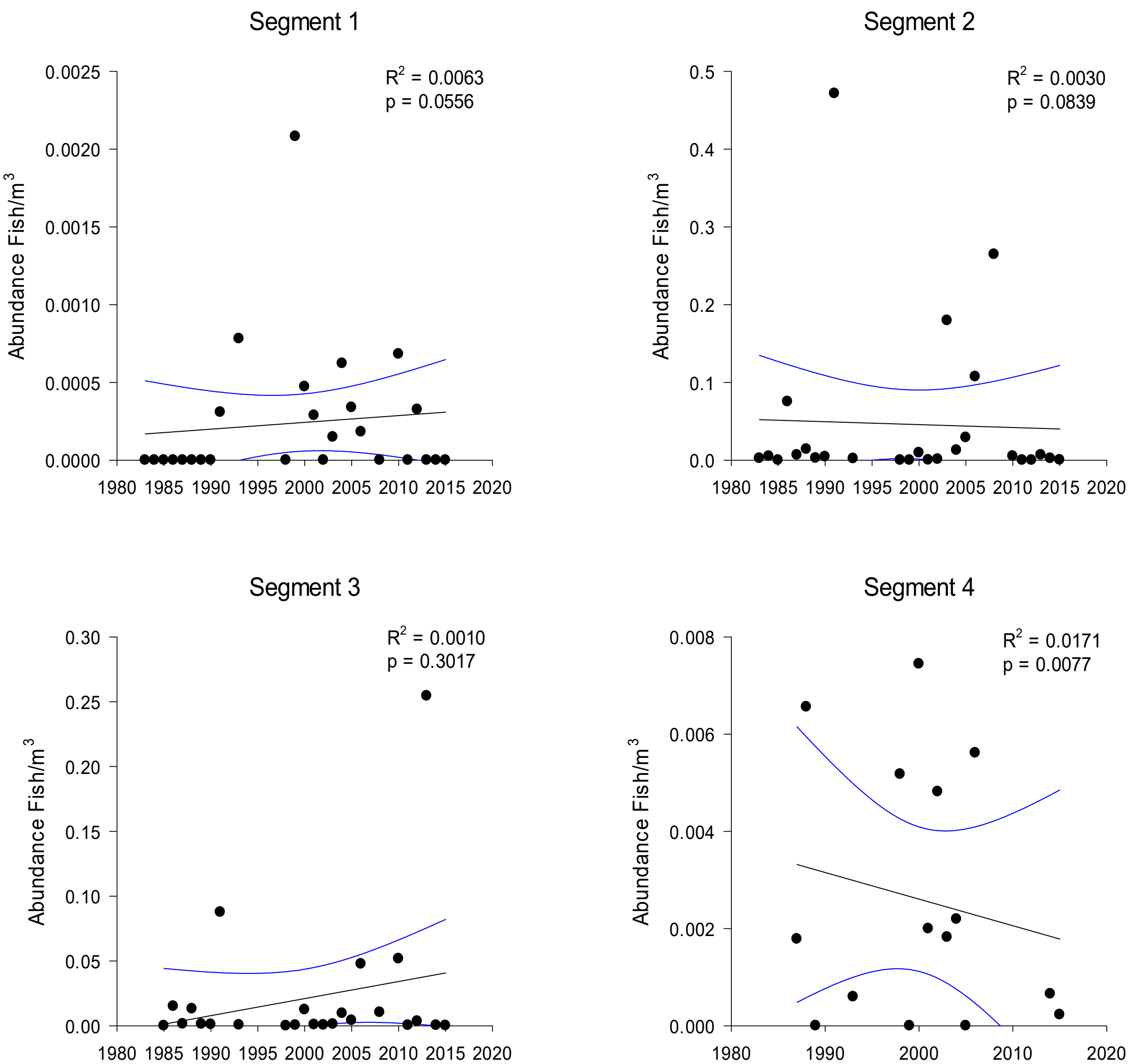


Figure A-21. Regression analysis for Clupeidae from 1983 to 2015 from surface larval drift nets deployed in four Segments of the Nebraska portion of the Missouri River. Bands indicate 95% confidence intervals. Segments 1 and 2 have no data from the years 1992, 1994 to 1997, 2007, and 2009. Segment 3 has no data from the years 1983 to 1984, 1992, 1994 to 1997, 2007, and 2009. Segment 4 has no data from the years 1983 to 1986, 1990 to 1992, 1994 to 1997, 2007 to 2013. Values on the y-axis are variable.

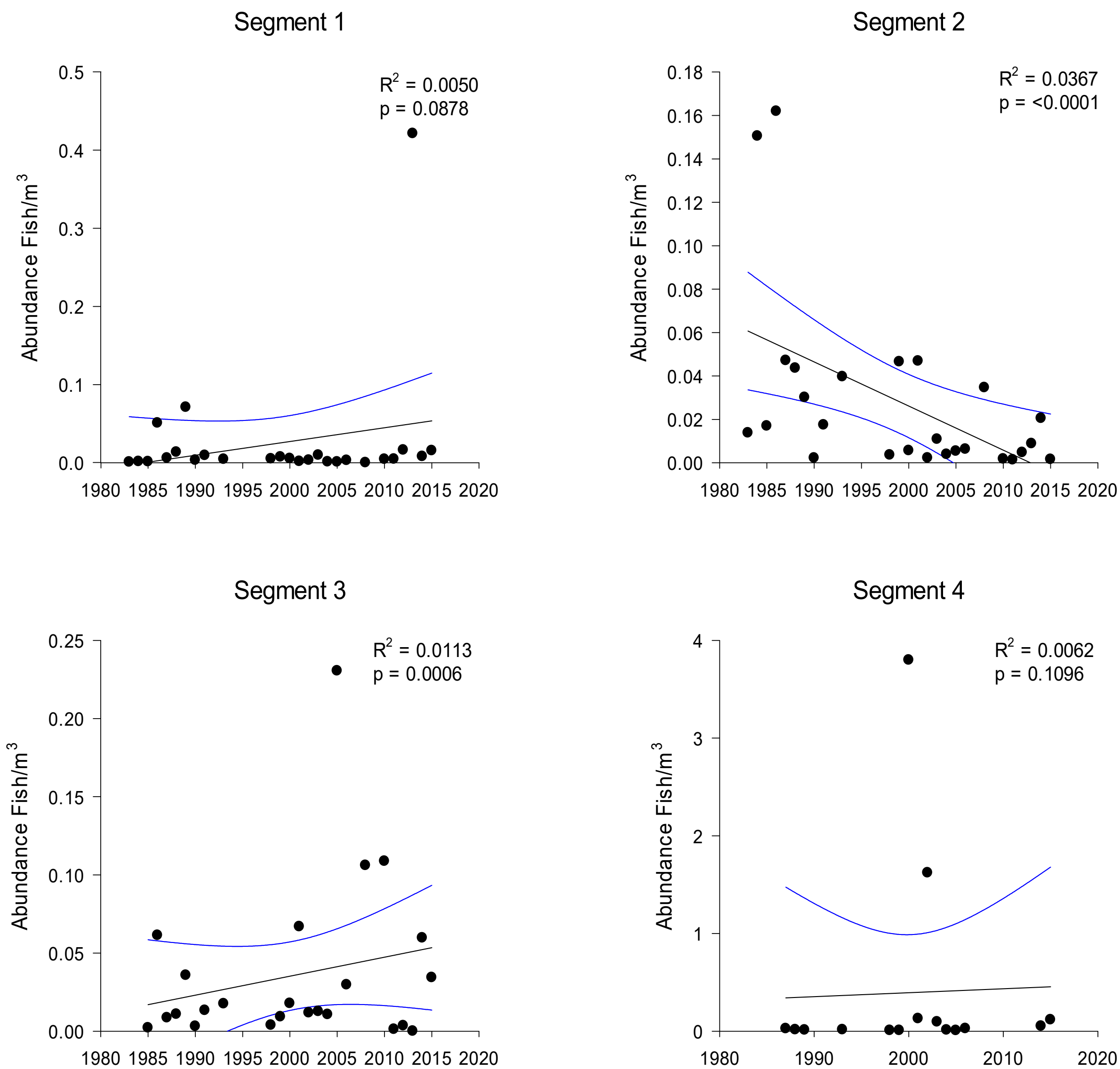


Figure A-22. Regression analysis for Cyprinidae from 1983 to 2015 from surface larval drift nets deployed in four Segments of the Nebraska portion of the Missouri River. Bands indicate 95% confidence intervals. Segments 1 and 2 have no data from the years 1992, 1994 to 1997, 2007, and 2009. Segment 3 has no data from the years 1983 to 1984, 1992, 1994 to 1997, 2007, and 2009. Segment 4 has no data from the years 1983 to 1986, 1990 to 1992, 1994 to 1997, 2007 to 2013. Values on the y-axis are variable.

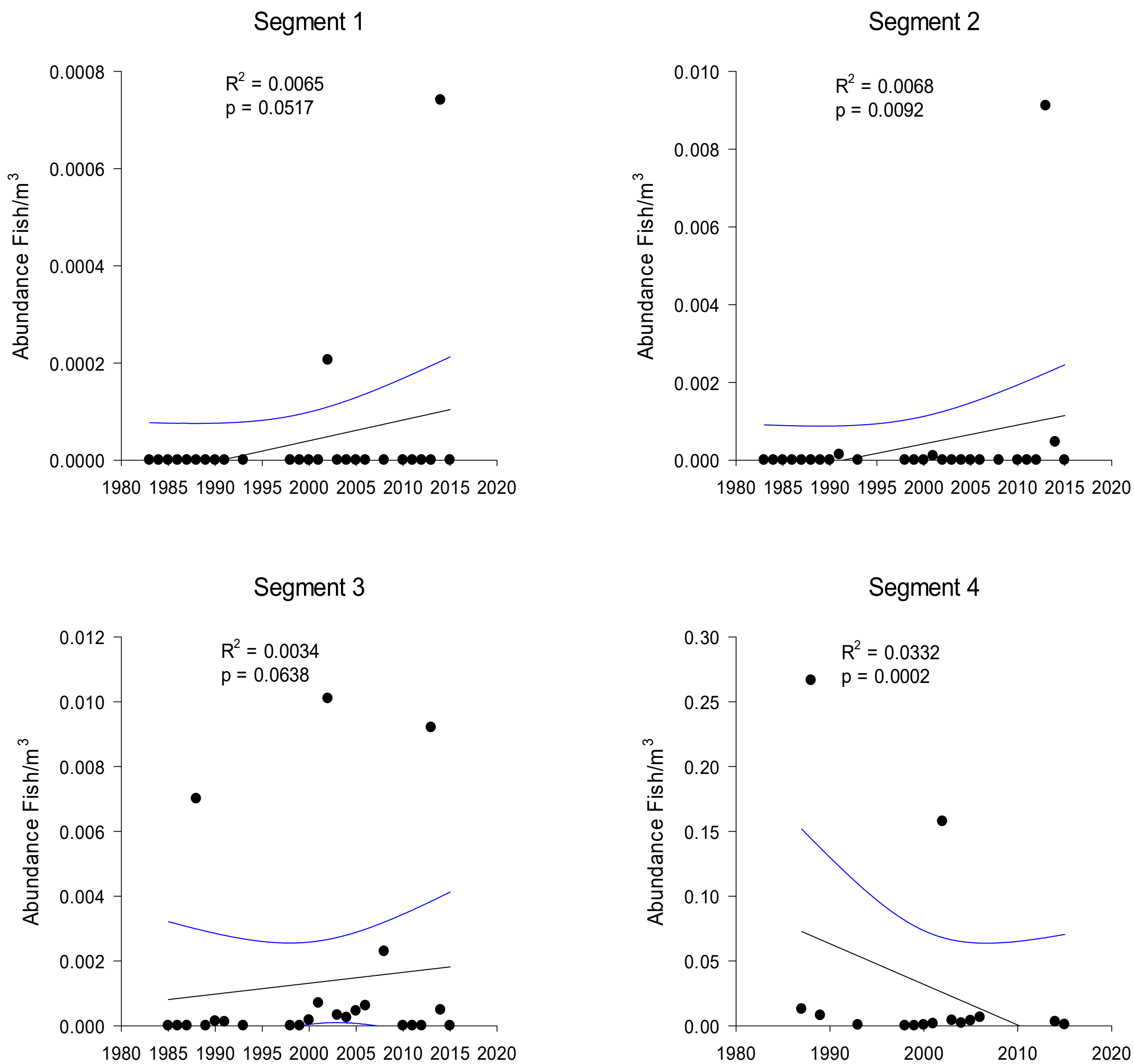


Figure A-23. Regression analysis for Hiodontidae from 1983 to 2015 from surface larval drift nets deployed in four Segments of the Nebraska portion of the Missouri River. Bands indicate 95% confidence intervals. Segments 1 and 2 have no data from the years 1992, 1994 to 1997, 2007, and 2009. Segment 3 has no data from the years 1983 to 1984, 1992, 1994 to 1997, 2007, and 2009. Segment 4 has no data from the years 1983 to 1986, 1990 to 1992, 1994 to 1997, 2007 to 2013. Values on the y-axis are variable.

