HABITAT USE AND MOVEMENT OF SUB-ADULT LAKE STURGEON IN THE LOWER WOLF RIVER, WISCONSIN

By

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EXECUTIVE SUMMARY

Lake Sturgeon *Acipenser fulvescens* populations have experienced precipitous declines over their native range due to high exploitation and habitat fragmentation. Because of these declines, harvest on many Lake Sturgeon populations was banned during the twentieth century and the need for research to aid in rebuilding populations was recognized.

Previous research has largely focused on adult Lake Sturgeon, including their habitat use and movement. However, there has been little research on sub-adult Lake Sturgeon. Since Lake Sturgeon do not mature until 12 to 27 years of age, changes in recruitment may go undetected for relatively long periods of time, if only the adult portion of the population is monitored in standard surveys.

Habitat use and movement of sub-adult Lake Sturgeon is largely unknown for most systems. Establishing patterns of habitat use and movement at this life stage could assist managers in capturing sub-adult fish, which would provide a better understanding of recruitment. Sampling sub-adult sturgeon can provide a more immediate and accurate method for assessing the effectiveness of management actions on Lake Sturgeon recruitment. This monitoring is especially important for exploited populations, where changes to harvest management could be implemented if recruitment declines and increases can be detected before cohorts reach adulthood.

The Lake Winnebago System Lake Sturgeon population supports an annual spear fishery with average annual harvests of approximately 1,400 fish from a population of adults that is estimated at approximately 42,000 fish. Little information on sub-adult

Lake Sturgeon in the Lake Winnebago System is available and standardized sampling has not targeted these fish in the past. Fishery managers are interested in determining habitat use of sub-adult Lake Sturgeon to aid in developing recruitment surveys to better understand the population at this life stage.

While sub-adult Lake Sturgeon likely occupy multiple habitats in the Lake Winnebago System, the first phase of this research focused on sub-adult Lake Sturgeon in the lower Wolf River. The objectives of my study were to determine if: 1) numbers of sub-adult Lake Sturgeon in the lower Wolf River are sufficient to justify sampling this portion of the Lake Winnebago system as part of a basin-wide recruitment survey; 2) linear home range or movements of sub-adult Lake Sturgeon in the lower Wolf River varies in relation to season, sex, or total length (TL) category (small $<$ 96.0 cm TL; large $\geq$ 96.0 cm TL) and 3) sub-adult Lake Sturgeon selectively occupy certain habitats in the lower Wolf River in terms of substrate and channel morphology.

A total of eighteen sub-adult Lake Sturgeon were captured on the lower Wolf River during fall 2013 and 2014 using various sampling techniques. A total of 618.5 hours were invested in attempting to capture these fish. Sub-adult Lake Sturgeon were surgically implanted with radio-transmitters and released back into the river near capture locations. Relocation of fish was attempted every two weeks over the two years of the study, except for winter, when relocation attempts occurred once per month. Latitude, longitude, and substrate type were recorded at each relocation. Data collected were used to determine overall, annual, and seasonal linear home range sizes for each fish.

Side-scan sonar was used to collect images of the lower Wolf River that were uploaded into ArcGIS™. Substrates were identified with color-coded polygons that corresponded to different substrate types to create a substrate map of the entire study area. This map was used in conjunction with fish relocations to determine substrate use.

Linear home ranges did not differ in relation to sex or TL category, but did vary among seasons. The majority of movement for sub-adult Lake Sturgeon occurred in spring, which is similar to trends observed in previous studies of adult fish. Additionally, fish usually exhibited limited movement during winter (linear home range < 0.5 rkm). Selection ratios indicated that sub-adult Lake Sturgeon were not selecting for any substrate or channel morphology type.

Although some sub-adult Lake Sturgeon do occupy the lower Wolf River, I conclude that sufficient numbers of sub-adult Lake Sturgeon do not reside in the river to justify extensive sampling as part of a recruitment index survey. This information is important because sampling effort is typically limited by cost and logistics and my study suggests this effort may be better expended in other locations within the system. However, additional work is needed to determine where the largest concentration of sub-adult Lake Sturgeon reside within the Winnebago System, as there is still interest in developing a method for sampling sub-adult Lake Sturgeon to monitor recruitment trends before fish reach adulthood.

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INTRODUCTION

Understanding fish behavior in relation to available habitat is important for identifying and preserving critical habitat (Levin 2005; Norton et al. 2012; Martin et al. 2013) and in developing sampling techniques that effectively monitor fish populations and communities (Hansen et al. 2007; Sweka et al. 2007). Fisheries managers often require information on both adult and sub-adult components of a population for effective management (Young and Blinkoff 2003; Haxton 2011; Taylor and Arndt 2013), but acquiring this information can require different sampling techniques when adults and sub-adults do not use similar habitats (Young and Blinkoff 2003; Glass et al 2012). Furthermore, collecting information on fish populations in large, relatively complex ecosystems (e.g., Mississippi River, Great Lakes), where failure to sample different habitats (e.g., lotic vs. lentic, tributary vs. main channel) could prevent capture of certain segments of the population is important (Lapointe et al. 2006; Starr et al. 2010). Biologists often attempt to circumvent this problem for adult fish by sampling in and around spawning locations (Baker et al. 1993; Bruch et al. 1999), under the premise that this targeted sampling will be representative of the adult population (Baker et al. 1993). Targeted sampling for sub-adult fish can be more difficult because immature fish may be widely distributed and not exhibit well-defined seasonal movements (Quinones and Mulligan 2005; Mosley and Jennings 2007).

Habitat Mapping

Characterizing fish behavior in relation to habitat attributes can be time consuming and expensive when using traditional transect-based survey methods (Laustrup et al. 2007; Kaeser and Litts 2010; Kaeser et al. 2013). To reduce sampling time, towable sonar units have been employed to more efficiently delineate certain aspects of aquatic habitat such as substrate, aquatic macrophyte density and diversity, and the availability of woody debris (Amima et al. 2007; Manley and Singer 2008). Both of these methods have limited application in many riverine systems where turbidity prohibits rapid visual assessment of habitat, while large variations in stream depth and presence of woody debris may prevent widespread use of towable sonar units (Kaeser et al. 2013).

Portable and relatively inexpensive (< $3,000) side-scan sonar units have proven effective for habitat and substrate mapping (Kaeser and Litts 2010; Kaeser et al. 2013; Richter 2015). Kaeser et al. (2013) and Kaeser and Litts (2010) used side-scan sonar to map substrate and wood in the Lower Flint River and Ichawaynochaway Creek, Georgia, and reported that these methods reduced sampling time by 90% compared to a traditional visual surveys. Both studies included visual validation of sonar-based habitat classifications and observed habitat classifications to be 77-84% accurate. Richter (2015) reported that side-scan sonar offered an accurate and efficient technique for assessing substrate composition and quantifying Walleye *Sander vitreus* spawning habitat in the littoral-zone of northern Wisconsin lakes. Although use of this technology is rapidly expanding, side-scan sonar has not been thoroughly tested as a means to characterize aquatic habitat in rivers and streams.

Sturgeon Habitat Use and Movements

Sturgeon (Acipenseridae) populations have experienced widespread declines over their range in the Northern Hemisphere (Rochard et al. 1990; Birstein et al. 1997; Billard and Lecointre 2001). These declines can be largely attributed to overexploitation related to the high value of caviar (Boreman 1997), but loss of habitat and river connectivity has limited spawning potential of many populations (Pikitch et al. 2005; Colombo et al. 2007; Tripp et al. 2009; Phelps et al. 2010).

Many species of sturgeon appear to use similar habitats, especially in riverine systems (Kynard et al. 2000; Parsley et al. 2008; Koch et al. 2012). Kynard et al. (2000) observed that shortnose sturgeon *Acipenser brevirostrum* in two Massachusetts rivers avoided run habitats and selected for deeper river bends with sand substrate. Koch et al. (2012) reported that pallid sturgeon *Scaphirhynchus albus* in the middle Mississippi River used habitat located off the tip of wing dikes that often create deep scour holes with sand bottoms. Both studies hypothesized that sturgeon are selecting for these habitats because of greater food availability (Kynard et al. 2000; Koch et al. 2012).

Although habitat use and movement of adults has been described for several sturgeon species (Rusak and Mosindy 1997; McKinley et al. 1998; Auer 1999), there is less information on the behavior of sub-adult fish (but see Smith and King 2005a; Barth et al. 2011; Haxton 2011; Altenritter et al. 2013). Describing the behavior of sub-adult sturgeon is important for both rehabilitation efforts and gathering recruitment information for monitoring population status (Haxton 2011). Most sturgeon sampling is focused on adult fish (Haxton 2003; Koch et al. 2012; Damstra and Galarowicz 2013) and is often conducted in and around spawning locations (Bruch 1999; Lindley et al. 2011). For some sturgeon species, fish may not visit spawning locations until they mature at ages ≥ 12 for males and ages ≥ 18 for females (Bruch 1999; Peterson et al. 2007). Therefore, changes in recruitment may go undetected for relatively long periods of time. Sampling sub-adult sturgeon can provide a more immediate and accurate method for assessing the effectiveness of management actions and monitoring recruitment (Harkness and Dymond 1961; Haxton 2011).

Lake Sturgeon Life History and Movements

Historically, Lake Sturgeon *Acipenser fulvescens* were distributed in lakes and rivers of the Mississippi, Great Lakes, and Hudson Bay drainages (Peterson et al. 2007). Similar to other sturgeon species, Lake Sturgeon populations have experienced precipitous declines due to high exploitation and habitat fragmentation (Auer 1999; Bogue 2000). Lake Sturgeon display rapid growth during a prolonged sub-adult stage and do not reach maturity until age 12 to 15 for males and 18 to 27 for females (Scott and Crossman 1973; Bruch 1999, Bruch et al. 2001). Delayed maturation results from a disproportionate energy investment in somatic growth during the sub-adult life stage (Beamish et al. 1996; LeBreton and Beamish 2004). Although this strategy delays reproduction, it also results in low natural mortality, which is largely size-dependent (Crouse 1999).

Adult Lake Sturgeon primarily feed on benthic invertebrates in fine substrates (Harkness and Dymond 1961; Binkowski and Doroshov 1985; Chiasson et al. 1997). Lake Sturgeon diets can vary considerably both spatially and temporally (Chiasson et al. 1997; Beamish et al. 1998), but soft-bodied insect larvae have been reported to comprise up to 90% of prey volume when abundant (Harkness and Dymond 1961; Priegel and Wirth 1974; Stelzer et al. 2008). Because primary diet items are found in fine substrates, Lake Sturgeon often relate to these habitats when not in spawning cycles (Harkness and Dymond 1961).

Lake Sturgeon typically spawn during spring when water temperatures reach 10 to 15° Celsius (Harkness and Dymond 1961; Kempinger 1988; Auer 1996b; Smith and King 2005b). Most populations spawn on high-gradient river sections with current velocities of 0.5-1.3 m/sec and substrates of coarse gravel or cobble (Auer 1996a; McKineley et al. 1998). Lake Sturgeon can migrate over 200 km to reach spawning locations (Harkness and Dymond 1961; Priegel and Wirth 1974).

Lake Sturgeon exhibit one of the highest fecundities (49,000-667,000 eggs per fish) of freshwater fish in North America (Harkness and Dymond 1961; Scott and Crossman 1973; Bruch et al. 2006; Peterson et al. 2007). Lake Sturgeon are broadcast spawners with no parental care and high egg production may overwhelm predators and maximize reproductive output during favorable spawning years (Beamesderfer and Farr 1997; Peterson et al. 2007). Although Lake Sturgeon fecundity is high, recruitment is low because of extended spawning periodicity (Harkness and Dymond 1961) and low survival from egg to fall fingerlings. Females spawn once every 3 to 9 years and males spawn once every 1 to 3 years (Roussow 1957; Fortin et al. 1996). After deposition, eggs hatch in 8 to 14 days depending on water temperature (Kempinger 1988). Newly-hatched larvae are 9 to 11 mm TL and have a yolk sac (Kempinger 1988). For the first 13 to 19 days post hatch, larvae actively search for suitable refugia within the interstitial spaces of rocky substrates available at spawning locations (Harkness and Dymond 1961; Wang et al. 1985; Kempinger 1988). After this time period, larvae emerge at night and drift downstream with the current until they settle back to the river bottom (Kempinger 1988; LaHaye et al. 1992). In the Peshtigo River, Wisconsin, estimated mortality of Lake

Sturgeon from eggs to age-0 was 99.9% and mortality from larvae to age-0 ranged from 90.5 to 98.3% (Caroffino et al. 2010).

Extensive research has focused on Lake Sturgeon behavior, particularly on the movement and habitat use of adult fish (Fortin et al. 1993; Rusak and Mosindy 1997; McKinley et al. 1998; Auer 1999). Adult Lake Sturgeon can exhibit complex movement patterns (Rusak and Mosindy 1997; Borkholder et al. 2002; Smith and King 2005a; Adams et al. 2006) including large-scale movements to spawning locations (≥ 200 km; Harkness and Dymond 1961; Priegel and Wirth 1971; Auer 1999). However, large-scale movements among habitats are not restricted to spawning migrations (Rusak and Mosindy 1997; Borkholder et al. 2002; Knights et al. 2002). Previous studies have suggested habitat selection by adult Lake Sturgeon in rivers and lakes is related to substrate composition (Hay-Chmielewski 1987; Knights et al. 2002; Werner and Hayes 2004; Boase et al. 2011). In general, adult Lake Sturgeon occupy habitats <10 m deep with silt, mud, gravel, or sand substrates (Harkness and Dymond 1961; Rusak and Mosindy 1997; Haxton 2003; Trested et al. 2011).

Although habitat use of adult Lake Sturgeon has been well studied, habitat use of sub-adult fish remains largely unknown (Haxton 2011; Altenritter et al. 2013). Similar to adult fish, sub-adult Lake Sturgeon are presumed to relate to silt, sand, and fine gravel substrates, likely due to the availability of macroinvertebrate prey in these areas (Peake 1999; Benson et al. 2005; Smith and King 2005a; Trested et al. 2011). Sub-adults have also been located in areas with coarse substrates, particularly within rivers (Kempinger 1996; Barth et al. 2009; Mann et al. 2011). Movement studies have reported that sub-adult Lake Sturgeon can exhibit high site fidelity within seasons, while occupying different habitats among seasons (Smith and King 2005a; Barth et al. 2011; Trested et al. 2011; Altenritter et al. 2013).

