Changes in Fish Use and Habitat Diversity Associated with Placement of Three Chevron Dikes in the Middle Mississippi River

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ABSTRACT

CHANGES IN FISH USE AND HABITAT DIVERSITY ASSOCIATED WITH PLACEMENT OF THREE CHEVRON DIKES IN THE MIDDLE MISSISSIPPI RIVER

by

BRANDON M. SCHNEIDER

Chairperson: Professor Richard B. Brugam

The Mississippi River system is third largest watershed in the world and comprises a vast number of unique habitats from ephemeral wetlands to backwaters to island complexes of the main channel. Over the years, a variety of changes in land use and construction projects have modified the river into more of a navigation channel and less of an ecosystem. The United States Corps of Engineers (USACE) may have the authority for maintaining a 2.7-meter (9-foot) navigation channel throughout the Mississippi River; however, USACE also has several mandates to work under to improve ecosystem function. One of these unique ecosystem restoration projects undertaken by the USACE was constructing three, large chevron dikes in the St. Louis Harbor. The unique dike structures were designed to reduce dredging and improve flows as barges enter and exit the Chain of Rocks canal, but also potentially to create new habitats in the Middle Mississippi River by modifying flows to create not only changes in flow but also changes in bathymetric diversity.

To evaluate changes in the fish community resulting from chevron dike construction a variety of techniques including benthic trawling and day time electrofishing were conducted from 2003 to 2007. A total of 1,987 fishes were collected from 477 samples from the St. Louis Harbor during the four years of monitoring comprising 14 families and 35 species of

fish. Catch per unit efforts ranged from 0.0 fish/min to 73.7 fish/min for trawling and between 0.0 fish/min to 8.14 fish/min for electrofishing. Electrofishing showed unique statistical differences between pre- and post-construction sites. While in electrofishing there was an increase in number of fish caught per minute, trawling showed a general decrease in the total number of fish caught per minute from pre-to post-construction between the experimental and control locations.

Also, while benthic chubs (*Macrhybopsis* and *Hybopsis*) were fairly abundant in pre-construction samples, they were somewhat scarce in post-construction samples and caught with great irregularity. This was one of the reasons why it was determined, at the beginning of the study, that ordinations with appropriate Analyses of Similarities (ANOSIM) would have Indicator Species Analyses (ISA) completed on them. If species that appeared to be unique to a habitat were lost or gained, the ordinations, ANOSIMs and ISAs could determine the true differences. These could be used to determine the fish communities and find the species that typify each of these communities.

Overall, the fish community changed due to habitat modifications from the chevron dikes from pre- to post-construction in favor of the post-construction sites. The new fish community is more diverse with stable populations being shown on most samples and the habitat has become quite diversified from the initial surveys with the two dominant habitat types of main channel and main channel border existing. Although the trawling pre-construction samples showed greater CPUE, this may have been due to very few samples that dominated the remainder of the samples where few fish, if any, were captured. While some negative impacts of the dikes were shown such as the loss of benthic chubs, the chevron dikes in the St. Louis Harbor of the Middle Mississippi River have shown several positive impacts that could aid the USACE in the future for developing ecosystem-friendly structures while maintaining the navigation channel.

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CHAPTER I

INTRODUCTION

Loss of habitat diversity has been noted as major problem in many large river systems including the Mississippi River (Johnson and Jennings 1998, Theiling 1999, Pedroli et al. 2002). Alterations to important physical and biological river functions have resulted in loss of habitat diversity and eventually loss of biological diversity (Junk et al. 1989). The St. Louis District United States Army Corps of Engineers (USACE) has been tasked with the objective of maintaining the Mississippi and Illinois rivers for navigation. This process has resulted in changes to these river systems over the last hundred years that have potentially impacted habitat diversity. In recent years, the USACE has attempted to improve habitat diversity through a variety of programs. Currently, the St. Louis District Army Corps of Engineers is responsible for maintaining the lower 300 miles of the Upper Mississippi River System and 80 miles of the Illinois River (Figure 1).

The St. Louis District's portion of the Upper Mississippi River system (Figure 1) starts just below Lock and Dam 22 at RM 300 near Saverton, Mo at Mississippi River mile (RM) 300 and extends downstream to the confluence of the Ohio and Mississippi rivers at RM 0. This portion of the Mississippi River includes four locks and dams – Lock and Dam 24, Lock and Dam 25, Melvin Price Lock and Dam (formerly Lock and Dam 26) and Lock 27 and the Chain of Rocks low water dam. Below Locks 27 and the Chain of Rocks dam, the Mississippi River is considered to be an open river. This stretch of the river frequently needs additional assistance to maintain the 2.7-m (9-ft) navigation channel. To maintain the appropriate depth, sediment that has moved to the navigation channel must be removed.

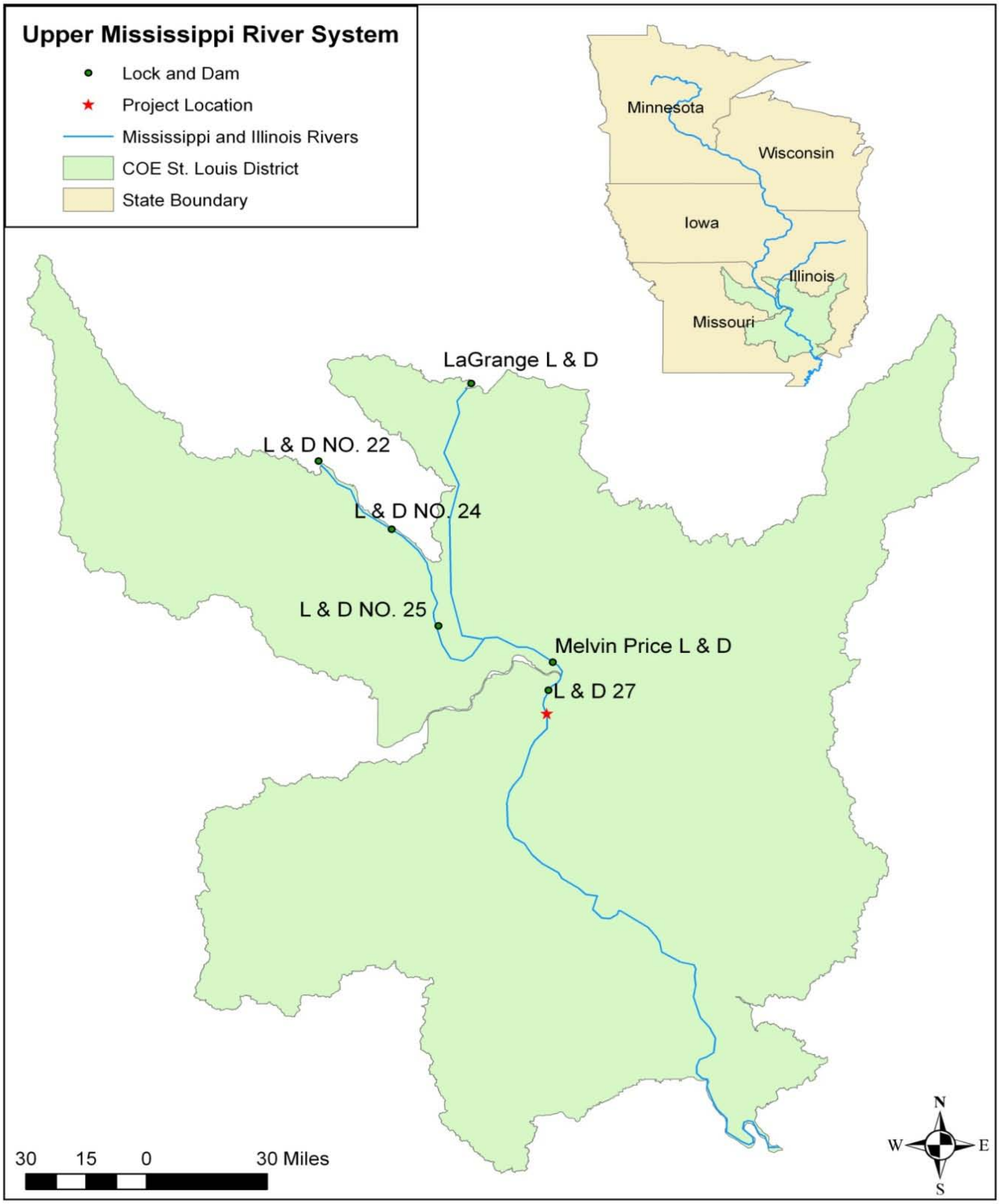

Figure 1. Upper Mississippi River System including the district boundary for the St. Louis District Army Corps of Engineers.

Two methods are commonly implemented by the Army Corps of Engineers in the Mississippi River to maintain adequate depth of the navigation channel, also commonly referred to as the thalweg. The first is known as maintenance dredging. Maintenance dredging involves removal of these naturally deposited sediments from the navigation channel. Dredging in the St. Louis District is accomplished by either a cutter head dredge or a hydraulic pipeline dredge. The hydraulic dredge, which is usually the preferred method, mixes large quantities of water with the excavated material to create a slurry which is then pumped out of the navigation channel to a predetermined location. This is also commonly referred to as side cast dredging as sediment is pumped up and then cast to the side of the dredging barge. Newer methods are currently being designed to allow more precise placement of dredge material using a flexible dredge pipe and various pumps to place the excavated material in a predetermined location without the restriction of the material being placed immediately adjacent to the dredging vessel. One issue with dredging is that it is very time consuming and financially exhausting (Henshaw et al 1999). Dredging also does not solve the immediate issue of redirecting sediments to prevent accumulation in the future. At certain locations, dredge cuts must be completed annually resulting in thousands of cubic yards of material removed each time (USACE 2011).

The second method to obtain the 2.7-m (9-ft) navigation channel consists of river training structures. River training structures are generally rock or wood structures placed into or adjacent to the river in a specific design to alter the flows of the river to cut specific areas of the river bed and reduce the need for dredging. Common river training structures include bendway weirs, off-bankline revetments, bullnose structures, wing dikes, and a variety of innovative structures continually being designed. These river training structures are constructed to work with existing flows (direction) and currents (velocities) to stabilize banklines, reduce sedimentation within the river, reduce erosion of banklines, and in some cases increase biological diversity with the overarching goal of providing a continual 2.7-m (9-ft) navigation channel.

A recently developed river training structure is known as the chevron dike. A chevron dike is a u-shaped rock structure that diverts water to each side of the structure creating a split flow in the existing flow regime of the river (Figure 2). As the water flows downstream it collides with the head of the chevron dike. The water then has three options, flow to one of the sides or overtop the structure. The shape, design and positioning of the chevron dike directs the majority of the flow to the navigational side of the chevron. Flows will still travel to the non-navigational side and overtop the chevron dike, especially during high-water periods. The structure is designed to allow and encourage flows to be directed to the non-navigation side and create a split flow similar to what an island might create. The water that flows to the navigation side is of high velocity and scours out the main channel of the river creating a deeper thalweg to allow for improved navigation. The water that flows to the non-navigation side is generally swift as well, but during modeling did not show a large increase in depth such as the navigation side (Lamm et al. 2004) The water that flowed over the chevron as in a high water event, created a large scour hole and an ephemeral island downstream of each chevron during the modeling process (Lamm et al. 2004).

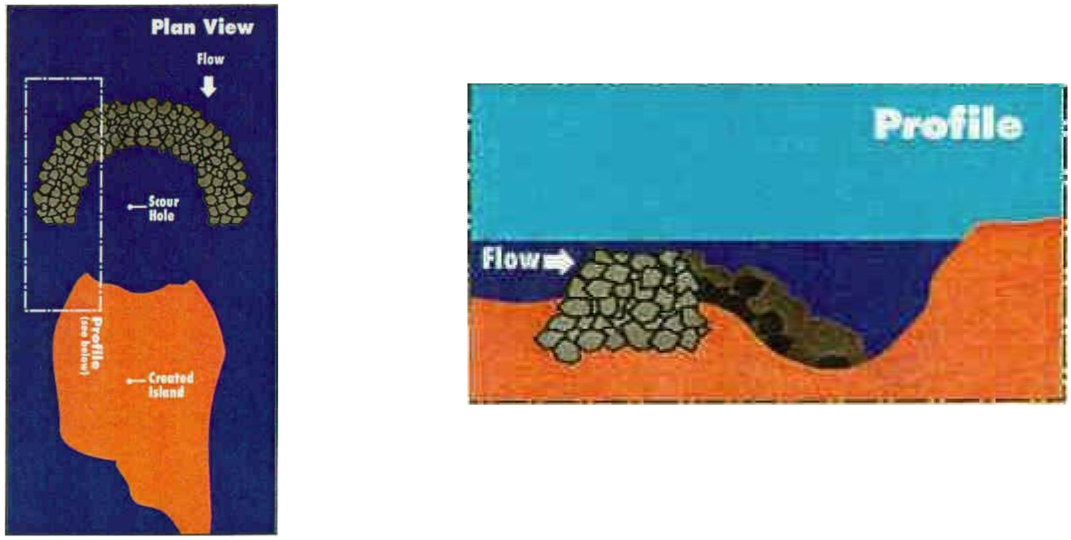

Figure 2. Typical plan and profile view of a chevron with potential scour hole and island formation behind the chevron.

Initially, in the St. Louis District, three chevrons were constructed in Pool 24 of the Upper Mississippi River near RM 290. One of the primary purposes was to protect dredged material; however initial biological monitoring showed the potential for creating a variety of aquatic habitats from shallow shoaling areas to deep, overwintering pools (Atwood 2001). Since then, several sets of chevrons have been constructed throughout the Upper Mississippi River System; however, no studies have been published focusing on fish communities associated with chevrons in the open river environment. All of the chevrons being studied at the start of this study were in the pools of the Mississippi River or focused on physical features associated with chevrons (Atwood 2001, Lamm et al. 2004).

Between 2003 and 2007, three chevrons were designed and constructed just below Lock 27 at RM 183 to RM 182 (Lamm et al. 2004). Through potential benefits to both navigation and environmental, the three chevrons were constructed in August 2007. The United States Fish and Wildlife Service (USFWS) believed that the rock dike substrate would provide habitat for epilithic macroinvertebrates that are capable of colonizing in very high densities and providing an important food source for fish (USFWS 2000). In addition, chevron dikes built in the pooled portion of the Upper Mississippi River have been noted to create habitat heterogeneity and appear to increase invertebrate abundance and diversity which could provide a valuable food source and habitat for a variety of riverine fishes (Atwood 1997, Ecological Specialists, Inc. 1997, USFWS 2000). According to Hurley et al. (2004), pallid sturgeon exhibit a strong preference for downstream island tips. These islands tips could potentially be created by the construction of chevrons with the scour hole and islands forming downstream. As noted above, prior to this study, chevron dikes appear to be capable of providing essential habitat for foraging, but no evidence has been shown yet of potential benefits to fish communities.

The chevron dikes were constructed to direct flows to align navigational vessels through the Merchants and McKinley Bridges, reduce dredging and possibly provide the aforementioned environmental benefits (Lamm et al. 2004). As mentioned previously, small studies had been conducted on the set of chevrons located in the pooled environment that led to the idea that chevron dikes may provide essential fish habitat (Atwood 2001). This study is designed to focus specifically on fish communities and how the chevron dikes operate in the open river environment. One of the key features that formed in the pools was the ephemeral islands downstream of each chevron that potentially could become permanent islands if they became vegetated.

To form the islands, water overtops the chevron and is directed downwards towards the river bed and scours out a large hole. The scoured sediment is then deposited immediately downstream forming small islands behind each chevron (Figure 2). This is only possible during higher flows when the structures are overtopped. Although the chevron dikes were primarily designed for navigational purposes to more efficiently and safely pass through the St. Louis Harbor and the multitude of bridges by directing flows to the navigation channel, potential ecosystem benefits added to the final decision for constructing chevron dikes over traditional wing dikes (Lamm et al. 2004).

The purpose of this study is to determine the ecosystem benefits to the local ichthyofauna as a result of the construction of the chevron dikes. Specifically, comparisons between pre- and post-construction fish surveys were completed to detect any shifts in fish communities and fish densities. Any shifts noted would provide insight into the possible benefits gained from the construction of chevron dikes. In addition, comparison between pre- and post-bathymetric surveys would allow one to see what habitats are forming or being lost as a result of the construction of chevron dikes. Some initial possibilities for habitat creation include the potential of the creation of deep scour holes which could used for overwintering habitat, shallow water habitat created by the islands that form behind the chevrons which support a wide variety of species, and a pool like habitat in the main channel of the river to support backwater habitat species. The end result of the study should answer whether the chevron dikes created a shift in community from the pre-construction and the control sites and what species are typifying these groups (i.e. whether the post-construction sites are statistically different from all other groups and the three remaining groups are statistically the same) , whether an increase in fish abundance occurred as a result of the construction of the chevrons (i.e. more fish are caught at the post-construction chevron group than any other groups and the three remaining groups and statistically the same), and lastly the chevron dikes altered flows creating different formations of the riverbed that lead to ephemeral islands, deep, slackwater pools, rocky substrate and a side channel.

<u>Definition of Terms</u>

To assist in understanding the complexity of the Mississippi River system and techniques used to gather and analyze data, the following terms must be defined and are listed alphabetically:

Bathymetry – The topography of a river or lake bed. This may be represented by elevation or LWRP and is generally presented in a 3-dimensional fashion such as TIN-modeling or raster formation.

Low Water Reference Plane (LWRP) – An imaginary plane set by the U.S. Army Corps of Engineers to aid in maintaining a 9-foot navigation channel. At 0 LWRP, the discharges are usually satisfactory to meet the requirement of the 2.7-meter (9-foot) navigation channel. The imaginary plane is related to total discharge through a specific river gage and can be related back to river stages read from river gages. For instance, if the St. Louis Mississippi River gage read 0.0, it would be at -3.5 LWRP at that location. LWRP provides a standard for comparison among stretches in the Mississippi and Illinois rivers that cannot be compared by direct elevation readings.

Middle Mississippi River – The portion of the Mississippi River from the confluence with the Missouri River near St. Louis, Mo to the confluence with the Ohio River near Cairo, IL.

National Geodetic Vertical Datum of 1929 -- A system of reference points used to compare vertical measurements established in 1929. This was later replaced by the

North American Vertical Datum of 1988 (NAVD 88); however, most river-related features and designs are still referred to in NGVD 1929.

Open River – the portion of the Mississippi River that is not pooled by a series of locks and dams below Lock and Dam 27 (Chain of Rocks Canal) to the intersection with the Gulf of Mexico near Pilottown, LA.

