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# HABITAT USE OF ADULT LAKE STURGEON *ACIPENSER FULVESCENS* IN POOL 24 OF THE MISSSISSIPPI RIVER

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**ABSTRACT**

Lake Sturgeon (*Acipenser fulvescens*) were nearly extirpated from Missouri waters in the early 1900's. The Missouri Department of Conservation started restocking lake sturgeon in 1984 and as of December 1, 2004 approximately 286,056 were released in Mark Twain Lake, the Missouri River and the Upper Mississippi River. We are lacking basic information needed to evaluate the current lake sturgeon population. The most critical information needed concerns adult lake sturgeon movement and habitat use, with special emphasis towards identifying spawning sites. Understanding habitat use, movement rates and natural recruitment are important for determining future stocking needs and assessing the current lake sturgeon population

Twenty five lake sturgeon were captured and implanted with radio or acoustic transmitters and tracked on a weekly basis during warm months of the year and on a monthly basis during the cold months between Fall of 2004 through Fall of 2006. Data were also collected from passive receivers that record data continuously. I used Geographical Information Systems (GIS) to summarize lake sturgeon habitat use. Habitat availability was measured individually based on the estimates of each fish's home range, and I compared habitat use to availability using Johnson's (1980) technique.

Lake sturgeon selected areas near Lock and Dam 22, but most fish used a variety of habitats. Side channels were the least selected habitat. Habitat selection was similar for all seasons, but home range locations varied with seasons. During winter, lake sturgeon used the downstream portions of the pool, and during summer frequented upstream portions of Pool 24. Lake sturgeon movement was highest in the spring and fall with

minimal movement during the winter. No lake sturgeon spawning was documented during the study period.

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# INTRODUCTION

## Distribution

Lake sturgeon (*Acipenser fulvescens*) are widely distributed in North America, and are found in three drainages: the Mississippi River, the Great Lakes, and the Hudson Bay (Priegel and Wirth 1977; Harkness and Dymond 1961). The Missouri Department of Conservation's (MDC) Lake Sturgeon Recovery Plan (MDC 1992) suggests that this large, primitive, freshwater fish occurs in greatest abundance in large lakes and rivers of the Great Lakes region of the United States and Canada, but most of its range in the United States is in the Mississippi River Basin from the upper Mississippi River and its major tributaries to the Southern border of Arkansas. Before the 1900's, lake sturgeon in Missouri historically occurred in the Mississippi, Missouri, and lower Osage rivers. Currently they are still found in these areas but in lower densities and are supported by a stocking program.

## History

During the late nineteenth century and early twentieth century, lake sturgeon populations in the Mississippi and Missouri Rivers were severely depleted by commercial overharvest, pollution, and habitat degradation. Lake sturgeon were important commercial fish in the Great Lakes region and the upper Mississippi River during this time. Most were processed as smoked sturgeon, caviar, isinglass and fish oil (MDC 1992). Because of the large market for sturgeon flesh, they were soon over-exploited

(Priegel and Wirth 1977). The Lake Erie sturgeon catch declined 80%, from over 22,680,000 kg per year to less than 4,536,000 kg per year between 1885 and 1895 (Harkness and Dymond 1961). Statistics compiled by the United States Fish Commission for 1895-1899 show that in Missouri, 22,680 kg of lake sturgeon were harvested commercially from the Missouri and Mississippi Rivers in 1895. Within five years harvest was almost nonexistent. Lake sturgeon populations in Missouri were devastated and remained low throughout the 1900's. Information from the Illinois Natural History Survey shows that commercial harvest of lake sturgeon has been nonexistent since at least 1931 for the Mississippi River in Missouri, Iowa, and Illinois (Barnickol and Starrett 1951).

As lake sturgeon were being overharvested, their habitat was also being radically altered. In the 1930's, the lock and dam system was built on the Mississippi River which created pools above dams and high velocity tailwaters below dams. The river channel was restricted and narrowed by the construction of wing dikes. Pollution levels in large rivers were also increasing at this time (MDC 1992).

In 1974 lake sturgeon were placed on the Missouri endangered species list, which prompted MDC to form a recovery plan. Although lake sturgeon populations have declined over much of their range, there is hope that populations can increase when there are sufficient numbers of mature fish and adequate habitat. The MDC's objective was to establish at least ten year classes in Missouri's large rivers by rearing and releasing 20-to-24 cm long lake sturgeon into Pool 24 of the Upper Mississippi River and at several locations on the Missouri River over a 20 year period. That effort and continued stockings are aimed at producing sufficient numbers of mature fish for a self sustaining population (MDC 1992).

Recovery of lake sturgeon populations may be hindered by several factors. One of the most notable is habitat alteration. The construction of low-head navigational dams on the Upper Mississippi River in the 1930's and the construction of hydroelectric and other industrial purpose dams are the most important factor influencing habitat (Knights et al. 2002). Locks and dams were built in areas of the river that were difficult to navigate or dredge for navigation. Theses areas were often rock covered rapids that were probable spawning sites for lake sturgeon. The dams also inhibit upstream migration and change the hydrograph. However, the dams might actually create spawning habitat in their tailwater areas or along the riprapped shorelines or wing dams in the Upper Mississippi River (Knights et al. 2002).

Poaching might be another potential hindrance to establishing lake sturgeon. The roe of a large female lake sturgeon commercially caught in Canada can be worth up to $20,000 (2007 U.S. dollars) on the caviar market and even more on the black market (Tracy Hill personal communication 2005).

**Reproductive Biology**

Lake sturgeon grow and mature slowly. They can live up to 150 years, reach two and a half meters in length and weigh over 137 kg. It takes four to five years for a lake sturgeon to reach a length of 50 cm and a weight of half a kilogram. By the time they are 20 years old the fish are over a meter long and weigh 9 – 14 kg (Pflieger 1997). Females are reported to live longer than males (Pflieger 1997). Males reach sexual maturity by 15 to 20 years of age while females mature by 20 to 25 years of age. Females reach larger sizes than males and are reported to lay more than 500,000 eggs per spawning event. Females only spawn once every three to five years while males spawn every one to two years (Pflieger 1997).

When lake sturgeon spawn, males usually appear at the site before females. Males arrive at the spawning sites with water temperatures between 6.6 -16.0 C while females arrive between 8.8-19.1 C (Bruch and Binkowski 2002). Often prior to and during the spawn the lake sturgeon will “porpoise” or breach the surface of the water. Damstra et al. (2003) observed male to female ratios of 7:1 at spawning sites. Lake sturgeon spawn in aggregations with one female being accompanied by several males that vigorously thrash against her body. This thrashing is thought to aid in the release of eggs from the abdominal cavity.  In the Wisconsin River, observed lake sturgeon spawning in shallow water (one to three meters) over gravel or cobble substrate in riffles (Ron Bruch personal communication 2003). However, not all lake sturgeon populations spawn in shallow water or have the same substrate preferences. In the Detriot River, Caswell et al. (2002) documented spawning in 12.2 meters of water on coal cinders, while Bruch and Binkowski (2002) and Manny and Kennedy (2002) described lake sturgeon spawning on gravel, cobble, rip rap and boulders. Although the above studies document spawning behavior in some of the lake sturgeon’s range, no information is known about historical lake sturgeon spawning in the Missouri portion of the Mississippi River.

## Current Status

The MDC lake sturgeon stocking program, which started in 1984, seems to be working. Lake sturgeon eggs were acquired from the Wisconsin Department of Natural

Resources with some eggs coming from Wisconsin River lake sturgeon and others from Lake Winnebago stocks that were raised at Blind Pony Hatchery near Neosho, Missouri. The first lake sturgeon were stocked in Missouri in 1984 in Mark Twain Lake. As of 2006, there were 32,819 lake sturgeon stocked in Mark Twain Lake, 139,258 in the Upper Mississippi River, and 119,345 in the Missouri River (MDC 1992). Over 100,000 have been stocked at Louisiana, Missouri which is in Pool 24 of the Upper Mississippi River. Also, the Salt River, which was impounded to form Mark Twain Lake (where lake sturgeon were originally stocked), empties into Pool 24. After the initial stocking in Mark Twain Lake in 1985, commercial fishermen reported catching small lake sturgeon near the mouth of the Salt River. These fish appeared to be coming through Clarence Cannon Dam which impounds Mark Twain Lake. Lake sturgeon are now reportedly being caught from Keokuk, Iowa to Cape Girardeau, Missouri on the Mississippi River and on the Missouri River from the confluence with the Mississippi River to Gavin's Point Dam in South Dakota.

**Project Goals**

Locating and identifying spawning sites for enhancement and protection is critical for evaluating future management needs. If spawning sites are located, there may also be opportunities to create new sites once the site characteristics are identified.

Determining habitat use and movement of adult lake sturgeon will allow for evaluation of habitat selection when compared to available habitat on a seasonal basis, at different discharges and for different temperatures. Measuring the distance travelled may also influence future management if lake sturgeon have seasonal migration patterns that take them into the jurisdictions of other states.

While determining spawning sites, habitat use, and movement patterns are important broad goals of this project, I also have very specific goals related to lake sturgeon passage from pool to pool. The lock and dam system on the Mississippi River is thought to be a barrier to fish passage. The U.S. Army Corps of Engineers (USACOE) has proposed building fish passage structures through or around some of the dams to allow migratory fish greater access to more of the river. Determining at what discharges and times of year lake sturgeon move through the dams will enable us to determine what flow regimes are needed to allow fish to migrate when desired. Large lake sturgeon are considered to be one of, if not the strongest swimming fish in the river and would have the easiest time passing through locks and dams. If lake sturgeon are unable to pass, then it is likely that the majority of other fish species are unable as well. Information gathered can also yield clues related to increasing sampling efficiency, sources of mortality, and seasonal habitat use changes.

Thus, the goals of this study are to: (1) identify and quantify current and potential lake sturgeon spawning sites; (2) determine lake sturgeon habitat use for Pool 24 of the Mississippi River; (3) evaluate to what extent locks and dams are a barrier to lake sturgeon movement; (4) determine movement rates; and (5) evaluate our ability to locate radio and acoustic tagged lake sturgeon.

# MATERIALS AND METHODS

## Study Site

Pool 24 of the Mississippi River begins at Saverton, Missouri (river km 484.9) which is 13 km downstream of Hannibal, Missouri (Figure 1). The pool ends at Lock and Dam 24 (river km 440.5) near Clarksville, Missouri. Locks and dams on the Mississippi River have six or eight smaller tainter gates positioned closest to each shore and three larger roller gates in the center of the dam. These gates are raised out of the water during high flow events or open river conditions. On one side is the lock and on the opposite side is the earthen portion of the dam whose only purpose is to channel water into the gates. The pool is approximately 44.4 km long and has a wide diversity of habitats including side channels, islands, dike fields, and sand bars. The only major tributary emptying into Pool 24 is the Salt River, approximately 3.2 km upstream from Louisiana, Missouri. Several state and federal wildlife refuges are located in the pool including Ted Shanks Conservation Area (MDC), The Upper Mississippi River Conservation Areas (MDC and Illinois Department of Natural Resources (ILDNR)), and Clarence Cannon National Wildlife Refuge  United States Fish and Wildlife Service (USFWS).