Lake Sturgeon in the Lake Winnebago System

The Winnebago System is a large, shallow, eutrophic system in east-central Wisconsin including Lake Winnebago and three upriver lakes (Butte des Morts, Winneconne, and Poygan), that collectively cover 668 km^2 of surface water (Figure 1). The upper Fox River and the Wolf River (along with their major tributaries) flow into the Winnebago Pool Lakes and collectively drain a 15,540 km^2 watershed. Adult Lake Sturgeon migrate up both river systems to spawn each spring (Bruch and Binkowski 2002).

The Lake Winnebago system supports a robust, naturally-reproducing population of Lake Sturgeon, with an adult population estimate exceeding 42,000 fish (R. Koenigs, Wisconsin Department of Natural Resources [WDNR], personal communication). The Lake Sturgeon population in the Lake Winnebago system is intensively managed and supports an annual spear fishery that occurs in February with an average annual harvest of approximately 1,400 fish over the last 10 seasons (R. Koenigs, WDNR, personal communication). To avoid overexploitation, harvest quotas have been implemented restricting harvest to 5% of the adult population. Therefore, accurate estimates of adult population size are required to effectively implement the harvest cap system. Population abundance is estimated through mark-recapture techniques, where passive integrated transponders (PITs) are implanted in adult fish captured at spawning locations during spring dip-netting surveys and the annual spear fishery has a mandatory creel that provides the recapture sample (Bruch 1999).

Recruitment and abundance of sub-adult fish are not currently known and biologists are interested in developing sampling protocols that would collect adequate numbers of fish to estimate these metrics. Understanding sub-adult movement and habitat use could assist biologists with developing targeted sampling protocols for sub-adult Lake Sturgeon in the Lake Winnebago system. These sampling methods could be used to generate an index of recruitment ultimately allowing managers to detect changes in recruitment years before fluctuations in recruitment are detected using the current, adult-based assessment methods.

While sub-adult Lake Sturgeon likely occupy multiple habitats in the Lake Winnebago system, my research focused on sub-adult Lake Sturgeon in the lower Wolf River. The objectives of my study were to determine if: 1) numbers of sub-adult Lake Sturgeon in the lower Wolf River were sufficient to justify sampling as part of a basin-wide recruitment survey for the Lake Winnebago system; 2) linear home range or movements of sub-adult Lake Sturgeon in the lower Wolf River varied in relation to season, sex, or total length; 3) sub-adult Lake Sturgeon selectively occupied certain habitats in the lower Wolf River in terms of substrate and channel morphology.

METHODS

Study Site

My study was conducted on the lower Wolf River located in Shawano, Outagamie, Waupaca, and Winnebago counties in central Wisconsin. This portion of the Wolf River begins at the Shawano Paper Mill Dam in Shawano, Wisconsin and ends where the river enters Lake Poygan (≈ 160 river km; rkm). From the Shawano Paper Mill Dam to Lake Poygan there is a 14.8 m elevation drop with a slope of 0.10 m/km. From Shawano downstream to Shiocton (upper 72.5 rkm), the Wolf River is characterized by a shallow (< 2 m deep), narrow (50-80 m wide), sandy river bed with intermittent sand bars and small, low lying islands. In comparison, the river from Shiocton downstream to Lake Poygan (lower 87.5 rkm), is characterized by runs (< 3 m deep) and bends containing relatively deep water (> 8 m) on outside portions. River widths in this section are typically wider than further upstream (75 to 175 m). Major fish species occurring in the Wolf River with Lake Sturgeon are Walleye, Smallmouth Bass *Micropterus dolomieu*, Largemouth Bass *Micropterus salmoides*, Northern Pike *Esox lucius*, Freshwater Drum *Aplodinotus grunnies*, White Sucker *Catostomus commersonii*, several species of redhorse *Moxostoma* spp., Channel Catfish *Ictalurus punctatus*, Flathead Catfish *Pylodictis olivaris*, several species of minnows (Cyprinidae), and several species of darters (Percidae).

Sub-Adult Sampling and Radio Telemetry

For my study, Lake Sturgeon between 40 and 130 cm total length (TL) that had not reached sexual maturity were classified as sub-adults. A total of 18 sub-adult Lake Sturgeon were collected during fall 2013 (n = 12) and 2014 (n = 6) using gill nets (n = 2), trotlines (n = 1), electrofishing (n = 13), and SCUBA diving (n = 2; Table 1). Gill nets consisted of 22.86-m x 1.83-m panels of multifilament mesh with stretch-measure sizes ranging from 2.54 cm to 15.24 cm (Leckies Net and Twine, Winnipeg, Manitoba). Trotlines were constructed with 550 paracord with 100 pound test, 1-m long droppers rigged with 4/0 hooks that were spaced at 1.5-m intervals. Hooks were baited with dead shrimp, dead young of year freshwater drum *Aplodinotus grunniens*, or earthworms *Lumbricus terrestris*. Electrofishing runs were conducted during the day with three Wisconsin-style boom shocking boats (pulsed DC current, 25% duty cycle, 550 pulses per second, 8-12 amps, 120-150 volts) sampling in a downstream direction. Boats were aligned in a perpendicular line to shore such that multiple downstream transects were simultaneously covered on each run. A total of 39.4 rkm were sampled with electrofishing over five different days (2 d in September 2013, 1 d in October 2013, and 2 d in November 2014). SCUBA diving targeted deeper holes with two SCUBA divers sampling simultaneously. SCUBA divers grabbed Lake Sturgeon by hand and placed fish into mesh bags before transporting fish to the surface. A total of 1.5 hours were spent diving with two divers at 4 different locations on the river (Table 2). To assess efficiency of using each gear type for collecting sub-adult Lake Sturgeon, catch per hour was calculated. Additionally, time required to collect 30 sub-adult fish was calculated for each gear type.

All sub-adult Lake Sturgeon were measured (nearest 0.25 cm TL) and weighed (nearest g). Passive integrated transponders (PIT; Biomark® FDX-A 125 kHz) were implanted via syringe under the skull plate of each fish. All fish were also implanted with radio transmitters (Advanced Telemetry Systems® models F1835 and F1840) to monitor movements and habitat use following release. Radio tags were surgically implanted into the sturgeon's abdomen and each transmitter weighed 14 g or 20 g in water. Larger radio transmitters were implanted in larger fish, such that transmitter weight was always < 2% of total fish weight (Knights and Lasee 1996). Expected radio transmitter life was 654 d for 14 g transmitters and 869 d for 20 g transmitters.

Radio transmitters were inserted through a 6 to 9 cm incision made distal of the midline, 4-5 ventral scutes posterior to the head. Sex and maturity of tagged fish were determined following methods presented by Bruch et al. (2001) using visual inspection of gonads through the incision. All tagged fish were considered immature and were not going to spawn within the timeframe of the study. External radio antennas were passed through a hole created posterior to the incision with a shielded needle. Incisions were closed using 2/0 monofilament sutures (typically 3 sutures were needed) and then flushed with oxytetracycline antibiotic. Fish were monitored in a tank until they exhibited normal movements and were able to maintain equilibrium.

Lake Sturgeon movements were monitored from date of tagging until 2 June 2015. Lake Sturgeon were located once every two weeks during the open-water period and once a month during months when the river was frozen. Lake Sturgeon were located by boat or airplane using an Advanced Telemetry Systems® Model R2100 receiver. Depth (m), stream width (m), general channel morphology (e.g., run, outside bend), fish position in river channel, and latitude and longitude when fish were located by boat. Depth, latitude, and longitude were collected using a Lowrance™ (Lowrance™ Electronics, Tulsa, Oklahoma) LMS-522C iGPS sonar unit mounted to the boat. Stream width was estimated with a Nikon® Laser 800 rangefinder by ranging the shoreline perpendicular to the channel on each side of the boat. Substrate was determined using an Ekman dredge deployed as close to the fish's location as possible. Substrates were grouped into categories using a modified Wentworth (1922) scale including fine (< 2 mm), gravel (> 2 mm and < 32 mm), cobble (> 32 mm and < 256 mm), boulder (> 256 mm), large woody debris (> 10 cm diameter), and rip rap classifications. Only latitude and longitude were recorded when fish were located by plane. Flights were used to locate fish in the Wolf River and in Lakes Butte des Morts, Winneconne, and Poygan. However, no effort was made to locate fish in Lake Winnebago because of the time required to adequately cover the entire lake.

Habitat Availability

Substrate composition and presence of large woody debris in the lower Wolf River was inventoried using a Lowrance™ Structure Scan® LSS-2 and a HDS® sonar mounted via a custom bracket to the bow of a flat bottom boat during spring 2014. Substrate mapping consisted of one downstream run of the entire stretch of river (≈ 160 km) with the boat positioned mid channel and moving at 6.5 to 8 km/hour. This allowed the sonar to scan both shorelines simultaneously. The sonar was set at 71% contrast, a frequency of 455 kHz, medium noise rejection, surface clarity off, with scroll speed set at normal. We conducted the sonar survey in spring when the river was out of its banks to capture all substrate and woody debris within the bank-full width.

The program SonarTRX© (Leraand Engineering Inc., Honolulu, Hawaii) was used to convert sonar files to keyhole markup language (KML) files, which are compatible with ArcGIS™ (ESRI, Redlands, California). SonarTRX© was also used with raw sonar files to export all depth readings at 1-second intervals to create a bathymetric map of the river using ArcGIS™. Sonar files were uploaded into ArcGIS™ to create a sonar image map (SIM). The SIM was layered over aerial images taken in 2010 and obtained from www.wisconsinview.org. The SIM and aerial images were based on the Wisconsin Transverse Mercator coordinate system. Aerial images were used to digitize the stream bank and the SIM was used to manually build a layer of substrate types available in the river. Substrates were grouped into the previously described categories following a modified Wentworth (1922) scale. Substrates were manually defined from the SIM. Polygons with color-coded boundaries were created around areas of specific substrates. A minimum map unit was established at a 3-m radius (area of 28.27 m^2); this area represented the smallest possible polygon for any substrate category.

To assess the accuracy of substrate assignments, thirty sampling points for each substrate category were randomly selected from the map. Only thirteen points were available for the boulder category, thus all were sampled. At each selected sampling point, I determined substrate using a substrate grab collected with an Ekman dredge or by visual inspection in shallow water. Three sites were unable to be confirmed due to water velocities and turbidity; these sites were not included in the analysis. An error matrix was used to assess accuracy of my sonar interpretations based on the randomly selected sampling points (Congalton 1991). This error matrix was also used to describe the total accuracy of the sonar-based substrate assignments by dividing total correct classifications by the total sampling points (Congalton 1991; Kaeser et al. 2013).

Data Analysis

Detection locations from each radio-tagged fish were used to estimate overall, annual, and seasonal linear home ranges (LHRs). Seasons were defined as: spring: April-May; summer: June-August; fall: September-November; winter: December-March. Linear home ranges represented total number of rkm between the furthest upstream and downstream detections for an individual fish (Young 1999; Crook 2004) within a specified time interval. Linear, rather than area-based, home ranges were used because the linear method allowed me to include airplane contacts that may appear to be on land and eliminated the need to account for variation in available habitat resulting from water level fluctuations. Seasonal LHRs were only calculated for fish detected at least twice within the lower Wolf River in a specific season. Seasonal LHR data was not normally distributed and standard transformations did not alleviate this violation of parametric statistical methods. Furthermore, these data represented repeated measures on individual fish. Therefore, I rank-transformed seasonal LHR data and used a Friedman's test (α = 0.05; PROC FREQ procedure available in SAS® version 9.2) to determine if LHR varied in relation to season while controlling for sex and TL category (small $<$ 96.0 cm TL; large $\geq$ 96.0 cm TL). Dunn's tests (α = 0.05) incorporating rank sums were used to make multiple comparisons (Zar 1999). Dunn's tests were performed in R version 3.0.1 using the CRAN package dunn.test.

Substrate selection by sub-adult Lake Sturgeon was assessed using individual fish as sampling units (Manly et al. 1993; Rogers and White 2007; Koch et al. 2012). Proportions of each substrate type available in the river were estimated from 1,000 points randomly-selected by ArcGIS from the substrate map. Log-likelihood ratio chi-square tests ($\alpha = 0.05$) were used to determine if fish selected for specific substrate types (Manly et al. 1993; DeGrandchamp et al. 2008; Koch et al. 2012). Specifically, I used the chi-square equation presented by Manly et al. (2002) to assess substrate selectivity:

$$\chi^2 = 2\sum_{j=1}^{n}\sum_{i=1}^{I} u_{ij} \log_e[u_{ij}/E(u_{ij})],$$

where u_{ij} = total amount of substrate type i used by fish j. Expected values were calculated as $E(u_{ij}) = \pi_i u_{+j}$, where π_i is the proportion of available units of substrate type i and u_{+j} is the total amount of all substrate units used by fish j. Analysis was performed using SAS® 9.2 with code provided in Rogers and White (2007). Probability values (P) from chi-square tests indicate if a fish was selective for certain substrate types (Manly et al. 2002; DeGrandchamp et al. 2008).

Selection ratios ($\hat{W}_i$; Manly et al. 2002) were used to determine the type of substrate selected for or avoided by the population of all radio tagged fish among seasons and over the entire duration of the study:

$$\hat{W}_i = {}^{u_{i+}}/_{(\pi_i \; u_{++})}$$

where u_{i+} is the amount of substrate type i used by all fish and u_{++} is the total number of substrate units used by all fish. A selection ratio ($\hat{W}_i$) > 1 indicated selection, $\hat{W}_i < 1$ indicated avoidance, and $\hat{W}_i = 1$ indicated neither selection nor avoidance (DeGrandchamp et al. 2008). Bonferroni confidence intervals (95%) were calculated for each mean selection ratio to determine if $\hat{W}_i = 1$ was within the confidence interval, suggesting neither selection nor avoidance occurred (Thomas and Taylor 1990;

DeGrandchamp et al. 2008). Selection ratios and Bonferroni confidence intervals were calculated in Microsoft® Excel 2010.

Lastly, habitat use of sub-adult Lake Sturgeon was assessed in relation to general channel morphology. Channel morphology was categorized as run, outside bend, inside bend, and mid-channel of a bend. I used a log linear model ($\alpha = 0.05$) to evaluate potential associations with channel morphology type in relation to season. Log-linear modeling was conducted using the PROC CATMOD procedure available in SAS® version 9.2.