River Mile (RM) – Designation used for navigating the river systems. Each river system has its own river mile and in some cases such as the Mississippi River there are multiple. Cairo, IL, or the confluence of the Ohio River, is designated as 0.0 of the Upper Mississippi River system and continues upwards as one travels upstream. In the Lower Mississippi River system, the confluence of the Ohio River is the upper end of the river system and starts at 0.0 at the confluence of the Mississippi River with the Gulf of Mexico.

St. Louis Harbor – A small section of the Middle Mississippi River that includes the exit of the Chain of Rocks canal to near the Jefferson Barracks Bridge south of St. Louis, Mo.

Triangulated Irregular Network (TIN)-modeling – The creation of a 3-dimensional image from elevation or depth point data displayed as a vector.

Upper Mississippi River – The portion of the Mississippi River from the source in Lake Itasca, MN to the confluence of the Ohio River near Cairo, IL.

CHAPTER II

LITERATURE REVIEW

Mississippi River and its Associated Habitats

Since the late 1800s and the enactment of the River and Harbors Act of 1899, human manipulation of the Mississippi River has occurred, sometimes for better and sometimes for worse (Turner and Rabalais 1991). Like many large rivers, loss of habitat diversity is commonplace (Pedroli et al. 2002, Fry 2002). As shipping interests grew, the development of the Mississippi River became more important as a navigation channel than an ecosystem (Stevens et al. 1975, Belt 1975). In 1878, the U.S. Congress authorized the first comprehensive project on the upper river consisting of a 4 1/2-foot navigation channel. This was later followed by authorizations for a 6-foot channel in 1907 and the current 9-foot channel in 1930. Primarily due to increasing barge sizes and the need to ship as much as possible at once without worry of running aground, Congress passed the River and Harbors Act of 1930 setting forth the authorization for the maintenance of a 9-foot navigation channel throughout the entire Upper Mississippi River. This was initially accomplished through the construction of a series of locks and dams to create “pools” that hold water back to allow depth to be maintained without the need to continually dredge. This depth is still being maintained by dredging and river training structures throughout the Mississippi River system as a minimum for the navigation channel.

Since the enactment, a series of locks and dams have been created in the Upper Mississippi River from Ford Dam, also known as Lock and Dam 1, in Minneapolis, MN to the Mel Price Lock and Dam in Alton, IL and the Chain of Rocks Lock in Granite City, IL. Through the creation of these series of locks and dams and the confinement of river from agricultural levees, the Upper Mississippi River has become a channelized, navigation river losing much of its habitat diversity and backwater areas (Sheaffer and Nickum 1986, Pedroli et al. 2002, Fry 2002). The creation of such regulated hydrologic flow regimes generally leads to reduced habitat as the river is longer able to flood backwaters and create new channels by meandering through the floodplain as it did before alteration (Sheaffer and Nickum 1986, Pedroli et al. 2002, Fry 2002).

Historically, the river would meander across the floodplain and split the channel into several subchannels or connect two or more smaller channels to create a larger one through the processes of erosion and deposition (Simons et al. 1974). Side channels and their associated islands would slowly migrate and merge with the land due to deposition. New side channels and oxbow lakes would be created from floods or higher water events and river migration (Fisk 1944).

In the Middle Mississippi River, the river, due to navigation structures and channel constriction and disconnection due to agricultural levees, is no longer able to migrate within the floodplain or create new habitats such as oxbow lakes, wetlands or side channels and their associated islands (Simons et al. 1974, Theiling 1995, Theiling 1999). Areas such as Thompson Bend where the river started to create a new channel are immediately modified to maintain the channel alignment and reduce damage to the riparian corridor (Rapp 2002).

In the Middle Mississippi River, dikes, revetments, agricultural levees and several other man-made features have contributed to a stable, narrow and deep habitat, ideal for navigation; however, this reduction in environmental heterogeneity, has resulted in a loss of backwaters, side channels and their associated islands(Simons et al. 1974, Theiling 1999, Barko and Herzog 2003). Figure 3 below gives a general idea of how much the river has changed over the course of a couple hundred years. The image is just a small sample within Louisiana showing the old channel alignments and resulting oxbows.

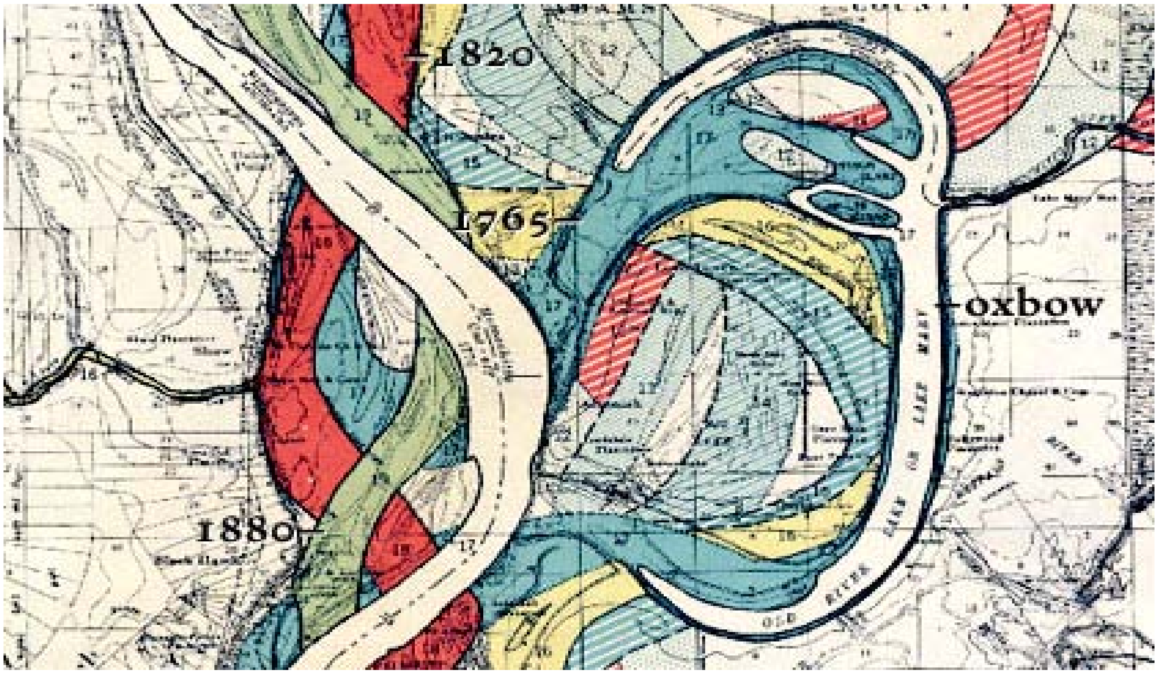

Figure 3. Historic map of abandoned river channels along the Mississippi in Louisiana (Fisk 1944)

Due to the impacts on the ecosystem as a result of anthropogenic factors, Federal and State agencies are attempting to create or at least restore these vital habitats in the Mississippi River. It is definitely an uphill battle to restore these habitats within the confined channel, let alone, create new habitats (Palmer et al. 2005). Several Federal and State programs work at accomplishing this task such as the Upper Mississippi River Restoration Environmental Management Program, Continuing Authority Programs for Ecosystem Restoration, Navigation and Ecosystem Sustainability, and the Missouri River Ecosystem Restoration Plan. Since the river centerline has become nearly a fixed object focusing on navigation, creating habitats such as side channels, sandbars, islands, and reconnections to backwaters outside of the main channel has become the goal of most studies (Stockton 2008, Hubbell 2011).

Big River Fish Communities

Habitat diversity , which is directly linked to fish success and fish community structure, is gradually being lost and has become an area of concern within the Middle Mississippi River (Simons et al. 1975, Theiling 1999). The reduction in habitat diversity is likely due to such factors as agricultural levee creation, which reduces access to back waters, dike construction, which constricts the channel reducing shoreline habitat, and a variety of other anthropogenic factors (Simons et al. 1974, Theiling 1999, Barko and Herzog 2003). Each one of these factors reduces the a specific river ecosystem function, such as the interaction with the main channel and its associated backwaters. These alterations result in decreases in habitat diversity and eventually losses in biological diversity (Junk et al. 1989, Thorp 1992, Ward and Stanford 1995, Ward et al. 1999).

Fish communities within the Mississippi River are immensely diverse with nearly 130 species and 40 families found within the Mississippi River system (Pflieger1997). In the mainstem of the Mississippi River, there are a variety of habitats that are still visible such as islands, both ephemeral and permanent, side channels, dike fields, main channel border habitats and side channel habitats . Not only are the macrohabitats still present, but a variety of microhabitats such as riffles, gravel bars and sandy sloughs exist.

Even though a wide diversity of habitat still remains within the Middle Mississippi River, some species of fish, such as the pallid sturgeon, are threatened or endangered.

As mentioned at the end of the Introduction in Chapter I, this study should address the following questions: Did the chevrons create a shift in the community that is unlike the pre-construction groups or control groups? What species typify of these groups? Were more fish captured in a set amount of time at the post-construction chevron group than any other group? Lastly, did the chevrons create a unique habitat that differed from lack of habitat present in the pre-construction main channel?

CHAPTER III

METHODS

Study Area

This study was conducted on the Middle Mississippi River between RM 182-184. The ecosystem that exists within this stretch currently is heavily modified from the river system that existed 150 years ago before any dams, levees and most bridges existed on the Mississippi River (Stevens et al. 1975). Several factors have changed the river system, including the creation of a series of locks and dams on the Mississippi River, levee systems, and numerous water control structures for directing flows and protecting banklines such as dikes and riprapped shorelines.

At approximately RM 184, the Chain of Rocks canal intersects with the Mississippi River. To prevent altering flows and sedimentation into the main channel at this location, a long trail dike was constructed to force flows downstream. The trail dike ends approximately 0.2 miles upstream of the first Chevron dike. In Figure 4, the location of the chevron dikes can be seen in relation to the Chain of Rocks canal and the trail dike that already exists. Also, two bridges are present within the St. Louis Harbor that the chevron dikes had to be designed to direct flow around, the Merchants Bridge at RM 183.3 and McKinley Bridge at RM 182.5, while reducing sedimentation into existing fleeting sites along the right descending bank.

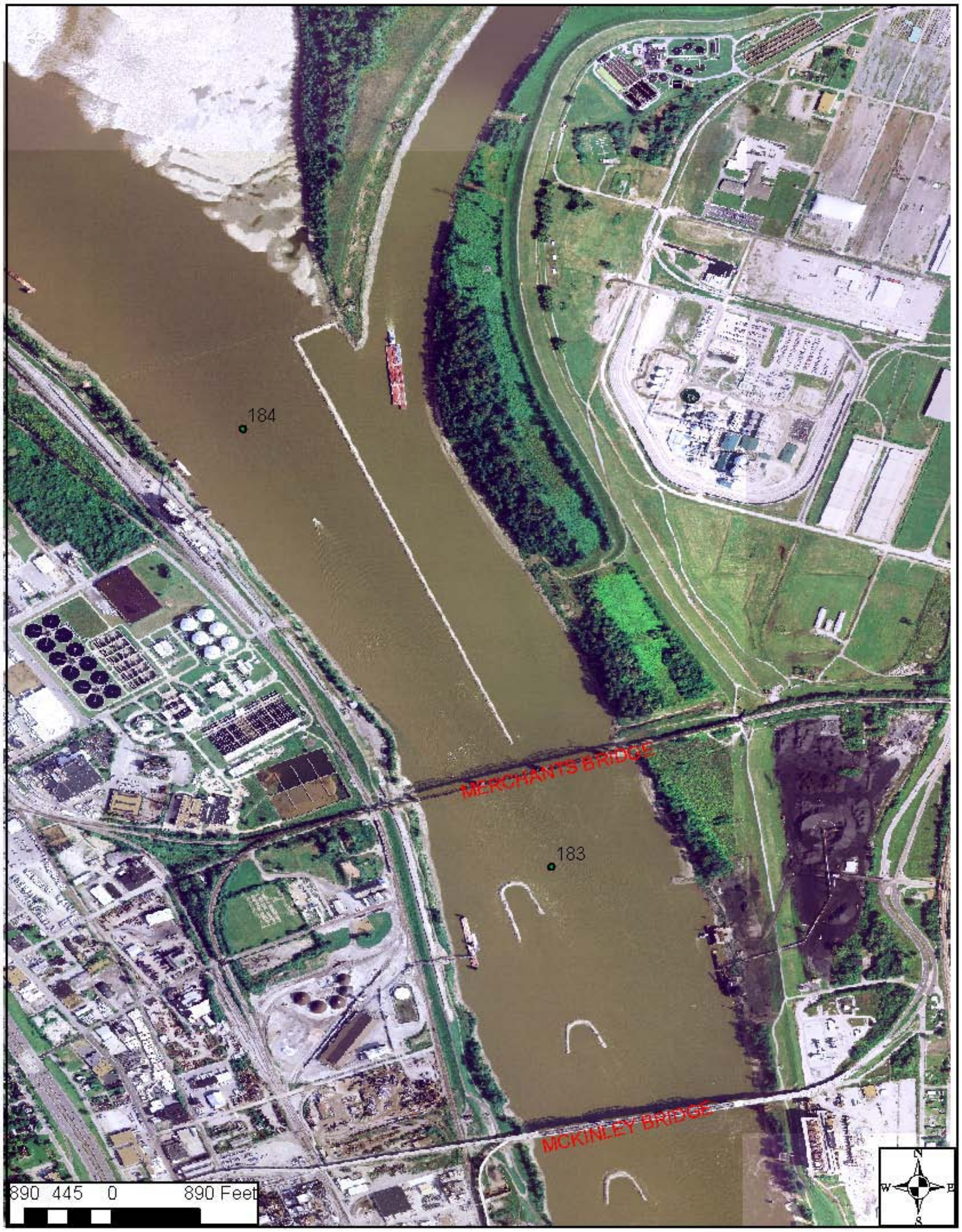

Figure 4. Location of chevron dikes in the St. Louis Harbor of the Middle Mississippi River.

Experimental Design

To adequately cover the full range of habitats that may exist in the St. Louis Harbor where the chevrons would be constructed a variety of techniques were used. To establish where habitat changes were likely to occur, a comparison of pre-construction bathymetric surveys were examined to determine changes in river bed elevations that would generally result in habitat changes. In addition, a hydraulic sediment response model (HSR) was conducted by the Corps of Engineers St. Louis District Applied River Engineer Center (AREC) prior to the construction of the chevron dikes. The model allows for the visualization of various alternatives and their impact on flows and sediment loads within the project area. In total, seventeen alternative design tests were conducted during the HSR study with varying impacts on flows and sediment accretion and erosion patterns . The final alternative involved eight specific structures including three experimental chevron dikes (Lamm et al. 2004).

After viewing pre-construction bathymetry from 2004 and the HSR model, four specific transects were created for each chevron dike. These transects would be used for electrofishing and trawling. The first transect is on the east side of the chevron and is known as the Illinois transect that follows the navigation channel. The second is on the west side of the chevron and is known as the Missouri transect. The Missouri transect is located in along a shallow sandy ridge. The third is directly down the center of the chevron and is known as the middle transect. During pre-construction sampling, the middle transect would cover the mid-range depths from the shallow shelf to the navigation channel. In post-construction sampling, the middle transect would sample two potential habitats including a deep scour hole and an ephemeral sand island as a result of the scour hole. The fourth transect slightly differs for pre- and post-construction monitoring. The fourth for pre-construction sampling was a non-standard, randomized pattern of electrofishing for 5-6 minutes between the Illinois transect and the Missouri transect to cover the area in which the chevron dike would be built. The time frame was sufficient to cover the entire footprint until no fish surfaced. For post-construction monitoring, electrofishing was conducted against the rock structure on the outside and inside of the chevron dike. Although the samples are not directly comparable, it allowed for the best view possible of the ichthyofauna associated with the area the chevron dikes would be constructed.

In addition to the four transects established for each chevron. Two specific sampling sites were selected within the St. Louis Harbor – control and experimental. The experimental site consisted of the area that encompasses all three chevron dikes and the potential island formation below each chevron. The control site was located slightly downstream of the chevrons and included the same transects as pre-construction monitoring throughout the entire project. Although the control site is located downstream of the experimental site, it was assumed at the beginning of the study that the control site was far enough downstream to be unaffected by impacts from the experimental site. The results from the study would be able to answer whether or not the control site was too close.

In addition, no other control sites could be located within the Mississippi River that have similar conditions to that of the experimental site other than the one chosen. Areas to the north of the experimental site are pooled or do not received adequate flow such as Mosenthein Chute since water is directed through the Chain of Rocks Canal. Sites further downstream could not be located due to the introduction of additional streams and rivers that change not only the habitat but different species. The three basic transects used for the experimental and control sites are depicted in Figure 5, with the actual transects used overlaid over aerial photography in Figure 6 and overlaid over pre-construction bathymetry referenced to LWRP in Figure 7 to view the depths of the transects.

To establish transects that could be used every time a sample was completed in the field, the transects designed in the previous paragraphs were designed in ArcGIS and shown in Figure 6. The coordinates of the transects were then transferred to the Lowrance chart plotter software known as MapCreate 6. The points, once formatted correctly in MapCreate 6, could be converted to an appropriate format (.usr) for the Lowrance chart plotter including unique identifiers to allow identification in the field of the appropriate waypoint and transect and saved to an SD card that could be loaded on the Lowrance LCX-19C Sonar/GPS chart plotter. In addition, maps were created in ArcGIS to visualize the chevron dikes, even during pre-construction monitoring, to allow for repeatable results during every sampling period.

Modifications to the transects became apparent as sampling started and continued throughout the project. During pre-construction sampling, it became evident that the Missouri transects would have to be altered due to a metal scrap facility located on the Mississippi River that loads and offloads scrap metal from barges and potentially loses scrap metal into the river. On several occasions, the trawl became snagged and tore on the lower Missouri transects near the scrap metal facility. To accommodate this change, the entire transect was shifted slightly east of the existing transect still remaining in the shallow water but avoiding known hazards.

Also, following construction of the chevrons, several factors could not be accounted for during the pre-construction monitoring such as water flow direction around the chevrons, water velocity changes and additional snags along the bottom of the river. Outside of shifting slightly east or west to accommodate for snags, the only other modification was to the middle transects for each chevron. The middle transect was slightly shortened, due to errors in the assumptions of the location of the built chevrons. The constructed chevrons were actually constructed over our middle transect and since, for safety reasons, the chevrons are not sampled until they are exposed, the middle transect was shortened to the head of the inside of each chevron to the original end point.