## Capture and Tracking

Lake sturgeon were captured using multiple capture techniques including: trotlines baited with nightcrawlers (*Lumbricus terrestris*), gillnets, and hoop nets. Spring and fall were the best times to catch lake sturgeon. Lake sturgeon that weighed at least 8

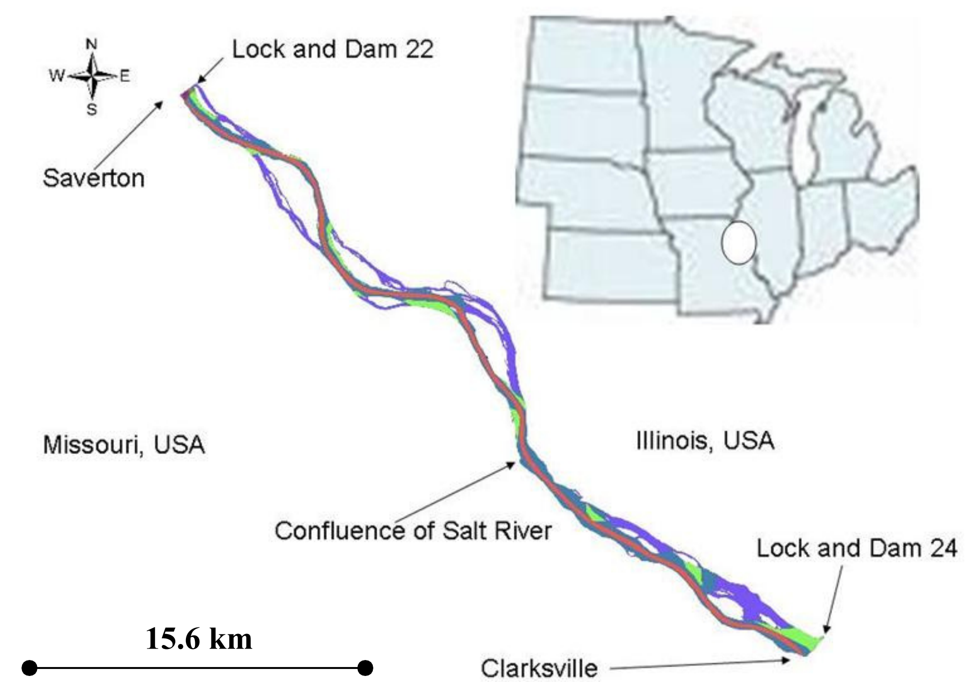


Figure 1. Pool 24 of the Mississippi River is on the border between Missouri and Illinois.

kg (approximately 15 pounds) were targeted since these fish were likely to be sexually mature.

*Surgical procedure*

Lake sturgeon were surgically implanted with radio or acoustic transmitters in the Fall 2004 through Fall 2006. Either a radio or an acoustic transmitter was surgically implanted in the study fish in order to compare these tag types and to increase the strength of the study that comes with having multiple tag types. Radio transmitters were made by Advanced Telemetry Systems (ATS) and transmitted at 164 mhz frequency with a battery life of three to five years. Radio tags were the first tags I used because I originally thought that spawning lake sturgeon would use tributaries and would be easy to detect in the shallower water with lower conductivity. Also, radio transmitters are easier to search for over a wide area. For example, I used a helicopter to search for radio tags once in the spring of 2005. I also had no idea how far lake sturgeon would roam from Pool 24 or the amount of effort that would be required to follow them. Once I realized that most sturgeon did not leave the pool and that the conductivity was too high for radio transmitters, I switched to acoustic transmitters. The acoustic transmitters were Vemco RO04K 6H models on the 69 KHz frequency, and had a battery life of 618 days. The acoustic transmitters were all on the same frequency but could be individually decoded.

Transmitters were surgically implanted into the fish's abdominal cavity. The incision was located on the ventral side of the fish between the midline and the ventral row of scutes, where an incision 50-75 mm long was made about 25 -50 mm anterior to the pelvic girdle. After the incision was made, sex was determined by examining the gonads. For radio transmitters a second smaller hole was made 25 mm posterior of the first incision for the antenna. Medical grade non-absorbable sutures were then used to close the incision and the fish was allowed to recover for several hours in a holding net before being released near the capture site.

*Tracking procedure*

Tracking was performed by simply boating down the river and listening for the signal. For radio tracking sessions one side of the navigational channel was followed going down the river and the other side on the way back upstream in an effort to cover as much of the channel as possible. The receivers scanned for every pre-set signal on a four second interval. Most radio tracking was conducted at 20 km/hr but slowed with increasing numbers of fish. When tracking was conducted by one person, equipment consisted of two directional antennas oriented 90 degrees apart and facing forward, and three antennas were used routed into one receiver or a second ATS receiver connected to a whip antenna when two people went tracking.

When using acoustic equipment, tracking was carried out in one pass down the river and was slightly slower since the hydrophone was placed in the water and was sensitive to noise caused by current. The speed used for acoustic tracking was11.5 km/hr but increased noise that accompanied high water levels slowed tracking speeds. Our acoustic tracking system consisted of three Sonitronics directional hydrophones oriented 45 degrees apart and connected to a Sonitronics receiver. The Sonotronics equipment was used for initial detections. The Sonotronics directional antennas are excellent a detecting transmitters in river environments but do not have the ability to decode the Vemco transmitters. When a fish was found, a Vemco receiver using an omnidirectional hydrophone was used to decode the transmitter since each Vemco transmitter has a unique sequential code of pings which identifies individual fish. Although Vemco offers a directional hydrophone which would work in the river environment, the Sonotronics hydrophones were just as effective at a lower cost.

When a fish was located, the position was marked using a Garmin 188 GPS with WAAS differential correction. The date, the time of day, the UTM coordinates, the water temperature, the maximum depth at the site, and a physical habitat description were also recorded. Substrate samples were taken during the 2006 tracking season at each lake sturgeon location and estimated on site. The sampler used was a 45 cm long, 12 cm diameter pipe with one end welded shut. Samples were divided into four categories (sand, silt, gravel, and rock) and a percentage of each was estimated for each sample. In most cases rock samples were unattainable in our sampling device but we could hear the sampling device bouncing on the hard bottom. After several attempts without obtaining another substrate we concluded that the substrate was too large to collect in our sampler and was categorized as rock.

*Movement data*

Although manual tracking is useful for pinpointing fish at a point in time, it is known to significantly underestimate movement when compared to stationary receivers (Ron Brooks personal communication 2006). So, Vemco VR2 remote stationary receivers were placed in the river at strategic locations to capture fish movements. SevenVR2's were placed in Pool 24 (Figure 2).VR2 receivers log information 24 hours a

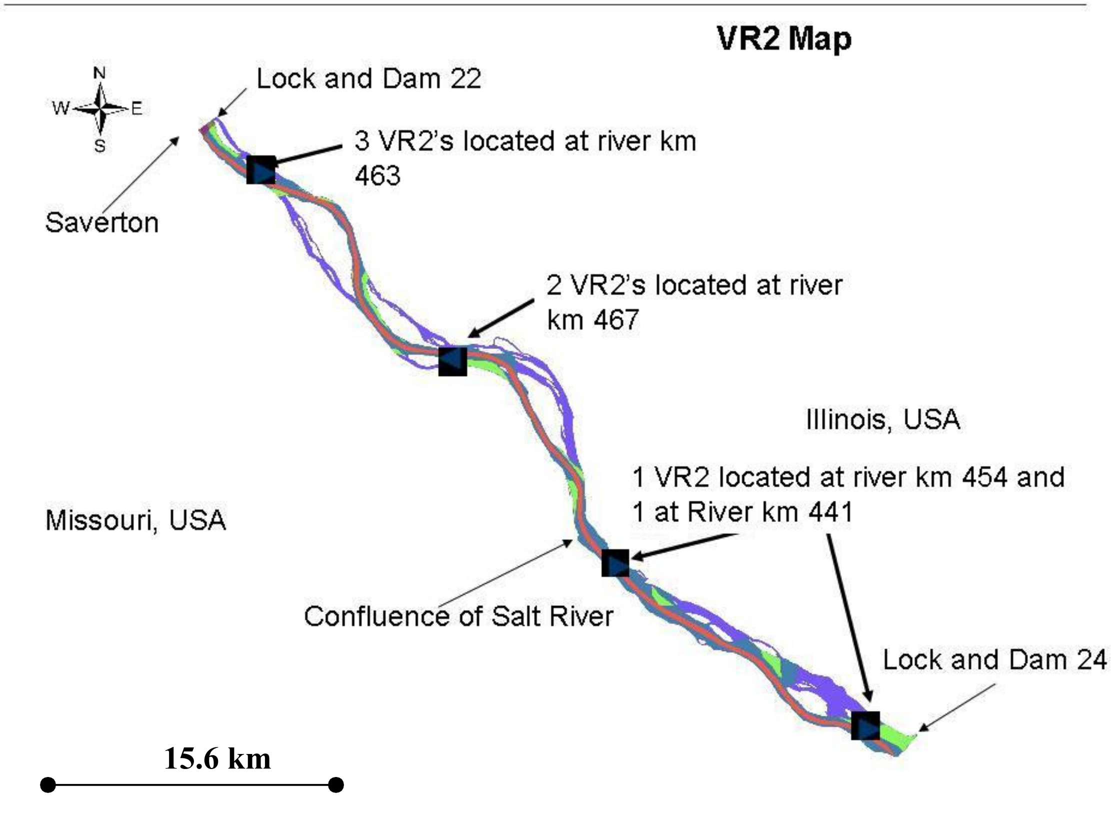


Figure 2. VR2 passive receiver locations for Pool 24. There are seven VR2's in Pool 24, three near Lock and Dam 22 (river Km 463), two near Blackbird Island (river Km 467), one near Louisiana, Missouri (river Km 454), and one near Clarksville, Missouri (river Km 441). Lock and Dam 22 is located at river km 484 and Lock and Dam 24 is located at river Km 441.

day, seven days a week, and when properly placed record all transmitters that pass by. They documented any acoustic-tagged fish that passed near the receiver and typically were placed where the river narrows to maximize reception. The advantage of using the VR2's was that they continuously logged information 24 hours a day but the disadvantage was that they did not recognize our radio transmitters.

**Analysis**

*Habitat classification*

Using ArcMap 9.1(ESRI Redlands, CA), I created a shapefile of habitats that are important to lake sturgeon. The model was developed by combining portions of the USACOE 1989 aquatic habitat classification and the Cobb classification scheme (St. Louis District of the USACOE). I used the habitats described as navigational channel, main channel border and side channel from the 1989 scheme, while the diked channel border habitat was digitized from the Cobb classification. The navigational channel was considered the area that barge traffic frequented and was marked by red and green buoys; main channel border was the area surrounding the navigational channel, and the channel border diked was the portion of the main channel border that included dike fields. Side channels were areas separated from the main channel by islands.  In addition, tertiary channels were combined with side channels under the same name. The dam and tailwater habitats were not part of USACOE schemes. The corners of the boundaries for the tailwater and dam habitats were marked using a GPS and then draw in Arcmap. The dam habitat was considered the area below the earthen portion of Lock and Dam 22, while the tailwater was considered the area below the gates. I felt that these areas provided the simplest scheme that practically represented habitat conditions for Pool 24 in an average year. Habitats were divided into individual polygons of area and distinguished by different colors (Figure 3). The areas of each polygon were calculated to get the available habitats.