RESULTS

I collected 18 sub-adult Lake Sturgeon that were implanted with radio transmitters. Capture locations ranged from rkm 85.3 to 198.8 with the majority of fish being captured above rkm 188.3 (Table 2). Electrofishing captured the majority of fish used in my study (0.542 fish/h; N = 13 fish), while fall SCUBA diving was the most effective sampling gear based on fish caught per hour (1.33 fish/h; N = 2 fish captured). A total of 209 gill net hours captured two sub-adult Lake Sturgeon (0.01 fish/h) and 384 trotline hours captured only a single fish (0.003 fish/h; Table 3). Time needed to capture 30 fish with each sampling gear ranged from 22.5 hours using SCUBA diving to 11,520.0 hours using trotlines (Table 3).

Ten of the fish tagged were male, six were female, and sex could not be determined for two fish. Mean TL of male fish was 107.3 cm (SD = 13.9; range = 93.5-129.3) with a mean weight of 5.4 kg (SD = 2.1 kg; range = 3.5-9.7). Mean TL of female fish was 90.9 cm (SD = 9.5; range = 77.7-99.1) with a mean weight of 3.7 kg (SD = 2.1; range = 2.3-4.7). The two fish of unknown sex were 84.6 cm and 67.6 cm long and weighed 2.6 kg and 1.4 kg, respectively.

Movement

Sub-adult Lake Sturgeon displayed variable movement patterns, with the majority of movement occurring in spring (Figures 2-20). However, some sub-adult Lake Sturgeon did exhibit similar movement patterns. Two Lake Sturgeon migrated >100 km upstream from winter home ranges to summer home ranges. Movements to summer home ranges in the upper river (rkm 184 to 201) occurred between early April and early

June, and the two fish migrated back downstream to winter home ranges (rkm 32 to 85) from September to January. Movements of these fish appeared to correspond to changes in water temperature. In particular these fish made their movements shortly after water temperatures started to change from yearly highs to yearly lows (18°C to near 0°C) and also when yearly lows started increasing back to yearly highs (0°C to 22°C; Figures 6 and Figure 17).

Six fish tagged above rkm 167 remained close to their original capture locations, but made upstream movements to or near known Lake Sturgeon spawning sites while spawning was observed at these locations. Specifically, five of these fish moved upstream to the Shawano Paper Mill Dam (rkm 201.4) which represents the upstream barrier to further movement and attracts the largest concentration of spawning Lake Sturgeon in the Lake Winnebago system (Figures 4, 5, 7, 12, 15, and 19). Movement to or near known spawning locations during Lake Sturgeon spawning season was observed in other tagged sub-adults as well (Figures 6, 9, 11, and 17). This behavior was exhibited by five of nine tagged fish (3 males, 4 females, 2 unknowns) that were within the river during spring 2014 and seven of ten fish (7 males, 2 females, 1 unknown) that were within the river during the spring 2015. When evaluating this by sex over both springs every male still within the river moved upstream to or near spawning sites, whereas only two females exhibited this behavior during spring of 2014 and no females exhibited this behavior in spring of 2015.

Four fish tagged above rkm 188.3 made large movements downstream (> 90 rkm) within a month after tagging and ultimately were located in Lake Poygan or Lake Winneconne (Figures 2, 3, 10, and 16). These fish were relocated at multiple locations within these lakes during the study and did not reenter the Wolf River during the study period. By the end of the tracking period three other fish had moved downstream into Lake Poygan or Lake Winneconne (Figures 6, 9, and 11). Two of these fish had remained in the river for nearly one year before moving downstream to the lakes. The third fish was in the river for five months before moving out of the river into Lake Poygan. Of the seven fish that left the river during the study, six did so in the fall with the other fish moving out of the river during spring. None of these three fish reentered the Wolf River during the study period, but were located at multiple locations within Lake Poygan on multiple dates. Lastly, by the end of the study period, two fish were unaccounted for despite numerous attempts, contact had not been made between 10 and 14 months prior to the end of the study (Figure 8, and Figure 14). One of these fish was last contacted at rkm 185.9 and the other at rkm 85.3. These fish were omitted from habitat selection and LHR calculations at overall and annual levels, but were included in seasonal calculations if I had multiple relocations of each within a season.

Median annual LHRs of sub-adult Lake Sturgeon were different between year 1 (106.2 rkm, range 0.8 to 166.6) and year 2 (34.2 rkm, range 1.6 to 162.5) of the study, but ranges were similar. Seasonally, sub-adult Lake Sturgeon had the largest median LHRs during spring (15.7 rkm, range 0 to 143.2) and smallest median LHRs during winter (0 rkm, range 0 to 5.7). Summer and fall had median LHRs of 6.1 rkm (range 0 to 12.1) and 2.4 rkm (range 0 to 174.7) respectfully.

Median LHR of sub-adult Lake Sturgeon was significantly different among seasons when controlling for sex and TL category ($\chi^2 = 23.99$, df = 6, $P < 0.001$, Figure 20). Dunn's multiple comparison tests indicated that ranked seasonal LHRs did not differ between sexes, TL categories, or years ($P > 0.05$). Most fish moved < 1 rkm during winter (i.e., median LHR = 0) and pairwise comparisons indicated LHRs during winter was significantly less than all other seasons (Figure 20). Pairwise comparisons also indicated sub-adult Lake Sturgeon had significantly larger LHRs in spring than during fall. Summer LHRs were also smaller than in spring, but this difference was not statistically significant.

Habitat Use

Based on in-field validation of substrate at 163 sites, the overall accuracy of the substrate map was 82.9% (Table 4). Boulder and wood substrates were classified with 100% accuracy, while rip rap and fine substrates were classified with > 90% accuracy (96.7% and 93.3%, respectfully). Gravel and cobble were identified with the lowest levels of accuracy (60.0% and 60.6%, respectfully) and were generally misclassified as fine substrates. Overall, the lower Wolf River was dominated by fine substrates (86.7%) with no other substrate comprising > 7.5% of the river (Figure 21).

I used 102 relocations of 15 fish to assess substrate use by sub-adult Lake Sturgeon. Sub-adult Lake Sturgeon were generally observed at locations with fine sediments (89% of locations; Figure 22) and were rarely located over gravel (3 relocations), rip rap (4 relocations), and wood (4 relocations; Figure 22). A log-likelihood chi-square test including all fish relocations indicated that sub-adult Lake Sturgeon were not selecting for specific habitats at the population level (χ^2=30.98, P = 0.89). Further, 95% Bonferroni confidence intervals for habitat selection ratios ($\hat{W}_i$) included 1 for all four substrate types where sub-adult Lake Sturgeon were relocated, indicating neither selection nor avoidance (Table 5). Lastly, frequency of relocations in different channel morphology types was not significantly different between seasons (χ^2=10.25, $P > 0.12$) or over the course of the study (χ^2=3.97, $P > 0.41$; Figure 23).

DISCUSSION

The large sampling effort required (618.5 h) to capture 18 sub-adult Lake Sturgeon suggests the lower Wolf River does not contain sufficient numbers of sub-adult fish to justify extensive sampling within the river as part of a basin-wide recruitment survey. If sampling for sub-adult Lake Sturgeon was conducted on the lower Wolf River, I recommend electrofishing as the primary sampling gear because we were able to capture 13 fish in a relatively short time period in comparison to the other gears used. SCUBA diving did lead to the capture of two fish in only one and a half hours of sampling, and this gear should be experimented further as it may yield more effective results than electrofishing. Both proposed methods have limitations within the lower Wolf River. Due to increasing water depths further downstream, electrofishing is only an effective sampling gear for the upper 40 km of the river, while SCUBA diving typically can only be performed in the late fall when water clarity is optimal. Further, diving in cold weather poses logistical and safety challenges, but this would be the preferred gear for sampling deeper pools within the lower Wolf River.

Realistically, none of the sampling gears I used represent feasible sampling options for Wisconsin DNR in light of projected costs and logistics. For example, 55.4 hours of electrofishing would be required to capture a sample of 30 sub-adult Lake Sturgeon (Table 3), but this sampling actually requires a minimum of nine people (i.e., three per boat). Consequently, nearly 500 personnel hours would be required to capture 30 fish, representing an approximate cost of between $6,000 and $10,000 depending on employee hourly wages. This cost does not include gas, mileage, lodging, or meals needed to complete the sampling.

Some sub-adult Lake Sturgeon residing in the Wolf River (7 of 18 tagged fish) move downstream and out of the river before reaching sexual maturity. This observation, combined with low capture rates suggest that the next phase of this research focus on developing sampling techniques and monitoring the movements of sub-adult fish within Lakes Butte des Morts, Winneconne, and Poygan. Initiating a pilot project on these waters to identify sampling methods that maximize capture of sub-adult Lake Sturgeon would seem a logical next step in this process.

The reasons for sub-adult fish moving out of the Wolf River are unknown at this time. Food availability may be a factor, as the upriver lakes and Lake Winnebago have a high abundance of Chironomid larvae, which are a primary diet item for Lake Sturgeon in the Lake Winnebago System (Stelzer et al. 2008). Energy expenditure may also lead to sub-adult Lake Sturgeon leaving the river, as the upriver lakes exhibit low current velocities compared to the lower Wolf River. Also, many adult Lake Sturgeon that will spawn in the Wolf River during spring start migrating upriver during fall (R. Koenigs, WDNR, personal communication), which could cause sub-adult fish to be displaced and abandon optimal fall and winter habitat within the river.

Linear home ranges of sub-adult Lake Sturgeon did vary among seasons and among individual fish. My results suggest that sub-adult Lake Sturgeon remaining in the lower Wolf River moved very little during winter and that the majority of in-river movement occurred during spring and summer. Borkholder et al. (2002) reported similar results for five adult Lake Sturgeon on the Kettle River, Minnesota; home ranges were largest in the spring with little to no movement observed during winter. Trested et al. (2011) radio tagged 23 Lake Sturgeon (12 sub-adults and 11 adults) on the Grasse River, New York, and reported that both adults and sub-adults exhibited significantly larger mean home ranges during spring compared to summer, fall, and winter. However, these studies did not observe significant differences in home range size among summer, fall, or winter and reported smallest home range sizes during fall, rather than winter.

Two of the tagged fish demonstrated clear seasonal home ranges (located 106 and 145 km apart), with a winter home range in the lower portion of the river and a summer home range located in the upper section of the river. Wishingrad et al. (2014) radio tagged 60 adult Lake Sturgeon on the Saskatchewan River, Saskatchewan, and reported these fish used separate summer and overwintering areas that were, on average, 92 ± 64 km apart. Altenretter et al. (2013) implanted acoustic transmitters into 20 sub-adult Lake Sturgeon (age 1-7) in Muskegon Lake, Michigan, and reported separate summer and fall spatial distributions of fish and seasonal movements coinciding with fall turnover and changes in dissolved oxygen. Fish moved from a shallow area near the mouth of the Muskegon River in the summer to the deepest part of the lake in the fall (Altenretter et al. 2013). These movements are consistent with those observed for the two fish in my study that occupied winter and summer home ranges in different portions of the Wolf River.

Most previous studies of sub-adult Lake Sturgeon have reported little movement, small home ranges, and little to no seasonal differences in movement (Smith and King 2005a; Lord 2007; Barth et al. 2011). Lord (2007) implanted nine sub-adult Lake Sturgeon in the St. Clair River, Michigan, with acoustic transmitters and reported home range sizes between 0.8 and 10.8 km^2 over two summers of tracking. Barth et al. (2011) tagged 20 sub-adult Lake Sturgeon in the Winnipeg River, Manitoba, and reported that half of the fish had home ranges less than 1.5 rkm over the course of the study. Lastly, Smith and King (2005a) estimated home range sizes between 4.79 and 7.27 km^2 for five sub-adult Lake Sturgeon in Black Lake, Michigan. All three of these studies reported substantially smaller home range sizes than I observed in the lower Wolf River. On average, the fish tagged in my study were larger and presumably closer to maturity than the fish tagged by Lord (2007) and Barth et al. (2011; TL < 83 cm), which may explain observed differences in behavior. Smith and King (2005a) tagged fish similar in size to the fish in my study, but their study took place in a lentic environment, so comparisons between studies may not be valid.

I observed many sub-adult fish exhibiting movements resembling migrations made by gravid adults to or near spawning areas. In particular, every male that was within the river during either spring made a pre-pubescent spawning run. Other studies investigating movements of sub-adult Lake Sturgeon reported no indication of these pre-pubescent, apparently "false" spawning runs (Smith and King 2005a; Barth et al. 2011). However, Lord (2007) and Barth et al. (2011) tagged smaller (< 83 cm TL) and presumably younger Lake Sturgeon for their studies. Many of the sub-adult Lake Sturgeon I tagged were likely within a few years of spawning for the first time, especially the males because they mature at a younger age and smaller size. Proximity to maturity may explain the adult-like movements to or near spawning sites within the lower Wolf River. Alternatively, Lake Sturgeon in the Lake Winnebago System are commonly viewed on the spawning grounds actively feeding on deposited eggs and sub-adult sturgeon may move to these spawning sites to consume sturgeon eggs.

The accuracy of the substrate map I created for the lower Wolf River was similar to accuracy reported in other studies applying similar side-scan sonar techniques in riverine environments (Kaeser and Litts 2010, 77%; Kaeser et al. 2013, 84%). Additionally, my errors in substrate classification were similar to those reported in previous studies. Specifically, previous studies combined gravel and cobble into a single substrate category referred to as “rocky-fine” and the authors often misclassified this substrate as “sandy”. This type of error was similar to my misclassification of gravel or cobble as fine sediments.

Accuracy of the substrate map would improve if multiple passes were taken with side-scan sonar. Additionally, Kaeser et al. (2013) recommended that best-quality images are obtained when the side-scan unit is set to record ≤ 49 m per side. Wider image areas can lead to distortion. My scanning was completed in one pass (usually scanning wider than 49m per side) and this could have contributed to map error. However, the substrate map I produced was similar in accuracy to the two studies that recorded < 49 m per side when collecting images with the side-scan sonar.

Substrate within the lower Wolf River primarily consisted of fine sediments (86.7%) and sub-adult Lake Sturgeon were generally observed over fine sediment. However, results indicate that fish were not selecting for any specific substrate. Other studies have reported that sub-adult Lake Sturgeon tend to relate to fine substrates and the preference has been related to the increased presence of prey species like Dipteran larvae within these substrates (Kempinger 1996; Chiasson et al. 1997; Beamish et al. 1998; Holtgren and Auer 2004; Smith and King 2005). Sub-adult Lake Sturgeon may select for fine substrates in the lower Wolf River and other rivers, but the predominance of fine substrates within the lower Wolf River system effectively eliminated my ability to determine selection for this substrate.