Fish sampling was conducted once each quarter in the spring (March – May), summer (June – August), fall (September – November), and winter (December – February) outside any high water event. Samples would only be obtained below 4.6 m (15 ft) LWRP to allow for visualization of the chevron dikes for safety reasons and consistency in sampling depths. Sampling when the chevrons are submerged is possible, but very dangerous, because the precise location of the dikes is not known. Habitat sampling would occur annually during high water to allow for survey boats to drive over the dikes and allow complete coverage of the area. During years of prolonged high water, two samples may be taken.

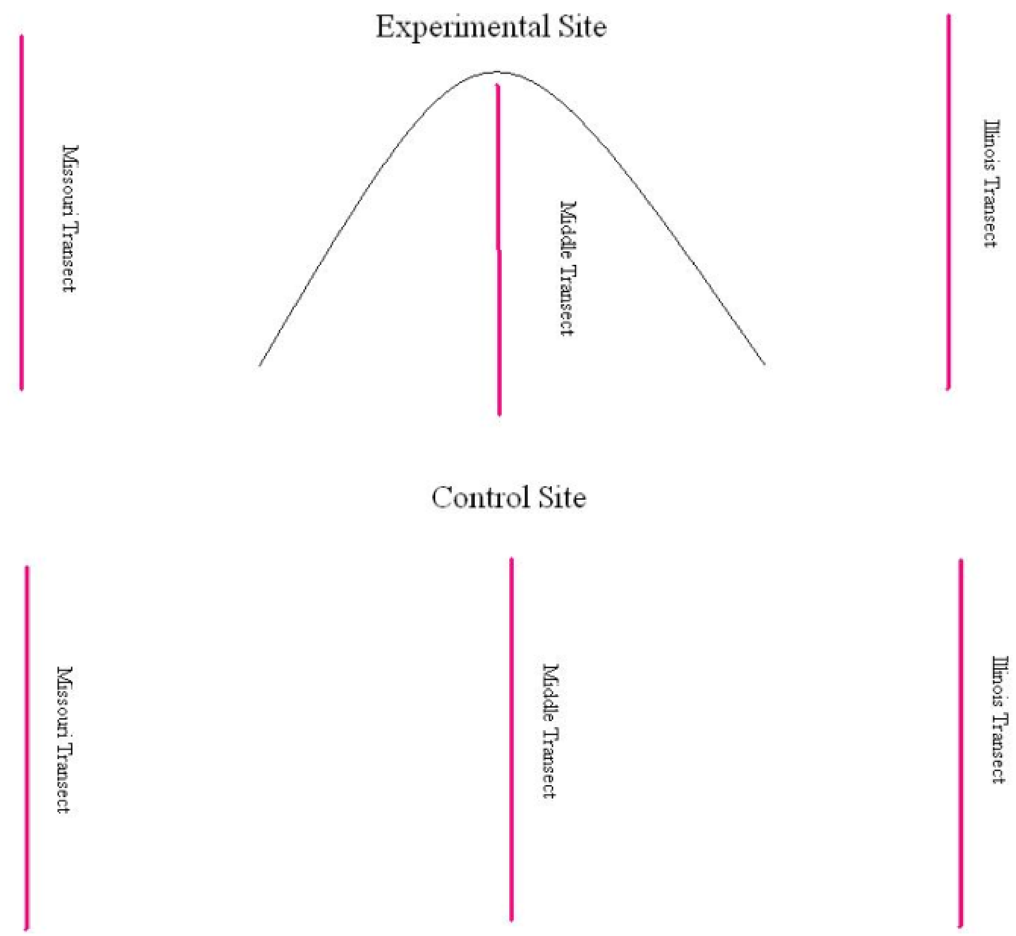

Figure 5. Generic transects for the experimental and control site.

Figure 6. Location of chevron dike field and actual transects.

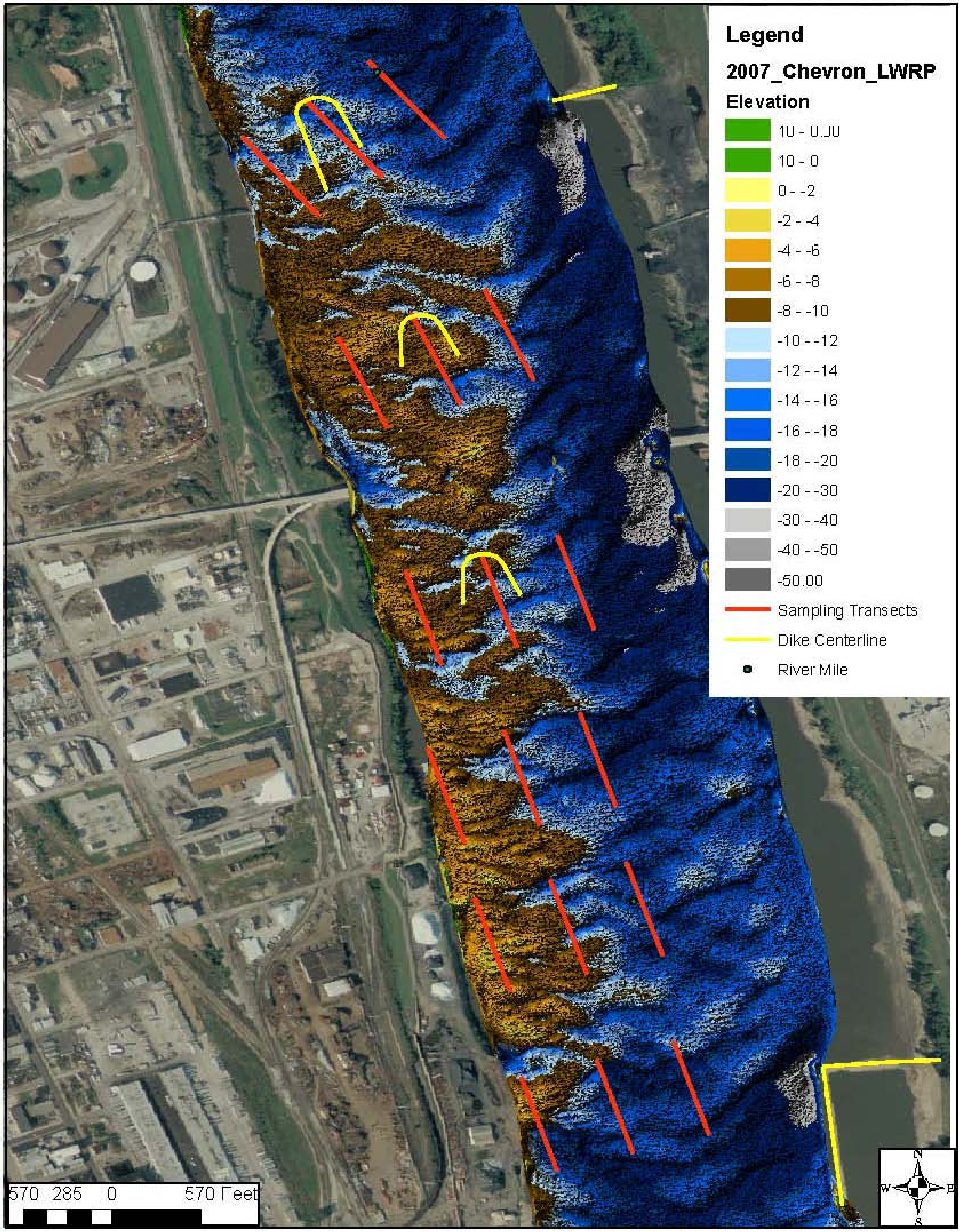

Figure 7. Location of chevron dike field and transects overlaid over 2007 bathymetry referenced to LWRP.

<u>Fish Sampling</u>

All fish sampling was conducted under scientific collection permits provided by the Illinois Department of Natural Resources and the Missouri Department of Conservation (Illinois permit numbers A10.5367 and A11.5367 and Missouri permit numbers 14697 and 14860). In addition, sampling for this research project was approved by the Southern Illinois University Edwardsville Institutional Animal Care and Use Committee (IACUC) under permit # 04-19-BS-1. As previously mentioned, two gear types were utilized to sample the project area – electrofishing and trawling. A multiple gear approach is usually warranted in sampling fish communities in large rivers because of biases associated with various types of gear and because of strong interactions between the environment and sampling efficiency (Sheehan and Rasmussen 1993). For instance, electrofishing samples a small surface area down to approximately 10 feet and generally within the distance between the two booms; whereas trawling samples the bottom of the river, no matter what river elevation and consistently samples the width of the mouth of the trawl.

Day electrofishing

The first of two measures that were conducted to examine fish communities located around the chevron dikes was day electrofishing. A flat-bottom aluminum boat approximately 18ft long and 6ft wide equipped with a 60 HP Yamaha outboard motor was used to conduct the electrofishing. Two booms were connected to the forward deck, which also provide a large enough area to accommodate two adults as dip-netters. Dip-netters were equipped with a dip net similar to the Duraframe Electro Wide Teardrop with a 12” deep bag with 1/8” mesh.

Each boom contains a ring of 12 electrodes approximately 60cm long. At the bow of the boat, several “dropper” electrodes are used along the front and side of the boat to act as cathodes and anodes. A portable 230-volt generator with 3500-watt capacity and 60-Hz frequency is used to power the electrofishing equipment. Power is operated by a foot control at the bow of the boat used by the dip-netters for safety reasons. In addition, a Smith-Root Model 5.0 GPP Electrofishing box was used to control power supplied to electrofishing booms and provide an emergency shutdown switch for additional safety. A consistent 3,000 watts of pulsed direct current was supplied to the booms to create ample current. Temperature and conductivity ratings determine the appropriate power setting on the electrofishing box to utilize. All power settings were obtained from the Long Term Resource Monitoring Procedures (Gutreuter et al. 1995).

Electrofishing was conducted going from upstream to downstream and was continued until no fish surfaced. A chase boat was not utilized, so if any fish emerged after the boat had passed that specific location, then electrofishing would be paused, the fish would be retrieved and then electrofishing would commence at the location where it was paused previously. This was very common for large catfish (Family Ictaluridae), suckers (Family Catostomidae), and Common Carp (Family Cyprinidae) located deeper in the water column. The amount of time for the fish to reach the surface was a result of the electric shock taking time to stun the larger fish and then additional time for the fish to surface.

As sampling continued into post-construction, the chevron dike rock structures slowly deteriorated and required maintenance. The two major changes that occurred were a large hole started to form on the eastern side of the most northern chevron dike and maintenance work was conducted in the winter of 2009 to level the dikes to the original constructed elevation. The problem with the hole in the most northern chevron dike was that if electrofishing was conducted during high water that allowed water through the hole but did not overtop the remainder of the dike, fish would be pulled through the hole due to the current and could not be retrieved by the dip netters and reduced fish counts and possibly species diversity and abundances. All fishes collected were measured for length, identified to species and enumerated. Fishes were placed back into the river in the same transect retrieved to prevent recaptures causing false increases in catch rates at other transects.

Trawling

The second method used for fish sampling was known as trawling. The specific type of trawl used was known as a Mini-Missouri trawl. The Mini-Missouri trawl is a modified two-seam slingshot balloon trawl.

A Mini-Missouri trawl is made of the standard two-seam 19.05 mm (0.75 in) mesh body that is then covered with a 4.76 mm (0.19 in) mesh cover. The footrope was 4.9 m (16 feet) in length with a 4.76 mm (0.19 in) diameter chain attached. The length of the footrope determines the opening of the mouth of the trawl net. The attached chain allows the footrope to drag along the bottom of the river. The Mini-Missouri trawl was the attached to the bow of the boat with 22.9-m (75-ft) towlines. The towline length was determined to be consistent with water depth and prevent the trawl from lifting off the bottom of the riverbed. Water depths in the chevron area and control area rarely exceeded 12.2 m (40 ft) during any sample.

Plates known as otter boards were attached to each end of the footrope and headrope to pull the mouth of the trawl open. The otter boards measured 15 in high by 30 in long. The otter boards were constructed of wood with a metal side plate to prevent excessive wear on the boards. Chains were fastened to the center of each otter board and then attached to the headropes and footropes.

At the codend, which is the area at the back of the net where the fishes are become entrained, of the Mini-Missouri trawl, a float was attached with a single ropeline that was tied to the codend to assist in closing the codend and retrieval of the trawl net if snagged by an object such as tree snags or other debris on the riverbed. This was very important as the trawl snagged frequently and required immediate removal due to oncoming barge traffic.

The trawl was manually released from the bow of the boat. The boat was then driven in reverse with the bow pointing upstream. Reverse direction trawling is considered safer with smaller boats in large rivers (Herzog 2004). The added benefit of reverse trawling is extra power in cases where the trawl became snagged and tension needs to be released in a quick, but safe manner.

Tension was kept on the towlines to force the mouth of the Missouri trawl open and prevent any twisting or rolling of the net. The standard haul defined by LTRMP guidelines is 375m long and lasts approximately 6 minutes (Gutreuter et al. 1995). The standard trawl length and time had to be modified to more adequately address the local environment. The trawl length was reduced to approximately 215m and lasts approximately 2 ½ minutes per trawl due to the swift currents. The trawl lengths were modified to prevent overlap of transects and prevent disturbance of nearby transects.

The trawl was towed at a speed slightly faster than surface water current velocity using the same jon boat as in the electrofishing samples. Speed, distance and location were monitored using a Lowrance LCX-19C. Total effort was recorded in time when the towlines became taught to when the net was brought back into the boat. If a trawl became snagged or ripped, the time and data was voided and was not recorded. Similar to day electrofishing, all fish were measured for length, identified to species and enumerated.

Smaller, benthic fish were trapped in the 4.76mm mesh outer net as they were able to pass through the larger inner mesh and larger fish were trapped in the 19.05mm inner net. This prevents larger individuals from crushing smaller individuals. All trawl transects were run in areas where no known mussel beds exist to reduce any ecological damage.

Habitat Sampling

Bathymetric surveys were conducted using the United States Army Corps of Engineers Motor Vessel (M/V) Boyer. The M/V Boyer is equipped with multibeam sonar to detect the river floor. Multibeam sonar is a type of echo sounding that provides a near-complete coverage of the river bed. Echo sounding is a technique for measuring water depths by transmitting acoustic pulses to the riverbed and receiving their reflection. The amount of time it takes for the "ping" to come back to the receiver allows for a measurement of depth to be recorded. The depth measurements along with the specific geographic coordinates allow for the data to be mapped resulting in a 3-dimensional view of the riverbed. The benefit of multibeam sonar over single beam sonar is the ability to produce higher resolution images than wide-angle, single beam sonar and in faster time than narrow-angle, single beam sonar (Melvin et al 2003).

After the data is retrieved, all points are formatted to remove any extraneous points and adjust for river stage. The extraneous points being removed are generally created from backscatter as either a result of prop wash or floating debris. These points are then input into ArcGIS. The result is thousands of points with x and y coordinates with corresponding elevations. The next step is to triangulate the individual points to create a 3-dimensional image. Using ArcGIS, the data points were converted into a triangular irregular network (TIN). The TIN is a vector-based, 3-dimensional representation of the riverbed. The TIN was then converted from elevation to low water reference plane (LWRP). The LWRP is an easier way to view the data, because it creates a standard for viewing river elevations among all stretches of the Mississippi River. Instead of an elevation of 463.8 feet, it might read -15.3 in reference to the LWRP. The LWRP for the open river of the Upper Mississippi River near the St. Louis Harbor is approximately 378 feet NGVD. For this study, bathymetry was recorded in May 2007, March 2008, July 2008, January 2009, November 2009 and July 2010. All surveys were compared to the prior year or prior survey if in the same year to see what habitats had been lost or gained.

Statistical Analysis

Two different types of statistical analyses were completed for fish community analysis. The first utilized univariate statistics to determine if positive changes occurred in catch per unit effort (CPUE) between pre- and post-chevron locations. Reference sites were conducted as well to make sure they remained constant from pre- to post-construction.

Catch per unit effort was measured in total number of fish caught per minute. Two-way Analysis of Variance (ANOVA) for the trawling and electrofishing for each chevron and control location were completed with post-hoc Tukey-Kramer tests to determine whether time (pre- and post-) and location (control and experiment) were significant. Trawling and electrofishing data were kept separate as sampling techniques are not directly comparable since they use different standardization methods as one technique is used along the surface with electricity and the other in the deep water with nets.

In addition to the univariate statistic approach, a community analysis was completed to complete a series of ordinations with corresponding analyses for all samples. It was necessary to complete a multivariate statistics approach to adequately evaluate the communities that existed and were created as a result of the chevron dike construction.

Ordinations are a type of multivariate technique that project groups of data points in a way that when projected into a multi-dimensional space, such as 2-dimensional or 3-dimensional, the patters can be viewed (Pielou 1984). In other words, the ordination summarizes the community data, in my case catch per unit effort and presence/absence, both of which represent species abundance, into a visible space. Groups with similar species and catch rates are grouped close together. Those with different species and abundances are placed farther apart.

More specifically, the ordinations are used to visualize any changes that might be occurring in the fish communities directly associated with a specific site or group. The ordinations were completed using non-metric multidimensional scaling (NMDS) as first discussed by Kruskal (1964). NMDS has been noted as one of the most robust ordination techniques commonly used in community ecology (Minchin 1987).

The ordinations present the data in a fashion to see if a shift in the community has occurred. Each sample taken, with a positive value, is represented by an individual point in the coordinate system. Those points that are grouped together are generally more alike in species composition than those that are separated by some distance.

Similar to the CPUE univariate analysis, electrofishing and trawling data were kept separate as a direct comparison between the two is not valid. Sampling effort, which is how the fish are caught, and sampling location (mid to top water for electrofishing and bottom for trawling) are distinctly different for the two types of sampling procedures. In addition to CPUE, an analysis of presence/absence was conducted for all samples combined. Since abundances are left out in a presence/absence matrix, the gears can combined. This allows one to visualize the entire fish community within the dike field; however information pertaining to abundances is lost as the species is either present or not.

All samples that contained no data, i.e. no fishes were caught, were removed prior to the ordinations being completed. Although zeroes represent data, the primary goal of this project was to determine what was happening to the fishes that exist at the site. Samples that contained no fishes when combined for the entire set of transects for that specific chevron or reference site represent a lack of community and therefore provide no valuable information to the ordination.