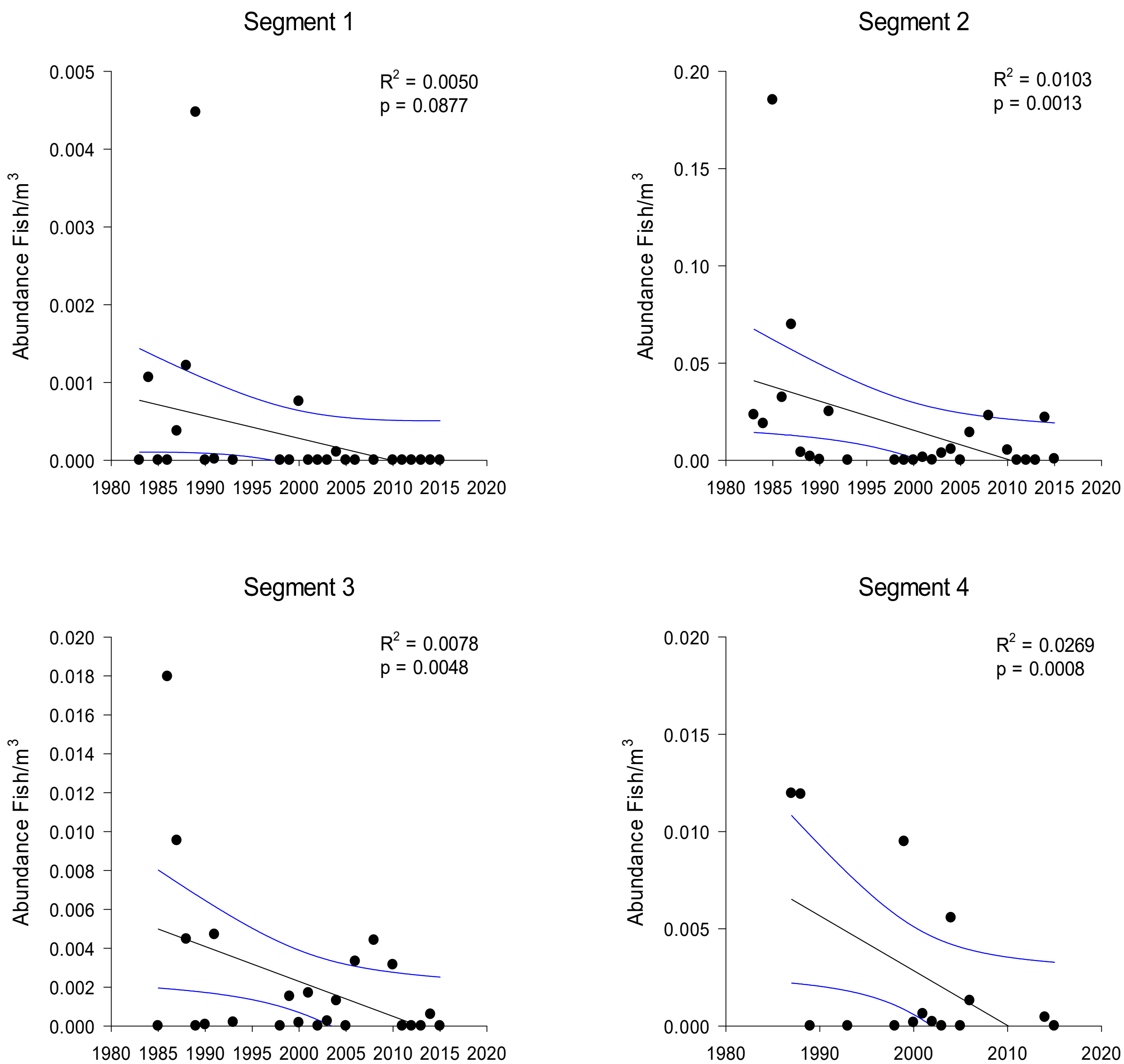


Figure A-24. Regression analysis for Moronidae from 1983 to 2015 from surface larval drift nets deployed in four Segments of the Nebraska portion of the Missouri River. Bands indicate 95% confidence intervals. Segments 1 and 2 have no data from the years 1992, 1994 to 1997, 2007, and 2009. Segment 3 has no data from the years 1983 to 1984, 1992, 1994 to 1997, 2007, and 2009. Segment 4 has no data from the years 1983 to 1986, 1990 to 1992, 1994 to 1997, 2007 to 2013. Values on the y-axis are variable.

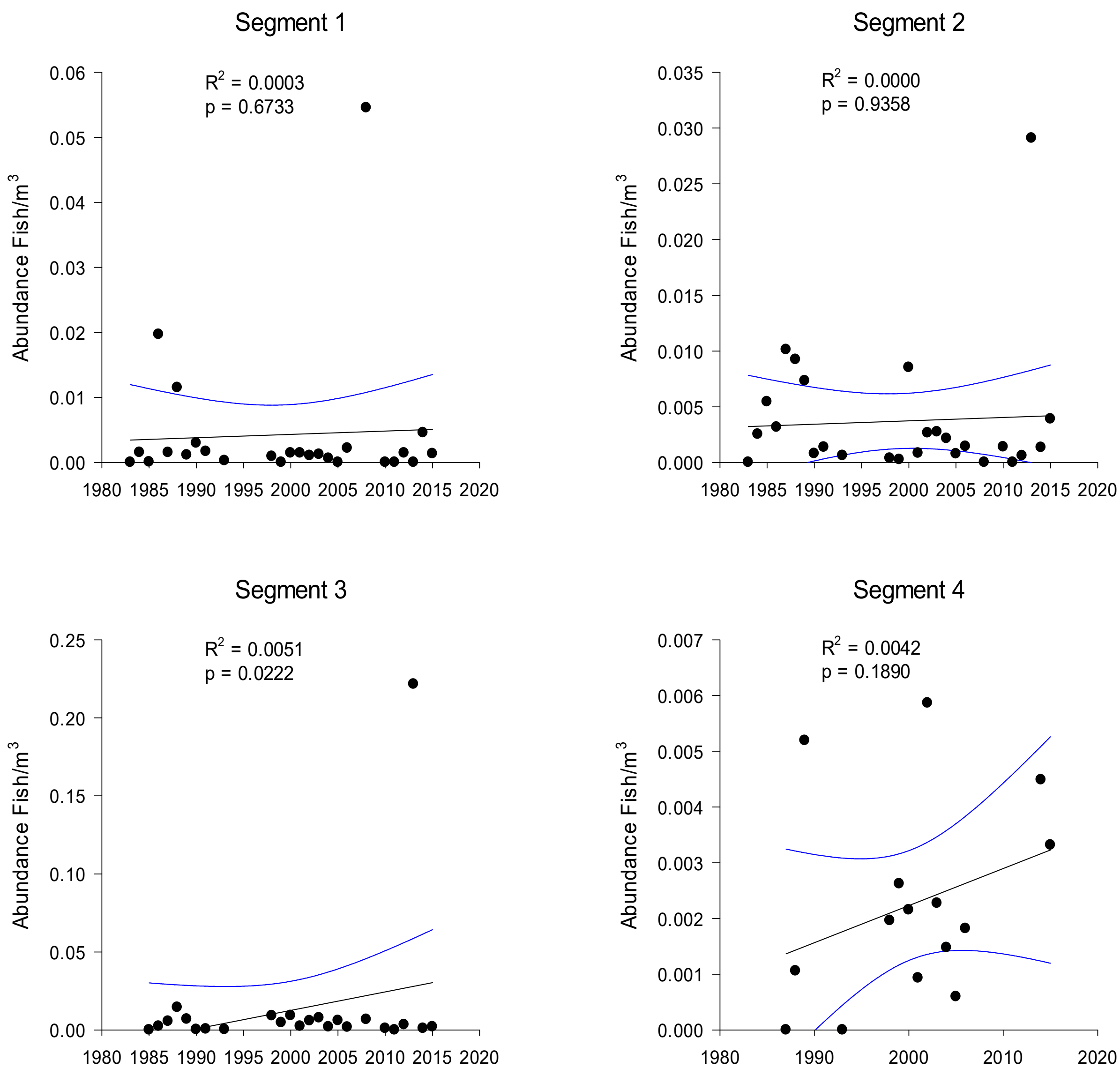


Figure A-25. Regression analysis for Percidae from 1983 to 2015 from surface larval drift nets deployed in four Segments of the Nebraska portion of the Missouri River. Bands indicate 95% confidence intervals. Segments 1 and 2 have no data from the years 1992, 1994 to 1997, 2007, and 2009. Segment 3 has no data from the years 1983 to 1984, 1992, 1994 to 1997, 2007, and 2009. Segment 4 has no data from the years 1983 to 1986, 1990 to 1992, 1994 to 1997, 2007 to 2013. Values on the y-axis are variable.

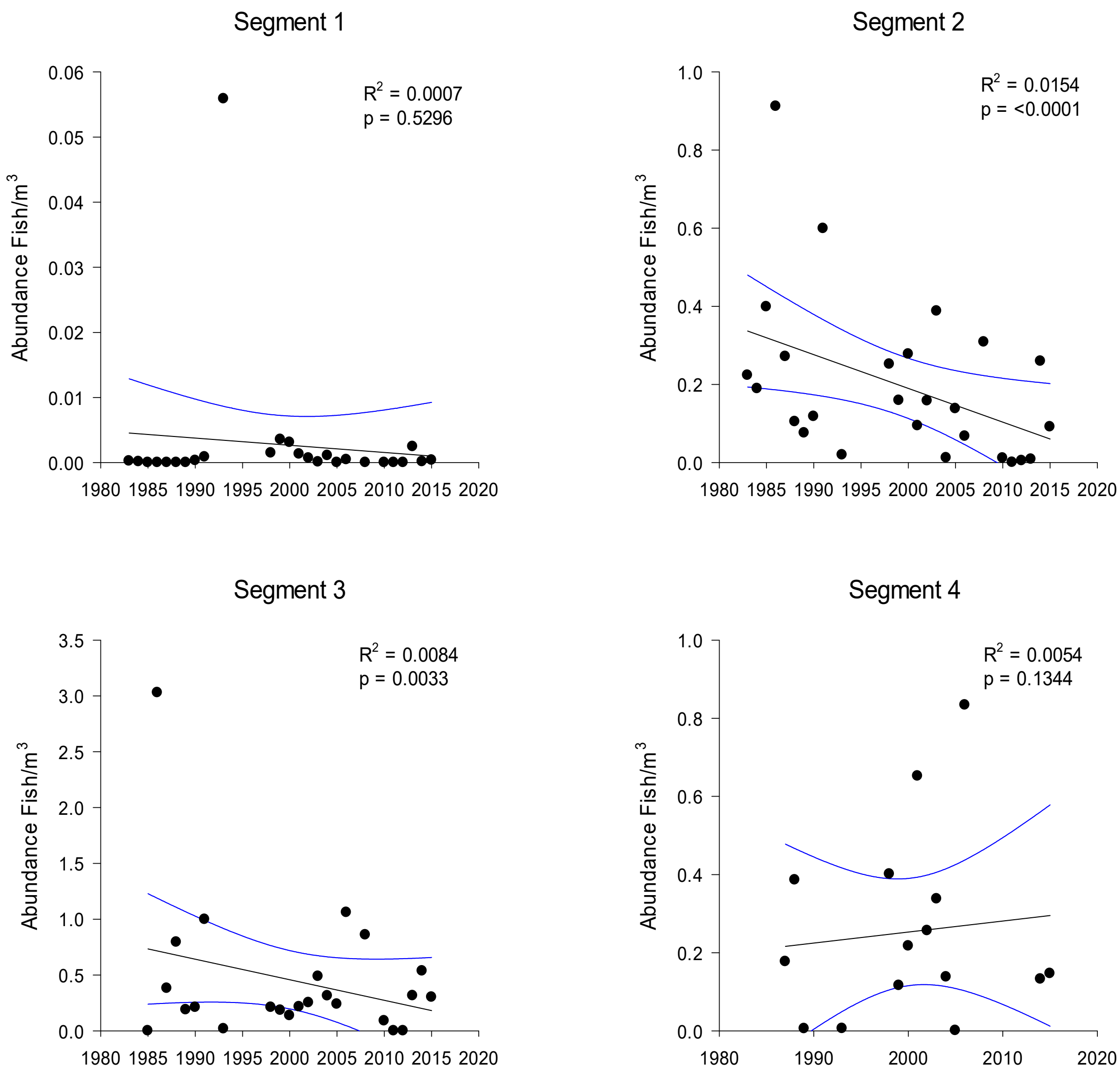


Figure A-26. Regression analysis for Sciaenidae from 1983 to 2015 from surface larval drift nets deployed in four Segments of the Nebraska portion of the Missouri River. Bands indicate 95% confidence intervals. Segments 1 and 2 have no data from the years 1992, 1994 to 1997, 2007, and 2009. Segment 3 has no data from the years 1983 to 1984, 1992, 1994 to 1997, 2007, and 2009. Segment 4 has no data from the years 1983 to 1986, 1990 to 1992, 1994 to 1997, 2007 to 2013. Values on the y-axis are variable