In conclusion, while some sub-adult Lake Sturgeon do occupy the lower Wolf River, I conclude that the river does not contain sufficient numbers of sub-adult Lake Sturgeon to justify extensive sampling as part of a basin-wide recruitment survey. Furthermore, over the course of my study, 39% of the sub-adult Lake Sturgeon I tagged left the river and never returned. Reducing the spatial extent of recruitment sampling is important because effort will be limited by cost and logistics. My results suggest that sampling effort may be better expended in other locations within the Winnebago system. However, additional work is needed to determine the location of sub-adult Lake Sturgeon in the Winnebago system as there is still interest in developing a method for sampling sub-adult Lake Sturgeon to measure recruitment before fish reach adulthood.

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Table 1. Dates and locations (local names and river km [rkm]) of sampling efforts to capture sub-adult Lake Sturgeon on the lower Wolf River, Wisconsin. Gear types are: EF = electrofishing, SC = SCUBA diving, TL = trotline, and GN = gill net.

Date Set	Date pulled	Gear	Location	River Km	Fish Captured
09/08/2013	09/09/2013	GN	Shiocton Foot Bridge	127.1	0
09/08/2013	09/09/2013	GN	Singlers	126.3	0
09/09/2013	09/10/2013	GN	Shawano Dam	201.2	0
09/09/2013	09/10/2013	GN	Bret Stempas	198.8	1
09/09/2013	09/10/2013	GN	The Pines	153.7	0
09/10/2013	09/11/2013	GN	Boom Cut	40.2	0
09/10/2013	09/11/2013	GN	Devil's Elbow	74.8	0
09/10/2013	09/11/2013	GN	Big Eddy	86.9	1
09/10/2013	09/11/2013	GN	Northport	84.5	0
09/10/2013	09/11/2013	GN	Oxbow	85.3	0
09/11/2013	09/12/2013	GN	Shirttail Bend	82.1	0
09/11/2013	09/12/2013	GN	Big Hole	74.8	0
09/11/2013	09/12/2013	GN	Upstream of Big hole	78.1	0
10/14/2013	10/16/2013	TL	Big Eddy	86.9	0
10/14/2013	10/16/2013	TL	Northport	84.5	0
10/14/2013	10/16/2013	TL	Oxbow	85.3	1
10/14/2013	10/16/2013	TL	Singlers	126.3	0
10/14/2013	10/16/2013	TL	Colwitz	129.6	0
10/14/2013	10/16/2013	TL	Bamboo Bend	127.9	0
09/12/2013		EF	HWY 156 - Fuhrmans	162.5-169.8	0
09/25/2013		EF	School Section Creek - Split Rail	185.9-193.1	2
10/29/2013		EF	School Section Creek - Split Rail	184.3-193.1	5
11/04/2013		SC	Lumberyard	127.9	1
11/04/2013		SC	Colwitz	129.6	0
11/04/2013		SC	Lower Singlers	125.5	0
11/14/2013		SC	Oxbow	85.3	1
11/05/2014		EF	Hwy 156	162.5-169.8	3
11/13/2014		EF	School Section Creek - Split Rail	184.3-193.1	3

Table 2. Total length (TL), weight, sex, sampling date, gear, capture location, and last contact information for sub-adult Lake Sturgeon implanted with radio transmitters in the lower Wolf River, Wisconsin, during fall 2013 and 2014. Transmitter ID represents radio frequency for each individual fish. Fish were relocated from August 2013 to June 2015. Sexes represent M = male, F = female, and UN = unknown. Gears were: EF = electrofishing, SC = SCUBA diving, TL = trotline and GN = gill net.

Transmitter ID	Date Tagged	Release Location (rkm)	Last Contact	Last Relocation (rkm)	TL (cm)	Weight (kg)	Sex	Gear
50.031	10/29/2013	188.3	05/13/2015	Lake Poygan	95.3	4.1	M	EF
50.071	11/13/2014	188.3	05/29/2015	Lake Poygan	77.7	2.3	F	EF
50.091	11/13/2014	188.3	06/02/2015	200.4	114.3	6.8	M	EF
50.101	11/05/2014	169.0	05/29/2015	200.4	114.0	6.7	M	EF
50.111	11/14/2013	85.3	05/29/2015	Lake Poygan	98.0	4.4	F	SC
50.122	10/29/2013	188.3	06/02/2015	193.9	93.5	4.2	M	EF
50.132	10/29/2013	188.3	04/24/2014	185.9	99.1	4.7	F	EF
50.153	09/25/2013	188.3	05/29/2015	Lake Poygan	96.8	4.5	M	EF
50.161	10/29/2013	188.3	03/11/2015	Lake Poygan	94.0	3.9	M	EF
50.171	11/13/2014	188.3	05/13/2015	Lake Poygan	121.2	N/A	M	EF
50.181	11/05/2014	167.0	05/29/2015	190.7	120.7	N/A	M	EF
50.191	11/04/2013	128.7	06/02/2015	135.2	81.0	2.3	F	SC
50.201	10/15/2013	85.3	08/20/2014	85.3	84.6	2.6	UN	TL
50.211	11/05/2014	169.0	05/29/2015	188.3	129.3	9.7	M	EF
50.223	09/09/2013	198.8	03/11/2015	Lake Poygan	98.6	4.4	F	GN
50.232	09/25/2013	188.3	06/02/2015	118.3	91.2	4.1	F	EF
50.243	09/10/2013	86.9	03/26/2015	85.3	67.6	1.4	UN	GN
50.251	10/29/2013	188.3	06/02/2015	186.7	94.5	3.5	M	EF

Table 3. Sampling methods used to capture sub-adult Lake Sturgeon in the lower Wolf River, Wisconsin, during fall of 2013 and 2014. Effort, number of fish captured, catch per hour (CPH), and hours to catch 30 fish (HC30) are reported for each method.

Sampling Gear	Days	Sets	Hours	Study Fish Caught	CPH	HC30
Gill Net	6	19	209.0	2	0.010	3,135.0
Trotline	3	8	384.0	1	0.003	11,520.0
SCUBA Diving	2	-	1.5	2	1.333	22.5
Boom Shocking	5	-	24.0	13	0.542	55.4
Total	16	27	618.5	18	-	-

Table 4. Error matrix describing total accuracy of map-based substrate assignments. Thirty reference sites for each substrate (only 13 total sites for boulder) were randomly selected on the substrate map using ArcGIS™. These sites were evaluated in the field using an Ekman dredge or visual inspection, substrate was unable to be determined at three field sites and these were not used in analysis (2 wood sites and 1 boulder site). Accuracy calculated represents total correct classifications divided by total sampling points.

	Reference Site Data (Field Data)							
Classified Data	Fine	Gravel	Cobble	Boulder	Rip Rap	Wood	Row Total	Accuracy
Fine	**28**	2	0	0	0	0	30	93.3%
Gravel	9	**18**	2	0	1	0	30	60.0%
Cobble	8	2	**20**	0	0	3	33	60.6%
Boulder	0	0	0	**12**	0	0	12	100.0%
Rip Rap	0	0	0	1	**29**	0	30	96.7%
Wood	0	0	0	0	0	**28**	28	100.0%
Column Total	45	22	22	13	30	31	**163**	
								Overall Accuracy: 82.9%

Table 5. Substrate selection ratios ($\hat{W}_i$) for all sub-adult Lake Sturgeon relocations in the lower Wolf River, Wisconsin, where $\hat{W}_i > 1$ indicates selection, $\hat{W}_i < 1$ indicates avoidance, and $\hat{W}_i = 1$ indicates neither selection nor avoidance. If $\hat{W}_i = 1$ falls within the Bonferroni 95% confidence intervals, neither selection nor avoidance of that substrate type was occurring.

Habitat	N	$\hat{W}_i$	Upper CI	Lower CI
Fine	91	0.989	1.041	0.936
Gravel	3	5.612	252.967	0.000
Rip rap	4	0.959	27.757	0.000
Wood	4	0.764	20.267	0.000

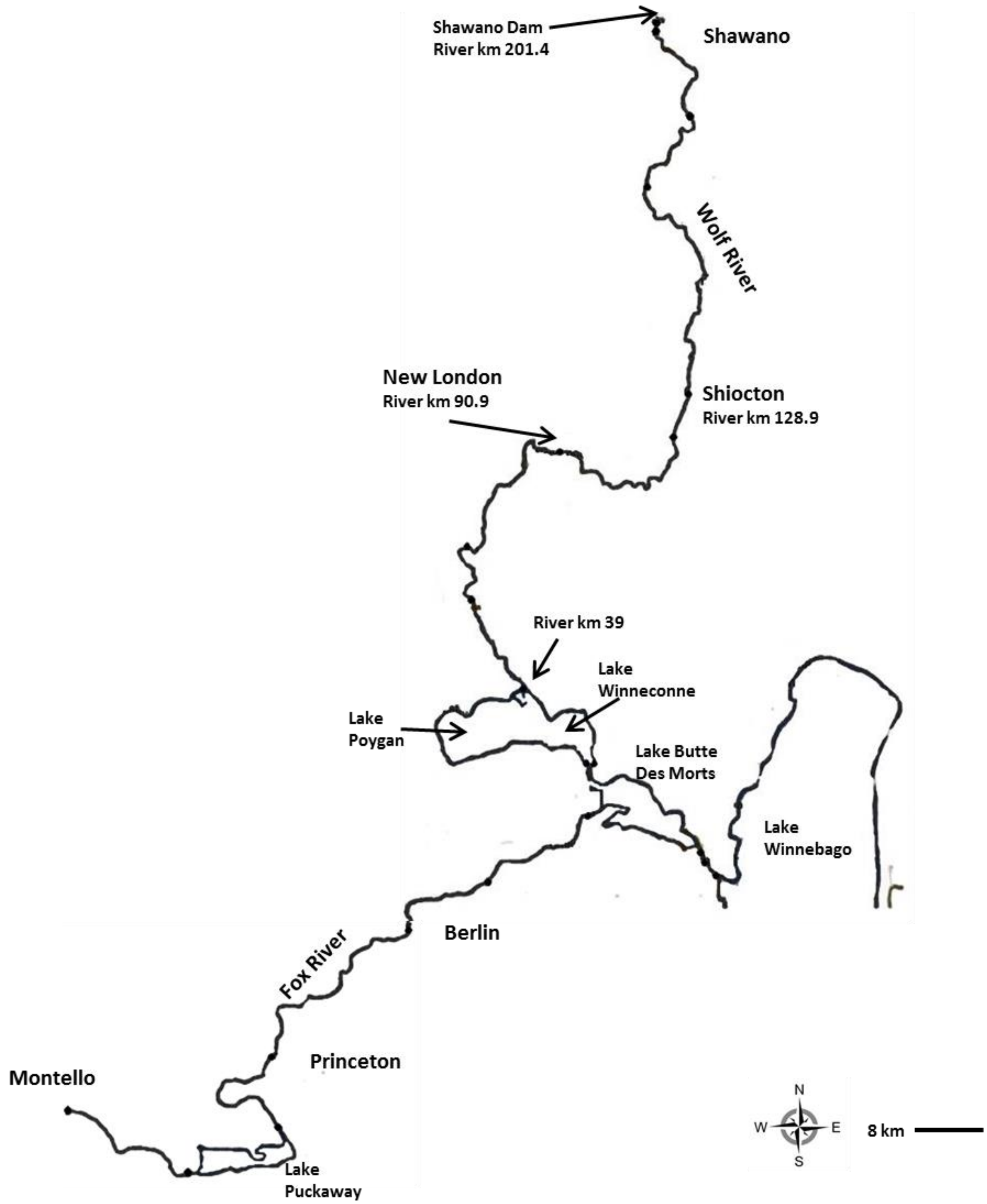

Figure 1. Map of the Winnebago System and the lower Wolf River above Lake Poygan, with important river locations and corresponding river km.

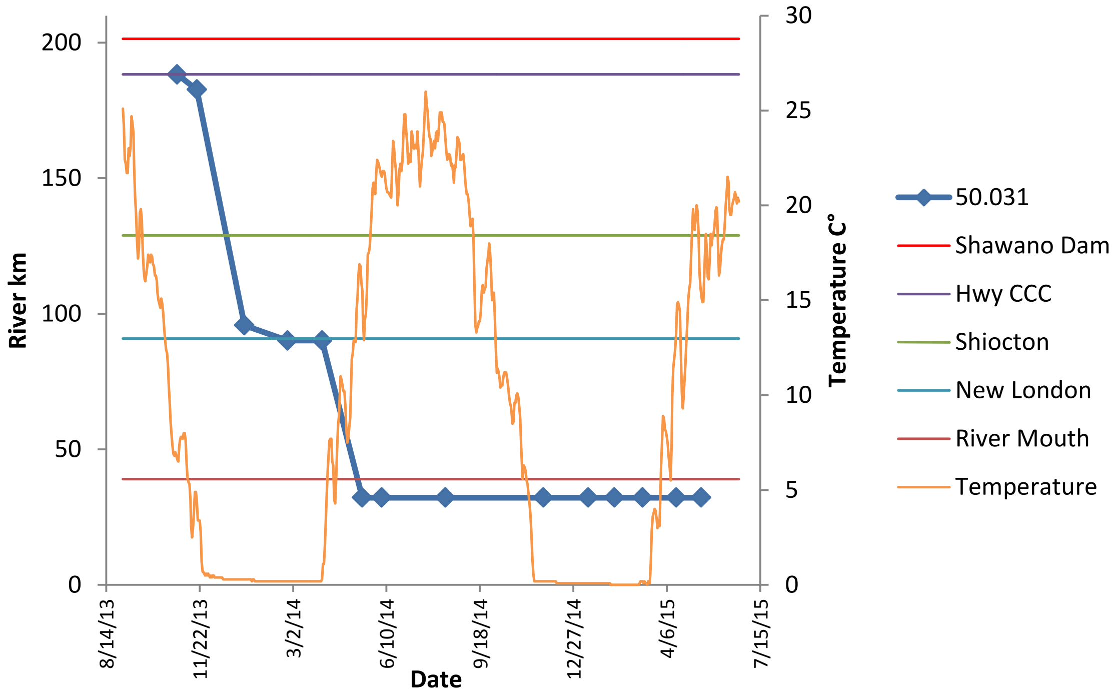

Figure 2. Relocations of fish 50.031 (blue line and diamonds) in the Winnebago System during August 2013-June 2015. Left *y*-axis represents river km (rkm) and the *y*-axis to the right represents average daily temperature (orange line) at the USGS stream gauge in New London, Wisconsin. Horizontal lines represent Shawano Paper Mill Dam (rkm 201.4), County Highway CCC Bridge (rkm 188.3), Shiocton, Wisconsin, (rkm 128.9), New London, Wisconsin, (rkm 90.9) and the point where the lower Wolf River enters Lake Poygan (rkm 39).