The Bray-Curtis dissimilarity index (Bray and Curtis 1957) was used to understand the differences within the communities in both CPUE and presence/absence. The Bray-Curtis dissimilarity index calculates the similarity of species within groups and their abundances. The Bray–Curtis dissimilarity is bound between zero and one. In the most simplistic form, as numbers approach zero, the two sites have the same composition of species and abundances. As the numbers approach one, the two sites do not share any species and if the species are shared the abundances are not the same (Bray and Curtis 1957). The Bray-Curtis dissimilarity index was used primarily for its robustness over other models without prior knowledge of the project site (Faith et al. 1987) and extensive use and acceptability within the ecology and environmental science fields (Faith et al. 1987, Gauch 1973).

Prior to completing the Bray-Curtis dissimilarity index, the CPUE data was transformed then standardized. The reason the data was transformed via square root was to reduce the impact that an occasional high catch at one site might have over all samples. The data was then standardized by species maximum. In other words, the transformed CPUE data within each species among samples were divided by the maximum transformed CPUE data attained by that species over all samples. This particular standardization of community data has been recommended as it has shown the dissimilarities are more correlated with the degree of environmental differences between samples (Faith et al. 1987). The presence/absence data was neither transformed nor standardized as all values are either one or zero so there are no exceptionally high or low numbers to result in skewing the dataset.

As discussed by Clarke (1993), NMDS is one of ideal choices for representing community relationships. NMDS can be used to construct a graphical representation of the samples by which relative distance apart represents similarity in species composition of the communities (Clarke 1993); however there is no guarantee that these rank similarities are accurately preserved in the multidimensional figure.

To find the best ordination that exists, the ordination must be completed several times at a variety of different starting points. Each time the ordination is completed it chooses a slightly different starting point to achieve the best fit. A statistic known as stress is compiled during all iterations. The stress measures the badness-of-fit, or distortion, of the ordination. The lower the stress the closer the fit to an ordination that adequately reflects the data. Clarke discusses the stress values and their importance to the ordination. Table 1 depicts what each level of stress represents and its validity to interpretation of the ordination (Clarke 1993).

Table 1. Stress values and validity of interpretation.

Stress Value	Value of Interpretation
< 0.05	Excellent representation. No prospect of misinterpretation.
< 0.10	Good representation. No real risk of misinterpretation. A higher dimensional plot is not likely to provide any additional benefits.
< 0.20	Useable representation. Could pose some risks in misinterpretation. A higher dimensional plot may yield additional information.
> 0.20	Dangerous to interpret. As the stress values near 0.35 – 0.40, the samples are effectively randomly generated.

In addition, it was necessary to run the ordinations from 100 different random starting points to avoid problems with ending up in a local minima that was not the global minimum. All ordinations were completed in both two dimensions and three dimensions to determine if there were additional factors that might be adding to the complexity of the chevron dike location besides just the construction of the chevron dikes. In an extreme situation when two sites represent completely different communities, the sample sites from one community would be tightly grouped together and the other community would be tightly grouped together as far away as possibly from the first community. This generally is not the case and a statistical test needs to be conducted to determine what groups are statistically different. For this study, an Analysis of Similarities (ANOSIM) was completed.

Three analyses were completed for the data set. Since most post-construction samples caught more fish, but the samples took longer, the first and second analyses utilized catch per unit effort among all samples in either electrofishing or trawling. These were not combined as CPUE rates as they are not directly comparable as the effort to collect number of individuals differs with the sampling gear used. The third analysis utilized presence/absence data of all species in all samples to provide the big picture of what might actually be happening at the site. Electrofishing and trawling data were combined for the presence/absence data since the same transects were used for both and it allows for a view at the entire fish community.

The ANOSIM is able to test the difference between the fish communities among all four groups (pre- and post-construction and experimental and control). Table 2 below lists the six comparisons completed during the ANOSIM. ANOSIM is a multivariate, non-parametric test based on the ranks of dissimilarities (Clarke 1993) that test whether each group is statistically similar or different. The test statistic, R, measures the extent to which groups are similar or dissimilar. In other words, if an R value approaches 1, the values are not similar and are likely in different groups. As the R value approaches 0, the values are similar and likely within the same group. The test statistic, R, is not based upon the distances between samples as this would change depending on the number of dimensions one had, but on the rank similarities between samples.

Table 2. List of groups compared during ANOSIM

Group 1	Group 2
Pre- Construction Control (Reference)	Pre-Construction Experimental (Chevron)
Pre- Construction Control (Reference)	Post-Construction Control (Reference)
Pre- Construction Control (Reference)	Post-Construction Experimental (Chevron)
Pre-Construction Experimental (Chevron)	Post-Construction Control (Reference)
Pre-Construction Experimental (Chevron)	Post-Construction Experimental (Chevron)
Post-Construction Control (Reference)	Post-Construction Experimental (Chevron)

The R statistic is calculated by subtracting the average of all rank similarities among replicates within sites ( ) from the average of rank similarities among replicates between sites ( ). The equation is shown below. M equals the number of samples under consideration (n) minus one times n divided by two.

The null hypothesis for the permutation test would state that there are no differences between sites. Therefore for the permutation test, the group labels are arbitrarily rearranged and the R statistic is recalculated while preserving the original sizes of the groups. The statistical significance of R was tested by randomly permuting group relationships 10,000 times. This provides a range of R values that the actual test is compared to. If the null hypothesis holds true, the actual R statistic would be the statistically the same as the range of R statistics from the permutations. If the group is statistically different, the actual R statistic would be outside that range of random permutations (Clarke 1993). As mentioned previously, separate ordinations and ANOSIM analyses were done for each of the three data matrices mentioned previously (CPUE trawling, CPUE electrofishing and presence absence). The final result is a list of all group comparisons and whether or not they are statistically similar or different.

For the comparisons that were deemed statistically significant from the ANOSIM, a technique known as indicator species analysis (ISA) was completed. The ISA developed by Dufrene and Legendre (1997) indicates species that characterize groups of samples, more specifically, which species that best separate one group of samples from all the others. There are two forces that drive the ISA, fidelity and constancy. Fidelity is the degree to which a species is confined to a particular group, i.e. if the species is only present at one group. Constancy the proportion of samples in a group in which the species occurs. In other words, how often was a particular species caught at a given group. The ideal indicator species for a site is only caught at within that site and no others and is consistently caught in every sample at that group.

The fidelity of species *j* to group *k* is calculated as:

$$F_{kj} = \frac{\bar{x}_{kj}}{\sum_{l=1}^{g} \bar{x}_{lj}}$$

where is the mean abundance of species *j* in group *k*. The denominator is equal to the sum of the mean abundances of species *j* over all *g* groups. These fidelity values range from 1.0 when species *j* is only found in group *k* to 0.0 when the species is never found in group *k*. The constancy of species j in group k is computed as:

$$C_{kj} = \frac{n_{kj}}{n_{k.}}$$

where n_{kj} is the number of sampling units in group *k* in which species *j* occurs and n_k is the number of sampling units in group *k*. Constancy values are proportions which range from 0.0 in which the species is never captured in group *k* to 1.0 in which the species is caught in every sample in group *k*. Fidelity and constancy are then combined into a single Indicator Value (IV) by merely multiplying the fidelity by the constancy and then by 100 to get a value between 0 and 100.

Since both fidelity and constancy are numbers between 0 and 1, a species must be both faithful and constant to get a high IV. If a species is one but not the other it will result in a lower IV. For example is a species has a fidelity value of 0.9 and a constancy value of 0.2, it will have an IV of 18 whereas if both were 0.9, the species would have an IV of 81 for that group.

The statistical significance of the highest IV attained by a species over all sites is tested by a random permutation tests identical to how the ANOSIM is conducted (Dufrene and Legendre 1997). In each test, 10,000 random permutations were used including the existing data set. ISA was completed on all ordinations, as each ordination provides a slightly different view into the community composition and any shifts in the community that might exist.

A variety of statistical software programs were used to complete all the analyses and present data in a clear and concise format. NMDS ordinations and ANOSIM tests were performed using Primer v6 and Permanova (Clarke and Gorley 2006). Indicator Species Analysis was performed using PCORD version 5 (McCune and Mefford 2006). Analysis of Variance was performed Systat 10 (SPSS 2000). Graphs were prepared using Sigma Plot version 11.0 (Systat Software Inc. 2008).

A comparison of pre- and post-construction bathymetric surveys was completed using ArcGIS and was completed to track and visualize changes in habitats, but no statistical analyses were applied to the habitat changes. All surveys were compared to the previous year's survey. The first post-construction survey was compared to the May 2007 pre-construction survey. The May 2007 survey was the most recent survey completed prior to construction and typical of pre-construction conditions. All post-construction changes provide a snapshot of sediment changes around the chevron dike field as sediment loads change daily. All subsequent surveys were compared to the previous year to see if scour and sedimentation is still occurring resulting in a dynamic environment.

CHAPTER IV

RESULTS

Fish Sampling

A total of 1,987 fishes were collected from 477 samples from the St. Louis Harbor during the 4 years of monitoring comprising 14 families and 35 species of fish. Table 3 shows the species caught in each location and if it was caught pre- or post-construction including total counts of each species per gear type. One of the most noticeable pieces of information is the large increase in species following post-construction in the chevron area. There is, however, one species not represented in post-construction samples that was in caught pre-construction, the Channel Shiner (*Notropis wickliffi*). Also, there is a general decrease in the total number of species in the control area following post-construction of the chevron dikes.

As mentioned previously, the first analysis method conducted was catch per unit effort (CPUE) for the sample. CPUE is the amount of fish caught during a specific time of standardized sampling. It is generally acceptable to show CPUE in fish collected per minute. Catch per unit efforts ranged from 0.0 fish/min to 73.7 fish/min for trawling and between 0.0 fish/min to 8.14 fish/min for electrofishing. The CPUE for electrofishing, represented in Figure 8 , are the resulting graphs from the ANOVA test between time (pre-construction and post-construction) and location (reference and chevron). The specific type of gear used was also separated out to determine if one gear type was more efficient than another and allow for different habitats to be analyzed separately.

Table 3. List of species including total counts for gear type, location, and time retrieved. Sorted by alphabetically by common name.

		Pre-Construction				Post-Construction			
		Experimental		Control		Experimental		Control	
Latin Name	Common Name	EF	Trawl	EF	Trawl	EF	Trawl	EF	Trawl
Hypophthalmichthys nobilis	Bighead Carp							1	
Ictiobus niger	Black Buffalo					5			
Pomoxis nigromaculatus	Black Crappie					1			
Ictalurus furcatus	Blue Catfish		17	3	52	112	18		4
Lepomis macrochirus	Bluegill					5			
Labidesthes sicculus	Brook Silverside						1		
Ictalurus punctatus	Channel Catfish		55	1	350	33	61		16
Notropis wickliffi	Channel Shiner		1		2				
Cyprinus carpio	Common Carp		1			10			
Notropis atherinoides	Emerald Shiner		2		4	17			
Pylodictis olivaris	Flathead Catfish				1	49	1		
Aplodinotus grunniens	Freshwater Drum		2		4	191	42		
Dorosoma cepedianum	Gizzard Shad	13	1	19		156	16	2	16
Hiodon alosoides	Goldeye					211	2		
Carassius auratus	Goldfish					6			
Ctenopharyngodon idella	Grass Carp					21			
Micropterus salmoides	Largemouth Bass					2			
Lepisosteus osseus	Longnose Gar					3			
Hiodon tergisus	Mooneye					1			
Polyodon spathula	Paddlefish					1			
Cyprinella lutrensis	Red Shiner				1	2			
Carpiodes carpio	River Carpsucker					33			
Notropis blennius	River Shiner					1			
Stizostidion canadense	Sauger					6			
Macrhybopsis hyostoma	Shoal Chub		35		102		1		1
Moxostoma macrolepidotum	Shorthead Redhorse					3			
Lepisosteus platostomus	Shortnose Gar					3			
Scaphirhynchus platorynchus	Shovelnose Sturgeon		16		2		1		1
Macrhybopsis meeki	Sicklefin Chub		10		8		3		1
Hypophthalmichthys molitrix	Silver Carp					56			
Macrhybopsis storeriana	Silver Chub		1		30		1		
Alosa chrysochloris	Skipjack Herring	1		3		2			
Ictiobus bubalus	Smallmouth Buffalo					85	1		
Gambusia affinis	Western Mosquitofish					1			
Morone chrysops	White Bass					44			
Total		**14**	**141**	**26**	**556**	**1060**	**148**	**3**	**39**
		155		**582**		**1208**		**42**	

Electrofishing showed unique statistical differences between not only location (P=0.007), but the interaction between time and location (P=<0.001). The interaction is of most concentration as this is pulls apart not only pre-construction compared to post-construction but also control compared to experimental. The Tukey-Kramer post-hoc test would be able to distinguish which groups specifically were statistically different and are shown in Figure 8. Table 4 below shows the initial two-way Anova results between time, location and the interaction.

Table 4. Results of two-way analysis of variance of square-root transformed catch per unit effort data for electrofishing.

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
Location	1.53	1	1.53	7.476	0.007
Time	0.269	1	0.269	1.315	0.252
Interaction (Time*Location)	4.098	1	4.098	20.027	<0.001
Error	57.494	281	0.205		

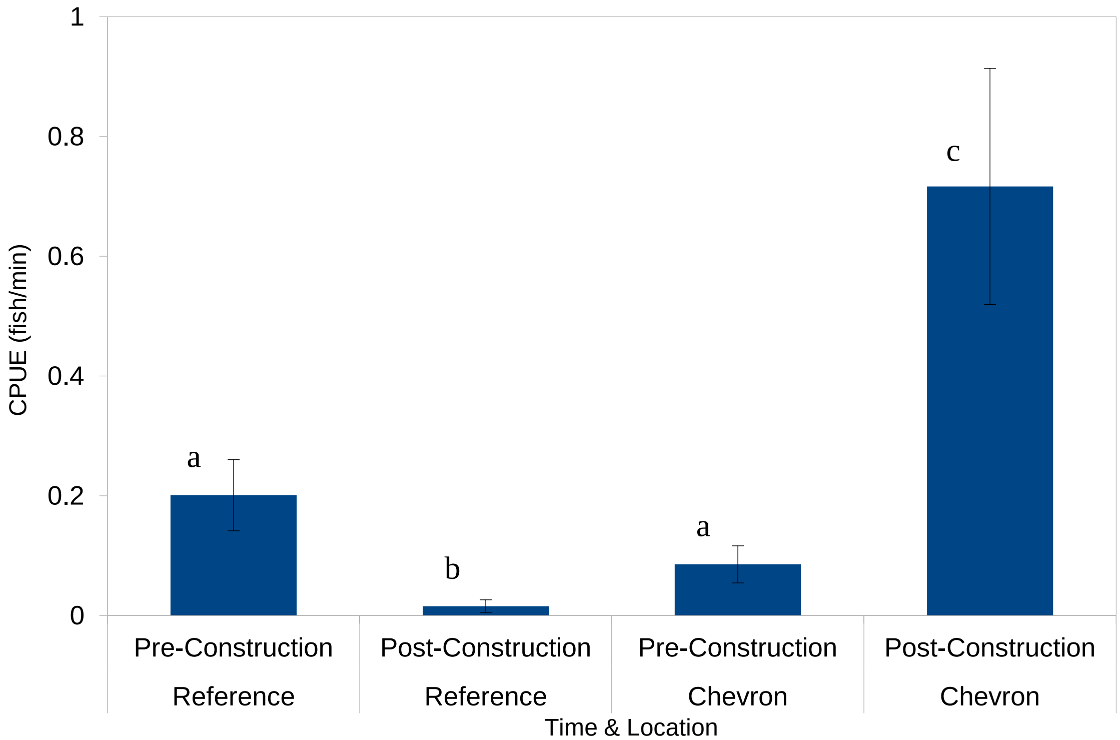

Figure 8. Electrofishing CPUE for each location during pre- and post-construction. Bars shown are standard error. Letters designate which sites are statistically the same from the Tukey-Kramer test. The same letter means they are statistically the same at the 0.05 level.

Trawling provided a slightly different response to the construction of the chevrons. Although location and the interaction itself were not statistically significant (P=0.545, P=0.262, respectively), time was statistically significant (P=0.002). While the pre-construction chevron site collected more fishes per minute during trawling, there were numerous samples similar to post-construction sampling that retrieved no fishes. Due to the large reduction in catch rate, the interaction was not significant. The Tukey-Kramer post-hoc test was still performed to see which individual sites were significantly different from one another and are shown in Figure 9 below. Uniquely, the pre-construction groups were statistically the same even though the pre-construction experimental site caught a much larger abundance of fishes. Both post-construction groups were also statistically the same since both had relatively low catch rates. Discussion of what may have caused the decrease in catch rates for trawling are explained further in the discussion.

Table 5. Results of two-way analysis of variance of square-root transformed catch per unit effort data for trawling.

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
Location	0.465	1	0.465	0.367	0.545
Time	12.969	1	12.969	10.234	0.002
Interaction (Time*Location)	1.59	1	1.59	1.255	0.264
Error	238.262	188	1.267		

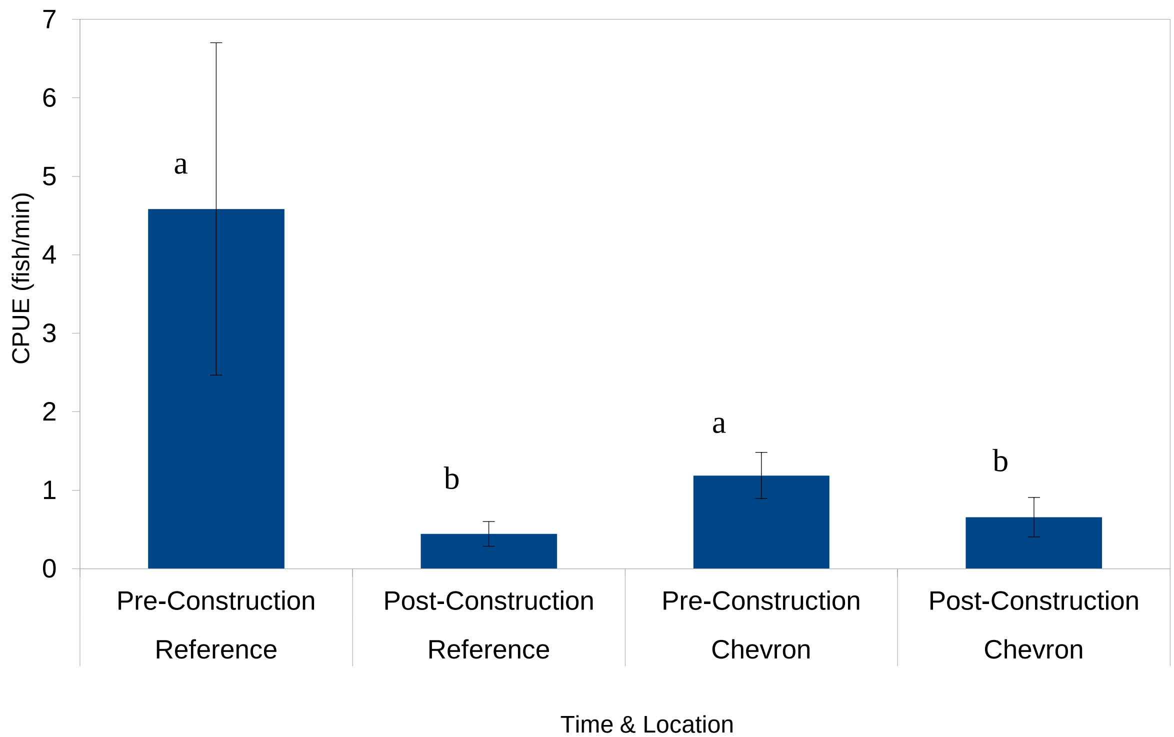

Figure 9. Trawling CPUE for each location during pre- and post-construction. Bars shown are standard error. Letters designate which sites are statistically the same from the Tukey-Kramer test. The same letter means they are statistically the same at the 0.05 level.