*Habitat analysis*

Habitat use data was analyzed by georeferencing each sturgeon's location to the habitat model of Pool 24 created in ArcMap. To determine if lake sturgeon were selecting certain habitats, I first used the GIS habitat model to determine the percent of each habitat type in Pool 24 (this represents the amount of each habitat available to lake sturgeon). Then, the lake sturgeon locations were spatially joined to the habitat model. A summary of the number of fish locations in each habitat type was produced and then converted to a percentage for use in the analysis. Thus, I could compare the percent of each fish's locations in the habitats to the percent availability of each habitat, and in this way I could see if the fish were selecting for or against certain habitat types. The unit of analysis was the individual fish, as suggested by Manly et al. (2002). The overall percentage habitat use data was entered into PREFER analysis software (http://www.npwrc.usgs.gov/resource/methods/prefer/index.htm) along with the available habitat percentages. This software uses the technique described in Johnson that is a nonparametric ranking test which compares use to availability to determine if use is random. If habitat use is found to be nonrandom, habitats are ranked according to selection. PREFER then uses the Waller-Duncan procedure to determine which ranks are

## Modified 1989 Classification

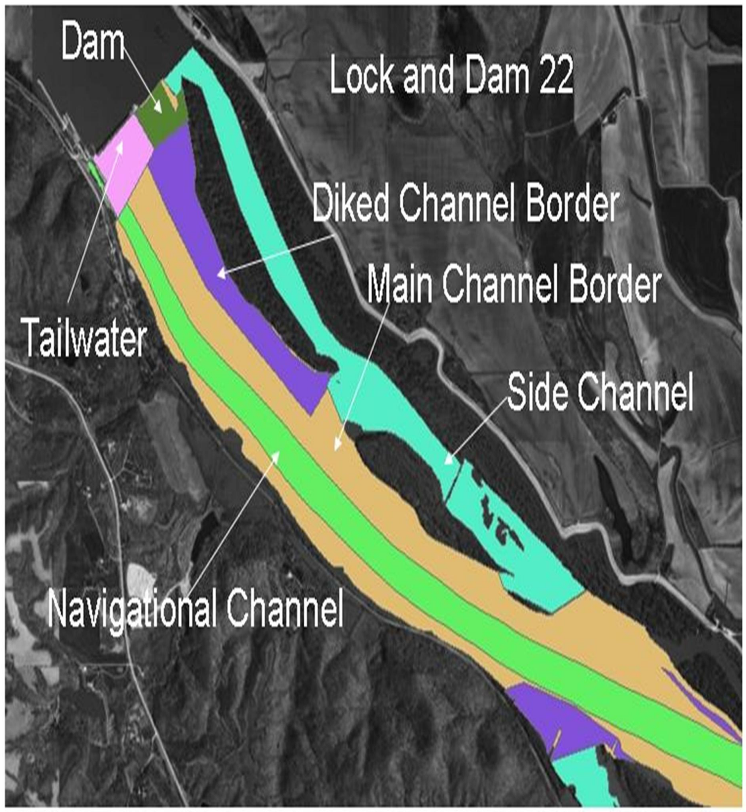


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Figure 3. Description of habitats used for analysis of lake sturgeon locations. The area shown is a stretch of Pool 24 below Lock and Dam 22 (river km 484) near Saverton, Missouri. The navigational channel was considered the area that barge traffic frequented and was marked by red and green buoys; the main channel border was the area surrounding the navigational channel; and the diked channel border was the portion of the main channel border that included dike fields. Side channels were areas separated from the main channel by islands. The dam habitat was considered the area below the earthen portion of Lock and Dam 22, while the tailwater was considered the area below the gates

significantly different. All test were at ($\alpha = 0.05$). I analyzed habitat selection for all tags combined and separately for radio and acoustic tags.

The analysis was also conducted on a seasonal basis. Seasons were determined based on natural temperature breaks. Spring and Fall (April 1st- June 15th and September 16th- November 30th) encompassed the extreme rising and falling temperatures 8-24 C; winter (December - March) comprised the relatively constant cold temperatures 0-7 C; and summer (June 16th- September 15th) the remaining highest water temperatures (24-35 C). The seasons were not even in length but accurately represented the seasonal water temperature changes.

*Home and core ranges*

Kernel density estimates of home range (95%) and core range (50%) were calculated using the method described by Vokoun (2003). Terrestrial home range estimates, such as the minimum convex polygon, are not appropriate for fish which live in a linear river system. Home ranges for river fish can be expressed based on the river km of each location. However, using the upper and lower river km as the boundaries of the home range for each fish is also not appropriate since single, extreme movements will greatly increase the size of the home range. The kernel density method reduces the influence of outlying locations by first creating a frequency histogram of locations by river km. Then, a smoothing function is applied to the histogram. In this way, one can determine the range of river km which contains 50% of the locations (core range) and 95% of the locations (home range). I used SAS software, 9.1.3 (SAS Institute Inc Cary, North Carolina) to determine home and core ranges for all fish that stayed in Pool 24.

Then, I determined the available habitat for each fish individually based on their home and core ranges and used these values to analyze habitat selection using the techniques outlined above. So, while the earlier analysis of habitat selection assumed that all fish had the same available habitat (which was the entire habitat in Pool 24), this analysis used the habitats available for each fish on an individual basis. An example is included in Figure 4.

Home range estimates were also used to make inferences about seasonal movement patterns within Pool 24. I used a Kruskal – Wallis test to compare the size and midpoint of lake sturgeon home ranges among seasons. If significant differences were found between seasons, a Dunn's nonparametric post hoc test with Bonferroni correction was used for pairwise comparisons. Linear regression was used to compare size of the home range and size of the core range to fork length.

*Movement*

Average monthly movement (km/day) and average seasonal movement (km/day) for each fish were compared to average monthly or seasonal discharge and water temperature. Analysis was conducted in SAS using a ANCOVA model which included temperature, discharge, and season. Discharge and water temperature data was obtained from the USACOE gauging station at Lock and Dam 24 with the exception of a few missing dates that were obtained from Lock and Dam 22 (Christopher Trefly personal communication 2006). A non-parametric Kruskal-Wallis Test with Dunn's post hoc test (Zar 1984) compared differences between seasons for average seasonal movement and average seasonal position (river km). Average seasonal position (river km) is the average of the upper river km minus the lower river km of each fish's home range. Another way to quantify movement within the pool was the seasonal size of the home range. A non-parametric Kruskal-Wallis test was calculated in SAS comparing the seasonal home range sizes as well.

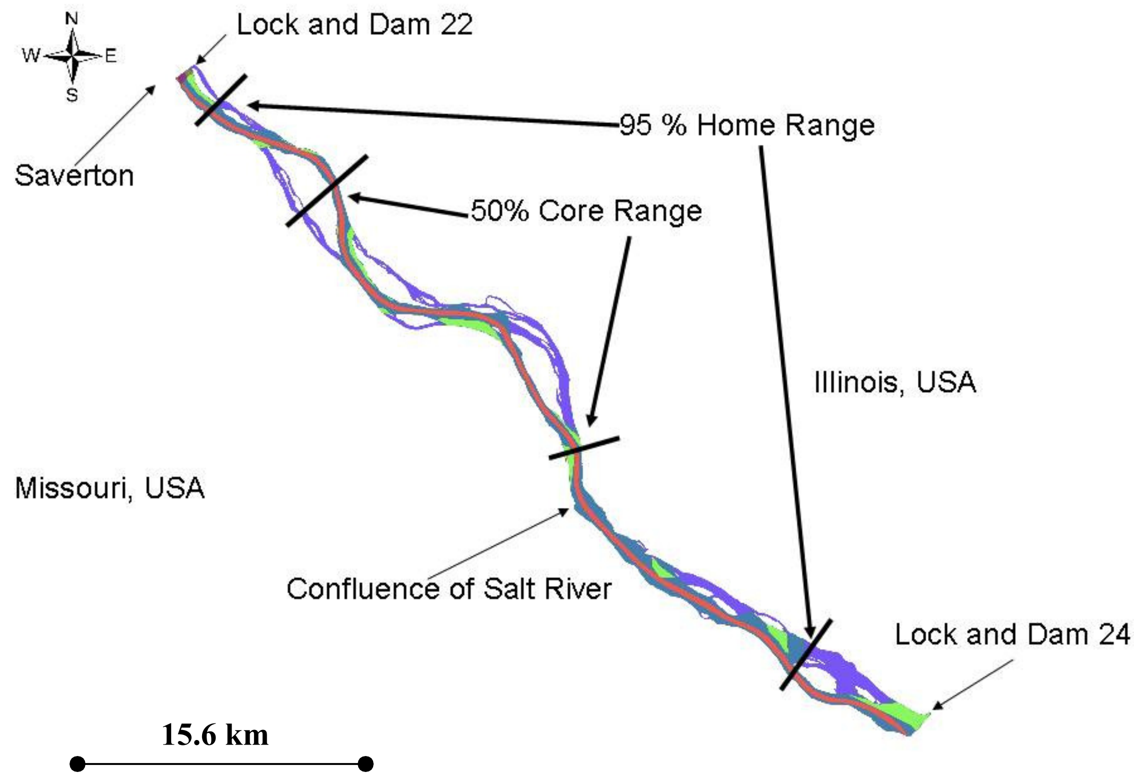


Figure 4. Example of 95% home range and 50% core range calculation for Pool 24 lake sturgeon number 164.314. Black diagonal lines indicate the boundaries for the home and core ranges.

# RESULTS

Twenty five lake sturgeon were tracked from October 2004 through November 2006. Three lake sturgeon were surgically implanted with ATS radio transmitters in the fall of 2004, and seven were implanted in the spring of 2005. In October of 2005, I started using acoustic transmitters and two were implanted that fall. Thirteen additional lake sturgeon were implanted with acoustic transmitters in the spring and summer of 2006. All lake sturgeon were caught and tagged in Pool 24. Lengths ranged from 796-1218 mm and weights from 3.94-14.65 kg (Table 1). When sexing fish during surgery I concluded there were 14 males, 10 females and 1 unknown. No fish with ripe eggs or mature gonads were observed although healthy looking early development stage eggs or gonads were present in all lake sturgeon.

In 2004, 16 tracking trips were conducted from October 8th thru December 8th covering approximately 137 river km and logging twenty lake sturgeon locations. In 2005, one hundred tracking trips were conducted from February 25th thru November 30th covering approximately 1,930 river km and logging 126 locations. We began using acoustic tags in the fall of 2005 and all fish implanted in 2006 received acoustic tags. In 2006, 70 tracking trips were conducted from February 28th thru November 2nd covering approximately 2,012 river km and logging 194 locations from both radio and sonic tags. It is important to note the majority of tracking trips were in Pool 24.

Table 1. Tracking and tagging information for all lake sturgeon in this study

| Tag Type | Frequency or ID # | Sex | Nickname | Length (mm) | Weight (kg) | Release Date | Status/last location |
|---|---|---|---|---|---|---|---|
| Radio | 164.012 | Male | Andy | 895 | 5.07 | 10/26/2004 | Dead Aug. 05 |
| Radio | 164.062 | Female | Aunt Bea | 804 | 3.94 | 10/6/2004 | Pool 24 in 06 |
| Radio | 164.114 | Male | Barney | 796 | 4.37 | 3/11/2005 | Pool 24 in 06 |
| Radio | 164.214 | Male | Goober | 1090 | 10.25 | 3/29/2005 | Pool 20 in 06 |
| Radio | 164.262 | Male | Amos | 912 | 5.71 | 3/11/2005 | Pool 24 in 06 |
| Radio | 164.314 | Male | Opie | 913 | 5.24 | 10/7/2004 | Pool 24 in 06 |
| Radio | 164.365 | unknown | Floyd | 1010 | 8.5 | 5/16/2005 | Pool 24 in 05 |
| Radio | 164.413 | Male | Earnest | 1060 | 11.5 | 6/2/2005 | Pool 24 in Spring 06 |
| Radio | 164.461 | Male | Gomer | 850 | 4.7 | 3/17/2005 | Dead Aug. 05 |
| Radio | 164.512 | Female | Thelma Lou | 1040 | 7.35 | 10/12/2005 | Pool 21 in Spring 06 |
| Acoustic | R04K 1286 | Female | n/a | 1218 | 14.65 | 9/5/2006 | Pool 24 in 06 |
| Acoustic | R04K 1287 | Female | n/a | 1188 | 12.65 | 9/8/2006 | Pool 24 in 06 |
| Acoustic | R04K 1288 | Male | n/a | 1032 | 8.65 | 10/3/2006 | Pool 24 in 06 |
| Acoustic | R04K 1289 | Female | n/a | 1060 | 9.26 | 9/28/2006 | Pool 24 in 06 |
| Acoustic | R04K 1290 | Male | n/a | 1058 | 8.14 | 10/31/2006 | Pool 24 in 06 |
| Acoustic | R04K 1623 | Male | Theodore Geisel | 1000 | 8.38 | 6/7/2006 | Pool 24 in 06 |
| Acoustic | R04K 1624 | Female | n/a | 1026 | 8.9 | 7/18/2006 | Pool 24 in 06 |
| Acoustic | RO4K 1615 | Male | Thing 1 | 1060 | 7.85 | 11/2/2005 | Pool 24 in 06 |
| Acoustic | RO4K 1616 | Male | Thing 2 | 1060 | 8.08 | 11/2/2005 | Pool 24 in 06 |
| Acoustic | RO4K 1617 | Male | Lorax | 1012 | 7.68 | 3/29/2006 | Dead Pool 24 in 06 |
| Acoustic | RO4k 1618 | Female | Red Fish | 978 | 6.75 | 5/16/2006 | Pool 24 in 06 |
| Acoustic | RO4K 1619 | Female | Blue Fish | 935 | 6.49 | 5/16/2006 | Pool 24 in 06 |
| Acoustic | RO4K 1620 | Female | Fox in Socks | 1120 | 10.52 | 5/31/2006 | Pool 24 in 06 |
| Acoustic | RO4K 1621 | Male | Marco | 1002 | 7.76 | 2/14/2006 | Pool 24 in 06 |
| Acoustic | RO4K1622 | Female | Daisy Head Mazy | 968 | 6.4 | 2/14/2006 | Pool 24 in 06 |