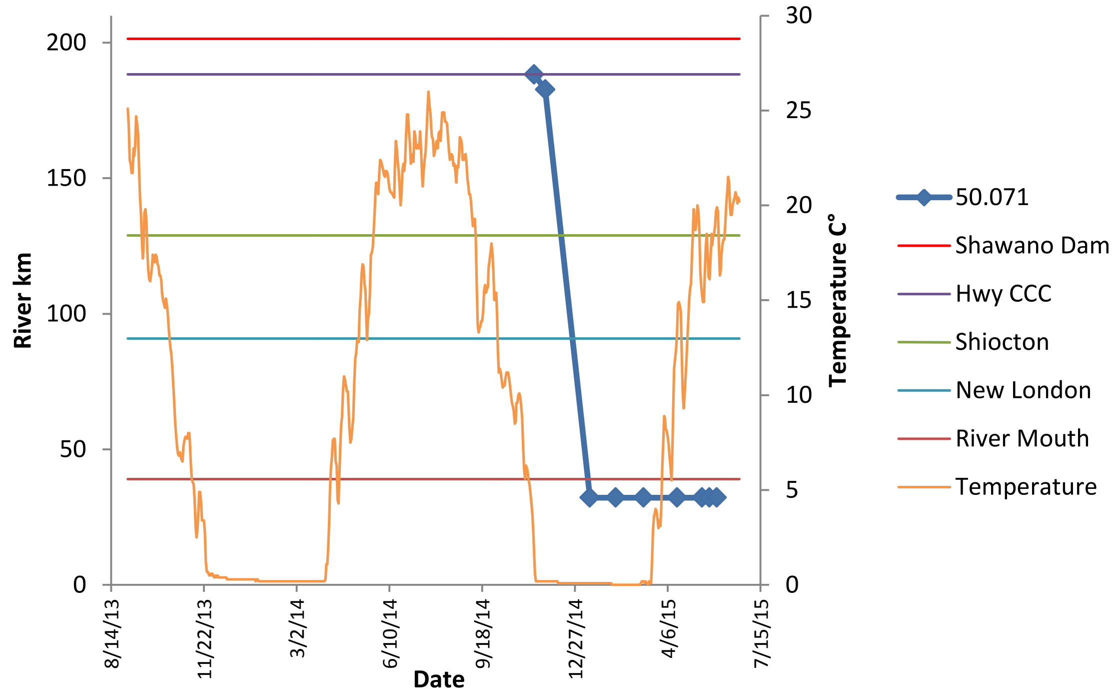

Figure 3. Relocations of fish 50.071 (blue line and diamonds) in the Winnebago System during August 2013-June 2015. This fish was not tagged until the fall of 2014. Left *y*-axis represents river km (rkm) and the *y*-axis to the right represents average daily temperature (orange line) at the USGS stream gauge in New London, Wisconsin. Horizontal lines represent Shawano Paper Mill Dam (rkm 201.4), County Highway CCC Bridge (rkm 188.3), Shiocton, Wisconsin, (rkm 128.9), New London, Wisconsin, (rkm 90.9) and the point where the lower Wolf River enters Lake Poygan (rkm 39).

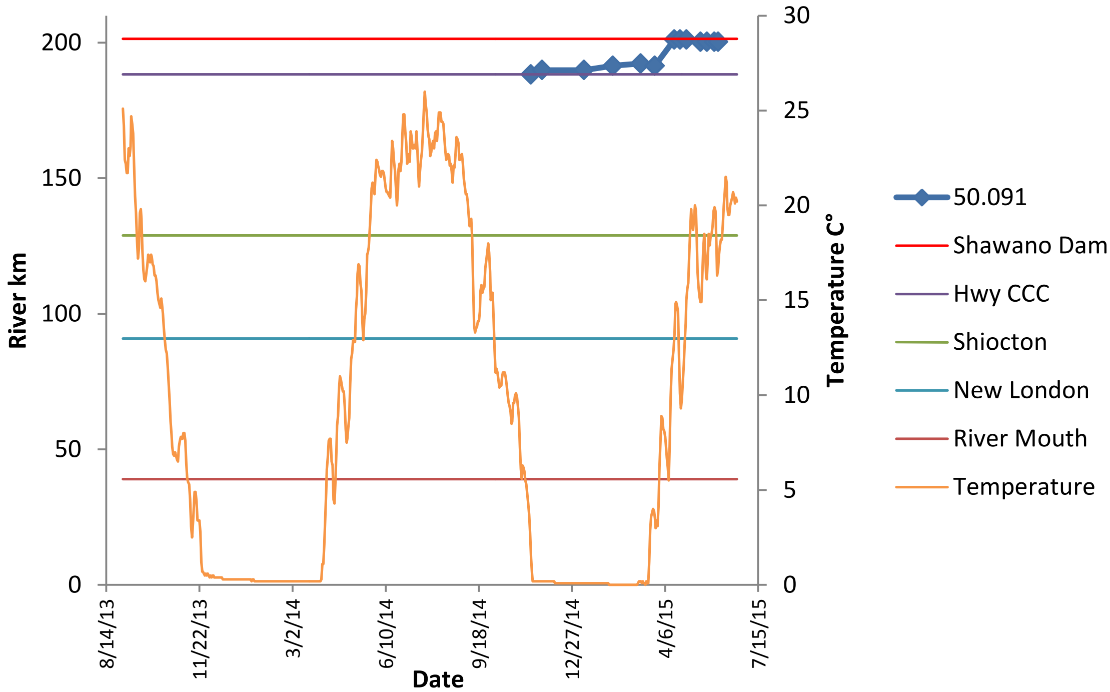

Figure 4. Relocations of fish 50.091 (blue line and diamonds) in the Winnebago System during August 2013-June 2015. This fish was not tagged until the fall of 2014. Left *y*-axis represents river km (rkm) and the *y*-axis to the right represents average daily temperature (orange line) at the USGS stream gauge in New London, Wisconsin. Horizontal lines represent Shawano Paper Mill Dam (rkm 201.4), County Highway CCC Bridge (rkm 188.3), Shiocton, Wisconsin, (rkm 128.9), New London, Wisconsin, (rkm 90.9) and the point where the lower Wolf River enters Lake Poygan (rkm 39).

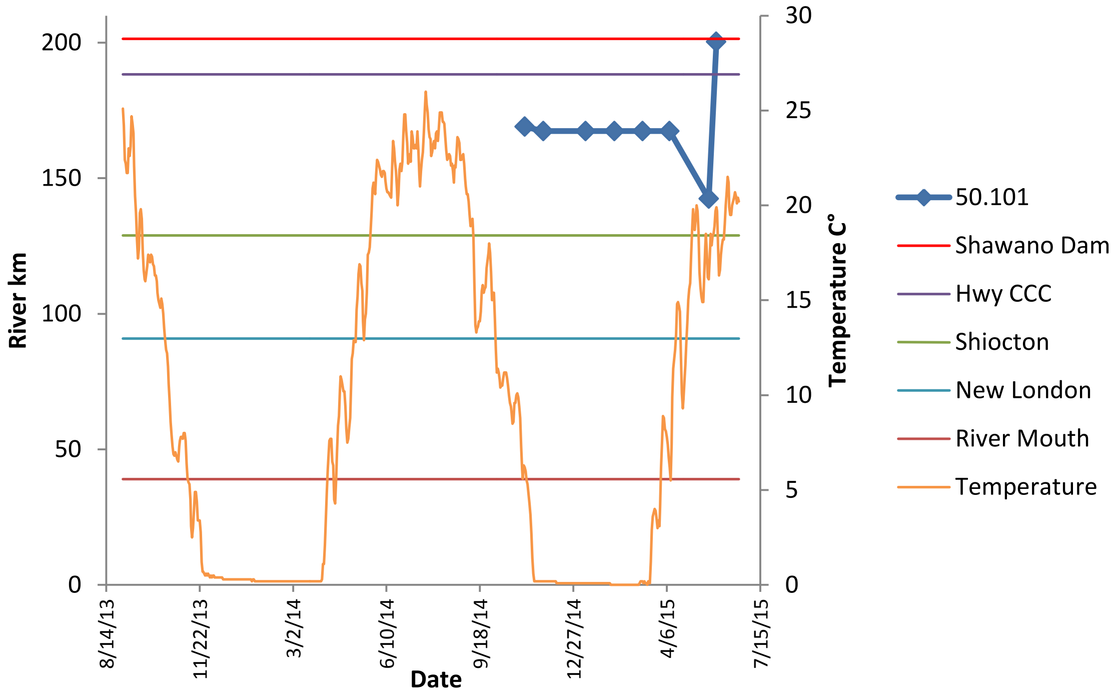

Figure 5. Relocations of fish 50.101 (blue line and diamonds) in the Winnebago System during August 2013-June 2015. This fish was not tagged until the fall of 2014. Left *y*-axis represents river km (rkm) and the *y*-axis to the right represents average daily temperature (orange line) at the USGS stream gauge in New London, Wisconsin. Horizontal lines represent Shawano Paper Mill Dam (rkm 201.4), County Highway CCC Bridge (rkm 188.3), Shiocton, Wisconsin, (rkm 128.9), New London, Wisconsin, (rkm 90.9) and the point where the lower Wolf River enters Lake Poygan (rkm 39).

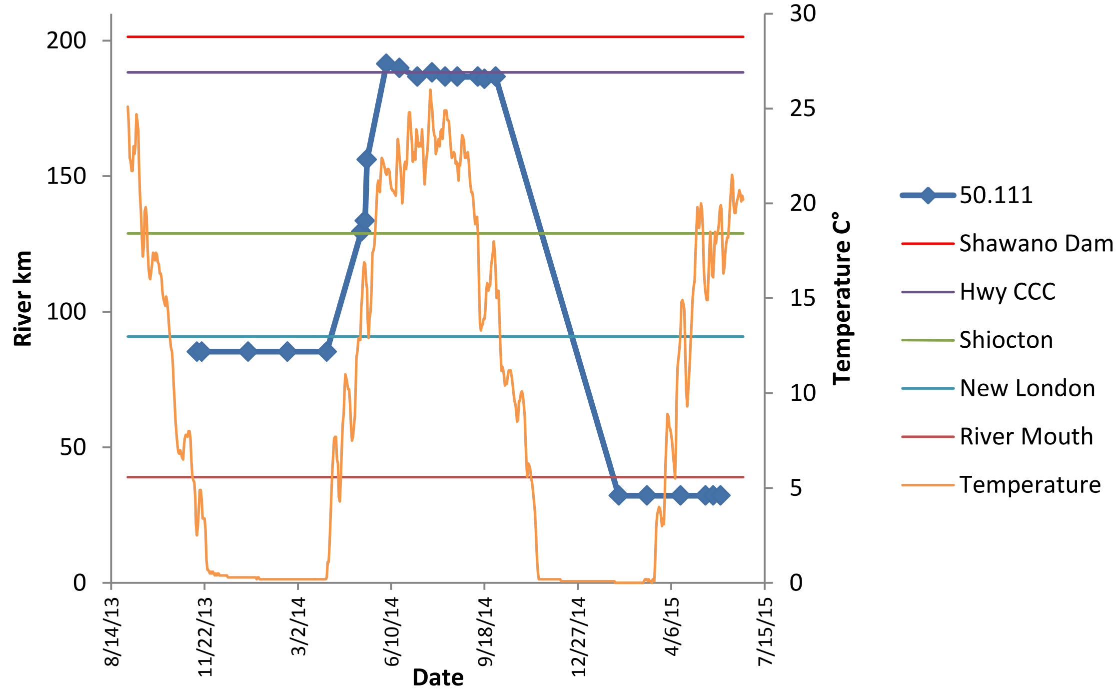

Figure 6. Relocations of fish 50.111 (blue line and diamonds) in the Winnebago System during August 2013-June 2015. Left *y*-axis represents river km (rkm) and the *y*-axis to the right represents average daily temperature (orange line) at the USGS stream gauge in New London, Wisconsin. Horizontal lines represent Shawano Paper Mill Dam (rkm 201.4), County Highway CCC Bridge (rkm 188.3), Shiocton, Wisconsin, (rkm 128.9), New London, Wisconsin, (rkm 90.9) and the point where the lower Wolf River enters Lake Poygan (rkm 39).

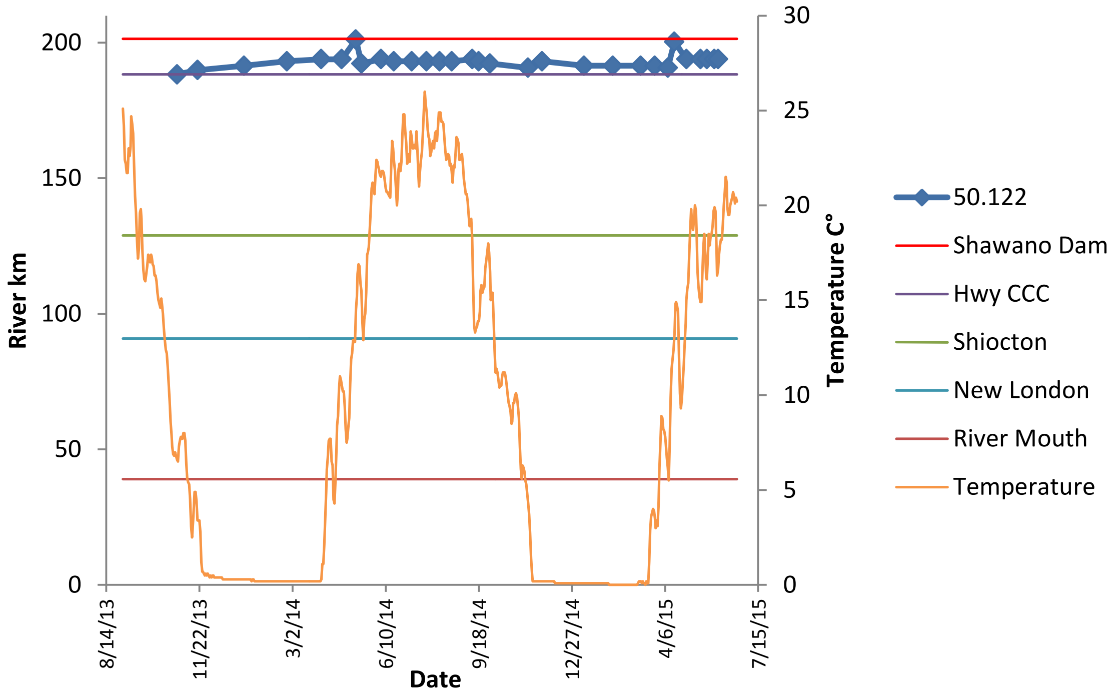

Figure 7. Relocations of fish 50.122 (blue line and diamonds) in the Winnebago System during August 2013-June 2015. Left *y*-axis represents river km (rkm) and the *y*-axis to the right represents average daily temperature (orange line) at the USGS stream gauge in New London, Wisconsin. Horizontal lines represent Shawano Paper Mill Dam (rkm 201.4), County Highway CCC Bridge (rkm 188.3), Shiocton, Wisconsin, (rkm 128.9), New London, Wisconsin, (rkm 90.9) and the point where the lower Wolf River enters Lake Poygan (rkm 39).