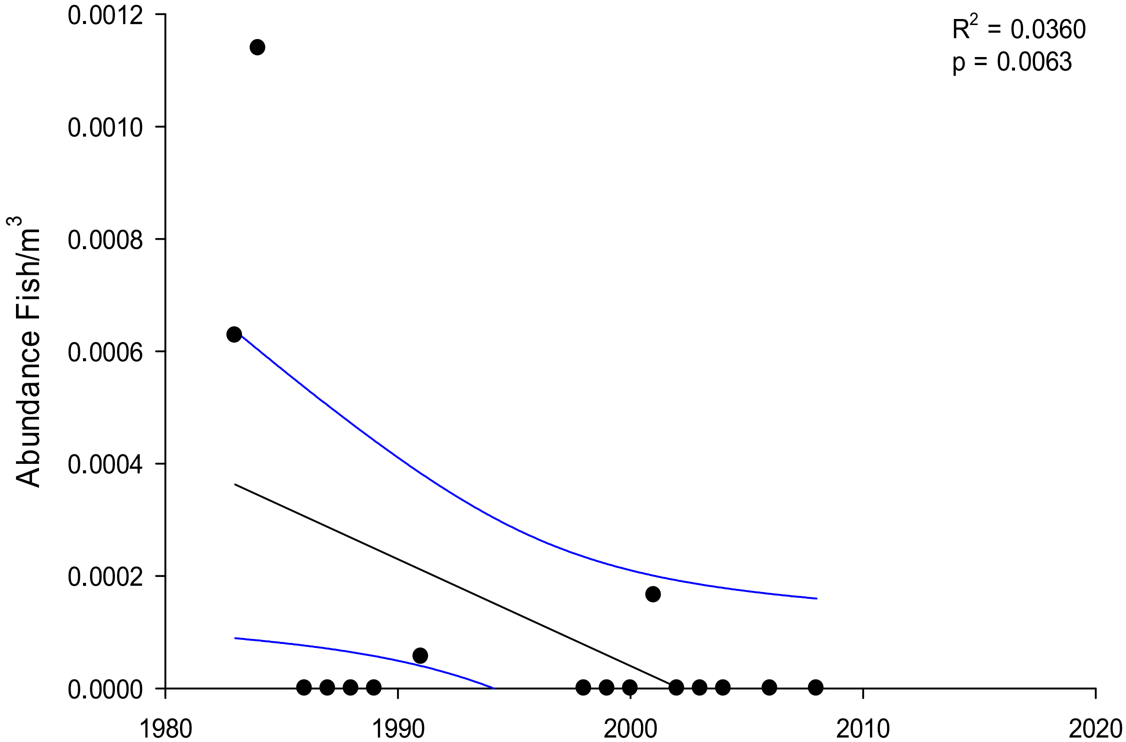


Figure A-27. Regression analysis for Centrarchidae from the Boyd/Verdel Site from 1983 to 2015. Fish were sampled using surface larval drift nets. Bands indicate 95% confidence intervals. This site has no data from the years 1985, 1990, 1992 to 1997, 2005, 2007, and 2009-2015.

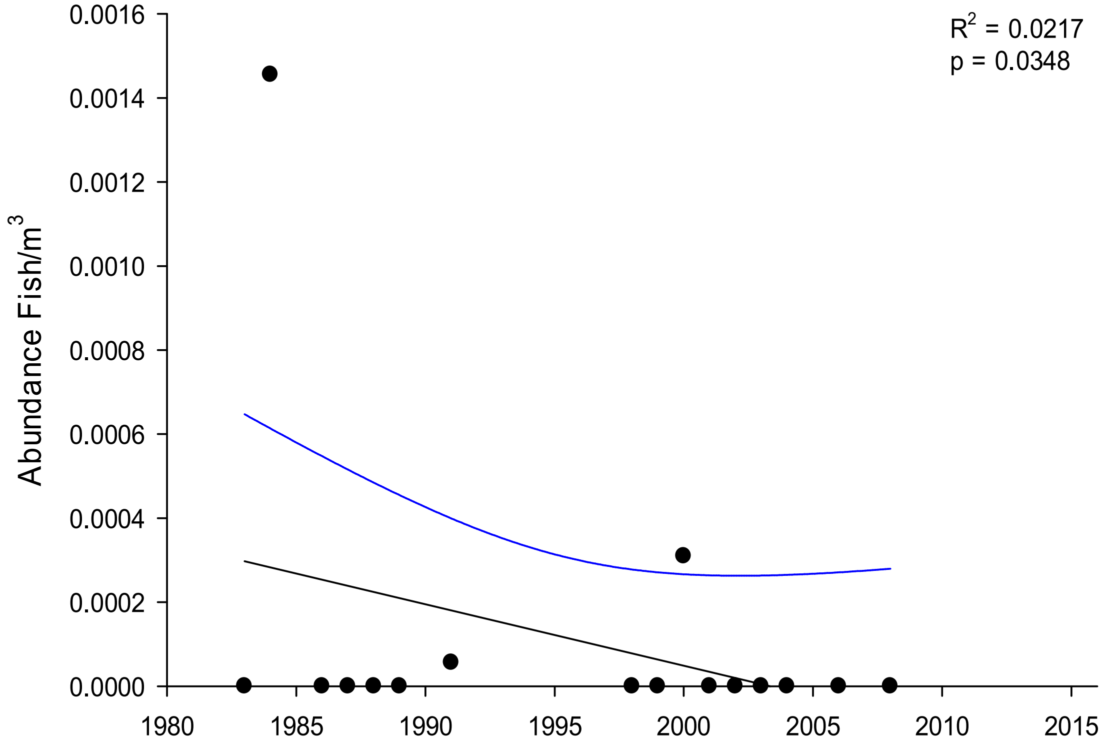


Figure A-28. Regression analysis for Moronidae from the Boyd/Verdel Site from 1983-2015. Fish were sampled using surface larval drift nets. Bands indicate 95% confidence intervals. This site has no data from the years 1985, 1990, 19921 to 1997, 2005, 2007, and 2009 to 2015.

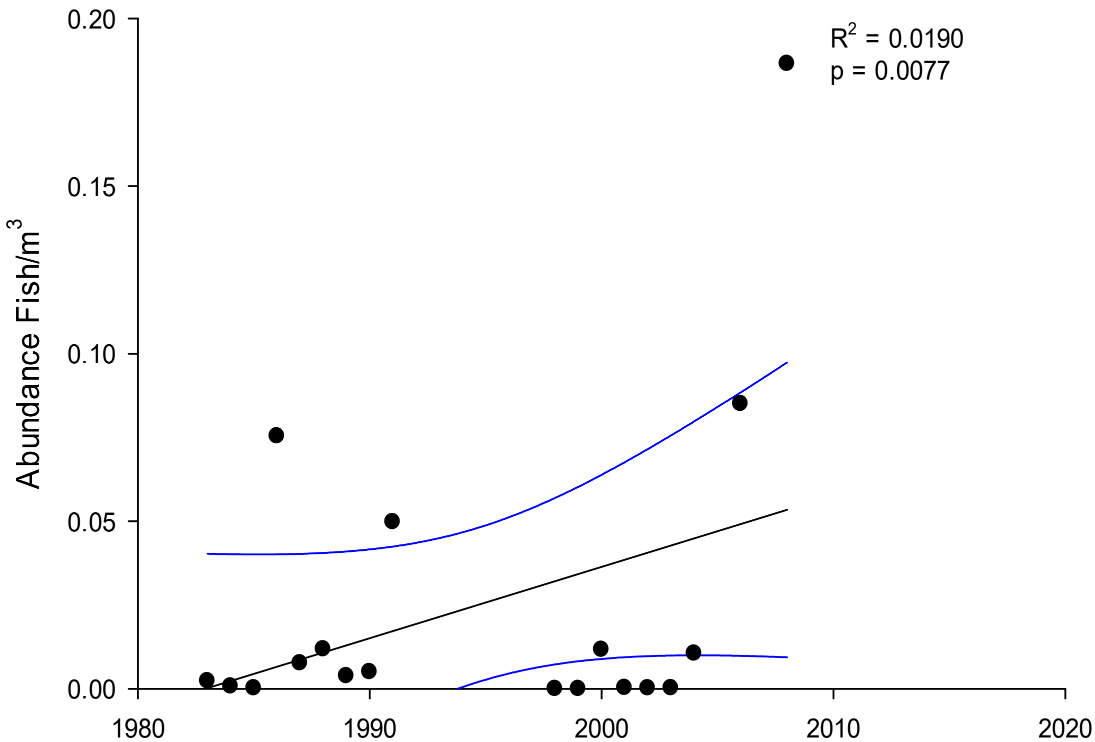


Figure A-29. Regression analysis for Clupeidae from the St. Helena Site from 1983 to 2015. Fish were sampled using surface larval drift nets. Bands indicate 95% confidence intervals. This Site has no data from the years 1992 to 1997, 2005, 2007, and 2009 to 2015.

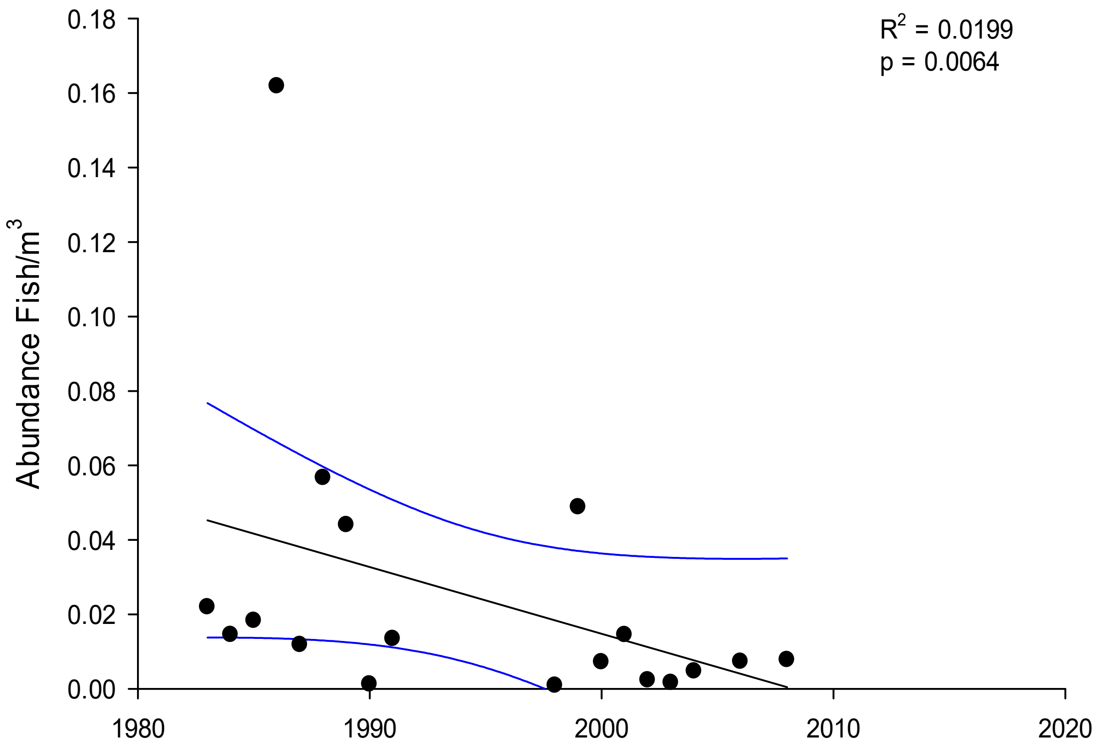


Figure A-30. Regression analysis for Cyprinidae from the St. Helena Site from 1983 to 2015. Fish were sampled using surface larval drift nets. Bands indicate 95% confidence intervals. This site has no data from the years 1992 to 1997, 2005, 2007, and 2009 to 2015.

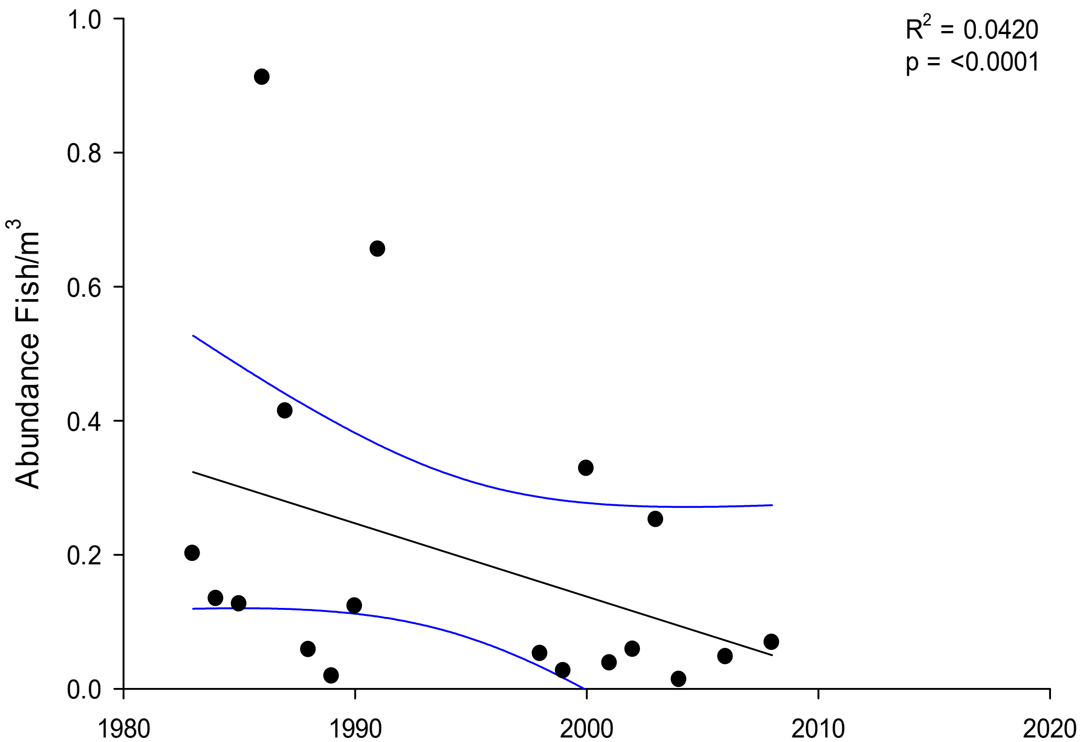


Figure A-31. Regression analysis for Sciaenidae from the St. Helena Site from 1983 to 2015. Fish were sampled using surface larval drift nets. Bands indicate 95% confidence intervals This site has no data from the years 1992 to 1997, 2005, 2007, and 2009 to 2015.