**Habitat Use**

In all of the habitat analyses (Table 2) lake sturgeon selected areas near lock and dam 22. Side channel was the least selected habitat in all analyses. Differences between the dam and tailwater habitat were considered minimal since these habitats adjoin one another and fish would use more of one habitat or the other depending on discharge and depth. In the combined radio and acoustic analysis (Figure 5), lake sturgeon used main channel border habitats the most, and side channels the least. Radio and acoustic tags had similar percent usage (Figure 6) except that more radio tagged fish were found in the main channel border areas and more acoustic fish were found in the navigational channel habitat. Using the Johnson technique, habitat use of radio-tagged fish was found to be random which means lake sturgeon showed no selection of one habitat over another. Thus, pairwise comparisons of habitat use for radio-tagged fish were invalid. Table 2 shows that lake sturgeon habitat selection was similar when looking at acoustic-tagged fish or the combination of acoustic-tagged and radio-tagged fish. Including the radio-tagged fish with the acoustic-tagged fish did not change the ranks of selected habitats, but it did affect the significant groupings. This is most likely due to bias associated with radio tags in deep water, meaning that only locations recorded for radio tagged lake sturgeon occurred when they ventured into shallower habitats.

*Seasonal analysis*

The seasonal analysis used both radio and acoustic location data and was broken up into four seasons (spring, summer, fall, and winter), but the winter was not used

Table 2. Pairwise comparison of habitats selected by both radio and acoustic-tagged fish (combined). Overall K=100 and W=1.91, Acoustic-tagged K=100 and W=2.07. Radio-tagged habitat use was determined to be random and pairwise comparisons could not be calculated. Habitat classifications and abbreviations (Figure 3) are as follows Dam (DM), tailwater (TW), diked channel border (diked), navigational channel (NAV.), Main channel border (MCB), and side channel (SC). Habitats with the same superscript letter signify no differences in the pair-wise comparisons. N=10 radio fish and N=15 acoustic fish.

| Rank | Acoustic/Radio combined | Acoustic | Radio |
|---|---|---|---|
| 1 | $DM^{A}$ | $TW^{A}$ | n/a |
| 2 | $TW^{B}$ | $DM^{A}$ | n/a |
| 3 | $Diked^{B}$ | $Diked^{A}$ | n/a |
| 4 | $NAV^{C}$ | $NAV^{B}$ | n/a |
| 5 | $MCB^{B}$ | $MCB^{A}$ | n/a |
| 6 | $SC^{D}$ | $SC^{B}$ | n/a |

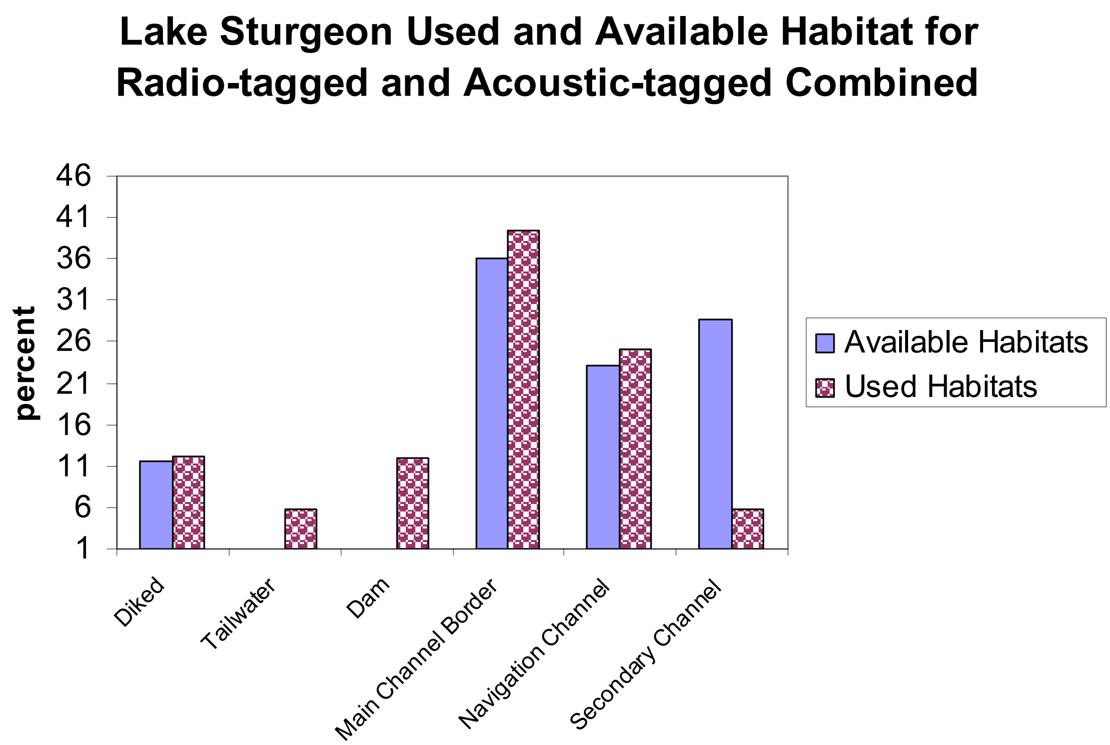


Figure 5. Comparison of percent use and percent available habitat in Pool 24. This figure represents data for all lake sturgeon in this study. See Figure 3 for description of each habitat. N=25.

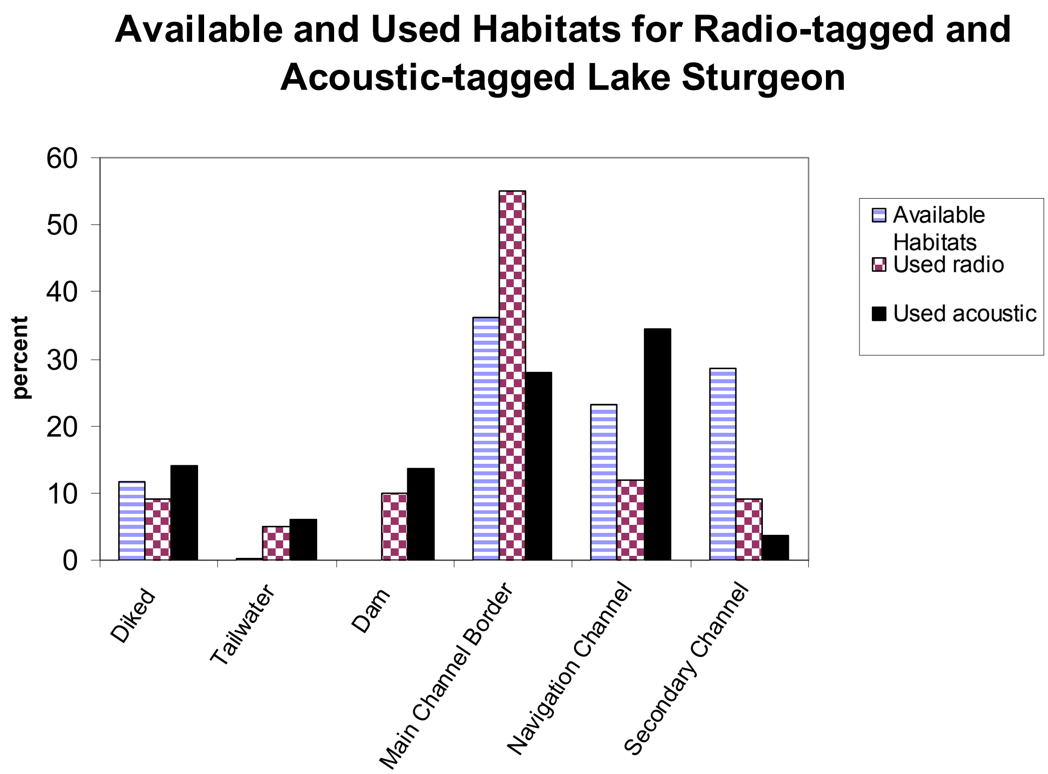


Figure 6. Comparison of radio and acoustic tagged lake sturgeon habitat use and the available habitat. See Figure 3 for description of each habitat. N=25.

because of few relocations. The habitat selection rankings were similar for all three seasons with spring and summer having the same rankings (Table 3). The dam habitat in spring is selected significantly more than all other habitats, but was not significantly different from tailwater in the summer. This is most likely due to lower discharge levels in the summer months that allow lake sturgeon greater access to tailwater areas. The differences in spring could be attributed to higher flows that push lake sturgeon into areas closer to the shore and away from the main flow of the river.

Since side channel is the least selected habitat, it continues to be significantly different from most habitats. The summers of 2005 and 2006 had lower than average water levels, which potentially limited the amount of available side channel habitat. Side channels may be used more during high water periods since the main flow of the river goes through some side channels. The water diversion dikes are as not effective during high flow; also, during high flow the dikes are not necessary because there is enough flow that water does not need to be diverted out of side channels to facilitate barge traffic. Another possibility is that main channel velocities are too high for lake sturgeon during high water events and optimal velocities can only be found in side channels out of the main flow.

Table 3. Seasonal habitat selection for by both radio and acoustic-tagged fish (combined), with pair-wise comparison of habitats for spring, summer, and fall season using the Waller-Duncan procedure. Spring K=100 and W=2.07, Summer K=100 and W=2.26, Fall K=100 and W=2.07. Habitats with the same letter signify no differences in the pair wise comparisons. Refer to Table 2 for habitat acronyms. Spring N=14, Summer N= 15, and Fall N= 16.

| **Rank** | **Spring** | **Summer** | **Fall** |
|---|---|---|---|
| 1 | $DM^{A}$ | $DM^{A}$ | $DM^{A}$ |
| 2 | $TW^{A,B}$ | $TW^{A,B}$ | $Diked^{B}$ |
| 3 | $Diked^{B}$ | $Diked^{B}$ | $TW^{B}$ |
| 4 | $NAV^{C}$ | $NAV^{B}$ | $NAV^{B}$ |
| 5 | $MCB^{B}$ | $MCB^{C}$ | $MCB^{C}$ |
| 6 | $SC^{C}$ | $SC^{C}$ | $SC^{C}$ |

*Home range*

All but two lake sturgeon home range estimates included the dam and tailwater area of pool 24 (Table 4) and average home range size was 26.57 Km. Average **c**ore range size was 9.2 km. A linear regression analysis comparing fork length to home range and core range showed that fish size had no effect on home range (p=0.49) or core range size (p=0.23).