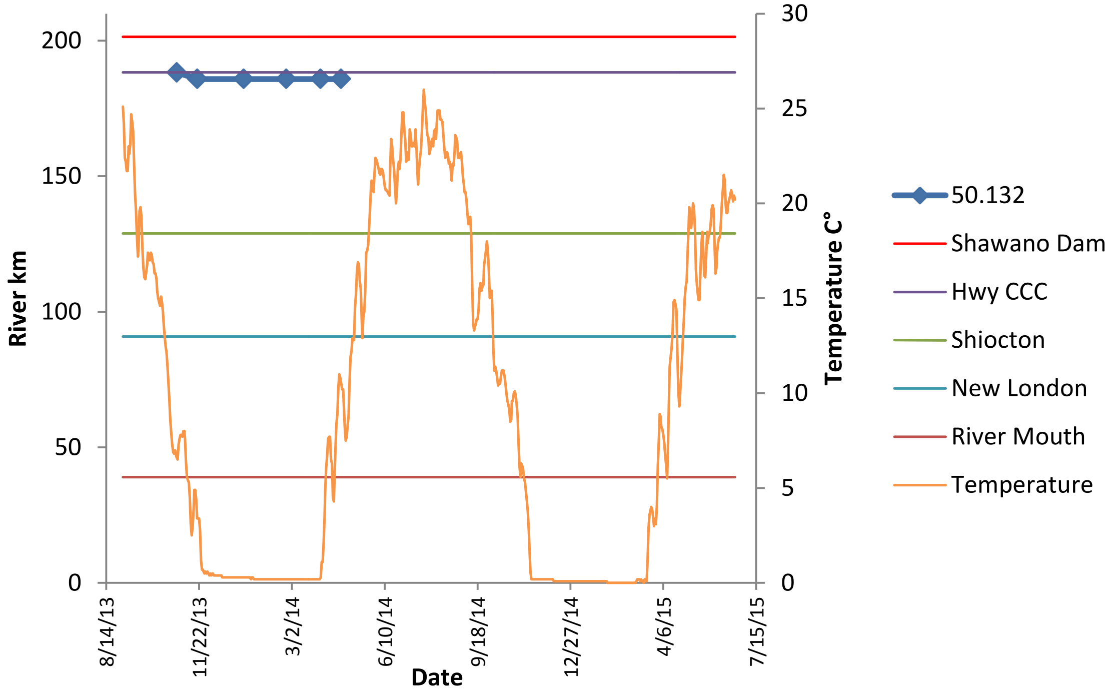

Figure 8. Relocations of fish 50.132 (blue line and diamonds) in the Winnebago System during August 2013-June 2015. This fish was lost early on in the study and was never relocated after 24 April 2014. Left *y*-axis represents river km (rkm) and the *y*-axis to the right represents average daily temperature (orange line) at the USGS stream gauge in New London, Wisconsin. Horizontal lines represent Shawano Paper Mill Dam (rkm 201.4), County Highway CCC Bridge (rkm 188.3), Shiocton, Wisconsin, (rkm 128.9), New London, Wisconsin, (rkm 90.9) and the point where the lower Wolf River enters Lake Poygan (rkm 39).

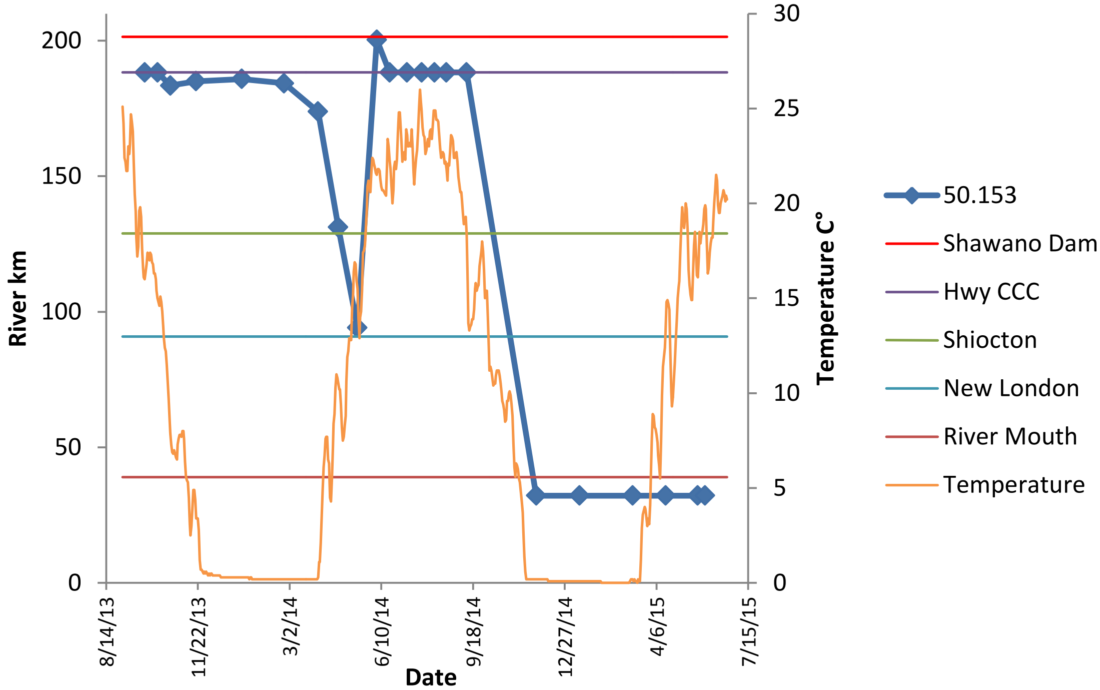

Figure 9. Relocations of fish 50.153 (blue line and diamonds) in the Winnebago System during August 2013-June 2015. Left *y*-axis represents river km (rkm) and the *y*-axis to the right represents average daily temperature (orange line) at the USGS stream gauge in New London, Wisconsin. Horizontal lines represent Shawano Paper Mill Dam (rkm 201.4), County Highway CCC Bridge (rkm 188.3), Shiocton, Wisconsin, (rkm 128.9), New London, Wisconsin, (rkm 90.9) and the point where the lower Wolf River enters Lake Poygan (rkm 39).

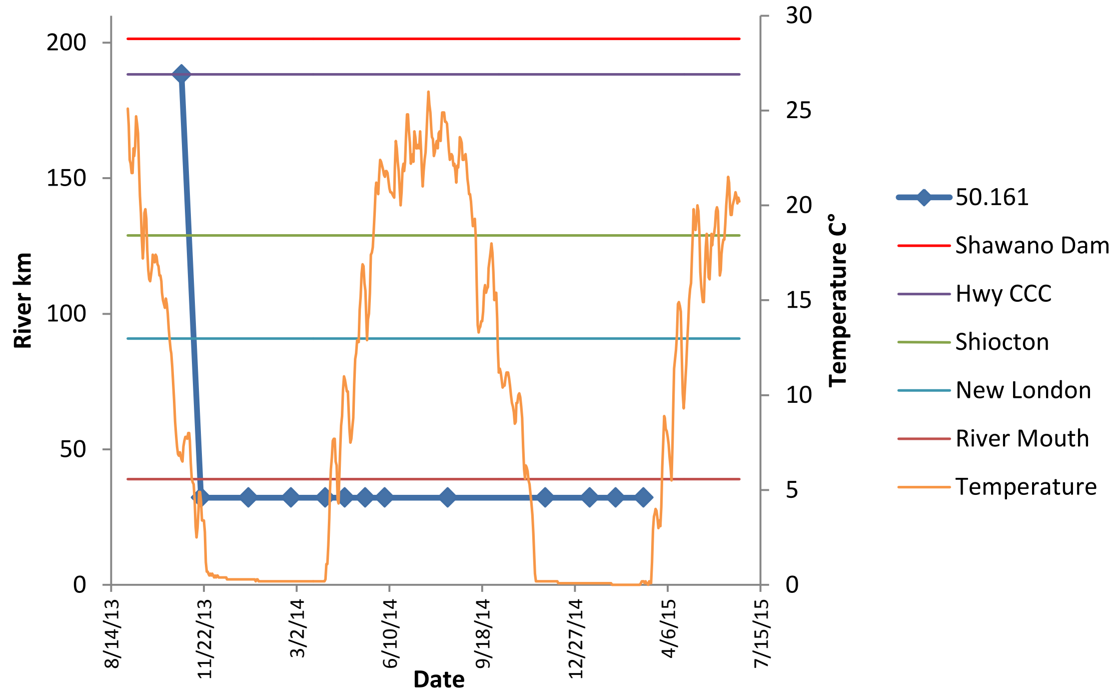

Figure 10. Relocations of fish 50.161 (blue line and diamonds) in the Winnebago System during August 2013-June 2015. Left *y*-axis represents river km (rkm) and the *y*-axis to the right represents average daily temperature (orange line) at the USGS stream gauge in New London, Wisconsin. Horizontal lines represent Shawano Paper Mill Dam (rkm 201.4), County Highway CCC Bridge (rkm 188.3), Shiocton, Wisconsin, (rkm 128.9), New London, Wisconsin, (rkm 90.9) and the point where the lower Wolf River enters Lake Poygan (rkm 39).

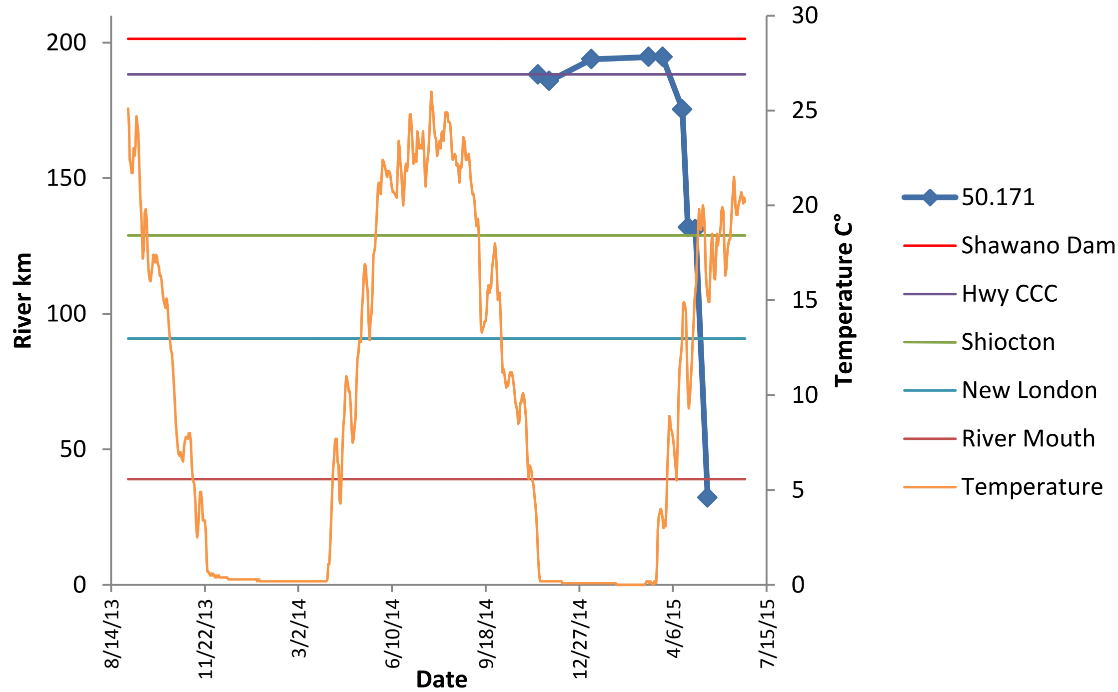

Figure 11. Relocations of fish 50.171(blue line and diamonds) in the Winnebago System during August 2013-June 2015. This fish was not tagged until the fall of 2014. Left *y*-axis represents river km (rkm) and the *y*-axis to the right represents average daily temperature (orange line) at the USGS stream gauge in New London, Wisconsin. Horizontal lines represent Shawano Paper Mill Dam (rkm 201.4), County Highway CCC Bridge (rkm 188.3), Shiocton, Wisconsin, (rkm 128.9), New London, Wisconsin, (rkm 90.9) and the point where the lower Wolf River enters Lake Poygan (rkm 39).