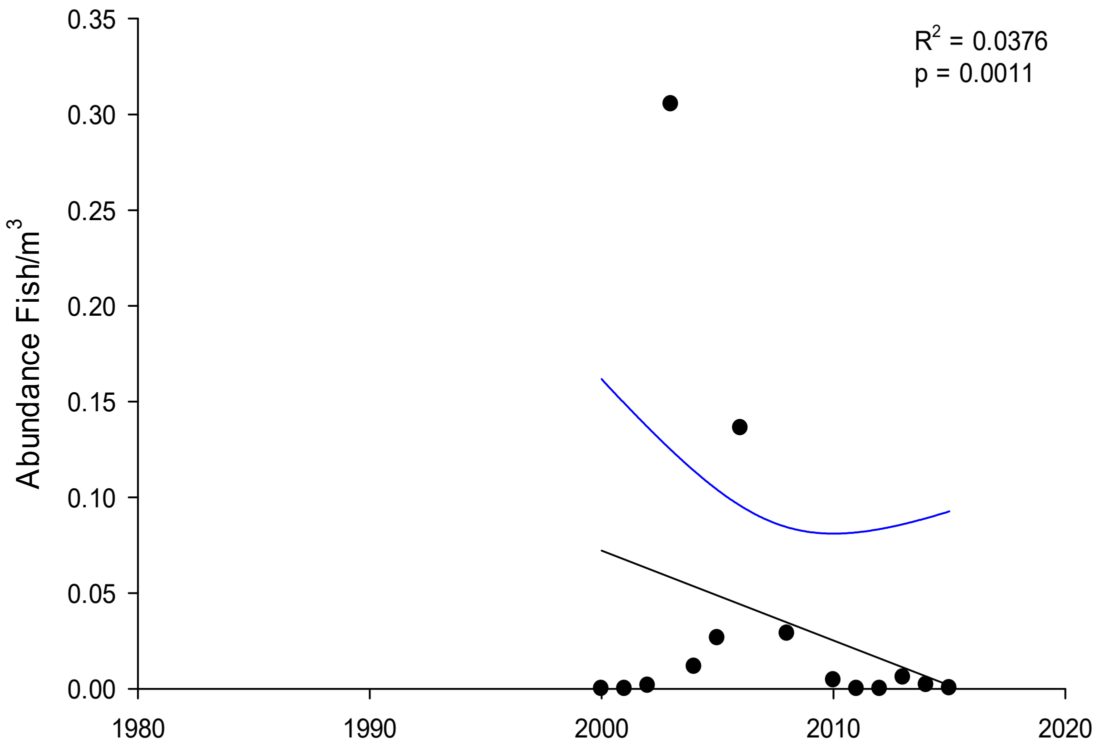


Figure A-32. Regression analysis for Clupeidae from the Mulberry Bend Site from 1983 to 2015. Fish were sampled using surface larval drift nets. Bands indicate 95% confidence intervals. This site has no data from the years 1983 to 1999, 2007, and 2009.

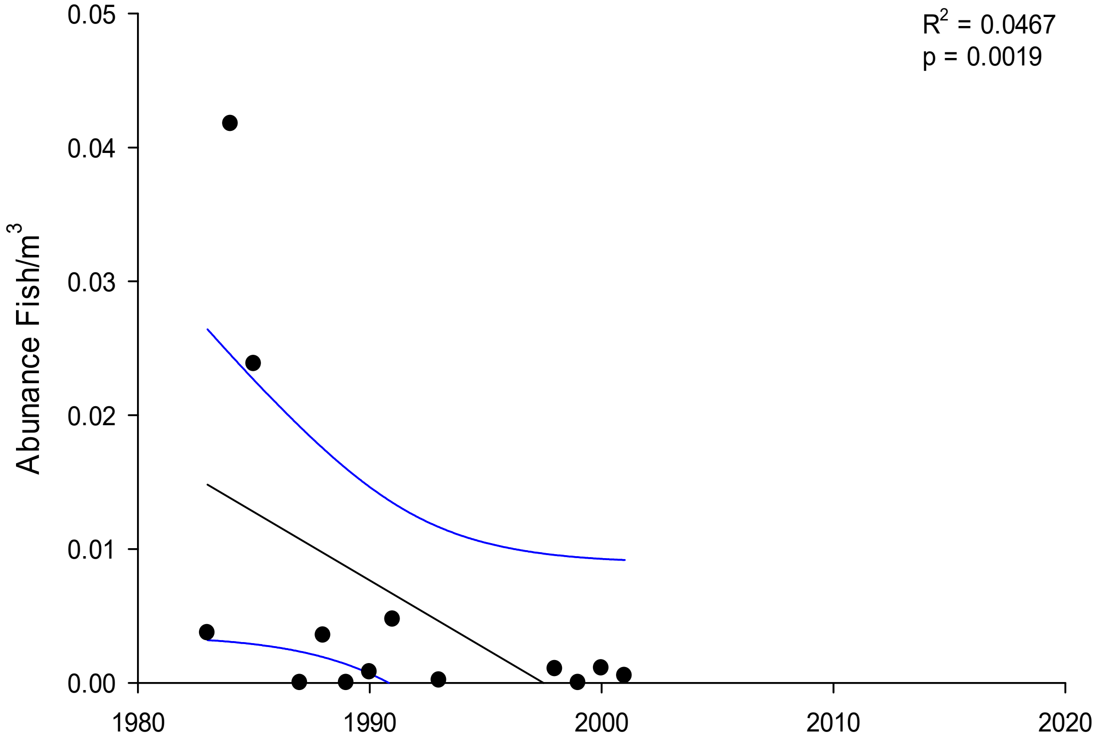


Figure A-33. Regression analysis for Centrarchidae from the Ponca Site from 1983 to 2015. Fish were sampled using surface larval drift nets. Bands indicate 95% confidence intervals. This site has no data from the years 1986, 1992, 1994 to 1997, 2002 to 2015.

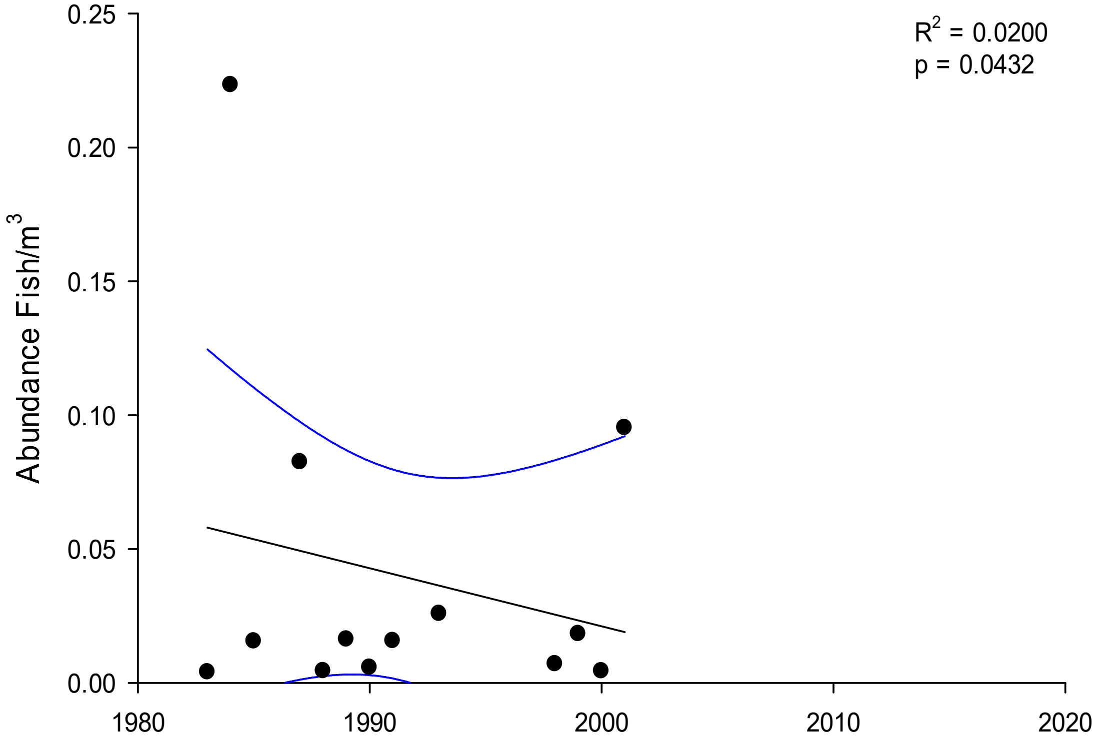


Figure A-34. Regression analysis for Cyprinidae from the Ponca Site from 1983 to 2015. Fish were sampled using surface larval drift nets. Bands indicate 95% confidence intervals. This site has no data from the years 1986, 1992, 1994 to 1997, 2002 to 2015.

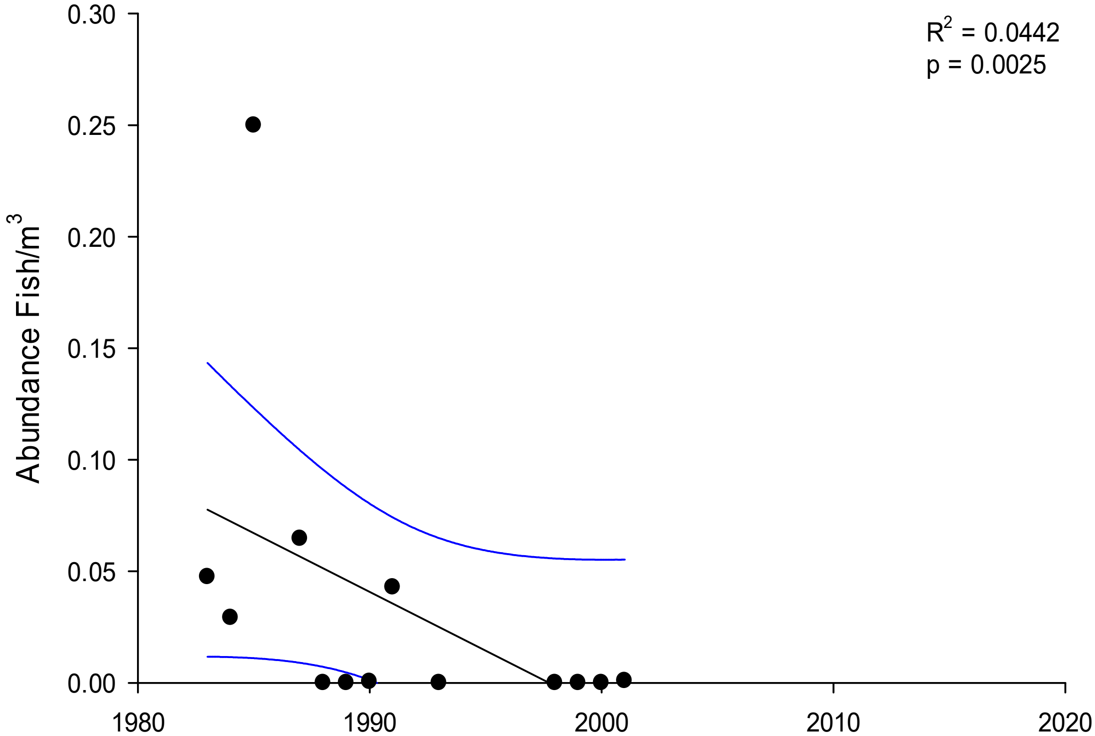


Figure A-35. Regression analysis for Moronidae from the Ponca Site from 1983 to 2015. Fish were sampled using surface larval drift nets. Bands indicate 95% confidence intervals. This site has no data from the years 1986, 1992, 1994 to 1997, 2002 to 2015.

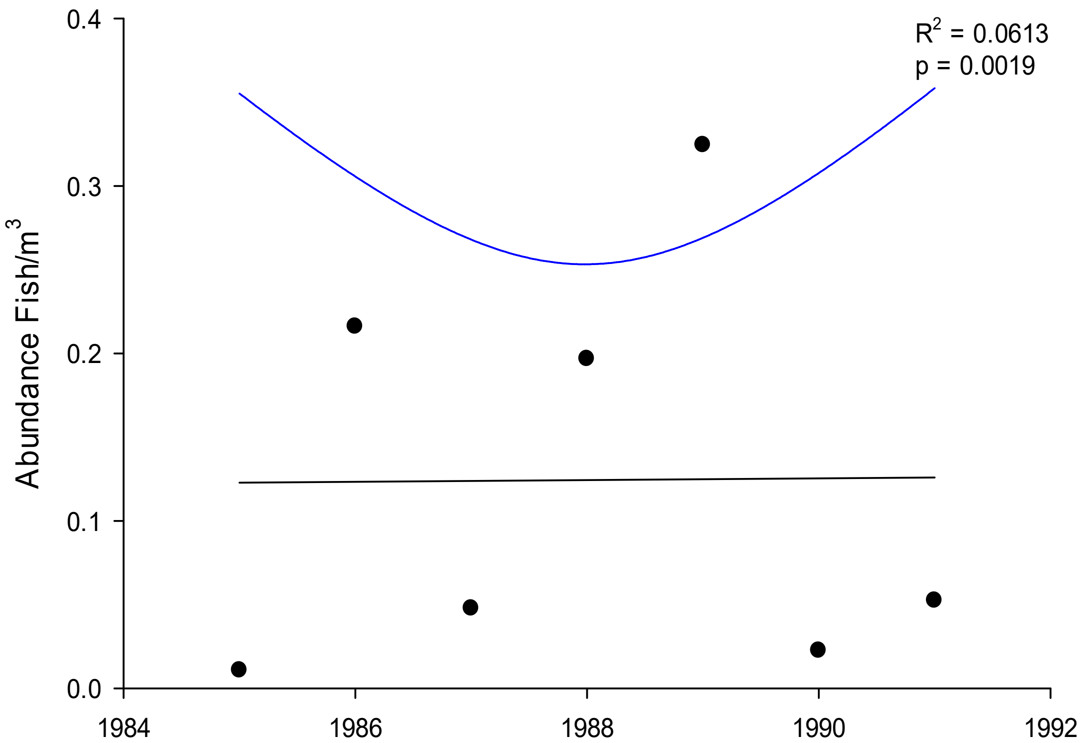


Figure A-36. Regression analysis for Catostomidae from the South Sioux City Site from 1985 to 1991. Fish were sampled using surface larval drift nets. Bands indicate 95% confidence intervals.