Habitat selection was no different when available habitat was based on each fish's individual home range (Table 5). Although calculating habitat in the home range for each fish was intended to provide a more accurate estimate of available habitat, this procedure did not have the intended effect since most fish used the entire pool. Thus, the available habitat in the fish home ranges was very similar to that available throughout the entire pool (Figure 7) Once available habitat was calculated for each fish's individual home range, the Waller Duncan procedure showed that dam, main channel border, and side channel habitats were significantly different from each other and the other habitats; and tailwater, diked, and navigational channel habitats were not significantly different (Table 5). Overall, the home range estimates were similar to combined radio and sonic analysis which is due to all lake sturgeon using most portions of Pool 24 during some point of the year.

Table 4. Size and scope of home ranges and core ranges for all lake sturgeon in pool 24. Reference river km can be found in Figure 2. Frequency is the tag frequency for acoustic-tagged and radio-tagged (combined), fork length (mm) is the fork length at release, upper and lower home range boundaries indicate the uppermost and lowermost river km for each lake sturgeon home range, home range length is the length of each home range, upper and lower core range boundaries indicate the upper most and lower most river km for each lake sturgeon core range, and core range length is the length of each core range. Home range equals the area with 95% probability of finding the fish, while core range is the area with 50% probability of finding the fish.

| Frequency | Fork Length (mm) | Upper Home Range Boundary (river km) | Lower Home Range Boundary (river km) | Home Range Length (km) | Upper Core Range Boundary (river km) | Lower Core Range Boundary (river km) | Core Range Length (km) |
|---|---|---|---|---|---|---|---|
| 164.012 | 895 | 484.61 | 442.75 | 41.86 | 484.61 | 455.63 | 28.98 |
| 164.062 | 804 | 484.61 | 470.12 | 14.49 | 484.61 | 483 | 1.61 |
| 164.114 | 796 | 457.24 | 454.02 | 3.22 | 455.63 | 454.02 | 1.61 |
| 164.262 | 912 | 479.78 | 445.97 | 33.81 | 455.63 | 450.8 | 4.83 |
| 164.314 | 913 | 484.61 | 442.75 | 41.86 | 484.61 | 447.58 | 37.03 |
| 164.365 | 1010 | 484.61 | 484.61 | 0 | 484.61 | 484.61 | 0 |
| 164.413 | 1060 | 484.61 | 474.95 | 9.66 | 483 | 483 | 0 |
| 164.461 | 850 | 484.61 | 454.02 | 30.59 | 483 | 473.34 | 9.66 |
| 164.512 | 1040 | 484.61 | 484.61 | 0 | 484.61 | 484.61 | 0 |
| 1286 | 1218 | 483 | 454.02 | 28.98 | 455.63 | 455.63 | 0 |
| 1287 | 1188 | 484.61 | 441.14 | 43.47 | 481.39 | 481.39 | 0 |
| 1288 | 1032 | 484.61 | 454.02 | 30.59 | 468.51 | 455.63 | 12.88 |
| 1289 | 1060 | 484.61 | 466.9 | 17.71 | 483 | 483 | 0 |
| 1615 | 1060 | 484.61 | 441.14 | 43.47 | 481.39 | 479.78 | 1.61 |
| 1616 | 1060 | 484.61 | 462.07 | 22.54 | 483 | 479.78 | 3.22 |
| 1617 | 1012 | 484.61 | 455.63 | 28.98 | 484.61 | 463.68 | 20.93 |
| 1618 | 978 | 484.61 | 454.02 | 30.59 | 484.61 | 481.39 | 3.22 |
| 1619 | 935 | 484.61 | 452.41 | 32.2 | 484.61 | 479.78 | 4.83 |
| 1620 | 1120 | 484.61 | 455.63 | 28.98 | 484.61 | 479.78 | 4.83 |
| 1622 | 968 | 484.61 | 478.17 | 6.44 | 481.39 | 481.39 | 0 |
| 1623 | 1000 | 484.61 | 454.02 | 30.59 | 484.61 | 466.9 | 17.71 |
| 1624 | 1026 | 484.61 | 441.14 | 43.47 | 483 | 483 | 0 |
| **Average** | 997.14 | 483.07 | 457.46 | 25.61 | 479.12 | 472.17 | 6.95 |

Table 5. Pairwise comparisons of acoustic-tagged and radio-tagged (combined). Overall K=100 and W=1.91, home range K=100 and W=1.94. Habitats with the same superscript letter signify no differences in the pairwise comparisons. Acoustic-tagged and radio-tagged (combined) results are the same as in Table 2 and Figure 5. Home range available habitat was based on individual home ranges for each lake sturgeon (Table 4). N=20 for the Home range analysis while N=25 for the combined analysis.

| **Rank** | **Acoustic/ Radio** | **Home Range** |
|---|---|---|
| 1 | $DM^{A}$ | $DM^{A}$ |
| 2 | $TW^{B}$ | $TW^{B}$ |
| 3 | $Diked^{B}$ | $Diked^{B}$ |
| 4 | $NAV^{C}$ | $NAV^{C}$ |
| 5 | $MCB^{B}$ | $MCB^{B}$ |
| 6 | $SC^{D}$ | $SC^{C}$ |

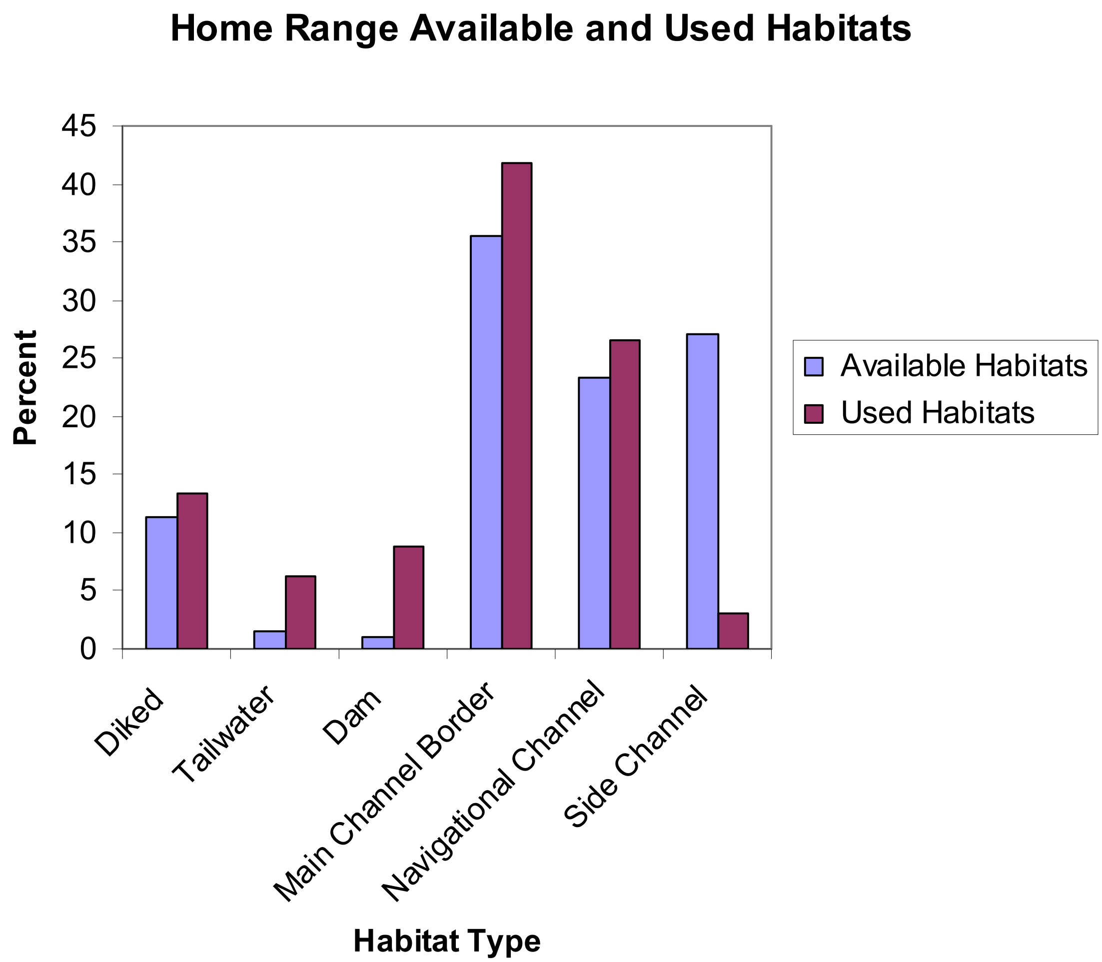


Figure 7. Average percent available habitat based on the individual home range of each fish compared to the average percent use. This analysis only included lake sturgeon that did not leave Pool 24. Average available habitats were based on each fish's individual home range. Used habitats are the same as in Figure 5 minus fish that left the pool. N=20.

**Movement**

Movement during each season was significantly different based on a nonparametric Kruskal Wallis test ($p = 0.01$). I then conducted a Dunn's post hoc test (Table 6) which only showed significant differences between spring and winter. I then conducted a linear regression comparing the absolute values of seasonal movement to seasonal temperature and discharge with no significant effect ($p=0.09$, $R^2 = 0.13$). Absolute values were used because lake sturgeon would move downstream several miles one day and move back near their previous location. Figure 8 shows average movement per season with spring having the highest movement rates and winter having no movement. Remote receivers were needed to document movement and were not in place until February 2006. Thus, all fish used for the movement analysis were acoustic tagged and from the 2006 season, and data used for the winter did not include an entire season.

To get more resolution on the relationship between movement, temperature and discharge, I performed a second regression but this time I used monthly averages of movement, temperature, discharge and their interaction ($p=0.89$, $R^2 = 0.01$). From Figures 9 and 10 we can see that discharge and temperature both seem to influence movement somewhat at different times of the year, (for example, during the spring when discharge increases there is also an increase in movement). I looked at the interaction between temperature and discharge as well as nonlinear relationships among the variables. However, I found no statistically significant relationships. I then conducted a linear regression using the monthly average movement to temperature and discharge ($p= 0.09$, $R^2 = 0.47$) without the interaction.