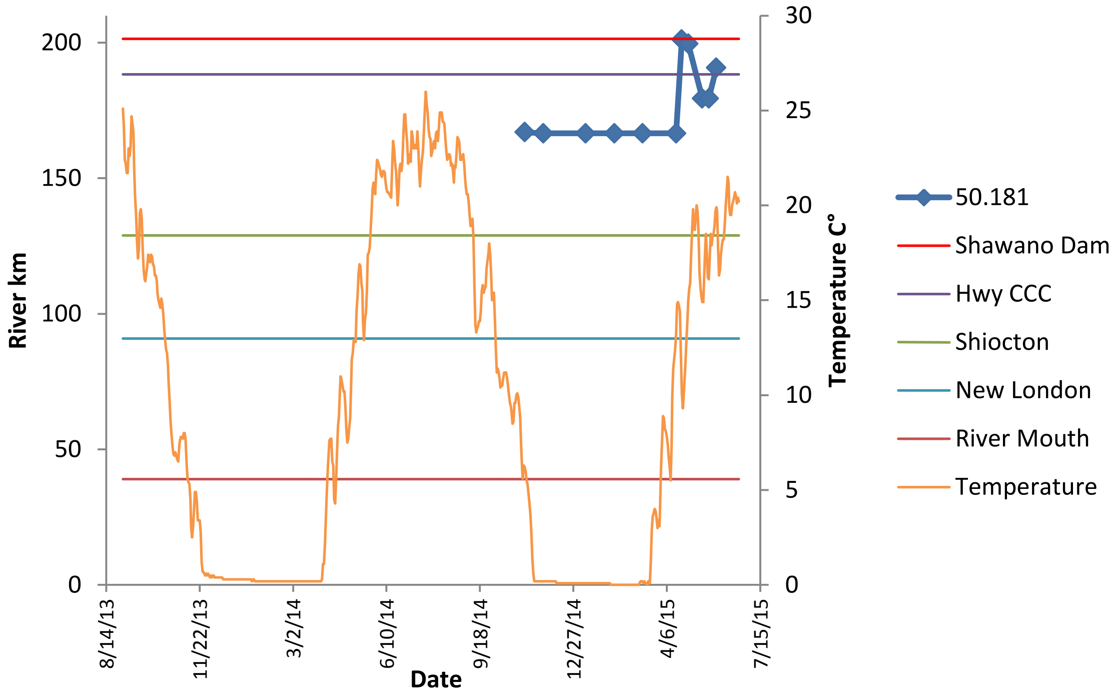

Figure 12. Relocations of fish 50.181 (blue line and diamonds) in the Winnebago System during August 2013-June 2015. This fish was not tagged until the fall of 2014. Left *y*-axis represents river km (rkm) and the *y*-axis to the right represents average daily temperature (orange line) at the USGS stream gauge in New London, Wisconsin. Horizontal lines represent Shawano Paper Mill Dam (rkm 201.4), County Highway CCC Bridge (rkm 188.3), Shiocton, Wisconsin, (rkm 128.9), New London, Wisconsin, (rkm 90.9) and the point where the lower Wolf River enters Lake Poygan (rkm 39).

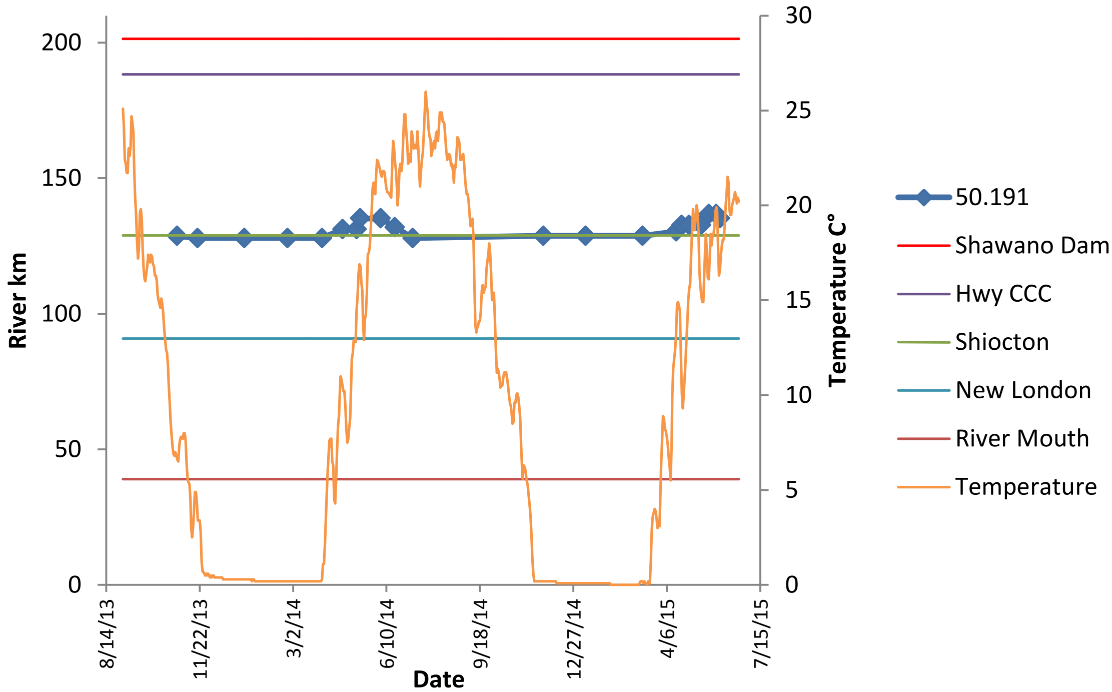

Figure 13. Relocations of fish 50.191 (blue line and diamonds) in the Winnebago System during August 2013-June 2015. Left *y*-axis represents river km (rkm) and the *y*-axis to the right represents average daily temperature (orange line) at the USGS stream gauge in New London, Wisconsin. Horizontal lines represent Shawano Paper Mill Dam (rkm 201.4), County Highway CCC Bridge (rkm 188.3), Shiocton, Wisconsin, (rkm 128.9), New London, Wisconsin, (rkm 90.9) and the point where the lower Wolf River enters Lake Poygan (rkm 39).

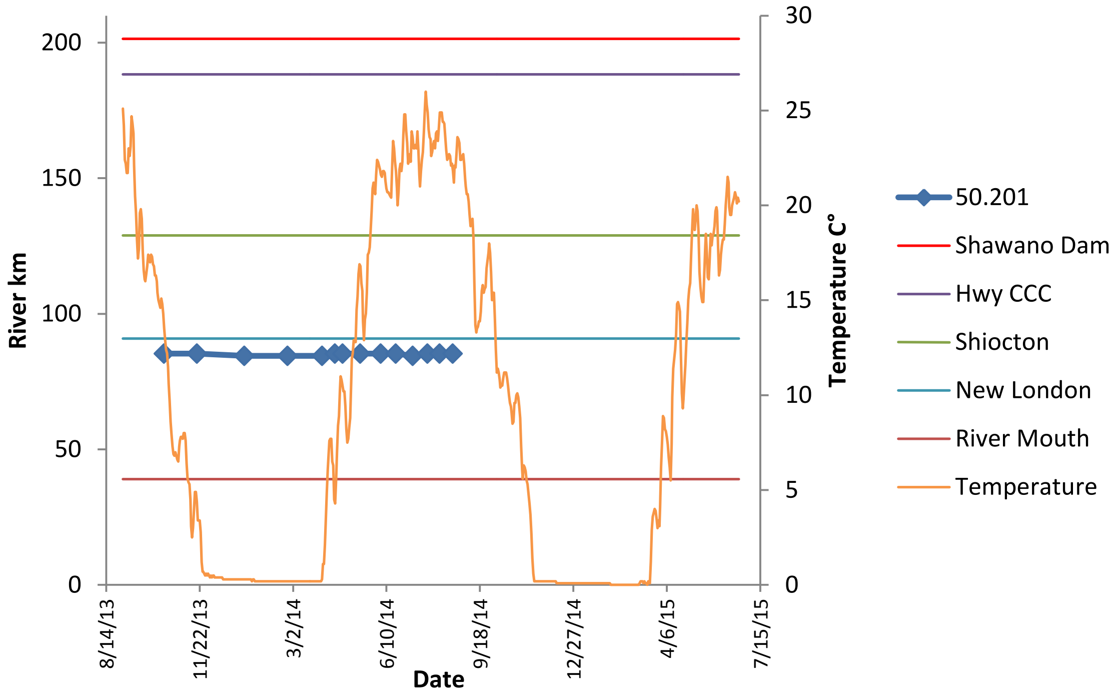

Figure 14. Relocations of fish 50.201 (blue line and diamonds) in the Winnebago System during August 2013-June 2015. This fish was lost after the first year of the study and was never relocated after 20 August 2014. Left *y*-axis represents river km (rkm) and the *y*-axis to the right represents average daily temperature (orange line) at the USGS stream gauge in New London, Wisconsin. Horizontal lines represent Shawano Paper Mill Dam (rkm 201.4), County Highway CCC Bridge (rkm 188.3), Shiocton, Wisconsin, (rkm 128.9), New London, Wisconsin, (rkm 90.9) and the point where the lower Wolf River enters Lake Poygan (rkm 39).

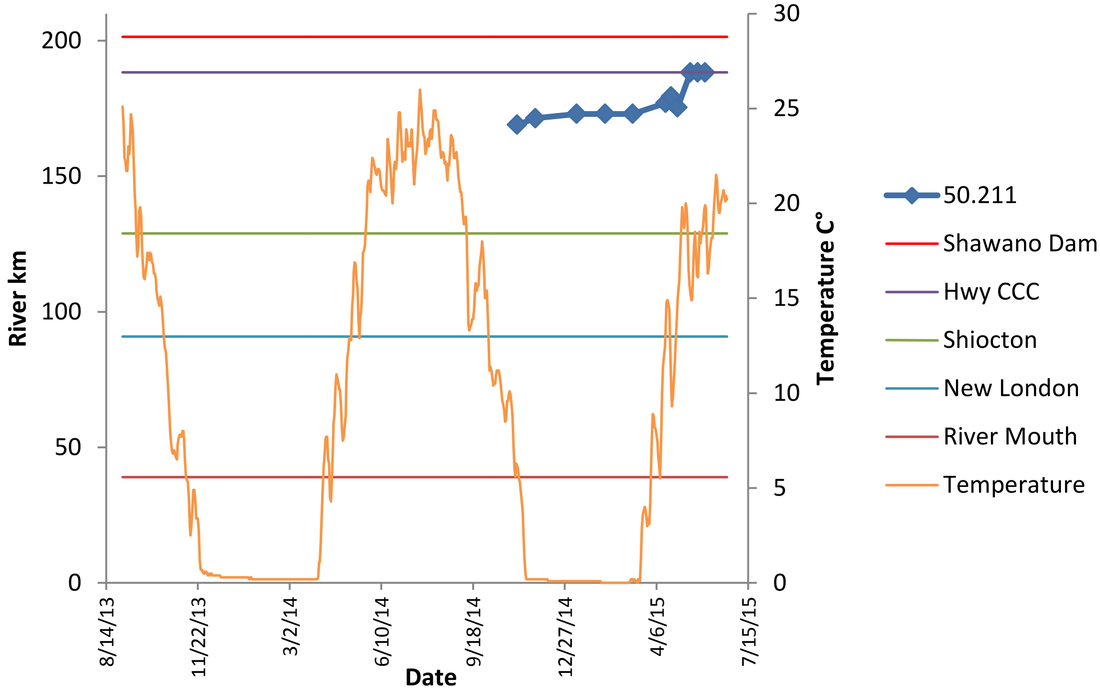

Figure 15. Relocations of fish 50.211 (blue line and diamonds) in the Winnebago System during August 2013-June 2015. This fish was not tagged until the fall of 2014. Left *y*-axis represents river km (rkm) and the *y*-axis to the right represents average daily temperature (orange line) at the USGS stream gauge in New London, Wisconsin. Horizontal lines represent Shawano Paper Mill Dam (rkm 201.4), County Highway CCC Bridge (rkm 188.3), Shiocton, Wisconsin, (rkm 128.9), New London, Wisconsin, (rkm 90.9) and the point where the lower Wolf River enters Lake Poygan (rkm 39).

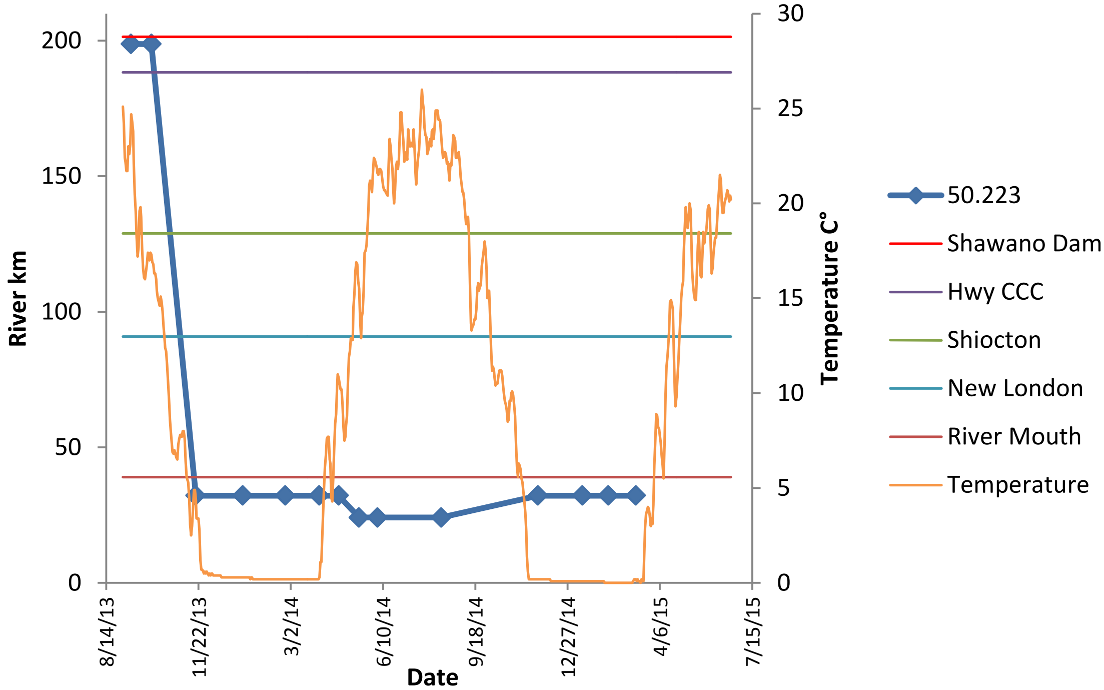

Figure 16. Relocations of fish 50.223 (blue line and diamonds) in the Winnebago System during August 2013-June 2015. Left *y*-axis represents river km (rkm) and the *y*-axis to the right represents average daily temperature (orange line) at the USGS stream gauge in New London, Wisconsin. Horizontal lines represent Shawano Paper Mill Dam (rkm 201.4), County Highway CCC Bridge (rkm 188.3), Shiocton, Wisconsin, (rkm 128.9), New London, Wisconsin, (rkm 90.9) and the point where the lower Wolf River enters Lake Poygan (rkm 39).