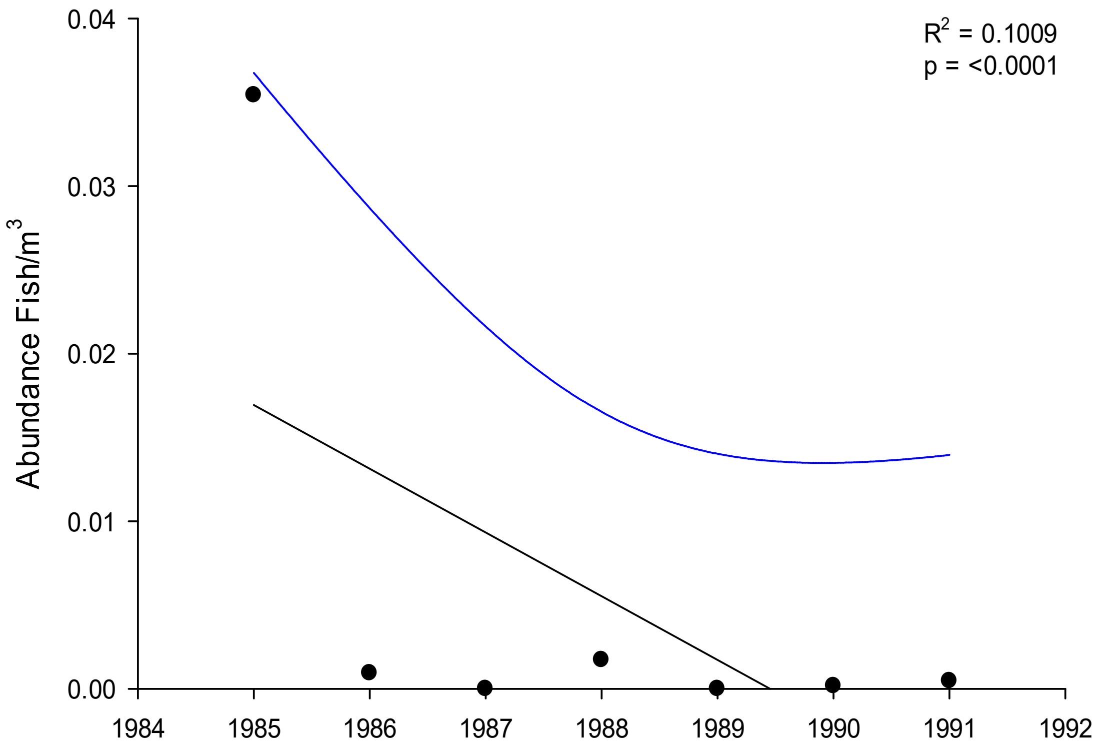


Figure A-37. Regression analysis for Centrarchidae from the South Sioux City Site from 1985 to 1991. Fish were sampled using surface larval drift nets. Bands indicate 95% confidence intervals.

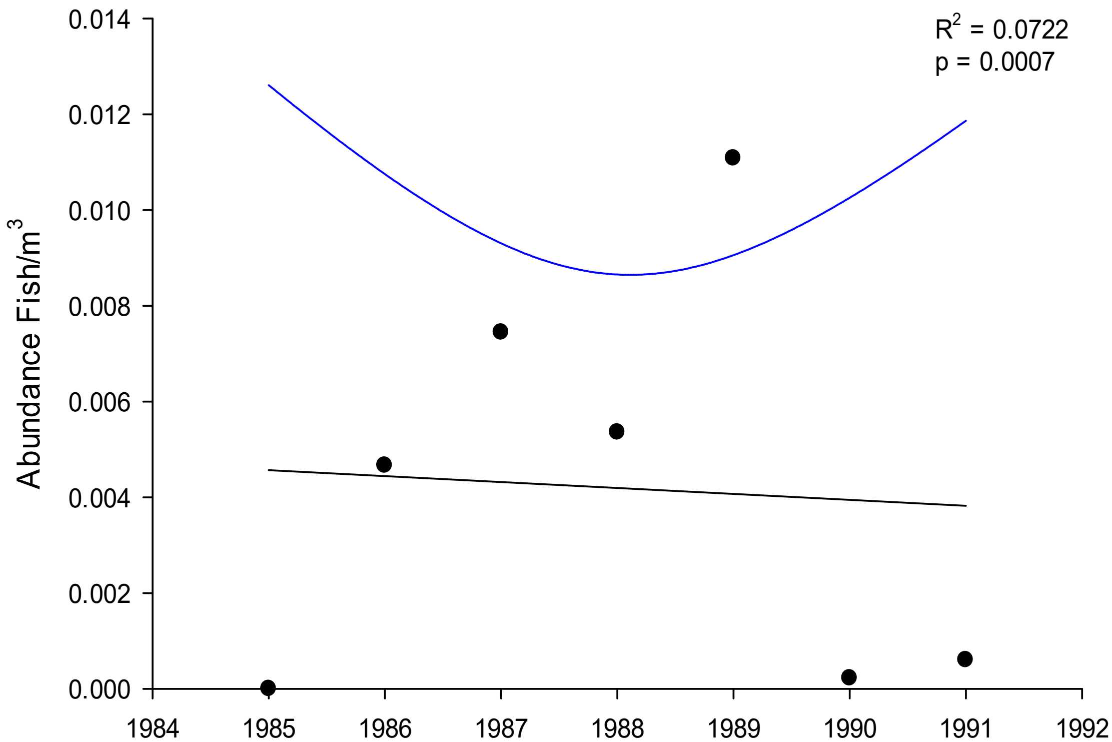


Figure A-38. Regression analysis for Percidae from the South Sioux City Site from 1985 to 1991. Fish were sampled using surface larval drift nets. Bands indicate 95% confidence intervals.

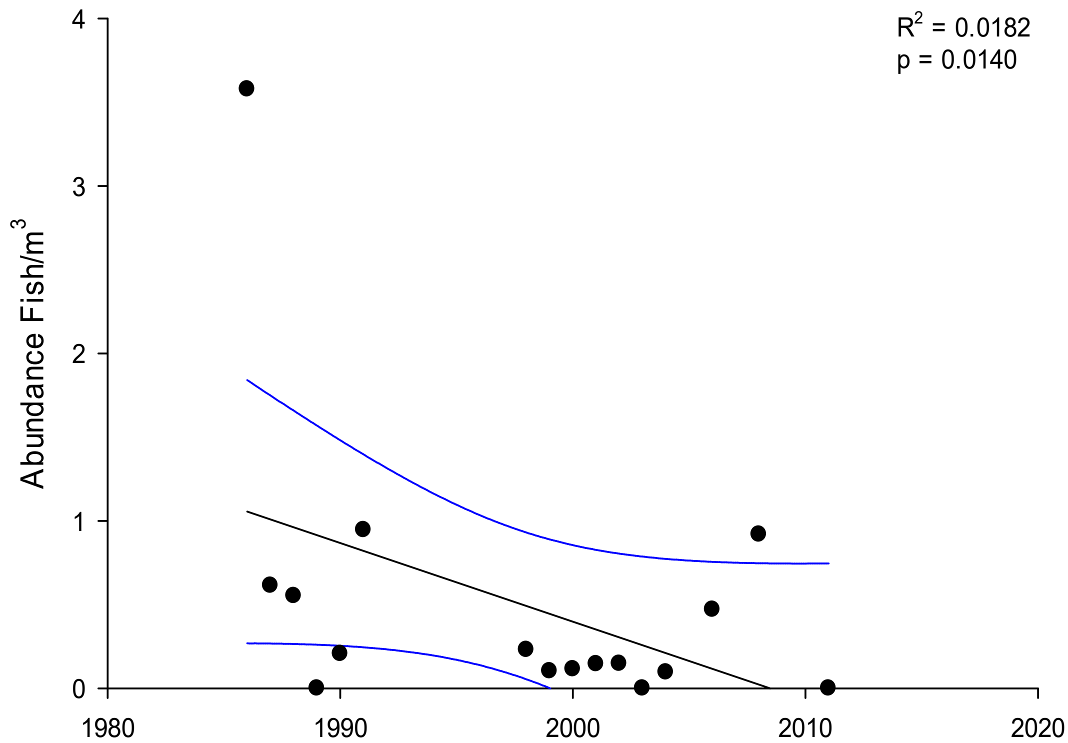


Figure A-39. Regression analysis for Sciaenidae from the Decatur Site from 1983-2015. Fish were sampled using surface larval drift nets. Bands indicate 95% confidence intervals. This site has no data from the years 1983 to 1985, 1992 to 1997, 1994 to 1997, 2005, 2007, 2009 to 2010, and 2012 to 2015.

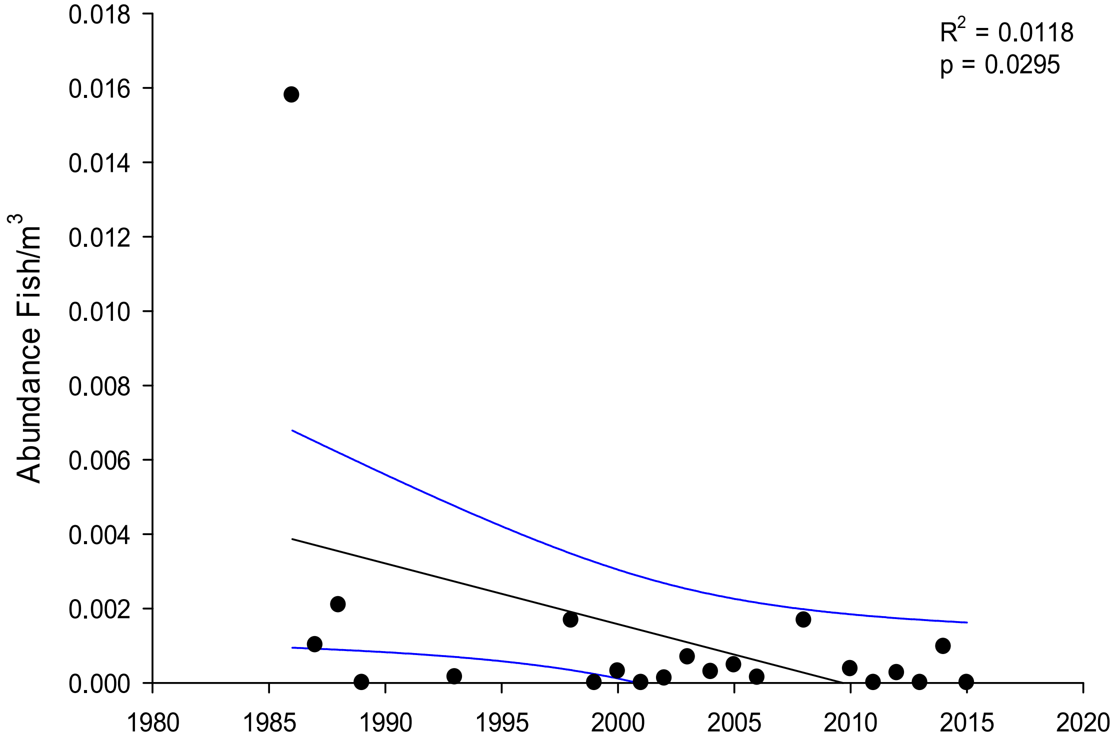


Figure A-40. Regression analysis for Centrarchidae from the Blair Site from 1983 to 2015. Fish were sampled using surface larval drift nets. Bands indicate 95% confidence intervals. This site has no data from the years 1983 to 1985, 1990 to 1992, 1994 to 1997, 2007, and 2009.