Table 6. Season pairwise comparisons calculated using a Dunn's nonparametric post hoc test after a significant Kruskal Wallis test (p=0.01).Seasons with the same letters are not significantly different. Season lengths were as follows; Spring= April 1st-June 15th , Fall= September 16th - November (Spring and Fall encompassed the extreme rising and falling temperatures 8-24 C), Winter= December 1st -March 31st (which comprised the relatively constant cold temperatures 0-7 C), and Summer= June 16th-September 15th (which included the remaining highest water temperatures 24-35 C). The seasons were not even in length but accurately represented the seasonal water temperature changes. N=25.

| **Season** | **Mean Movement (km)** |
|---|---|
| $\text{Spring}^{A}$ | 6.0 |
| $\text{Fall}^{A,B}$ | 3.4 |
| $\text{Summer}^{A,B,C}$ | 3.2 |
| $\text{Winter}^{B,C}$ | 0.0 |

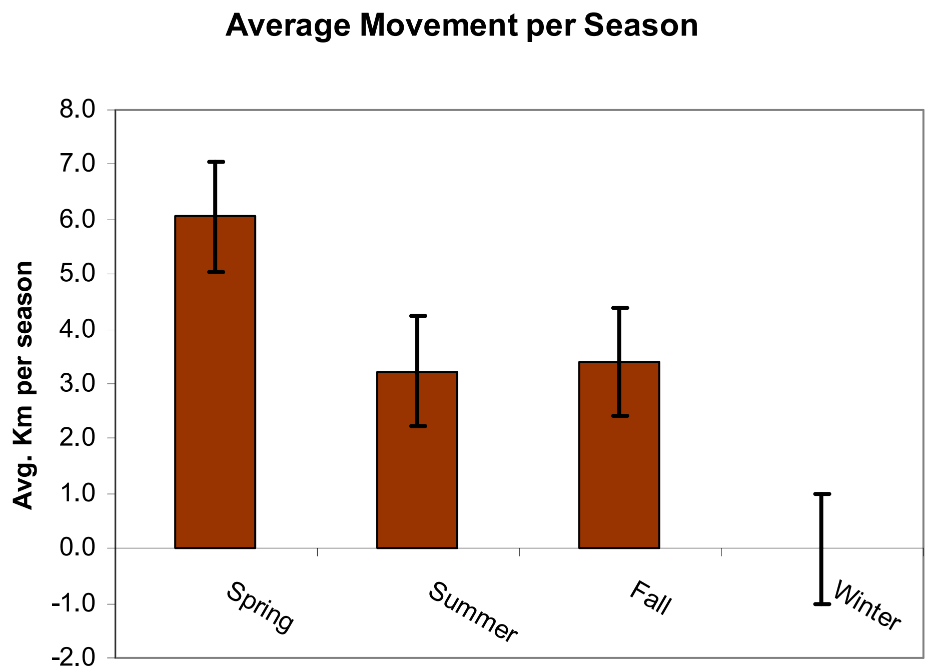


Figure 8. Average acoustic-tagged lake sturgeon movement per season (error bars represent 95% CI). Season lengths were as follows; Spring= April 1st-June 15th , Fall= September 16th - November (Spring and Fall encompassed the extreme rising and falling temperatures 8-24 C), Winter= December 1st -March 31st (which comprised the relatively constant cold temperatures 0-7 C), and Summer= June 16th-September 15th (which included the remaining highest water temperatures 24-35 C). The seasons were not even in length but accurately represented the seasonal water temperature changes. Spring N=9, Summer N=11, Fall N=12, and Winter N=4.

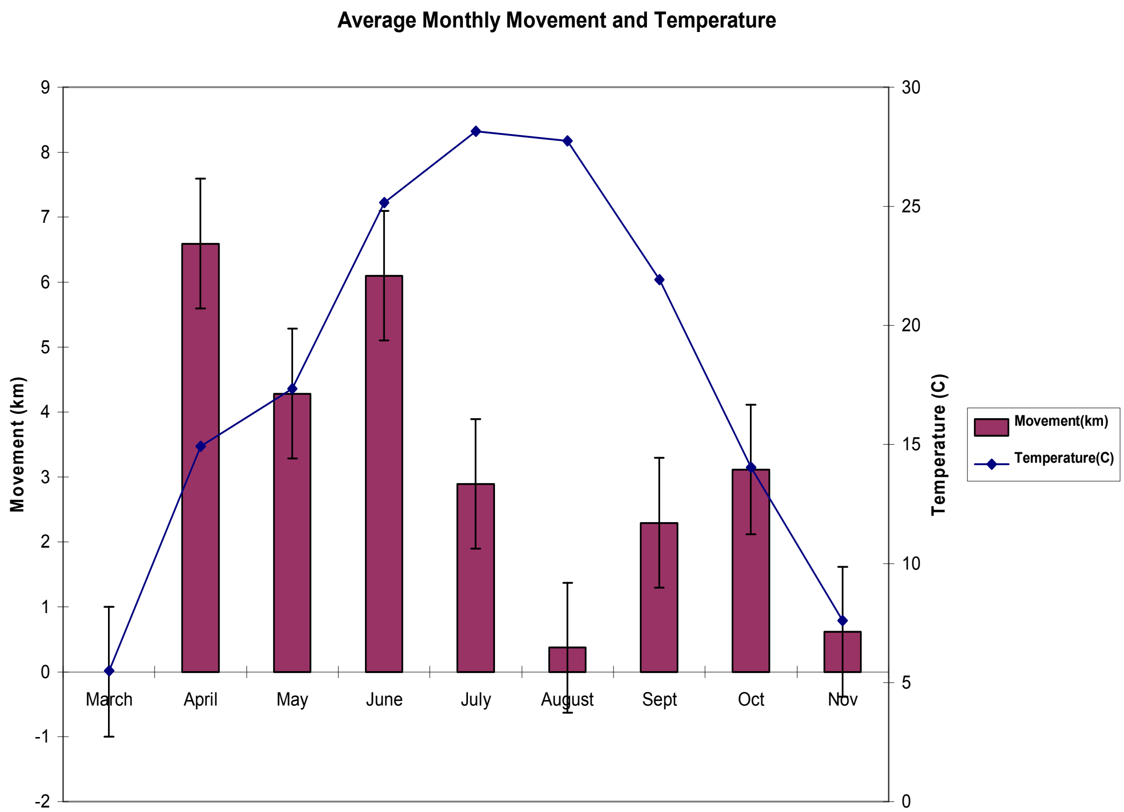


Figure 9. Average monthly movement of all lake sturgeon and the average monthly temperatures for 2006 (error bars represent 95% CI). N = 25.

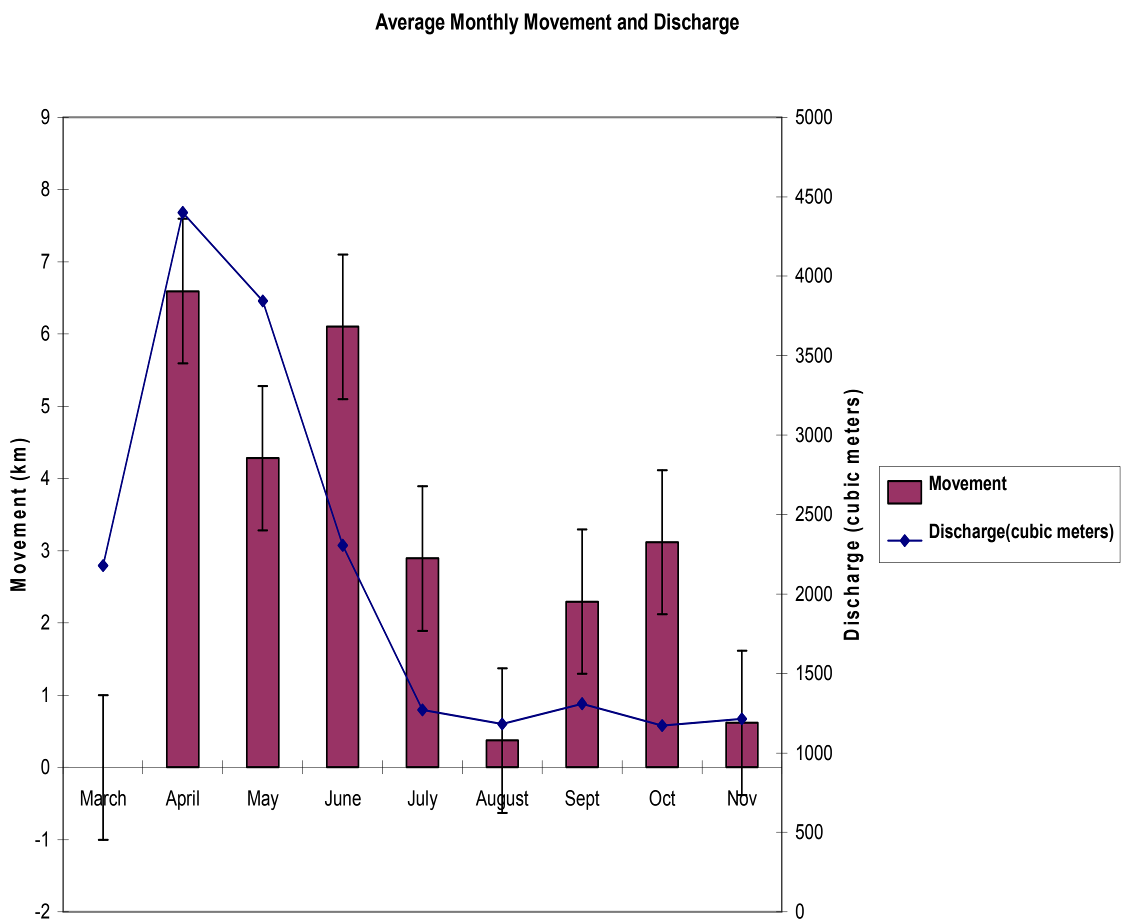


Figure 10. Average monthly movement of lake sturgeon in pool 24 and the average monthly discharge (error bars represent 95% CI). N = 25

Although the model with temperature and discharge was not significant, discharge alone had a significant effect on average monthly movement ($p= 0.03$, $R^2 = 0.52$).

Another way to look at movement was by comparing the linear estimates of home range on a seasonal basis. Not only was I interested in movement rates, but also I wanted to examine the general location of each fish within the pool. I calculated home range for each fish during each season and then calculated the midpoint of each home range. Figure 11 compares how the average pool position or home range midpoint of lake sturgeon changes with each season. During the spring and winter lake sturgeon are found much farther downstream than in the summer and fall. A nonparametric Kruskal-Wallis test compared the average pool position of the seasonal home ranges in SAS ($p = 0.03$). Upon running Dunn's non-parametric post hoc test, no significant differences between the seasons were found because the Dunn's test did not have enough power to detect statistical differences.

The seasonal size of the home range was another way to quantify movement within the pool. A nonparametric Kruskal-Wallis test was calculated in SAS comparing the seasonal home range sizes, but it showed not significant differences between the seasons ($p= 0.19$). In Figure 12, the smallest home range size was the winter season. Lake sturgeon that left the pool in the spring were not included in the analysis and therefore underestimated the spring home range size.

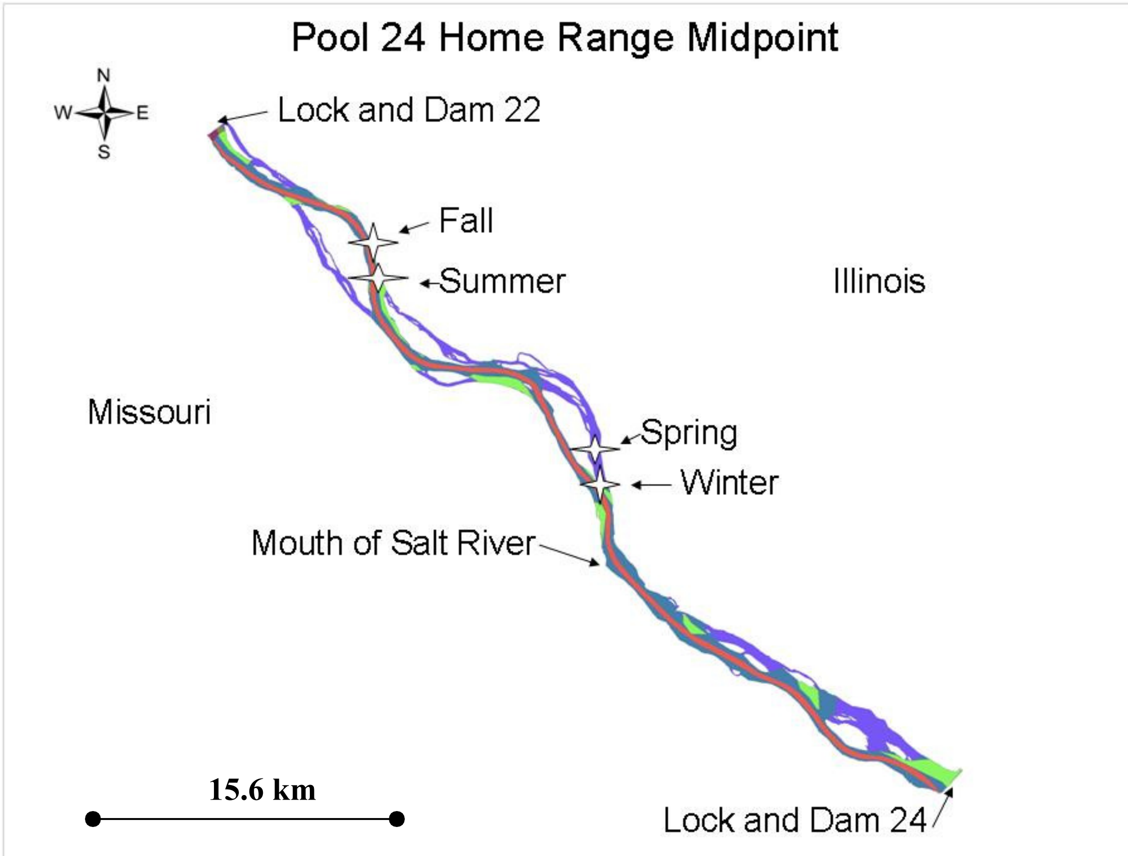


Figure 11. Average midpoint of the home range. There were differences between cold and warm seasons with Spring and Winter being river km 470, while was Summer river km 474, and Fall was river km 475. Lock and Dam 22 is at approximately river km 485 and Lock and Dam 24 is approximately river km 441. N = 20.