Below each ordination is a table that shows the ANOSIM with statistically significant comparisons italicized. As a result of any relationships that were considered significant from the ANOSIM, the ISA table for each ordination is listed below that ANOSIM table. This provides useful information in identifying which species characterize groups.

The ordination, shown in Figure 10, captures a distinct shift in the original community that existed in within the St. Louis Harbor. The initial ANOSIM detects whether or not there is a statistical difference among all groups before completing the pairwise comparisons. The initial ANOSIM for the overall tests was significant for electrofishing CPUE (R=0.305, P=0.0002)

Ideally, the post-construction chevron site would be significantly different from all other groups, yet no other group comparison would be significant. This is exactly how the data appears in Figure 10 and the ANOSIM statistical tests reveal the same in Table 2. There are four subset figures within Figure 10. These represent each group (pre-construction control, pre-construction chevron, post-construction control, and post-construction chevron). Due to the tight clusters and the unique patterns, the samples are identified by location as either Missouri, Illinois, middle or chevron. The first three represent the transects as shown in Figure 5. Chevron identifies those samples as the ones taken to represent the area where the chevrons would be built or its approximate location in the control sites and in post-construction the chevrons themselves.

The first feature that stands out from the ordination are the overwhelming number of post-construction experimental site samples compared to all other sites. This was not a result of more samples taken during post-construction, but that the post-construction experimental site caught more fish. As mentioned previously all samples without any catches were removed.

Another unique feature is that although the post-construction chevron samples were statistically different from all other samples, they are not grouped tightly together. There appears to be two distinctive groupings of post-construction chevron samples compared to all other samples. All other samples among the three other sample site are grouped fairly closely close together.

From the ISA, six species were shown to be statistically significant as indicator species. All six species were indicators for the post-construction chevron site. Of the six indicator species – flathead catfish (*Pylodictus olivaris*), freshwater drum (*Aplodinotus grunniens*), goldeye (*Hiodon alosoides*), river carpsucker (*Carpiodes carpio*), silver carp (*Hypopthalmichthys molitrix*), and smallmouth buffalo (*Ictiobus bubalus*) – five of them are considered to be large bodied, riverine fishes. Goldeye is generally a smaller bodied fish, but like the other indicator species is restricted primarily to larger rivers and reservoirs. Also, most of these species, including the freshwater drum, smallmouth buffalo, and river carpsucker, although characteristic of larger rivers (Pflieger 1997), avoid strong currents, which might provide insight as to the habitat use of the chevron dikes by riverine species.

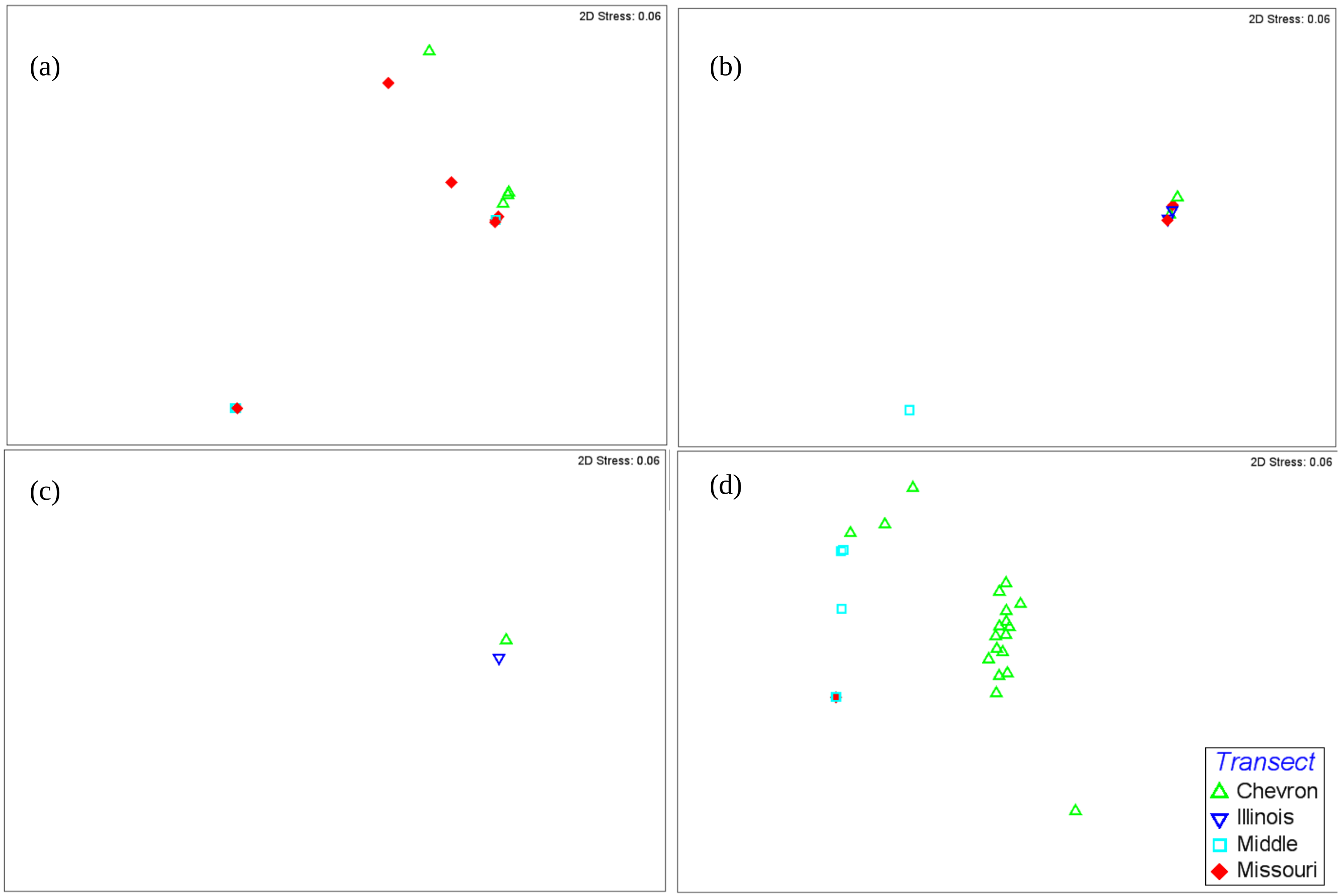

Figure 10. Ordinations of transformed and standardized electrofishing for each group (a) pre-construction control, (b) pre-construction chevron, (c) post-construction control, and (d) post-construction chevron. Note the relatively low stress value of 0.06. Since the value was so low, the 2-dimensional ordination was chosen and other dimensions were not required.

Table 6. Pairwise ANOSIM tests among all pairs of groups for electrofishing. Any comparison with a P value less than 0.05 was considered significant and are italicized.

Pairwise Tests			
Groups		**R Statistic**	**P**
Post-Construction Chevron	*Pre-Construction Chevron*	*0.501*	*0.0001*
Post-Construction Chevron	*Pre-Construction Reference*	*0.427*	*0.0001*
Post-Construction Chevron	*Post-Construction Reference*	*0.469*	*0.019*
Pre-Construction Chevron	Pre-Construction Reference	-0.077	0.887
Pre-Construction Chevron	Post-Construction Reference	-0.224	0.933
Pre-Construction Reference	Post-Construction Reference	-0.189	0.742

Table 7. Significant Indicator Species for catch per unit effort electrofishing data. Indicator scores are listed with the associated P-value. Only the species that were significant are shown in the tables. Those that are bolded are the significant indicator value for that group.

		Reference		**Chevron**		
Species	**Common Name**	**Pre-Construction**	**Post-Construction**	**Pre-Construction**	**Post-Construction**	**P**
Pylodictus olivaris	Flathead catfish	0	0	0	**46**	0.363
Aplodinotus grunniens	Freshwater Drum	0	0	0	**58**	0.0081
Hiodon alosoides	Goldeye	0	0	0	**73**	0.0021
Carpiodes carpio	River Carpsucker	0	0	0	**38**	0.0504
Hypophthalmichthys molitrix	Silver Carp	0	0	0	**58**	0.0089
Ictiobus bubalus	Smallmouth Buffalo	0	0	0	**50**	0.0163

The trawling ordination is very different. At first glance, no patterns appear to emerge from the ordinations (Figure 11) as no sampling sites appear to be grouped together; however, the ANOSIM (Table 4) showed that the overall test was significant (R=0.131, P=0.001) and that there are four statistically different comparisons. The post-construction chevron site was statistically different from both the pre-construction experimental site and the post-construction reference site. One of issues with the ordination was that the pre-construction reference site was significantly different from the post-construction reference site. This was an unexpected result as a site that should have remained constant throughout the experiment had changed significantly from pre- to post-construction.

In addition, an ISA was completed even though the significant indicators may be of no interest. The ISA revealed only two species that were considered relatively good indicators. The two species were channel catfish (*Ictalurus punctatus*) for pre-construction reference sites and gizzard shad (*Dorosoma cepedianum*) for the post-construction reference sites. These two species are two of the most common occurring species present within the Mississippi River. In fact, the channel catfish is considered to be the most abundant and widely distributed catfish in Missouri (Pflieger 1997) and the gizzard shad is considered to one of the most common and widely distributed fishes in Missouri, occurring in every principal stream system in the state (Pflieger 1997). Although, these two species are considered to be the most abundant in the river system, this does not mean that they did not change in abundance from pre-construction to post-construction or from experimental to control. Notable though, the two benthic chubs, the silver chub (*Macrhybopsis storeriana*), and the shoal chub (*Macrhybopsis hyostoma*) were not considered statistically significant, but were relatively close (P=0.0642 and 0.1379, respectively) for pre-construction sites.

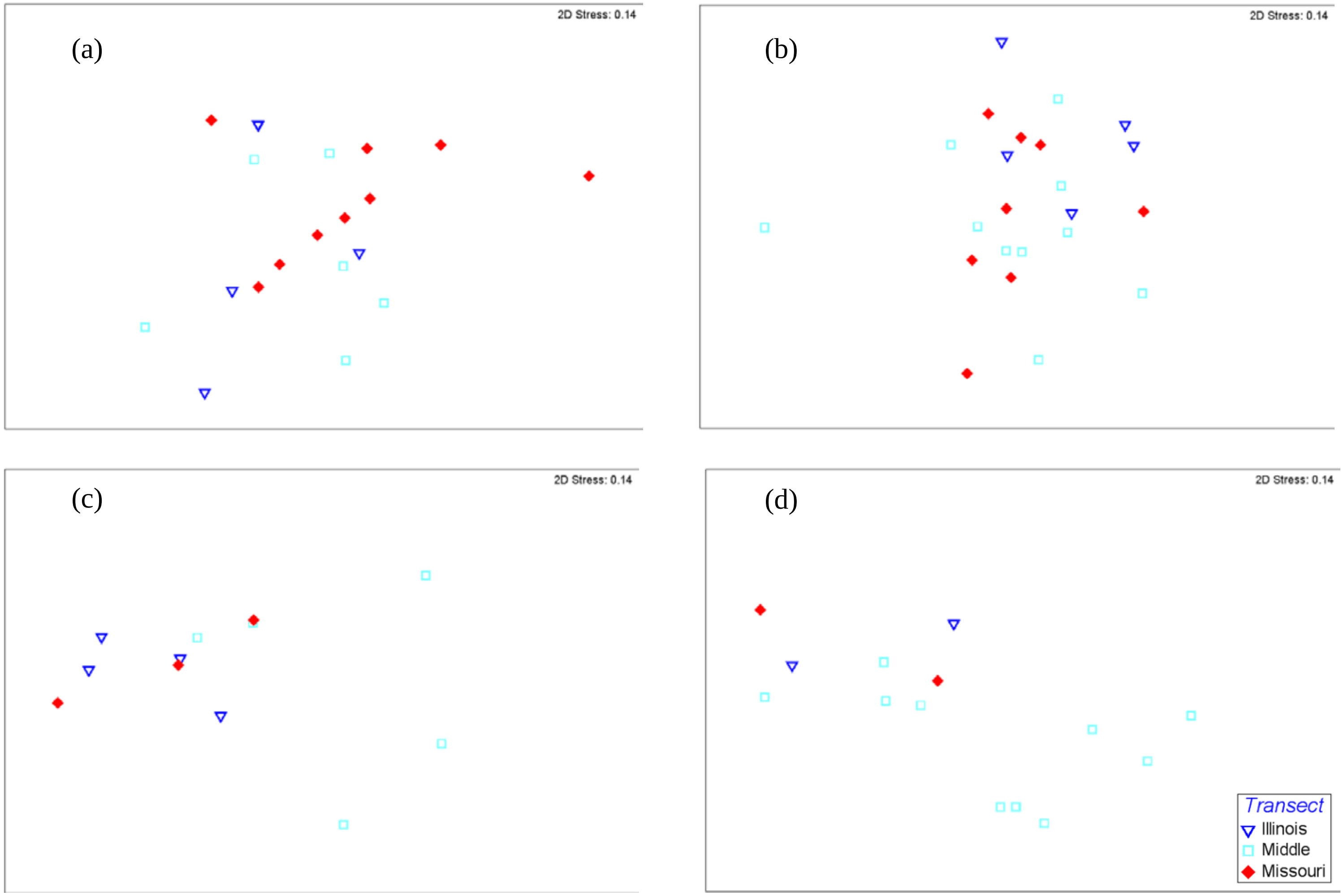

Figure 11. Ordinations of transformed and standardized trawling for each group (a) pre-construction control, (b) pre-construction chevron, (c) post-construction control, and (d) post-construction chevron. Note the relatively low stress value of 0.14. Since the value was so low, the 2-dimensional ordination was chosen and other dimensions were not required.

Table 8. Pairwise ANOSIM tests among all pairs of groups for trawling. Any comparison with a P value less than 0.05 was considered significant and are italicized.

Pairwise Tests			
Groups		**R Statistic**	**P**
Pre-Construction Chevron	*Post-Construction Chevron*	*0.198*	*0.0004*
Pre-Construction Chevron	*Post-Construction Reference*	*0.427*	*0.002*
Pre-Construction Reference	*Post-Construction Reference*	*0.469*	*0.004*
Post-Construction Chevron	*Pre-Construction Reference*	*-0.077*	*0.008*
Pre-Construction Chevron	Pre-Construction Reference	-0.224	0.107
Post-Construction Chevron	Post-Construction Reference	-0.189	0.44

Table 9. Significant Indicator Species for catch per unit effort trawling data. Indicator scores are listed with the associated P-value. Only the species that were significant are shown in the tables. Those that are bolded are the significant indicator value for that group.

		Reference		**Chevron**		
Species	**Common Name**	**Pre-Construction**	**Post-Construction**	**Pre-Construction**	**Post-Construction**	**P**
Ictalurus punctatus	Channel Catfish	**53**	5	6	3	0.0245
Dorosoma cepedianum	Gizzard Shad	0	**42**	0	10	0.0003

Lastly, although the electrofishing and trawling ordinations provide valuable pieces to the big picture, a third ordination was completed to view all samples for both gear types at the same time. The presence/absence ordination allows for the comparison between gear types as it merely lets one know whether or not a species was present within that area, and the abundance of that species. This was of great value because it allowed for some of the problems of the CPUE ordinations to be removed. The problems include few samples from the sites other than the post-construction chevron in electrofishing and a wider diversity of species among all samples as opposed to trawling that resulted in only two of the most species as indicator species.

The presence/absence ordination (Figure 12) resulted in similar ANOSIM results (Table 6) as that of the electrofishing ordination with the overall test being significant (R=0.138, P=0.0001) and the three post-construction groups significantly different from all other groups; however, the ISA revealed a different array of species as indicator species than in the electrofishing ordination and ISA. In total 14 species were shown to be good indicators for the various groups. Of the fourteen indicators, thirteen are indicators for the post-construction chevron group. There was only one indicator species not representative of the post-construction chevron site and this was the shoal chub. Notably there were no species that are considered to be indicators of pre- or post-construction communities in the reference site.

Similar to the electrofishing ordinations and ISA, most of the indicator species are large-bodied, riverine fishes such as flathead catfish, buffalo, and carp. Uniquely, a variety of other riverine fishes became prevalent as well such as sport fish like white bass and sauger. Also, a variety of non-native species have were indicators for the post-construction chevron site including grass carp, silver carp and goldfish. One species that was an indicator for the post-construction chevron site, bluegill, is of interest because it is not considered a riverine fish but a lentic species inhabiting backwater lakes and farm ponds (Pflieger 1997). Lastly, the indicator species for the pre-construction chevron site, shoal chub, is a benthic inhabitant and demonstrates that disturbance has occurred to the riverbed that may have had negative impacts on certain species.