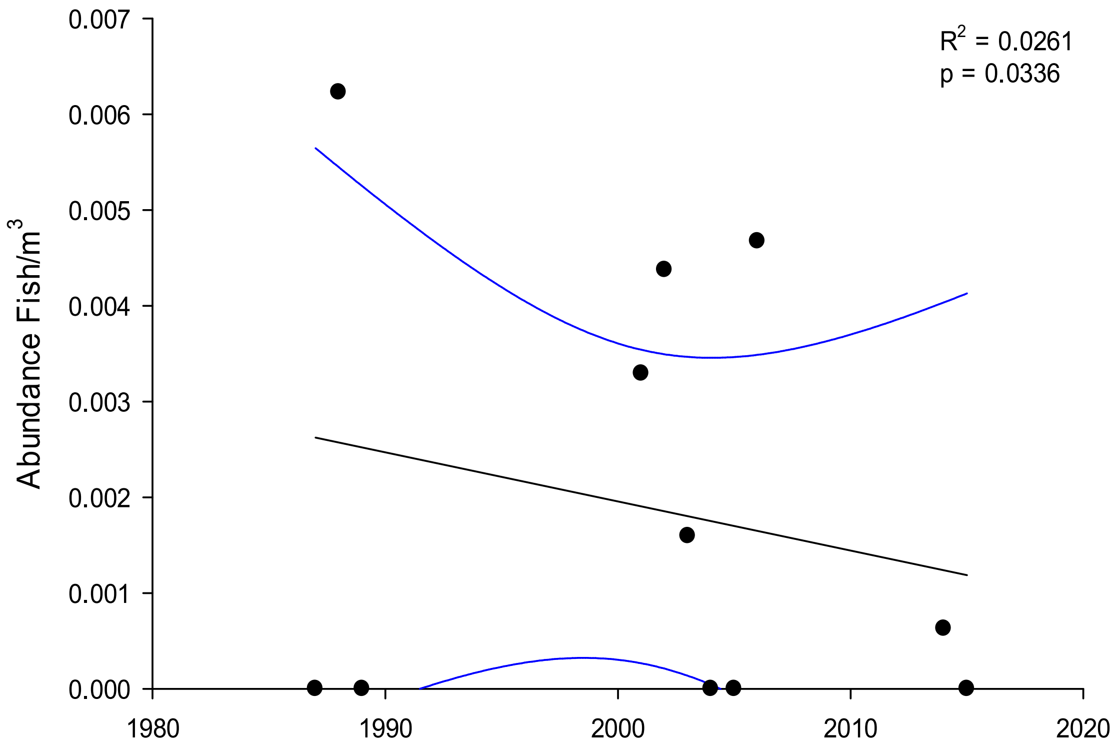


Figure A-41. Regression analysis for Clupeidae from the Nebraska City Site from 1983 to 2015. Fish were sampled using surface larval drift nets. Bands indicate 95% confidence intervals. This site has no data from the years 1983 to 1986, 1990 to 2000, and 2007 to 2013.

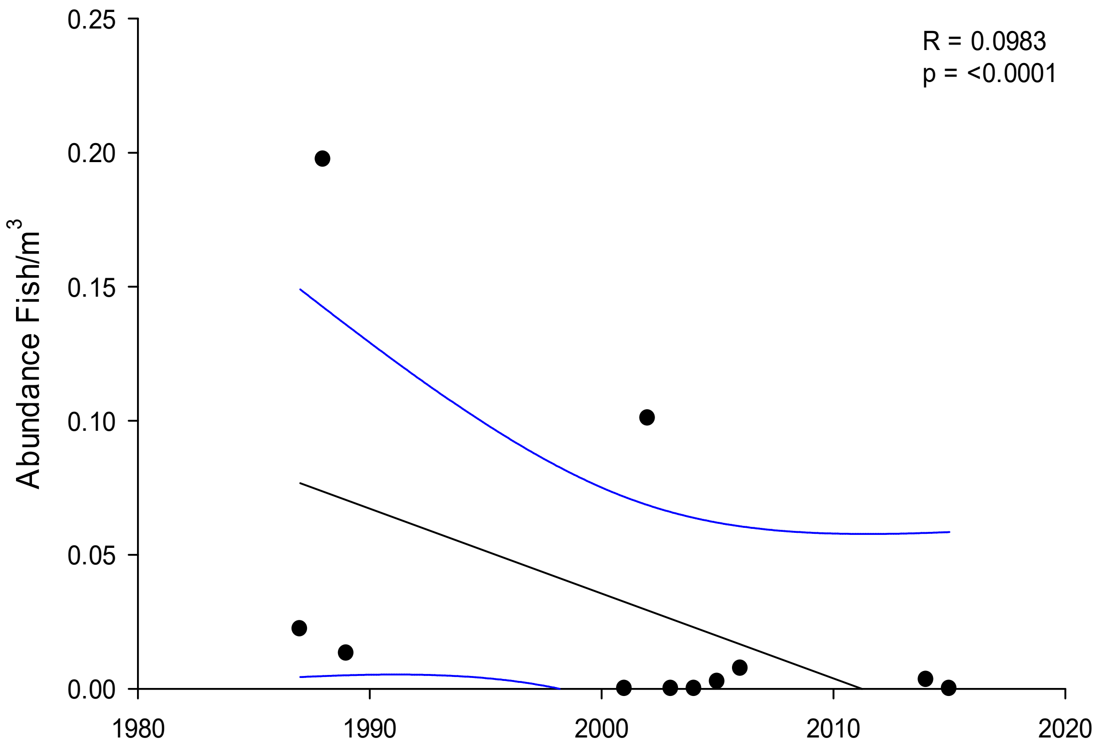


Figure A-42. Regression analysis for Hiodontidae from the Nebraska City Site from 1983 to 2015. Fish were sampled using surface larval drift nets. Bands indicate 95% confidence intervals. This site has no data from the years 1983 to 1986, 1990 to 2000, and 2007 to 2013.

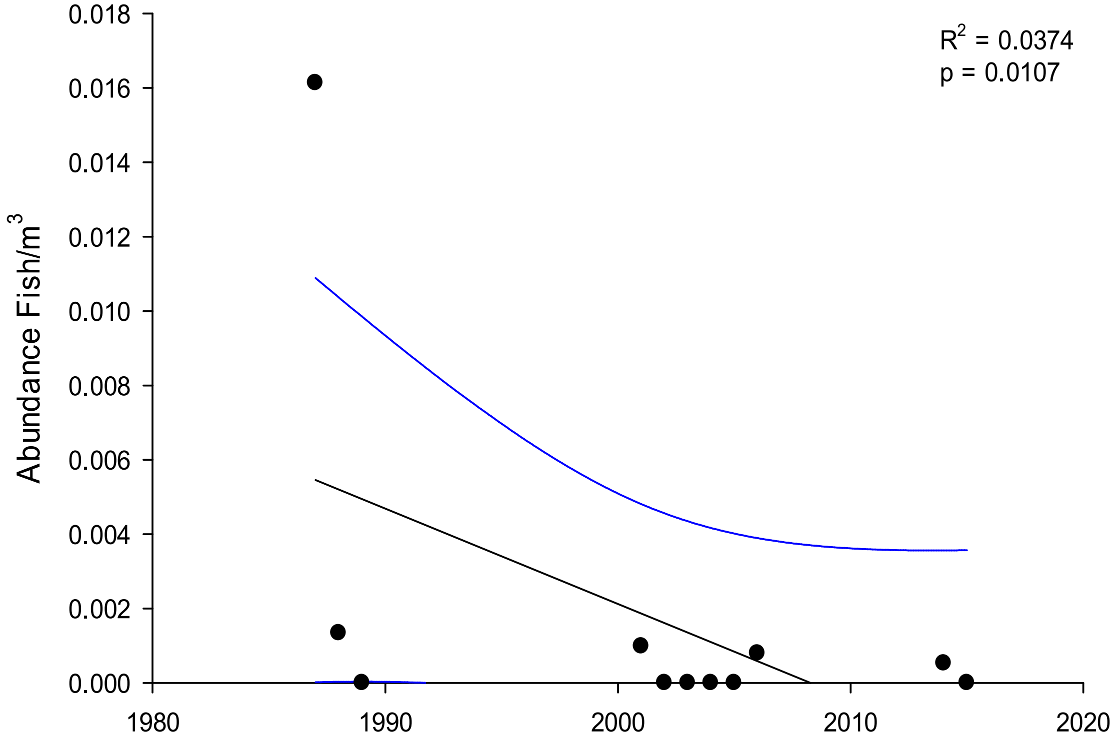


Figure A-43. Regression analysis for Moronidae from the Nebraska City Site from 1983 to 2015. Fish were sampled using surface larval drift nets. Bands indicate 95% confidence intervals. This site has no data from the years 1983 to 1986, 1990 to 2000, and 2007 to 2013.

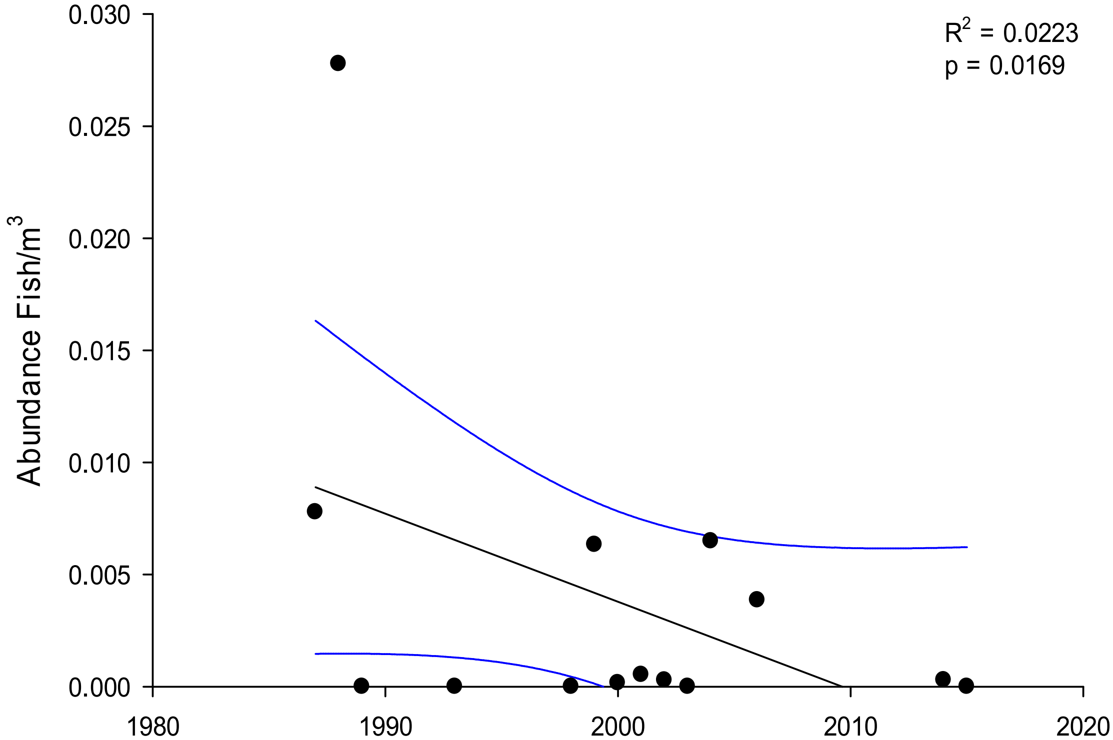


Figure A-44. Regression analysis for Moronidae from the Brownville Site from 1983 to 2015. Fish were sampled using surface larval drift nets. Bands indicate 95% confidence intervals. This site has no data from the years 1983 to 1986, 1990 to 1992, 1994 to 1997, 2005, and 2007 to 2013.

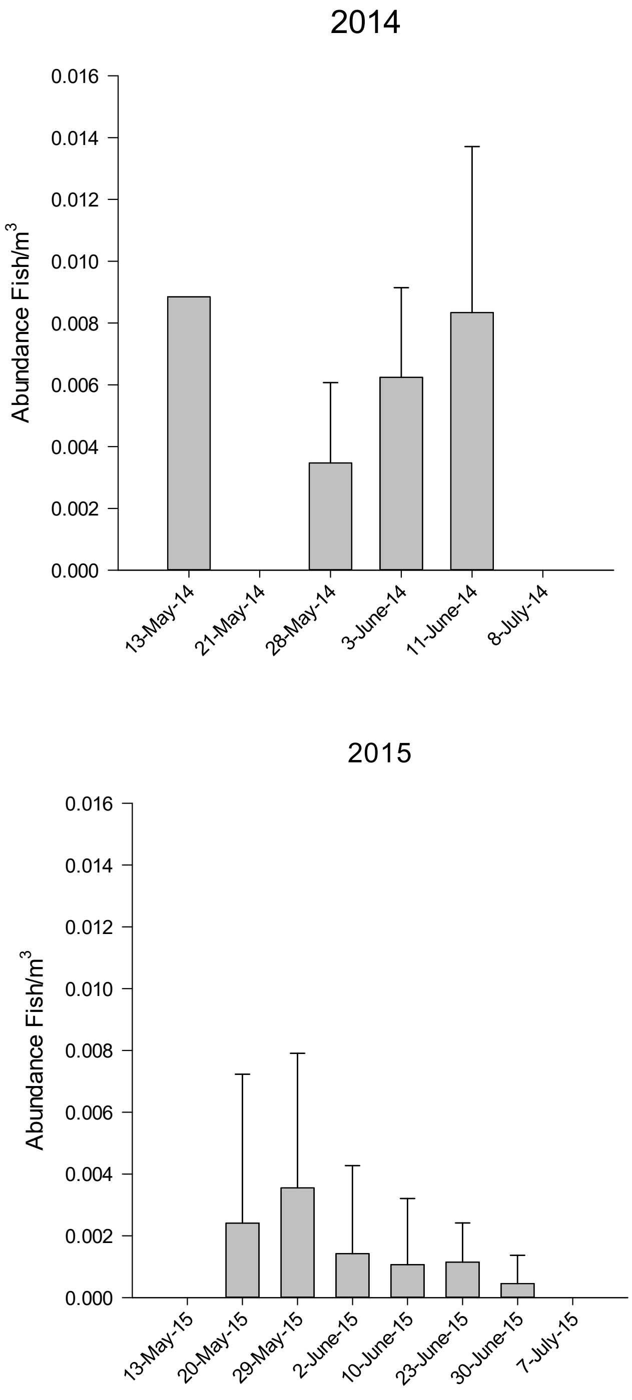
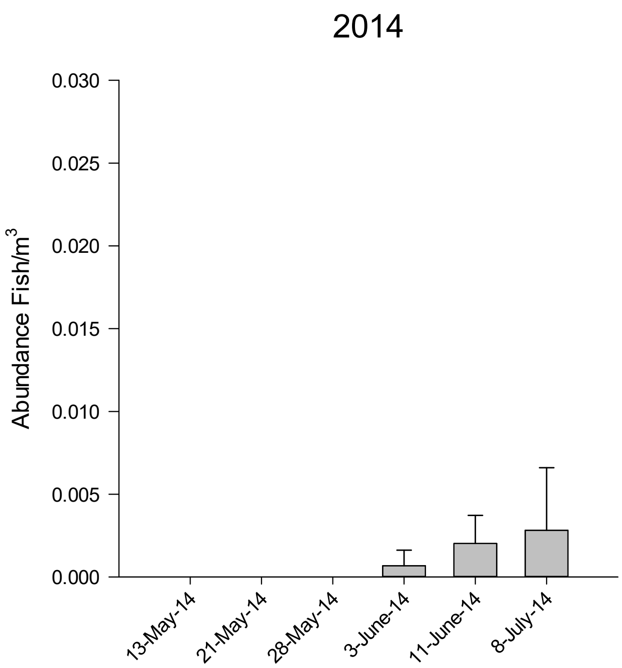


Figure A-45. Weekly abundance (fish/m^3 ± 2 SE) for Acipenseridae from benthic larval drift nets deployed in the Lower Missouri River in 2014 and 2015. No sampling occurred from mid-June through early July 2014 due to high water.