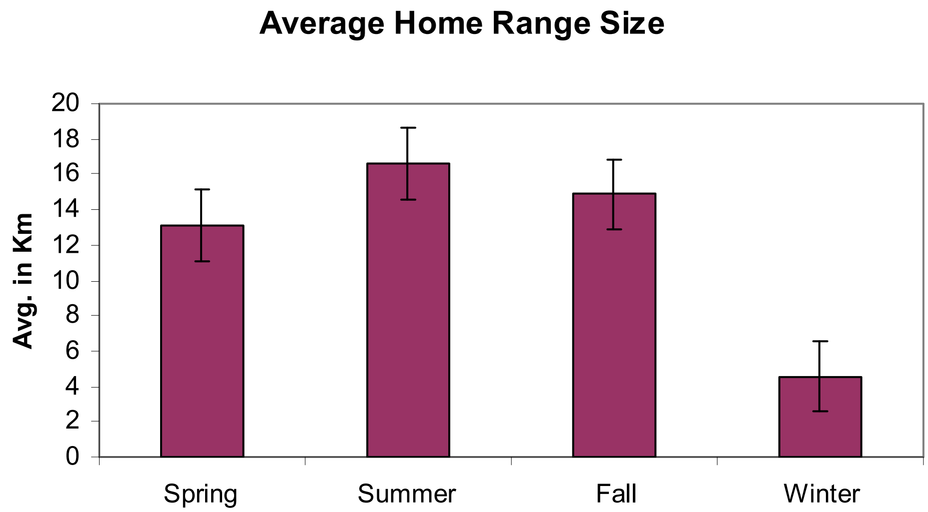


Figure 12. Seasonal average size of home range for lake sturgeon in Pool 24 (error bars represent 95% CI).Season lengths were as follows; Spring= April 1st-June 15th , Fall= September 16th - November (Spring and Fall encompassed the extreme rising and falling temperatures 8-24 C), Winter= December 1st -March 31st (which comprised the relatively constant cold temperatures 0-7 C), and Summer= June 16th-September 15th (which included the remaining highest water temperatures 24-35 C). The seasons were not even in length but accurately represented the seasonal water temperature changes. N = 20.

**Substrate**

In 2006, 156 substrate samples were collected after each fish location (19 lake sturgeon) (Table 7). I calculated average substrate composition for each fish, and then I averaged the compositions across all fish. From these calculations we see that sand was the most common substrate in most samples (68.86%) with rock being second (13.88%), gravel being third (8.76%), and silt being fourth (8.50%). The dominant substrate (composed >50% of the sample) was sand 70% of the time, silt 8% of the time, rock 13% of the time and gravel 8% of the time**.** Most samples were from the spring, summer, or fall season. Knights et al. (2002) found that lake sturgeon in Mississippi River pools 5A and 10 selected sand and silt substrates. However, I had no estimate of available substrate and thus could not measure selection.

Table 7. Results of substrate samples taken during the 2006 sampling season.

| Fish ID | # of samples | sand % | silt % | rock % | gravel % |
|---|---|---|---|---|---|
| 164.062 | 1 | 100.00 | 0.00 | 0.00 | 0.00 |
| 164.114 | 5 | 41.00 | 59.00 | 0.00 | 0.00 |
| 164.262 | 7 | 21.43 | 0.00 | 57.14 | 21.43 |
| 164.314 | 7 | 67.14 | 17.14 | 14.29 | 1.43 |
| 164.413 | 1 | 0.00 | 0.00 | 100.00 | 0.00 |
| 164.512 | 2 | 75.00 | 0.00 | 0.00 | 25.00 |
| 1286 | 6 | 85.00 | 0.00 | 0.00 | 15.00 |
| 1288 | 1 | 80.00 | 0.00 | 0.00 | 20.00 |
| 1289 | 4 | 95.00 | 0.00 | 0.00 | 5.00 |
| 1615 | 2 | 100.00 | 0.00 | 0.00 | 0.00 |
| 1616 | 26 | 80.19 | 0.00 | 15.00 | 4.81 |
| 1617 | 18 | 100.00 | 0.00 | 0.00 | 0.00 |
| 1618 | 16 | 64.69 | 0.31 | 31.25 | 3.75 |
| 1619 | 12 | 90.42 | 0.42 | 8.33 | 0.83 |
| 1620 | 12 | 44.17 | 25.00 | 16.67 | 14.17 |
| 1621 | 4 | 65.00 | 22.50 | 0.00 | 12.50 |
| 1622 | 20 | 44.25 | 18.00 | 21.00 | 16.75 |
| 1623 | 6 | 78.33 | 18.33 | 0.00 | 3.33 |
| 1624 | 6 | 76.67 | 0.83 | 0.00 | 22.50 |
| total/avg. | 156 | 68.86 | 8.50 | 13.88 | 8.76 |

# DISCUSSION

## Reproduction

My main goal was to document spawning activity but no lake sturgeon with mature eggs or milt were captured in Pool 24. Lake sturgeon in Pool 24 appear to mostly be young adult fish that may begin spawning in the next few years. All of the larger fish (>6.81 kg or 15 lb.) possess clearly distinguishable gonads. Our estimate of 15-20 years for males and 20-25 years for females to reach sexual maturity is a conservative estimate of age at sexual maturity. Bruch and Binkowski (2002) speculated that lake sturgeon may mature at an earlier age in warmer climates where growth is better. A low density of mature adults may limit spawning since adults may have difficulty locating each other. Lake sturgeon introduced from the Upper Mississippi do not have traditional spawning sites established in the lower pools of the river and it may take time to develop these areas. The lake sturgeon eggs used for stocking come from Wisconsin where they run up tributaries to spawn but no lake sturgeon were located in tributaries during the course of this study.

Additionally, only one lake sturgeon (164.214) was documented making what might be characterized as a spawning run. In mid April of 2005 and 2006 the river was at open river stage for two to four weeks and water levels and temperature both rose quickly during this period. This time period coincided with the documented range of spawning temperatures for lake sturgeon (8.8-21.1 C; Bruch and Binkowski 2002, Caswell et al. 2002, Chiotti et al. 2003). In 2005, this lake sturgeon (1090 mm 10.25 kg male) traveled

129 km in six days, going upstream through three locks and dams (22, 21, 20) when the river was at open river stage. This fish moved to within two km of Lock and Dam 19 and stayed in that area during 2005 and 2006.

All other lake sturgeon stayed in pool 24, or moved to adjacent pools. From field observations, fish that left the pool in 2006 did not appear to have a particular destination. It must also be noted that some of the earlier radio tagged fish were not located in 2006 which could be attributed to battery failure, or movement to adjacent pools where less tracking effort was expended.

**Radio vs. Acoustic Tags**

Acoustic tags were more effective for consistently locating lake sturgeon in the Mississippi River. On average, 80% of acoustic tags were located on each day of tracking in Pool 24 while only 10-20% of radio tags were located. Radio tags have a diminished range with deeper water and no tags can be heard in water >9.15 m. The higher frequency of radio transmitters (sound travels farther at lower frequencies (Winter 1996)) in conjunction with the characteristics of the water in the Mississippi River (i.e. high conductivity, high amounts of suspended matter, current etc.) made acoustic tags more effective. The original assumption was that lake sturgeon may run up tributaries to spawn. If this was the case, lake sturgeon would frequent shallower areas and additional resources (helicopters, land based tracking) would have made radio tags more effective. Tributaries were checked numerous times during the spring in 2005, 2006, and 2007 with no lake sturgeon ever being located in a tributary. Since lake sturgeon in this study frequented deeper habitats, acoustic tags were more effective and eliminated any bias associated with only being able to locate tags in shallow water.

Another advantage to the acoustic equipment was that all the tags were on the same frequency while the radio receiver we used could only monitor one frequency at a time. The radio receiver was set to scan each frequency for four seconds and more fish were added to the study, the chances of missing one increased. As a general rule, acoustic tags could be heard at greater distances, and in deeper water. The acoustic tags became increasingly important during the high water events (> 5,770 cubic meters per second (cms)), when most of the river rose to a depth that was deeper than our minimal detectable depth for radio tags. We could cover more water using the acoustic equipment as well, since in most instances only one pass down the river channel was required to locate fish. We were able to drive faster while conducting radio tracking but were never really sure if we were detecting fish that were present. During periods of high water, time constraints forced us to track the main channel more than side channels and using acoustic equipment increased the likelihood of finding lake sturgeon in the deeper water that in most areas was beyond the detectable depth of radio tags.

The acoustic equipment also allowed us to document movement 24 hours a day with the VR2 stationary receivers. The only disadvantage to acoustic equipment was that during low water periods (<2000 cms) when there was little noise or distortion in the river the tags could be heard and decoded up to a km away. This became confusing when several fish were in the same area. Our receiver needed to hear a full, uninterrupted ping interval to decode the tag. If any other tag was picked during the ping interval, it would not decode either of them. This was also a problem while manual tracking since multiple tags made pinpointing an individual fish extremely difficult. In those situations lake sturgeon were located by decoding the tag first and then using the Sonotronics equipment to get a precise fix on the location.

**Habitat Use**

Lake sturgeon selected areas close to Lock and Dam 22. Lock and Dam 22 is considered a barrier to upstream fish movement unless there are high flows. Fish that would instinctively move upstream tend to congregate below the dam. Bait fish and other forage may be in higher abundances here than in other portions of the pool or may be stunned after passing through the gates. The site also provides a great diversity of depths, velocities, and substrates that may offer diverse feeding opportunities for minimal effort. Areas near the dam may also have higher dissolved oxygen concentrations.
Lake sturgeon frequently used an area referred to as the current seam or the area where the gates stop and the earthen portion of Lock and Dam 22 begins (Figure 13). This area lies perpendicular to the dam, extending downstream from the eastern side of the last tainter gate. A large shallow sandbar is present adjacent to the current seam downstream of the earthen dam's plunge pool. Flow in the current seam is generated by both the releases from the dam and the multi-hectare eddy that encircles the sandbar. While many fish species are attracted to the site it appears to be particularly important to both lake sturgeon and shovelnose sturgeon (*Scaphirhynchus platorynchus)*.