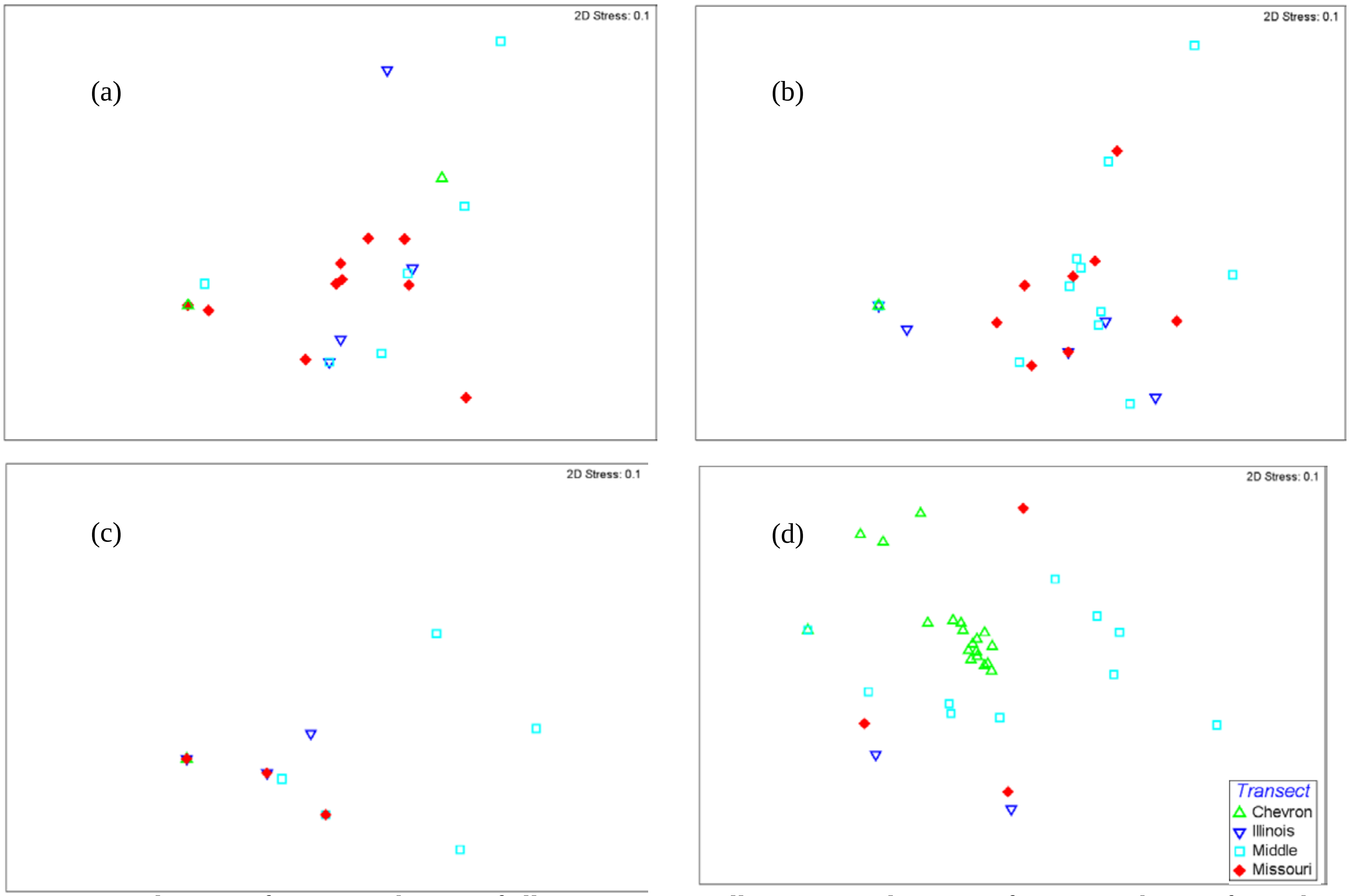

Figure 12. Ordination of presence/absence of all species among all groups. Ordinations of presence/absence for each group (a) pre-construction control, (b) pre-construction chevron, (c) post-construction control, and (d) post-construction chevron. Note the relatively low stress value of 0.1. Since the value was so low, the 2-dimensional ordination was chosen and other dimensions were not required.

Table 10. Pairwise ANOSIM tests among all pairs of groups for presence/absence. Any comparison with a P-value less than 0.05 was considered significant and is italicized.

Pairwise Tests			
Groups		**R Statistic**	**P**
Post-Construction Chevron	*Pre-Construction Chevron*	*0.251*	*0.0001*
Post-Construction Chevron	*Pre-Construction Reference*	*0.18*	*0.0001*
Post-Construction Chevron	*Post-Construction Reference*	*0.237*	*0.001*
Pre-Construction Chevron	Post-Construction Reference	0.027	0.255
Pre-Construction Chevron	Pre-Construction Reference	0.003	0.366
Pre-Construction Reference	Post-Construction Reference	-0.001	0.457

Table 11. Significant Indicator Species for catch per unit effort presence/absence data. Indicator scores are listed with the associated P-value. Only the species that were significant are shown in the tables. Those that are bolded are the significant indicator value for that group.

		Reference		Chevron		
Species	**Common Name**	**Pre-Construction**	**Post-Construction**	**Pre-Construction**	**Post-Construction**	**P**
Macrhybopsis hyostoma	Shoal chub	8	1	**21**	0	0.0175
Hiodon alosoides	Goldeye	0	0	0	**56**	0.0001
Hypopthalmichthys molitrix	Silver Carp	0	0	0	**42**	0.0001
Ictiobus bubalus	Smallmouth Buffalo	0	0	0	**39**	0.0001
Aplodinotus grunniens	Freshwater Drum	1	0	1	**38**	0.0001
Pylodictis olivaris	Flathead Catfish	0	0	0	**33**	0.0006
Carpiodes carpio	River Carpsucker	0	0	0	**28**	0.0004
Cyprinus carpio	Common Carp	0	0	0	**19**	0.005
Morone chrysops	White Bass	0	0	0	**19**	0.0082
Ictiobus niger	Black Buffalo	0	0	0	**14**	0.0233
Stizostedion canadense	Sauger	0	0	0	**14**	0.0256
Ctenopharyngodon idella	Grass Carp	0	0	0	**11**	0.0269
Carassius auratus	Goldfish	0	0	0	**11**	0.272
Lepomis macrochirus	Bluegill	0	0	0	**11**	0.0285

Bathymetry

The following images (Figures 13, 14, 15, 16, 17 and 18) depict the bathymetric surveys after input into ArcGIS and referenced to the LWRP. Distinct changes can be noted from the pre-construction bathymetry in 2007 to the changes seen in 2008, 2009, and 2010. The key features tracked for environmental reasons were the changes behind the chevron dikes such as deep holes and islands and changes in the shallow water habitat on the west side.

It is clear almost immediately following construction that the habitat is quite different from pre-construction. A deep scour hole formed behind the chevron dike creating an ephemeral island downstream at all dike locations. The right descending bank maintained a large portion of its shallow water habitat. In 2008, as a result of exceptionally high water, the scour hole grew larger, but the flows nearly completely removed the ephemeral islands. Also, a large portion of the shallow water habitat on the west side had been lost, moving downstream. In early 2009, when flows were slightly less, the islands started to form again and the scour holes shrunk slightly from sedimentation. The west side also started to see shallow water habitat again. As the year progressed and another high-water event occurred, the islands were reduced in size and the west side shallow water habitat appeared to be sporadic at best. The last survey that was conducted was in July of 2010. This survey was similar to the early surveys in the that more of the downstream area was included that provided additional insight as to what may be occurring on the west side along the bank. When the survey was taken, the islands had nearly been removed due to high water. Although, directly adjacent to the chevrons, the shallow water habitat present in the early surveys was nearly completely gone, it is very clearly still prevalent slightly downstream. The habitat is not nearly as unique as the March 2008 survey less than a year after construction, but several years of high water have the ability to determine what the dikes will do to the surround ecosystem.

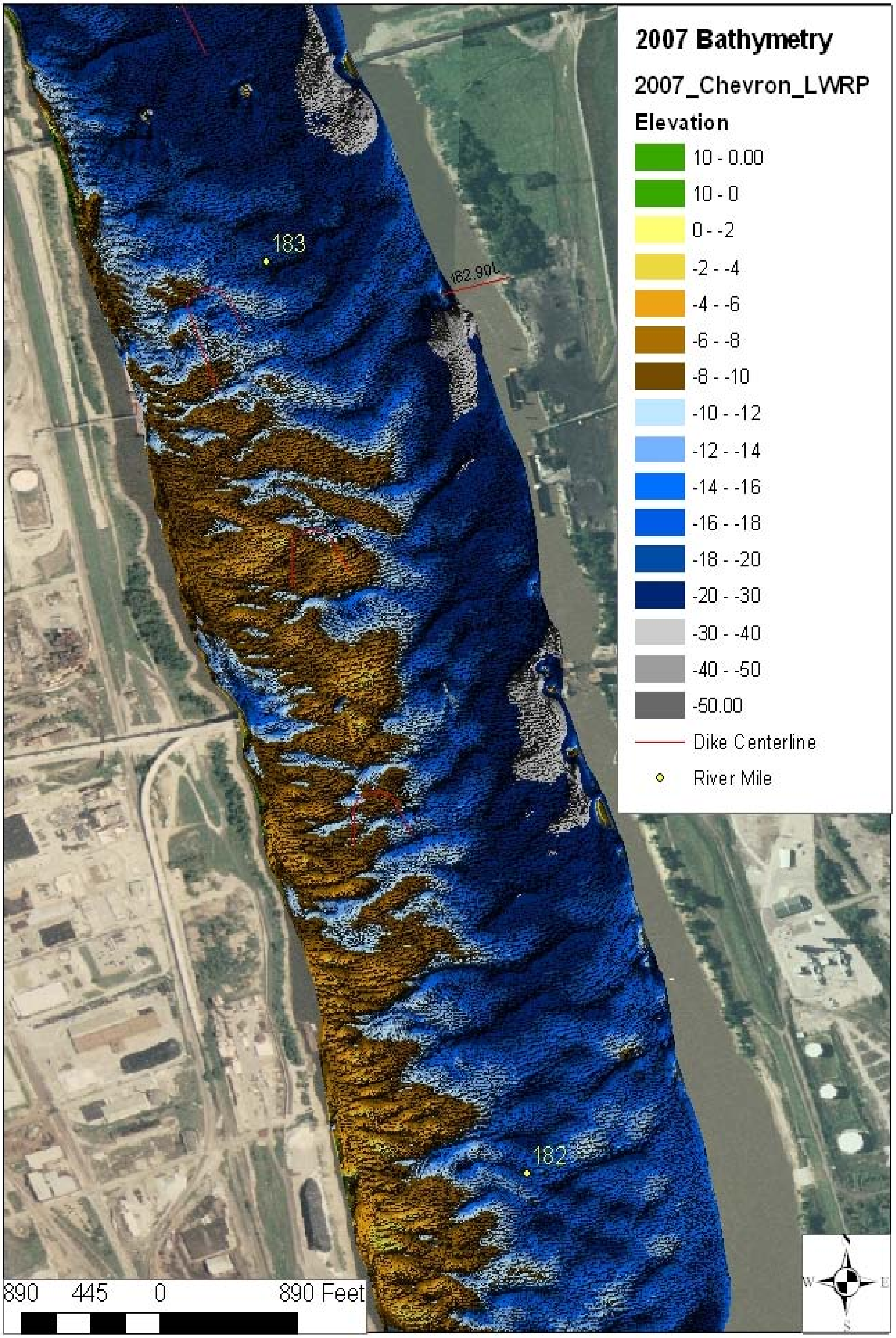

Figure 13. Bathymetric survey of St. Louis Harbor referenced to the LWRP, May 2007.

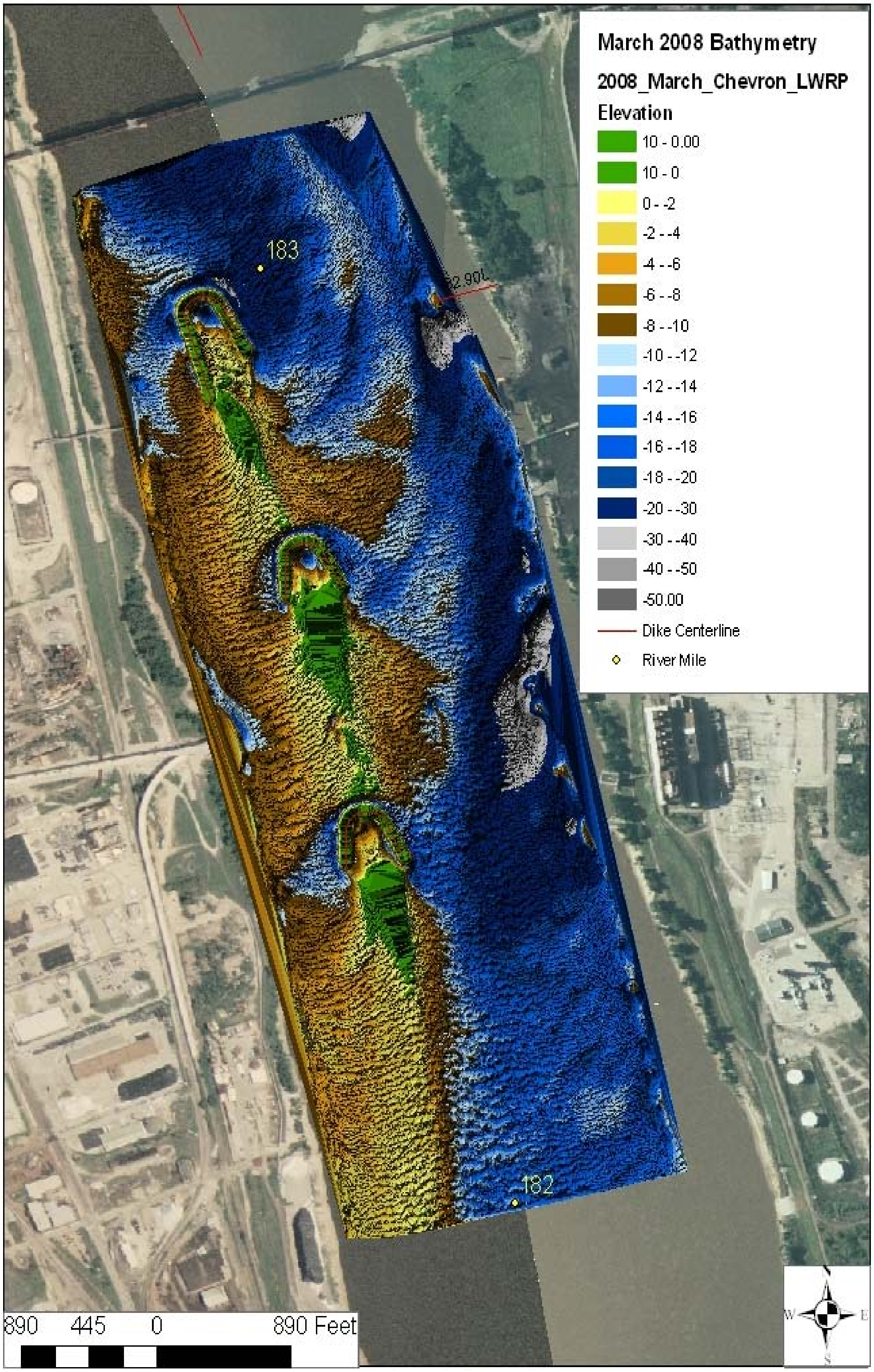

Figure 14. Bathymetric survey of St. Louis Harbor referenced to the LWRP, March 2008.

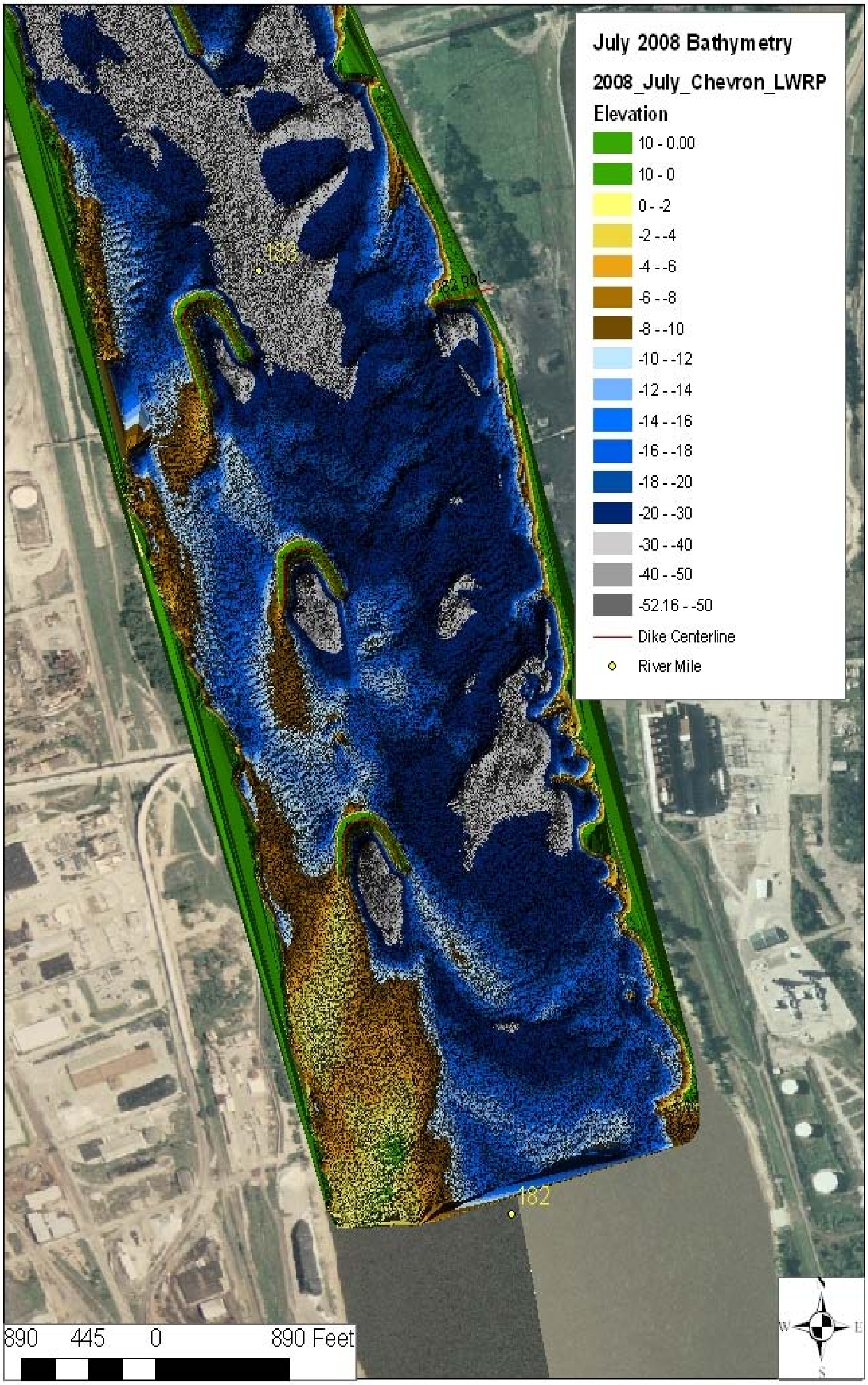

Figure 15. Bathymetric survey of St. Louis Harbor referenced to the LWRP, July 2008.