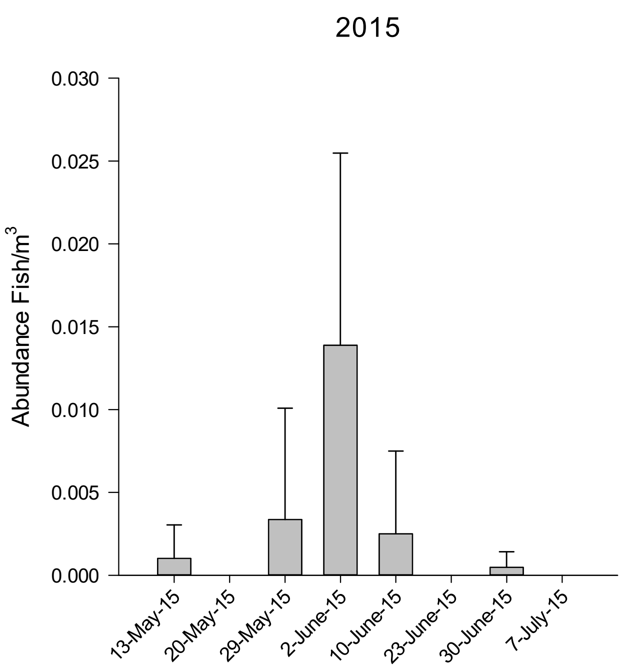
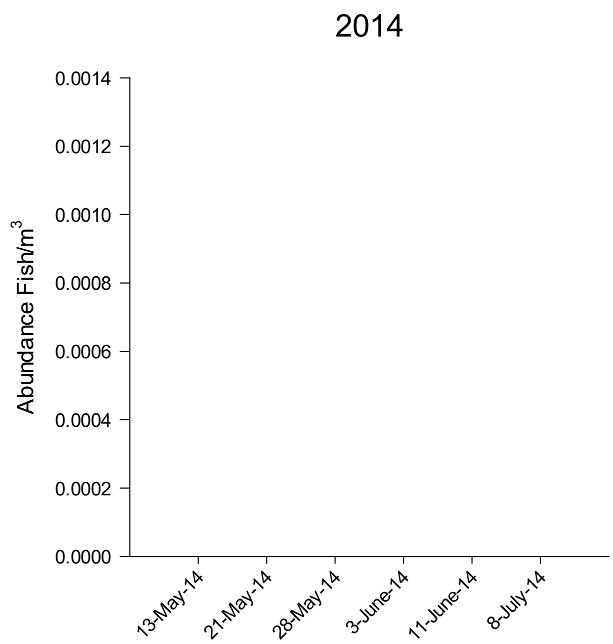


Figure A-46. Weekly abundance (fish/m^3 ± 2 SE) for Catostomidae from benthic larval drift nets deployed in the Lower Missouri River in 2014 and 2015. No sampling occurred from mid-June through early July 2014 due to high water.



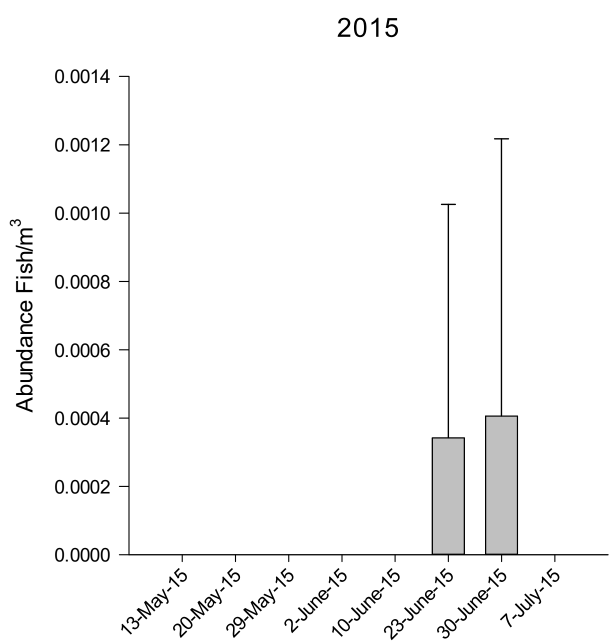
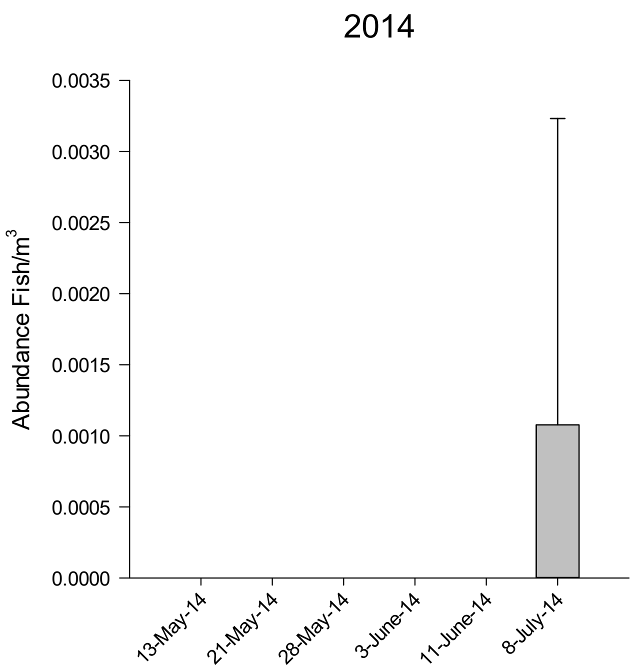


Figure A-47. Weekly abundance (fish/m^3 ± 2 SE) for Centrarchidae from benthic larval drift nets deployed in the Lower Missouri River in 2014 and 2015. No sampling occurred from mid-June through early July 2014 due to high water.



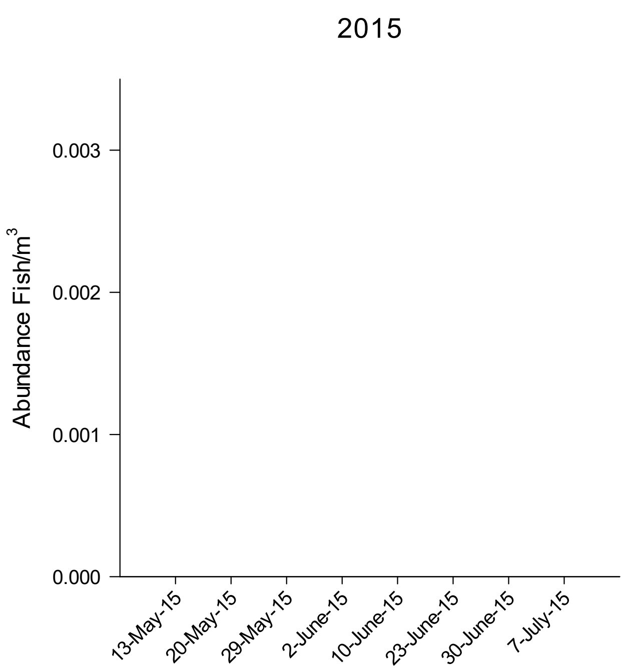


Figure A-48. Weekly abundance (fish/m^3 ± 2 SE) for Clupeidae from benthic larval drift nets deployed in the Lower Missouri River in 2014 and 2015. No sampling occurred from mid-June through early July 2014 due to high water.

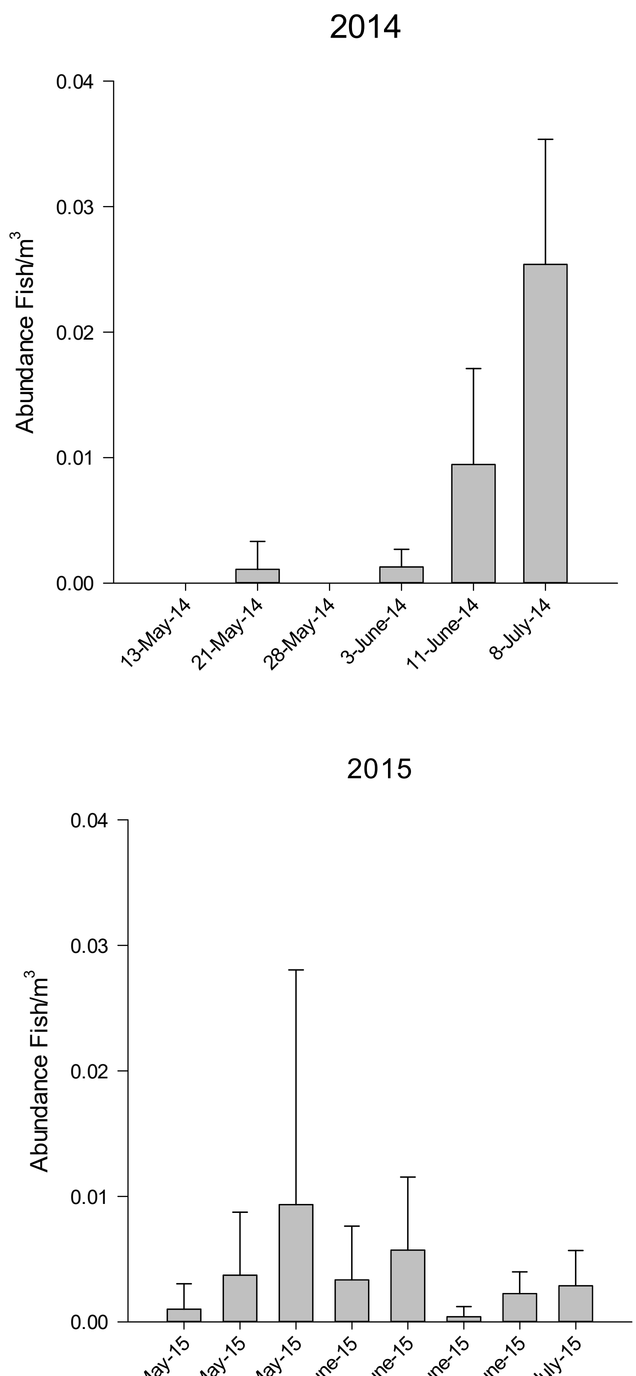


Figure A-49. Weekly abundance (fish/m^3 ± 2 SE) for Cyprinidae from benthic larval drift nets deployed in the Lower Missouri River in 2014 and 2015. No sampling occurred from mid-June through early July 2014 due to high water.