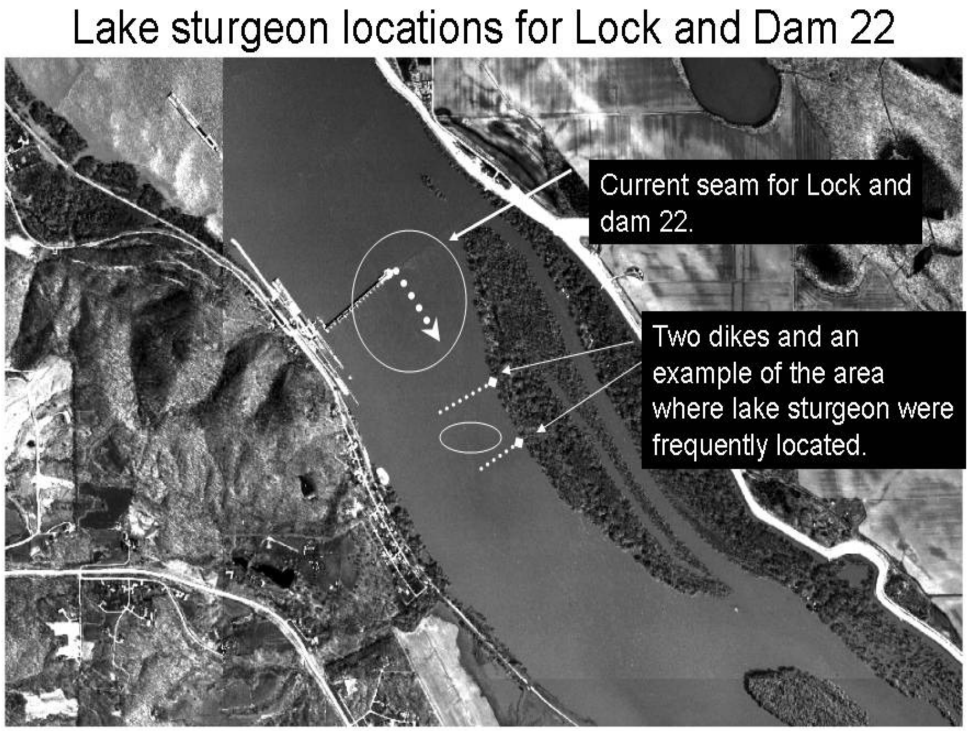


Figure 13. Lock and Dam 22 near Saverton, Missouri. This photo was taken at high water levels when water is covering the earthen portion of the dam on the Illinois (right) side of the river. The lock is parallel to and along the Missouri shoreline. The earthen portion of the dam is exposed for most of the year. The arrow that starts at the dam and extends downstream represents the current seam which is the end of gated section where discharge occurs. Along this line there is a rapid change is depth where the high velocity discharge meets the slower water below the earthen dam portion. The lower dashed lines represent two dikes below the dam and the oval illustrates a location where lake sturgeon were frequently located.

It is likely that the site provides a desirable combination of substrate, water velocity, dissolved oxygen, and food supply. The area over the sandbar creates a large eddy that constantly circulates water and potentially brings food around repeatedly. Lake sturgeon were most frequently located in slower water on the edge of the eddy created across the sand flat on the Illinois side of the river but were located in all portions of the dam and tailwater habitat. The large sand flat of the dam habitat may be a feeding area and provides quick access to deep water in the tailwater portion (Figure 13).

Similar hydrologic conditions to the dam current seam are created off the tips of dikes downstream of the dam; Knights et al. (2002) noted that lake sturgeon in Pools 5A and 10 of the Upper Mississippi River used hydraulically similar areas characterized by transition zones from high current velocities to slower velocities, and Curtis et al. (1997) found that during extreme low flow periods shovelnose sturgeon in Pool 13 of the Upper Mississippi River frequented main channel border areas that had dikes present in 29 % of locations. Lake sturgeon in Pool 24 also used some of these areas but in the habitat analysis some of these areas fell on the border between diked channel border and main channel border. I had no buffer area between habitats and subsequently, locations fell into one habitat or the other. The largest area of concern for this problem was the area near the dam between the dam and tailwater habitats but other transition areas were missed as well. In the future research more emphasis should be placed on the transition areas between two types of habitats.

As previously mentioned, at low water levels lake sturgeon which were not near the dam used areas in or adjacent to the main channel. Curtis et al. (1997) found that shovelnose sturgeon in Pool 13 of the Upper Mississippi River frequented main channel areas in 50% of locations. Lake sturgeon may use these areas more in the summer because of higher oxygen levels, or food availability in the form of young-of-the-year fish. During late July and August of 2005, several lake sturgeon were discovered dead and floating with injuries that appeared to be caused by propellers. Two of our radio tagged lake sturgeon also died during this time and one other fish has not been located since this time period. The U. S. Army Corps of Engineers placed a drafting restriction on barges during this time period. Low water conditions created an overlap in the navigational channel and desirable lake sturgeon habitat use and potentially increased lake sturgeon mortality in areas immediately downstream of locks and dams where cooler water or greater food availability concentrated lake sturgeon. Mortality in sturgeon has been shown to be higher during low water periods when sturgeon density is highest in and near the locks Keevin et al. (2005). Most lake sturgeon used the dam/tailwater areas at some time during the summer season while no lake sturgeon were ever located in these habitats in the winter season. Most likely, lake sturgeon avoided the area immediately below Lock and Dam 22 in the winter because the lowered metabolic rate caused by cooler water temperatures limited use of higher flow areas. Hurley et al. (1987) found that shovelnose sturgeon in the Upper Mississippi River had discrete areas of use during spring and summer but the study ended in the fall and did not have winter habitat use data. They also found that shovelnose sturgeon tended to be closer to main channel areas at low flows and moved farther away from the main channel during high flows. Pool 24 lake sturgeon followed this pattern as well.

Dike tips also act as a current seam and allow fish access to food drifting. During low flows there is a much higher proportion of main channel habitat available and these areas may have more desirable flows, oxygen levels, and chances at passing food particles than areas out of the main channel.

Lake sturgeon were rarely found near individual dikes in a multi-dike field and were frequently located on the large flats between two dikes or directly in line with the two dike tips (Figure 13). Most dikes in Pool 24 are submerged and do not create the large plunge pools directly downstream that are found with emergent dikes. Consequently there are few low velocity areas in Pool 24. The one exception was the first trail-dike downstream from Lock and Dam 22, on the Missouri side. This dike is in the first downstream channel crossover and out of the water most of the year. This area was frequented by lake sturgeon throughout the course of the study and was one of the best areas for capturing them as well. This was the only dike in Pool 24 where lake sturgeon were consistently located and was also this first area below the dam that provided a significant velocity refuge.

Side channels were the least selected habitat but use increased with higher water levels. Side channels in the downstream half of the pool are much larger than ones in the upper third of the pool and have a similar water volume to the main channel. Consequently, side channels in the lower half of the pool were used more than side channels farther upstream. Side channels increase in width, depth, and flow downstream in Pool 24.

No lake sturgeon were located in side channels during the winter season, or in the farthest downstream two km of Pool 24 at any time while conducting manual tracking. The only locations in the lower two km of the pool were from VR2 stationary receivers and these fish continued on downstream through Lock and Dam 25. This is interesting considering that Knights et al.(2002) found that lake sturgeon in Pool 5A of the Mississippi River used the impounded portion of the pool a considerable amount of time. The locks and dams on the Upper Mississippi where their research was conducted create lentic areas in the forms of large flat lakes while Pool 24 and the surrounding pools are more lotic in nature. Substrate was only recorded for 2006 but 156 samples were taken. From calculating the average percent composition sand was the most common substrate followed by rock, gravel, and silt was the least common substrate found.

**Movement**

During the course of this study no lake sturgeon were documented making upstream movements through the Lock and Dam 22 unless the dam was at open river conditions (approximately 5,770 cubic meters per second (cms)). The gates are raised out of the water during open river conditions and during the rest of the year they are lowered into the water, thus constricting flow. All upstream movements were in the spring when water temperatures were rising. Lake sturgeon movement both upstream and down increased in the spring. Several fish made downstream out-of-pool movements when the river was not at open river levels. Lake sturgeon either went under the water control gates or had to lock through in order to pass downstream. Most downstream movements were in the fall of the year when water temperatures were falling.

Lake sturgeon moved both longer distances and more frequently than at other times of the year from mid-April until water cooled off in mid-October. Winter movement patterns could not be properly evaluated since VR2's were not in place, but observations from manual tracking indicate movement was considerably less. With two years of observations of radio-tagged fish, we noticed that once a lake sturgeon was located in a particular area in the winter, the fish was found in that general area several consecutive days.

Lake sturgeon movement in spring, summer, and fall was underestimated since lake sturgeon tended to make large daily movements (2-6 km) away from a site, and then move close to their original location, the next day. The pattern of continuous upstream and downstream movements was particularly evident in summer and fall when water levels were lower, temperatures were high, and lake sturgeon could not pass freely upstream through the locks and dams.

There was also the potential for VR2 stationary receivers to underestimate movement rates during low water periods. During periods of low flow, tags could be decoded 0.80 -1.61 km away. Lake sturgeon that moved within the radius of the decodable range of the VR2 were documented on one VR2 and did not have a documented movement outside of the VR2's range. Thus, lake sturgeon could potentially have moved 1-2 km upstream or downstream of the VR2 without showing any recorded movement.

**Conclusion**

Lake sturgeon have definite seasonal habitat use. They congregated in areas below Lock and Dam 22 in the summer, while avoiding these areas in the winter. Lake sturgeon also used deeper habitats (i.e. main channel, channel border habitats) in the summer and winter while frequenting the peripheral habitats more in the spring and fall.

Lake sturgeon were more active in the spring and fall and consequently used more of the available habitats during this time.

Lake sturgeon upstream movement appears to be restricted by locks and dams. This is evident when you consider the differences between movement patterns when the river was not at open river. When the river was at open river stage, lake sturgeon moved up to 95 km upstream of Pool 24. Lake sturgeon were not able to move upstream at lower water levels but continued to have high movement rates within Pool 24. If not limited by locks and dams, lake sturgeon would likely move freely throughout the entire Mississippi River system. Auer (1996) considered a barrier-free 250-300 km range a minimum distance to support self-sustaining lake sturgeon populations and distances of 750-1000 km should not be considered unusual.

Locks and dams can segregate fish by pools and reduce the chances of reproductive fish finding one another. No historical spawning or movement data is available for the extirpated lake sturgeon of this area. These fish may previously have moved hundreds of kilometers as part of seasonal migration or for spawning and are no longer able to. Lake sturgeon may not use Pool 24 tributaries because they do not possess the ideal hydrological conditions during spawning periods. The Salt River, which is largest the tributary in Pool 24, is subject to rapid changes in water level due to the operation of Clarence Cannon Dam.

On a positive note, the U.S. Army Corps of Engineers is designing fish passage structures for Locks and Dams 22 and 26. If they prove to be successful, they may design similar structures for the other locks and dams. Auer (1996) proposed that fisheries managers should give barrier removal or fish passage greater consideration than habitat enhancement for populations currently isolated and restricted in range. The proposed structures could help to reconnect partially fragmented fish populations and allow access to other pools year round. This may prove to be critical since large adults may disperse hundreds of kilometers downstream as part of normal historical seasonal movement patterns.

Future research should concentrate on locating mature adults, identifying and reducing sources of mortality in all age groups, and evaluating the usefulness of fish passage structures. Comparing abundance, habitat use, and movement rates of lake sturgeon in the pooled portion of the Mississippi River to the open river conditions found on the Lower Mississippi River and the Missouri River may also give a better estimate of true movement rates and habitat selection since lake sturgeon in unobstructed reaches are not restricted by dams.

The lake sturgeon population in the Missouri portion of the Mississippi River continues to mature and increase in number of fish, but it is not yet capable of sustaining itself. Stocking must continue if lake sturgeon are to become reestablished to the point when there are enough reproductive adults available to provide for consistent natural recruitment. Also, with the ability of lake sturgeon to migrate across state lines, the dispersal of Missouri-raised lake sturgeon to other river systems must be taken into account. Restocking of lake sturgeon must be at the basin-wide level and not just a statewide level. The intent of Kentucky and Tennessee to implement their own stocking programs may aid in increasing the numbers of fish needed to occupy such a large river system.

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