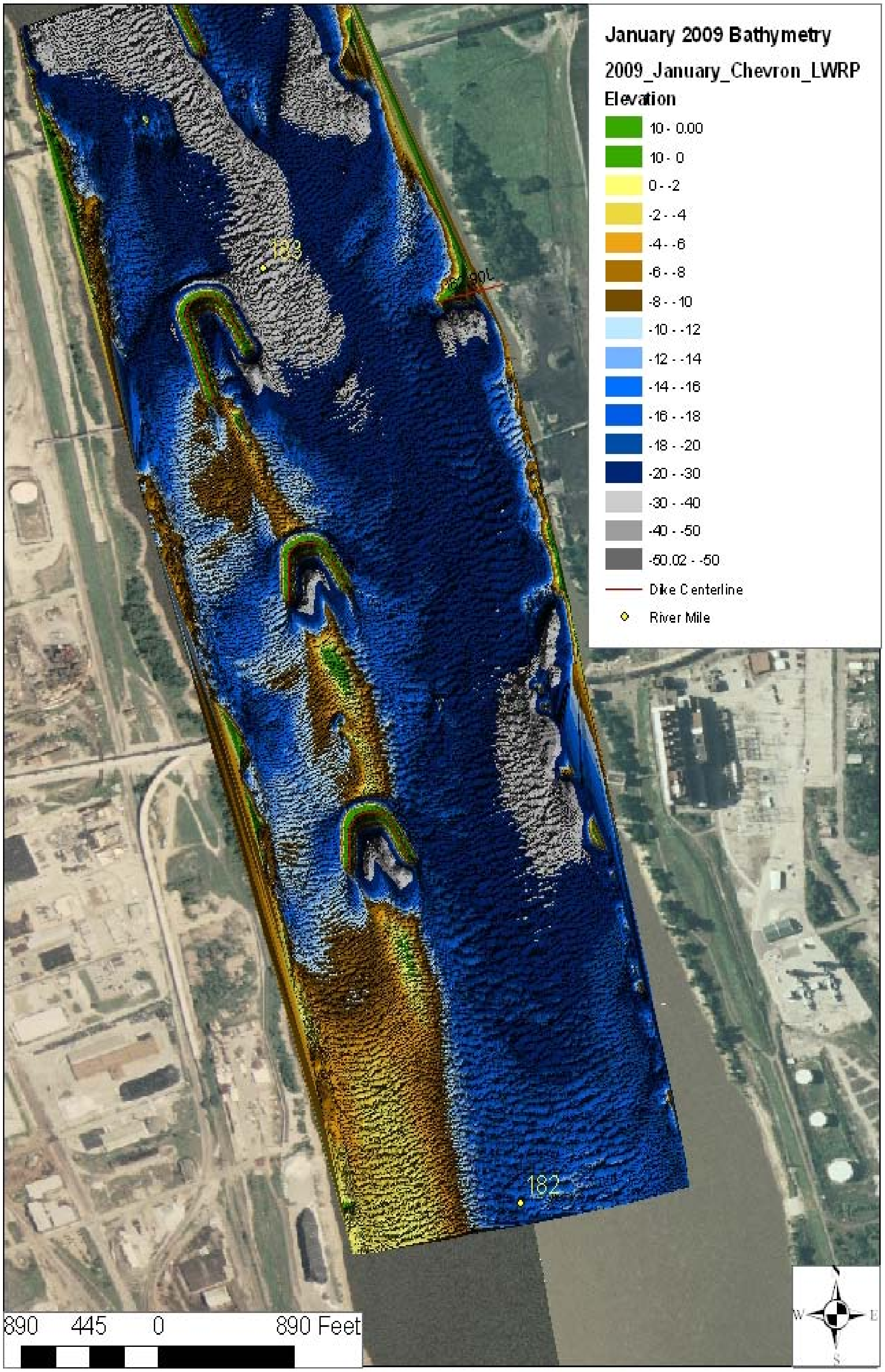

Figure 16. Bathymetric survey of St. Louis Harbor referenced to LWRP, January 2009.

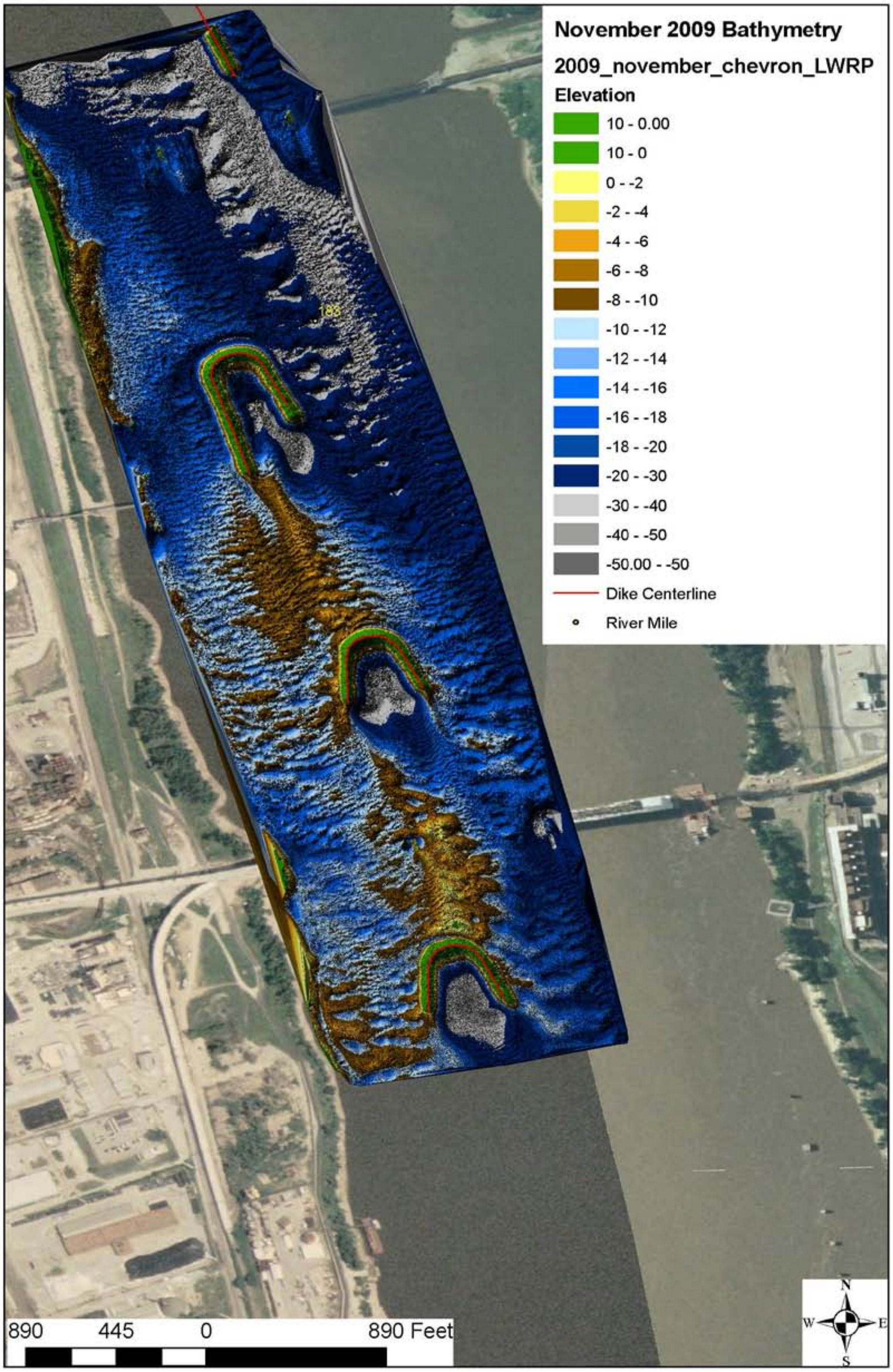

Figure 17. Bathymetric survey of St. Louis Harbor referenced to LWRP, November 2009.

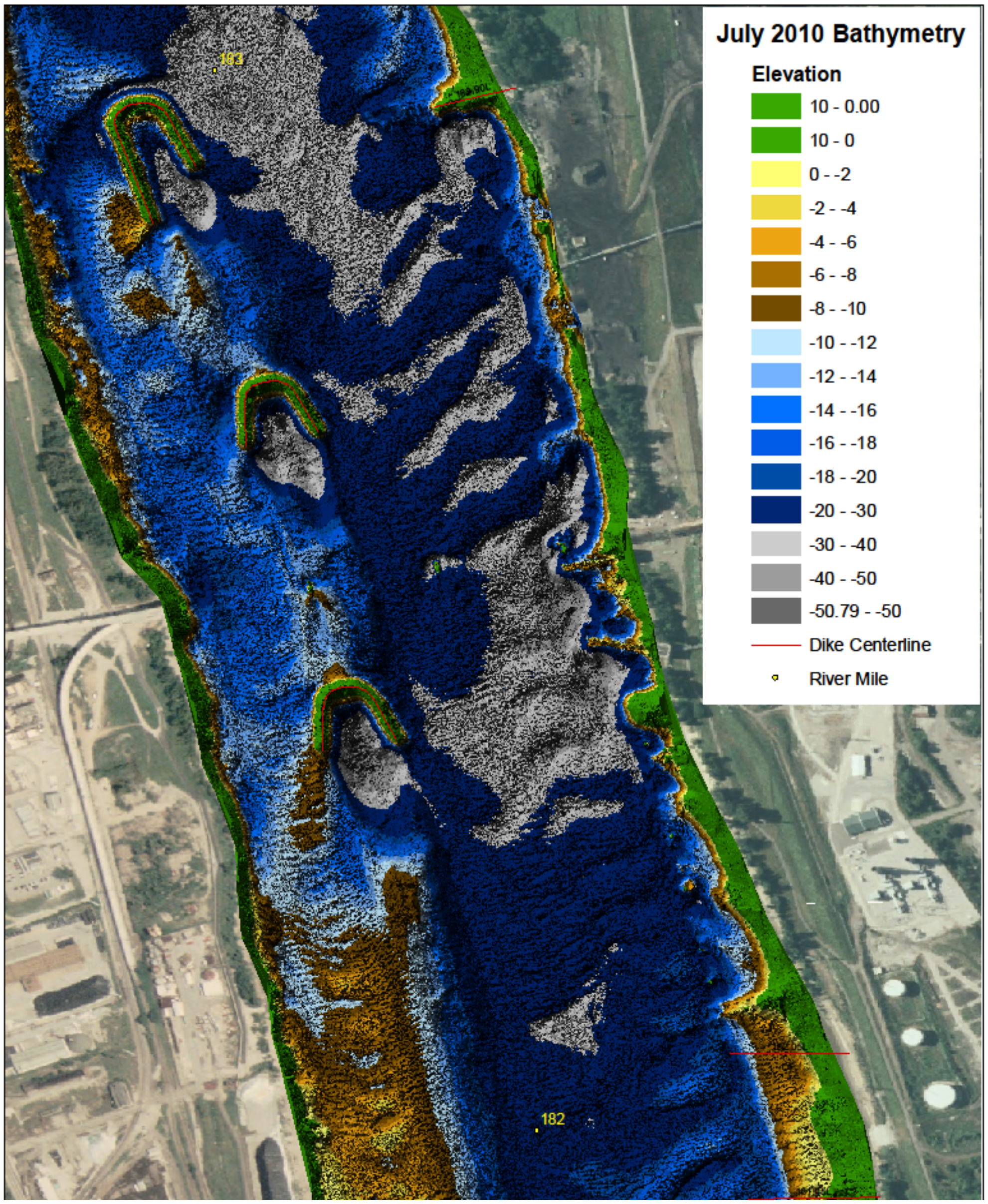

Figure 18. Bathymetric survey of St. Louis Harbor referenced to LWRP, July 2010.

CHAPTER V

DISCUSSION

The main question was to determine what changes occurred as a result of the construction of chevron dikes to fish communities and habitat diversity and specifically whether there was a shift in the community following the construction of the chevrons, what species typify the groups and whether the catch rates increased. With the potential to create a backwater habitat in the main channel of the river, special attention was paid to communities that were linked to these backwater habitats. This is due to most backwater and island habitats slowly diminishing on the lower portions of the Middle Mississippi River due to construction activities and sedimentation as opposed to the vast backwaters present in the pooled sections of the Upper Mississippi River (Janvrin 2005). The key component of the research was to determine effects of the construction of chevron dikes in the main channel of the Mississippi river on local ichthyofauna. A key Bathymetric surveys were conducted to reveal overall habitat diversity and changes that resulted from altered flows due to the construction of the series of chevron dikes within the St. Louis Harbor.

Fish Populations

The fish populations changed quite significantly from pre-construction to post-construction. Initially, there were only 11 species caught at the experimental site during the two years of pre-construction data. During post-construction samplings, 33 species have been caught at the experimental site.

During pre-construction trawling, the catch was dominated by channel catfish (*Ictalurus punctatus*) 58.1%, shoal chub (*Macrhybopsis hyostoma*) 19.7%, blue catfish (*Ictalurus furcatus*) 9.9%, and silver chub *(Macrhybopsis storeriana*) 4.4%. The remaining

7.9% was comprised of 9 species with less than 2.5% of total catch per species. A slight shift occurred during post-construction trawling. The catch was dominated by channel catfish 40.7%, freshwater drum (*Aplodinotus grunniens*) 23.1%, gizzard shad (*Dorosoma cepedianum*) 16.5%, and blue catfish 12.1%. The remaining 7.6% was comprised of 8 species.

One of the most notable changes following from pre-construction to post-construction was the reduction in benthic chubs including the shoal chub, sicklefin chub (*Macrhybopsis meeki*) and the silver chub from trawling samples. The majority of the benthic chubs caught during pre-construction monitoring resulted from just a few trawl samples. The ISA also revealed that the shoal chub is a likely indicator species for pre-construction at the chevron site though.

The reduction in benthic chubs is likely due to a loss of habitat along the right descending bank on the Missouri side. Chubs are benthic dwellers associated with shallow water areas with strong currents over a bottom of sand or fine gravel (Pflieger 1997). Because the Mississippi River is an enormously dynamic system, the sandbars that were being sampled during pre-construction have shifted downstream beyond the current transects as seen in Figure 18. The bathymetric surveys show that the transects no longer cover most of the shallow water habitat on the west side.

By examining just the trawling data and ordination, there appears to be a slight shift in communities at the chevron locations. A reduction in benthic chubs appears to occur, but this could be that either the habitat previously sampled is no longer being sampled due to the restricted transects of a quantitative study or possibly that the habitat is no longer present due to the construction of the chevron dikes. In addition the catch rates significantly decreased from pre-construction to post-construction at both the experimental site and control site. This could be due to construction of the chevrons or since all post-construction chevrons were sampled during periods of high water and the efficiency of the trawl may have decreased.

Electrofishing tells a completely different story however. During pre-construction electrofishing only 40 individuals were captured among all samples. Of these 40 individuals, the catch contained Gizzard Shad 80.0%, Skipjack Herring (*Alosa chrysochloris*) 10.0%, blue catfish 7.5%, and channel catfish 2.5%. Post-construction electrofishing produced 1,063 individuals. Of these individuals, the catch comprised Goldeye (*Hiodon alosoides*) 19.8%, freshwater drum 18.0%, gizzard shad 14.9%, blue catfish 10.5%, smallmouth buffalo (*Ictiobus bubalus*) 8.0%, and silver carp (*Hypophthalmichthys molitrix*) 5.3%. The remaining 23.5% consisted of 23 species with less than 5% of the total catch. As a reminder, 5% of the catch is still over 50 individuals.

All species collected during pre-construction electrofishing sampling were also collected during post-construction sampling. In total, electrofishing revealed 25 additional species. Of these 25 additional species, the ISA has shown six species from the electrofishing CPUE ordination and thirteen species from the presence/absence ordination are strong indicators for the post-construction chevron site. The list of indicators shown in tables 4 and 7 consist of predominantly large riverine fishes such as river carpsucker (*Carpiodes carpio*), smallmouth buffalo, black buffalo (*Ictiobus niger*), and common carp (*Cyprinus carpio*). In addition, three commonly sought after game fish have become associated with the chevron dikes. These species are flathead catfish (*Pylodictus olivaris*), white bass (*Morone chrysops*) and sauger (*Stizostedion canadense*).

In total, of the three ordinations completed, 14 or the 17 indicator species were found for the post-construction chevron site. A large percentage of these fishes are large riverine fishes associated with slightly slower moving water that is provided by the breakwater created from the chevron dike. The chevron dikes appear to be from both a fisheries standpoint and a habitat standpoint providing a unique habitat not originally present within the St. Louis harbor of the Mississippi River.

In addition to the compositions of the communities and the indicator species of those communities, the ordinations with corresponding ANOSIMs conducted provide one of the clearer pictures for the community shift. The trawling data is very strange and no real patterns seemed to emerge. While it showed that a variety of interactions were significant, the control site from pre-construction to post-construction was significant as. If the control site did not remain stable throughout construction, it is difficult to assess whether the remainder of the interactions are actually significant. As previously mentioned, the two indicator species as a result of the ordinations are two of the most common species in Missouri and provide no real insight as to an actual community that exists within the Mississippi River.

The electrofishing and presence/absence data show the same significantly different interactions. They show that when analyzing the electrofishing data, the post-construction chevron site is significantly different from all other. In addition, the presence/absence data show that the chevron site is significantly different from all other sites as well. Therefore, a nearly definitive shift in the fish community has occurred and is observable at the chevron location. The ISA shows that the community that now exists is formed of larger riverine fishes such as suckers, catfish and larger cyprinids such as carp. During pre-construction, the habitat was vary sparse and those species collected were not likely residents of the area, but merely utilizing resources present at that moment in time.

Overall, after reviewing all of the fisheries data and habitat evaluations using GIS, it is evident that the chevron site has been converted from main channel and main channel border habitat to a unique area that has enhanced the local ichthyofauna throughout the site. Although a reduction in benthic chubs was noticed during sampling, this does not mean that the benthic chubs have been lost. The chevron dike field has been completely transformed and the initial habitat where the benthic chubs were caught is likely no longer present. As the chevron dike continues to utilize the river flows to carve out a new habitat in the St. Louis Harbor, the habitat will continue to change and may result in more habitat suitable for benthic chubs.