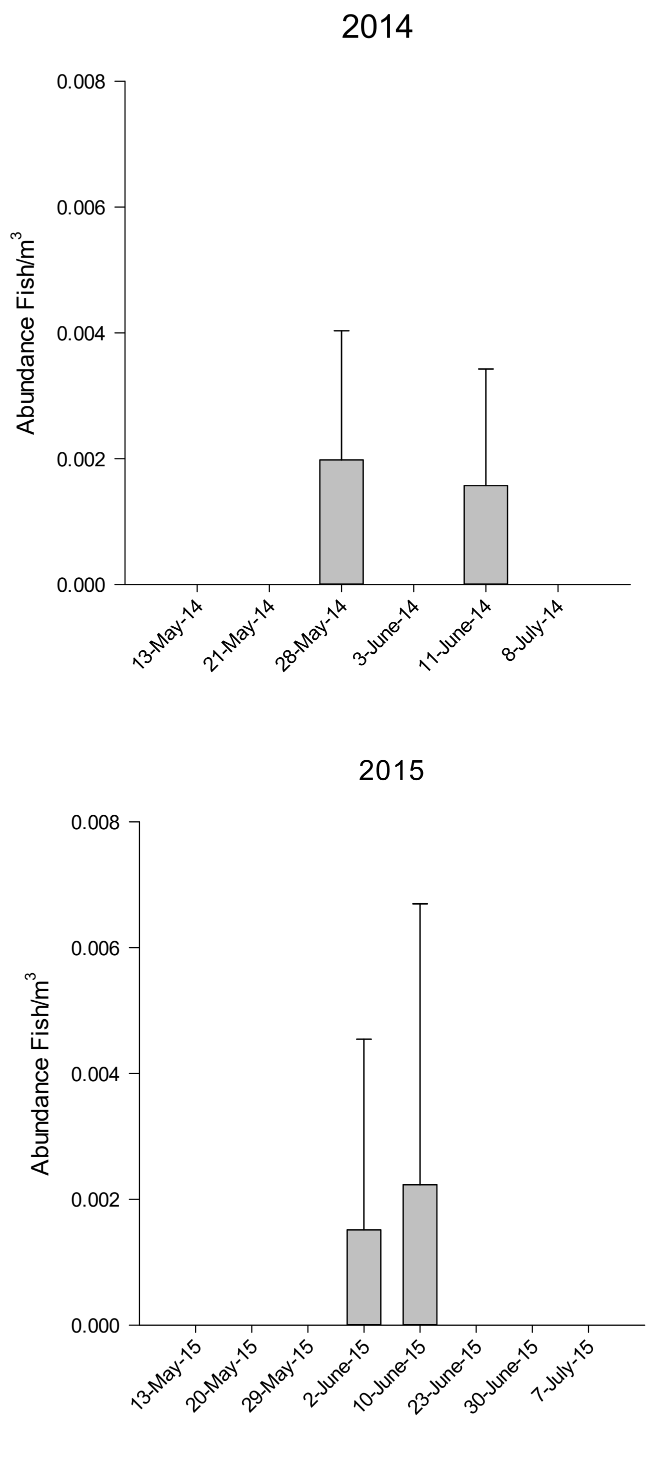
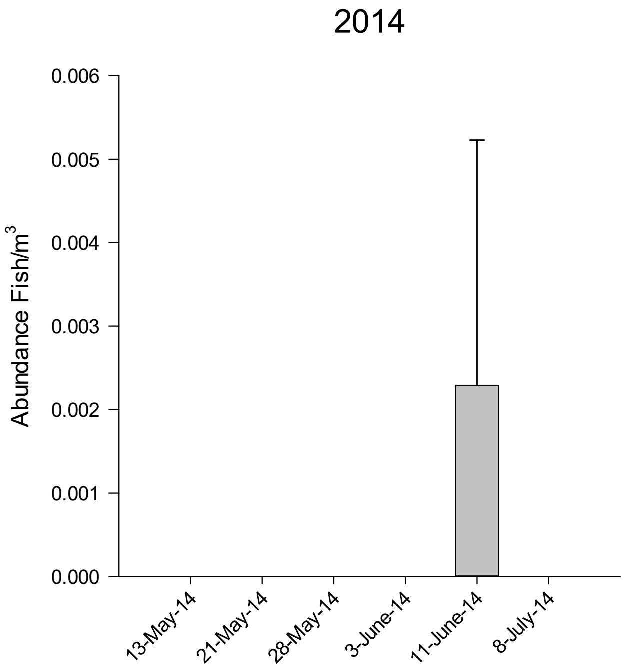


Figure A-50. Weekly abundance (fish/m^3 ± 2 SE) for Hiodontidae from benthic larval drift nets deployed in the Lower Missouri River in 2014 and 2015. No sampling occurred from mid-June through early July 2014 due to high water.



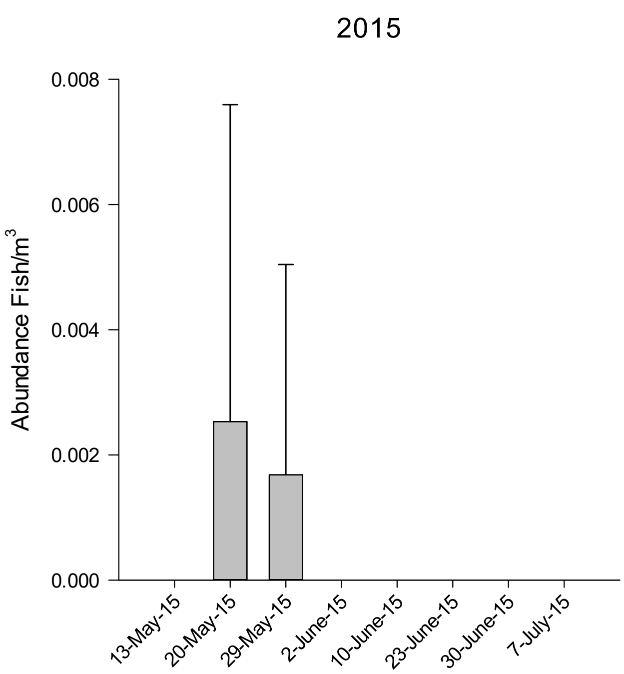
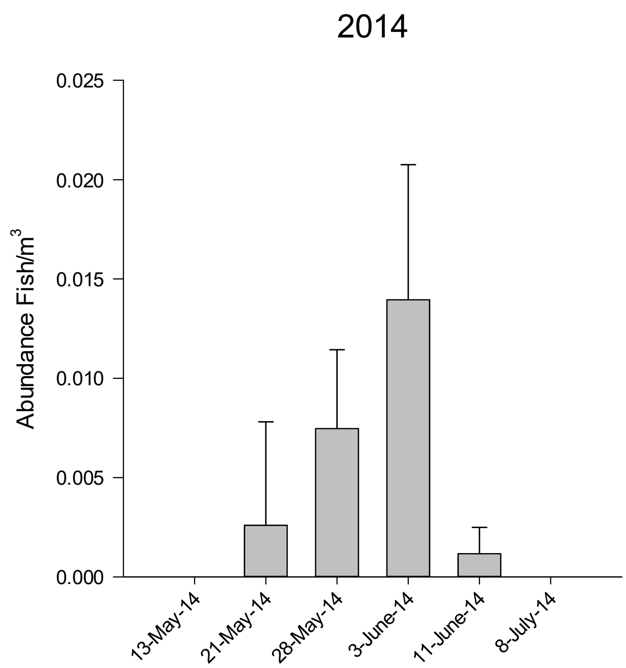


Figure A-51. Weekly abundance (fish/m^3 ± 2 SE) for Percidae from benthic larval drift nets deployed in the Lower Missouri River in 2014 and 2015. No sampling occurred from mid-June through early July 2014 due to high water.



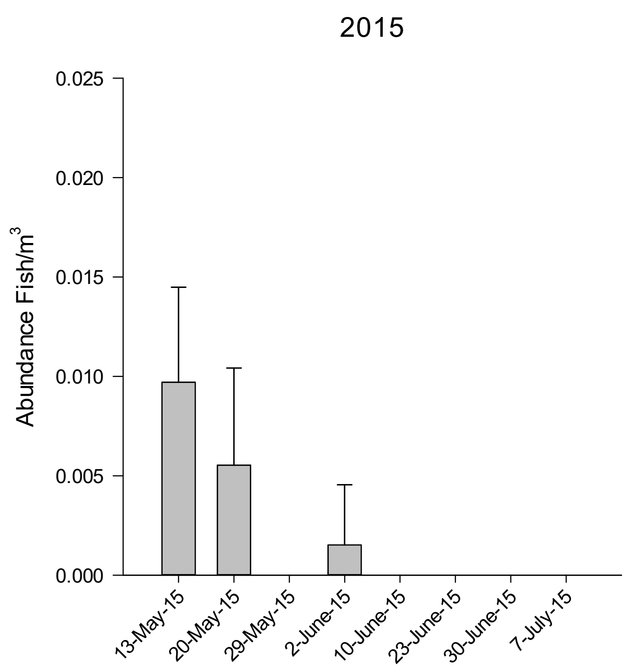


Figure A-52. Weekly abundance (fish/m^3 ± 2 SE) for Polyodontidae from benthic larval drift nets deployed in the Lower Missouri River in 2014 and 2015. No sampling occurred from mid-June through early July 2014 due to high water.

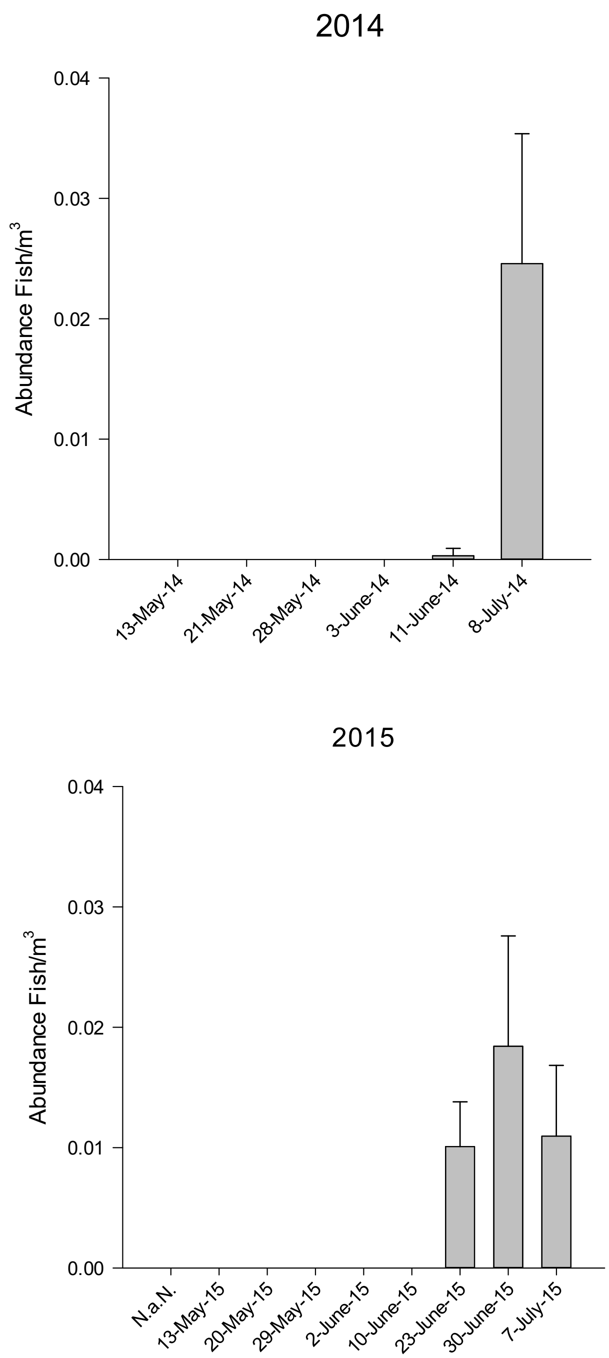
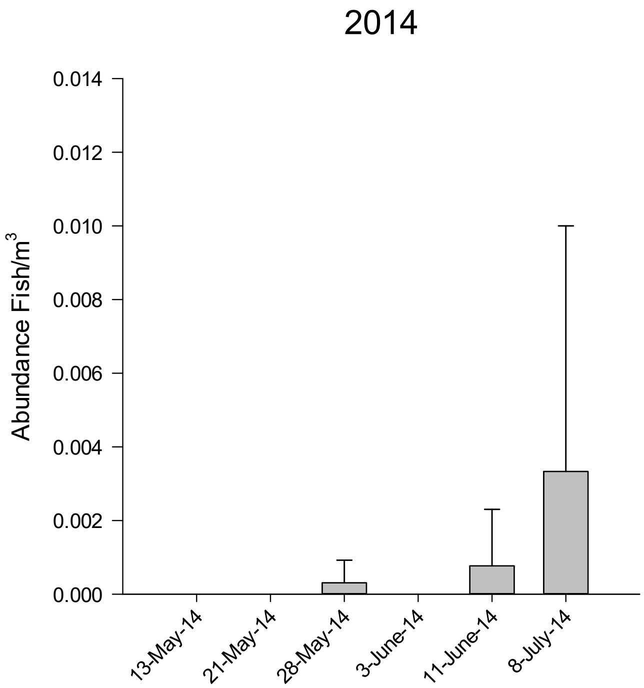


Figure A-53. Weekly abundance (fish/m^3 ± 2 SE) for Sciaenidae from benthic larval drift nets deployed in the Lower Missouri River in 2014 and 2015. No sampling occurred from mid-June through early July 2014 due to high water.



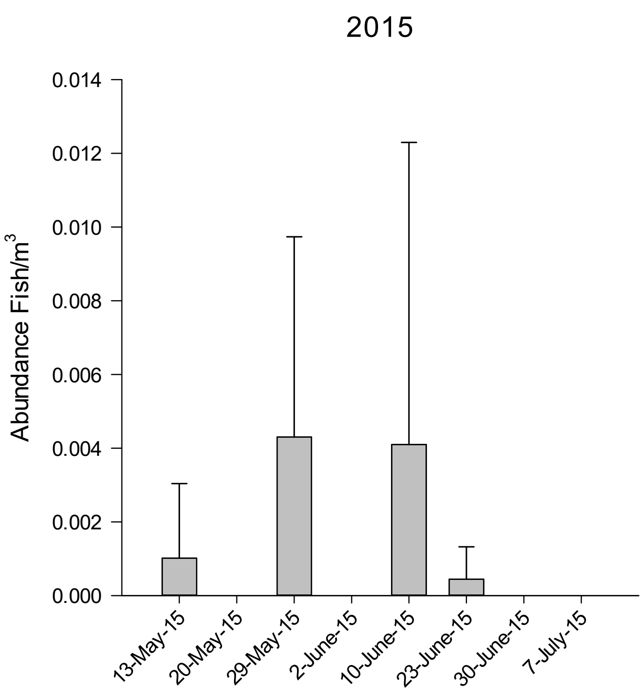


Figure A-54. Weekly abundance (fish/m^3 ± 2 SE) for unidentified larval fish from benthic larval drift nets deployed in the Lower Missouri River in 2014 and 2015. No sampling occurred from mid-June through early July 2014 due to high water.