In addition to the large increase in riverine fishes, a variety of backwater species have been noted throughout the collections including one indicator species such as bluegill (*Lepomis macrochirus*), largemouth bass (*Micropterus salmoides*), and black crappie (*Pomoxis nigromaculatus*); however, the majority of these species have not been caught with enough regularity to become an indicator species with the exception of bluegill. These species would likely be utilizing the slower moving water behind the chevron dikes that acts similar to a small pond with reduced flows and fluctuations.

Lastly, when examining the ordination for electrofishing CPUE, Figure 10, it appears that it is possible that not only has there been a shift in communities from pre-construction to post-construction, but it is possible that there are multiple communities present in the post-construction chevron site. This is not as easily seen in the presence/absence data with the inclusion of trawling data. Although, it was not tracked throughout the entire study, it is possible that the potential difference in post-construction communities arises from the slow-moving backwater type habitat formed behind the chevron dike compared to the swift-flowing rocky substrate habitat on the outside of the chevron dike. Although this was not the focus of this study, it could be evaluated in the future to determine if multiple communities exist within the chevron dike field such as an inside and an outside community.

In conclusion, the chevron dikes have drastically changed the habitat within the St. Louis Harbor of the Mississippi River. Not only have more fishes been caught, but more species have been caught on a regular basis. This is even more remarkable as the majority of this study was conducted during periods of high water when generally reduced catch rates exist (Pierce et al 1985).

The most important habitat that formed is the slack water habitat behind the chevrons. It provides a unique area with slow moving currents, deep water and ephemeral islands that provides refuge for a wide range of species. This can be seen from the data, as almost all species listed as indicators prefer slower moving water and would be able to utilize the deep water behind the chevrons for overwinter habitat.

Bathymetry

A very interesting feature that resulted from the bathymetric surveys was the evolution of the riverbed due to the construction of the chevron dikes as well as the dynamic nature of the Mississippi River system. The creation of deep pools directly behind the chevron dikes can be seen in all of the post-construction bathymetric surveys and may be the important feature. In July 23, 2008 survey, Figure 15, the deep holes appear to be really accentuated. This is likely due to a local high water event that occurred during 2008 and continued through 2009. As a result, the when the water overtopped chevron dikes more sediment was removed creating deeper and larger holes.

Also, the high water event resulted in the loss of the islands directly behind the deep holes. Usually, as the hole is created the sediment is deposited directly behind the hole creating and island that becomes larger as more sediment is added. Due to high current velocities during the high water event, the sediment was removed creating the deep hole, but was too swift to allow the sediment to settle and create the islands. As noted in Figure 16, following the high water event, the river levels started to normalize. Upon normalization, the deep holes started to shrink and the islands started to form again, but another high water event later in 2009 reduced the ephemeral islands and enlarged the deep scour hole once again. This is likely to continue to happen until substantial vegetation such as cottonwoods (*Popululus deltoides*) and willows (*Salix spp.*) stabilize the islands making the islands more permanent. Similar islands have been formed behind chevron dikes located adjacent to banklines whereas cottonwoods and willows vegetated the islands and reduced erosion such as the chevron dikes located in Pool 25 of the Mississippi River between RM 290 and 289.

CHAPTER VI

CONCLUSION

Overall, the main channel chevron dikes have improved habitat diversity while diversifying the current fish populations resulting in newly formed fish communities at the site. In the Upper Mississippi River system, there are nearly 130 fish species present. Nearly ¼ of current species existing in the Upper Mississippi River have been caught at the St. Louis Harbor chevrons as opposed to the usual main channel pre-construction conditions where only 10-15 species are usually caught. The Mississippi is likely to continue to lose backwater habitats such as sloughs, islands with side channels and many more if no further restoration techniques are applied.

The main channel chevron dikes are proving to show that a complex habitat can be formed in the main channel of the open river including small backwaters, sandy, ephemeral islands, and shallow sand bars. The chevron dikes appear to be great compromise between traditional wing dikes and the need for water navigational structures. The advantages have included a deeper thalweg for navigation; currents that flow around the Merchant's and the McKinley Bridges; shallow, swift flowing water on the west side; deep, pool-like water flows directly behind the chevron dikes; and sandbar islands behind the pools created by the chevrons. As mentioned previously, it appears that the slower moving water created behind the chevrons might be of most importance as the majority of species collected and associated with the chevrons are riverine fishes that prefer or need slower moving water for part of the life cycle and may provide essential overwintering habitat.

As data continues to be collected, a better visualization of how chevron dikes in the main channel of an open river affect fish populations and habitat diversity will develop.

Several future research areas have been developed as a result of this study. A comparison of traditional dikes to chevron dikes including changes in fish populations and habitats would be greatly beneficial to the U.S. Army Corps of Engineers. Also, a comparison of chevron dikes built with dredge spoil islands already created as compared to the St. Louis Harbor Islands where no islands were initially created could answer the questions about whether islands form quicker with dredge spoil or if the dynamic system of chevrons without the initial islands allow the river to create a more natural environment. Several research topics are available from this starting point of the examination of the benefits of main channel chevron dikes in the main channel of the open river of the Mississippi River near St. Louis, Missouri.

In addition to the aforementioned research topics, an examination of the chevron dikes located within the St. Louis Harbor could be conducted to determine if the benthic chub habitat has been lost or if it has merely moved. Also, a comparison of the interior fish community as compared to the outer fish community could show whether or not multiple communities exist within the chevron dike field. The U.S. Army Corps of Engineers is striving to create ecosystem benefits, whenever applicable, in riverine systems alongside navigational structures and are moving away from strictly riprapping shorelines and traditional dike fields of previous years.

REFERENCES

Atwood, B. 1997. Cottonwood Island chevron dike fisheries evaluation update. In: Melvin Price Locks and Dam, Progress Report 1997 for Design Memorandum No. 24, Avoid and Minimize Measures. U.S. Army Corps of Engineers, St. Louis District, St. Louis, Missouri.

Atwood, E.R. 2001. Cottonwood Island Chevron Dike Fisheries Evaluation Update Design Memorandum No. 24 Avoid and Minimize Measures 2000 Progress Report. U. S. Army Engineering District – St. Louis, June 2001.

Barko, V.A. And D.P. Herzog. 2003. "Relationship among side channels, fish assemblages, and environmental gradients in the unimpounded Upper Mississippi River." *Journal of Freshwater Ecology*. 18: 377-382.

Belt, C.B. Jr. 1975. "The 1973 Flood and Man's Constriction of the Mississippi River." *Science.* 189: 681-684.

Bray, J. R., and Curtis, J. T. 1957. "An ordination of the upland forest communities of Southern Wisconsin." *Ecological Monographs.* 27:325–349.

Clarke, K.R. 1993. "Non-parametric multivariate analysis of changes in community structure." *Australian Journal of Ecology* 18:117-143.

Clarke, KR, Gorley, RN, 2006. PRIMER v6: User Manual/Tutorial. PRIMER-E, Plymouth.

Dettmers, J. M., Wahl, D. H., Soluk, D. A. and S.Gutreuter. 2001. "Life in the fast lane: fish and foodweb structure in the main channel of large rivers." *Journal of North American Benthological Society*. 20: 255-265.

Dettmers, J. M., Gutreuter, S., Wahl, D. H. and D. A Soluk. 2001. "Patterns in abundance of fishes in main channels of the Upper Mississippi River system." *Canadian Journal of Fisheries Aquatic Science*. 58: 933-942.

Dewey, M.R., Richardson, W.B. and S. J. Zigler. 1997. "Patterns of foraging and distribution of bluegill sunfish in a Mississippi River backwater: influence of macrophytes and predation." *Ecology of Freshwater Fish*. 6: 8-15.

Dufrene, M., and P. Legendre. 1997. "Species assemblages and indicator species: the need for a flexible asymmetrical approach." *Ecological Monographs.* 67:345-366.

Eckblad, J. W., Volden, C. S. and L. S. Weilgart. 1984. "Allochthonous drift from backwaters to the main channel of the Mississippi River." *The American Midland Naturalist*. 111: 16-22.

Eckbald, James W and Walter G. Duffy. 1986. “The ecology of pools 11-13 of the Upper Mississippi River A community profile.” *Biological Report 85(7.8)*.

Ecological Specialists, Inc. 1997. Macroinvertebrates Associated with Habitats of Chevron Dikes in Pool 24 of the Mississippi River. Design Memorandum No. 24 Avoid and Minimize Measures 2000 Progress Report. U.S. Army Engineering District – St. Louis, December 1997.

ESRI 2008. ArcGIS Desktop: Release 9.3.1. Redlands, CA: Environmental Systems Research Institute.

Faith D.P.,Minchin, P.R, and L. Belbin. 1987. Compositional dissimilarity as a robust measure of ecological distance. V*egetatio.* 69: 57–68.

Fisk, 1944. Geological Investigation of the Alluvial Valley of the Lower Mississippi River.

Fry, B. 2002. “Stable isotopic indicators of habitat use by Mississippi River fish.” *Journal of the North American Benthological Society*: 21: 676-685.

Galat, D. L. and I. Zweimuller. 2001. “Conserving large-river fishes: is the highway analogy an appropriate paradigm.” *Journal of North American Benthological Society*. 20: 266-279.

Gauch, H. G. 1973. A Quantitative Evaluation of the Bray-Curtis Ordination. Ecology 54: 829-836

Gore, J. A. and F. D. Shields Jr. 1995. “ Can large rivers be restored?” *BioScience*. 45: 142-152.

Gutreuter, S., Burkhardt, R. and K. Lubinski. 1995. “Long Term Resource Monitoring Program Procedures: Fish Monitoring.” *Program Report 95-P002-1*.

Henshaw, P. F., Cervi, S. and J. A. McCorquodale. 1999. “Simple Cost Estimator for Environmental Dredging in the Great Lake.” . *Journal of Waterway, Port, Coastal, Ocean Engineering.* 125: 241-246.

Herzog, D. P. 2004. M.S. Thesis. “Capture Efficiency and Habitat Use of Sturgeon Chub (*Macrhybopsis gelida*) and Sicklefin Chub (*Macrhybopsis meeki*) in the Mississippi River.” Southeast Missouri State University.

Hubbell, M. E., 2011. Upper Mississippi River Restoration-Environmental Management Program, Illinois, Iowa, Minnesota, Missouri, and Wisconsin Fact Sheet.

Hurley, K. L., Sheehan, R. J., Heidinger, R. C., Wills, P. S. and B. Clevenstine. 2004. “Habitat Use by Middle Mississippi River Pallid Sturgeon.” *Transactions of the American Fisheries Society*. 133: 1033-1041.

Janvrin, J. A. 2005. “A comparison of the pre- and postimpoundment fish assemblage of the Upper Mississippi River (Pools 4-13) with an emphasis on Centrarchids.” *American Fisheries Society Symposium*. 45:323-343.

Johnson, B. L., Richardson, W. B. and T. J. Naimo. 1995. “Past, present, and future concepts in large river ecology.” *BioScience*. 45: 134-141.

Johnson, B. L. and C. A Jennings. 1998. “Habitat associations of small fishes around islands in the Upper Mississippi River.” *North American Journal of Fisheries Management*. 18: 327-336.

Joy, Michael K. and Russell G. Death. 2004. “Predictive modeling and spatial mapping of freshwater fish and decapod assemblages using GIS and neural networks.” *Freshwater Biology*. 49: 1036-1052.

Junk, W.J., P.B. Bayley, and R.E. Sparks. 1989. The flood pulse concept in river floodplain ecosystems. Proceedings of the International Large River Symposium. D.P. Dodge (ed.). Canadian Special Publication of Fisheries and Aquatic Sciences 106.

Kruskal, J.B. 1964. “Nonmetric multidimensional scaling: a numerical method.” *Psychometrika* 29: 15-129.

Lamm, Dawn, Davinroy, Robert D., Gordon, David C., Riiff, Edward H., Brauer, Edward J., and Jasen L. Brown. 2004. Sedimentation and Navigation Study of the Middle Mississippi River in the St. Louis Harbor. River Miles 192.0 to 172.0: Hydraulic Micro Model Investigation. *Technical Report M31*.

Lowrance Electronics, Inc. 2002. MapCreate 6. Tulsa, OK.

Littlejohn, S., Holland, L., Jacobson, R., Huston, M. and T. Hornung. 1985. “Habits and Habitats of Fishes in the Upper Mississippi River.”

Lubinski, K. S., Van Vooren, A., Farabee, G., Janecek, J. and S. D. Jackson. 1986. “Common carp in the Upper Mississippi River.” *Hydrobiologia*. 136: 141-154.

McCune, B. and M. J. Mefford. 2006. PC-ORD. Multivariate Analysis of Ecological Data. Version 5. MJM Software, Gleneden Beach, Oregon, U.S.A.

Melvin, G. D., Cochraneb, N. A. and Y. Lic. 2003. “Extraction and comparison of acoustic backscatter from a calibrated multi- and single-beam sonar.” I*CES Journal of Marine Science*. 60: 669-677.

Minchin, P.R. 1987. An evaluation of the relative robustness of techniques for ecological ordination. Vegetatio 69: 89-107.

Olden, J. D., Joy, M. K. and Russell G. Death. "Discovering the species in community-wide predictive modeling." *Ecological Applications*. 16: 1449-1460.

Palmer, M.A., Bernhardt, E.S., Allan, J.D., Lake, P.S., Alexander, G., Brooks, S., Carr, J., Clayton, S., Dahm, C. N., Follstad Shah, J., Galat, D.L., Loss, S.G., Goodwin, P., Hart, D.D., Hassett, B., Jenkinson, R., Kondolf, G.M., Lave, R., Meyer, J.L., O'Donnell, T.K., Pagano, L., and E. Sudduth. "Standards for Ecologically Successful River Restoration." *Journal of Applied Ecology*. 42: 208-217.

Pegg MA., McClelland MA. 2004. "Spatial and temporal patterns in fish communities along the Illinois River. *Ecology of Freshwater Fish*. 13: 125-135.

Pedroli, B., G. de Blust, K. van Looy, and S. van Rooij. 2002. "Setting targets in strategies for river restoration." *Landscape Ecology* 17:5-18.

Pielou, E. C. 1984. The Interpretation of Ecological Data: A Primer on Classification and Ordination. Wiley, New York

Pflieger, W. L. 1997. *The Fishes of Missouri*. Missouri Department of Conservation. Jefferson City, MO.

Pierce, R. B., Coble, D. W and S. D. Corley. 1985. "Influence of river stage on shoreline electrofishing catches in the Upper Mississippi River." *Transactions of the American Fisheries Society*. 114: 857-860.

Rapp, J. 2002. Thompson Bend Riparian Corridor Project. Accessed from http://www2.mvr.usace.army.mil/WaterControl/Districts/MVS/thompson/index.htm on September 10, 2011.

Sheaffer, W. A. and J. G. Nickum. 1986. "Backwater areas as nursery habitats for fishes in pool 13 of the Upper Mississippi River." *Hydrobiologia*. 136: 131-139.

Sheehan, R.J., and J.L. Rasmussen. 1993. "Large Rivers." *Inland Fisheries Management in North America.* American Fisheries Society. Bethesda, Maryland. 445-468.

Shields Jr., F. D. 1995. "Fate of Lower Mississippi River habitats associated with river training dikes." *Aquatic Conservation: Marine and Freshwater Ecosystems*. 5: 97 108.

Simons, D.B., S.A. Schumm, and M.A. Stevens. 1974. Geomorphology of the Middle Mississippi River. Engineering Research Center Colorado State University, Fort Collins, Colorado. 124 pp.

Simons, D.B., M.A. Stevens, P.F. Lagasse, S.A. Schumm, and Y.H. Chen. 1975. "Environmental inventory and assessment of navigation Pools 24, 25, 26, Upper Mississippi and lower Illinois Rivers: A geomorphic study." U.S. Army Corps of

Engineers, St. Louis District, St. Louis, Missouri.

Smith, P.W. 1979. *The Fishes of Illinois*. University of Illinois Press. Urbana, Illinois.

SPSS, Inc. 2000. Systat v10 Statistical Software.

Stevens, M. A., Schumm, S. A., and D. B. Simons. 1975. Man-Induced Changes of Middle Mississippi River." *Journal of the Waterways Harbors and Coastal Engineering Division.* 101 119-133.

Stockton, S. L. 2008. Record of Decision: Upper Mississippi River-Illinois Waterway Navigation Feasibility Study.

Southall, P. D. and W. A. Hubert. 1984. "Habitat use by adult paddlefish in the Upper Mississippi River." *Transactions of the American Fisheries Society*. 113: 125-131.

Systat Software, Inc. 2011. SigmaPlot. San Jose, Ca.

Theiling, C. 1999. "River geomorphology and floodplain features." *Ecological status and trends of the Upper Mississippi River system*. USGS Upper Midwest Environmental Sciences Center, LaCrosse, Wisconsin. 241 pages.

Theiling, C. 1995. Habitat rehabilitation on the Upper Mississippi River. Regulated Rivers: Research and Management 11:227-238.

Thorp, J.H. 1992. "Linkage between islands and benthos in the Ohio River, with implications for riverine management." *Canadian Journal of Fisheries and Aquatic Sciences.* 49:1873-1882.

Turner, R. E. and N. N. Rabalais. 1991. "Changes in Mississippi River Water Quality this Century." *Bioscience*. 41: 140-147.

U.S. Army Corps of Engineers (USACE). 2011. Dredge Surveys. Accessed from http://www.mvs.usace.army.mil/navigation1/dredge.html on September 10, 2011.

U.S. Fish and Wildlife Service (USFWS). 2000. Biological Opinion for the Operation and Maintenance of the 9-foot Navigation Channel on the Upper Mississippi River System.

Ward, J.V., and J.A. Stanford. 1995. "Ecological connectivity in alluvial river ecosystems and its disruption by flow regulation." *Regulated Rivers: Research and Management* 11:105 119.

Ward, J.V., K. Tockner, and F. Schiemer. 1999. "Biodiversity of floodplain river ecosystems: ecotones and connectivity." *Regulated Rivers: Research and Management* 15:125-139.

Wilcox, Daniel B. 1993. "An aquatic habitat classification system for the Upper Mississippi River system." *Technical Report 93-T003*.

Zigler, S. J., Dewey, M. R., Knights, B. C., Runstrom, A. L. and M. T. Steingraeber. 2003. "Movement and habitat use by radio-tagged paddlefish in the Upper Mississippi River and tributaries." *North American Journal of Fisheries Management*. 23:189-205.

Zigler, S. J., Dewey, M. R., Knights, B. C., Runstrom, A. L. and M. T. Steingraeber. 2004. Hydrologic and hydraulic factors affecting passage of paddlefish through dams in the Upper Mississippi River." *Transaction of the American Fisheries Society*. 133: 160-172.