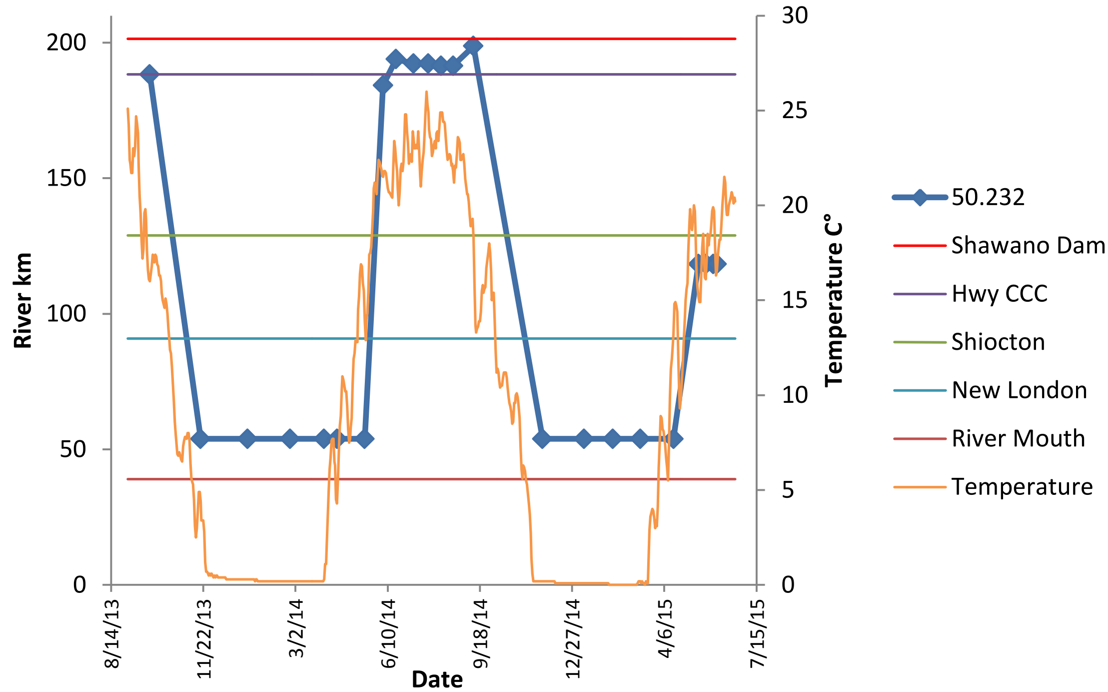

Figure 17. Relocations of fish 50.232 (blue line and diamonds) in the Winnebago System during August 2013-June 2015. Left *y*-axis represents river km (rkm) and the *y*-axis to the right represents average daily temperature (orange line) at the USGS stream gauge in New London, Wisconsin. Horizontal lines represent Shawano Paper Mill Dam (rkm 201.4), County Highway CCC Bridge (rkm 188.3), Shiocton, Wisconsin, (rkm 128.9), New London, Wisconsin, (rkm 90.9) and the point where the lower Wolf River enters Lake Poygan (rkm 39).

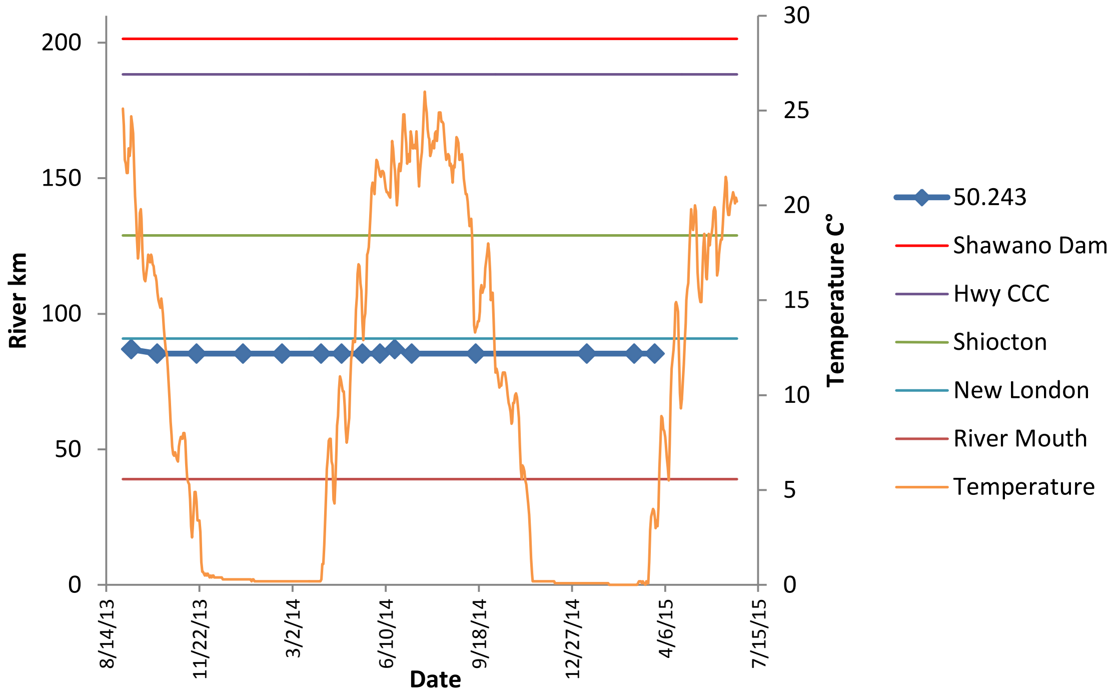

Figure 18. Relocations of fish 50.243 (blue line and diamonds) in the Winnebago System during August 2013-June 2015. Left *y*-axis represents river km (rkm) and the *y*-axis to the right represents average daily temperature (orange line) at the USGS stream gauge in New London, Wisconsin. Horizontal lines represent Shawano Paper Mill Dam (rkm 201.4), County Highway CCC Bridge (rkm 188.3), Shiocton, Wisconsin, (rkm 128.9), New London, Wisconsin, (rkm 90.9) and the point where the lower Wolf River enters Lake Poygan (rkm 39).

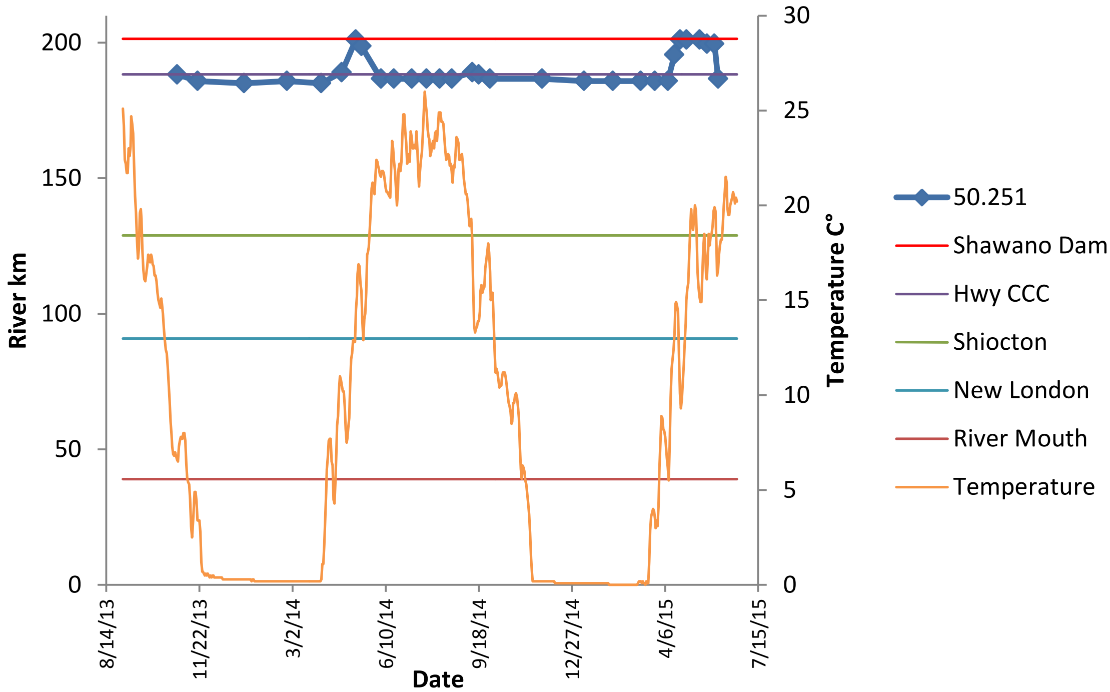

Figure 19. Relocations of fish 50.251 (blue line and diamonds) in the Winnebago System during August 2013-June 2015. Left *y*-axis represents river km (rkm) and the *y*-axis to the right represents average daily temperature (orange line) at the USGS stream gauge in New London, Wisconsin. Horizontal lines represent Shawano Paper Mill Dam (rkm 201.4), County Highway CCC Bridge (rkm 188.3), Shiocton, Wisconsin, (rkm 128.9), New London, Wisconsin, (rkm 90.9) and the point where the lower Wolf River enters Lake Poygan (rkm 39).

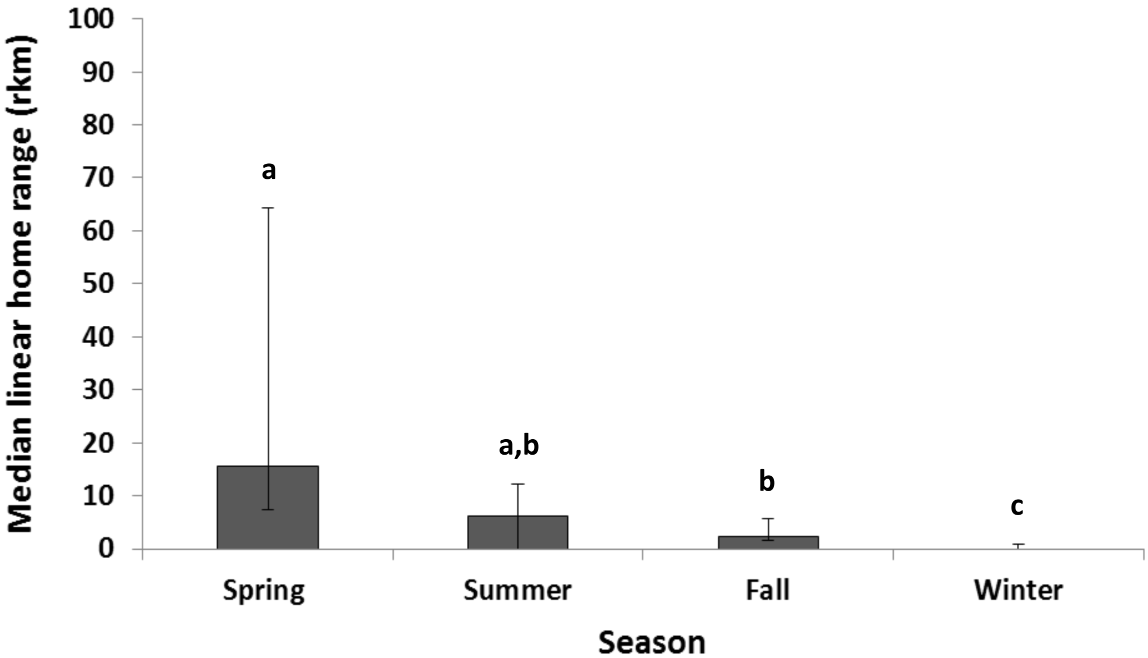

Figure 20. Median linear home ranges (LHR) with 95% confidence intervals by season for 18 sub-adult Lake Sturgeon captured from the Lower Wolf River, Wisconsin, and implanted with radio transmitters. Fish that had only one relocation or were not located within the lower Wolf River within a specific season were not included in calculations of LHR for that season. Different letters above each bar denote statistically significant differences of median LHR ($P < 0.05$) among seasons. Fish relocations from both years of the study were combined to calculate median LHR for each season.

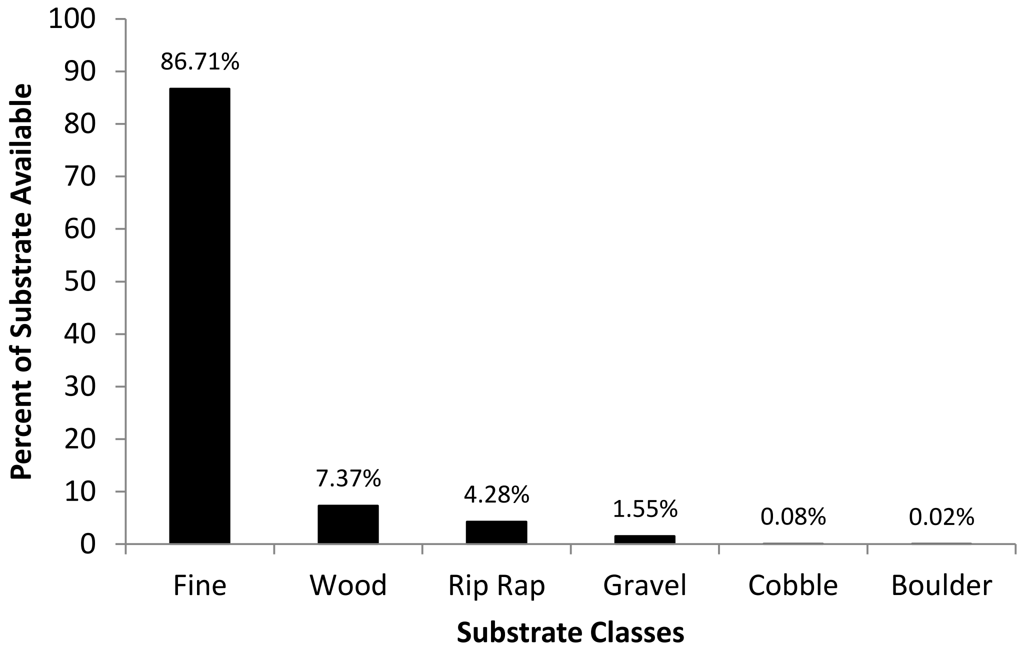

Figure 21. Substrate composition of the lower Wolf River of Wisconsin. Side-scan sonar was used to record the entire 160 km of the lower Wolf River in the spring of 2014 and those images were used to delineate the different substrates throughout the river.

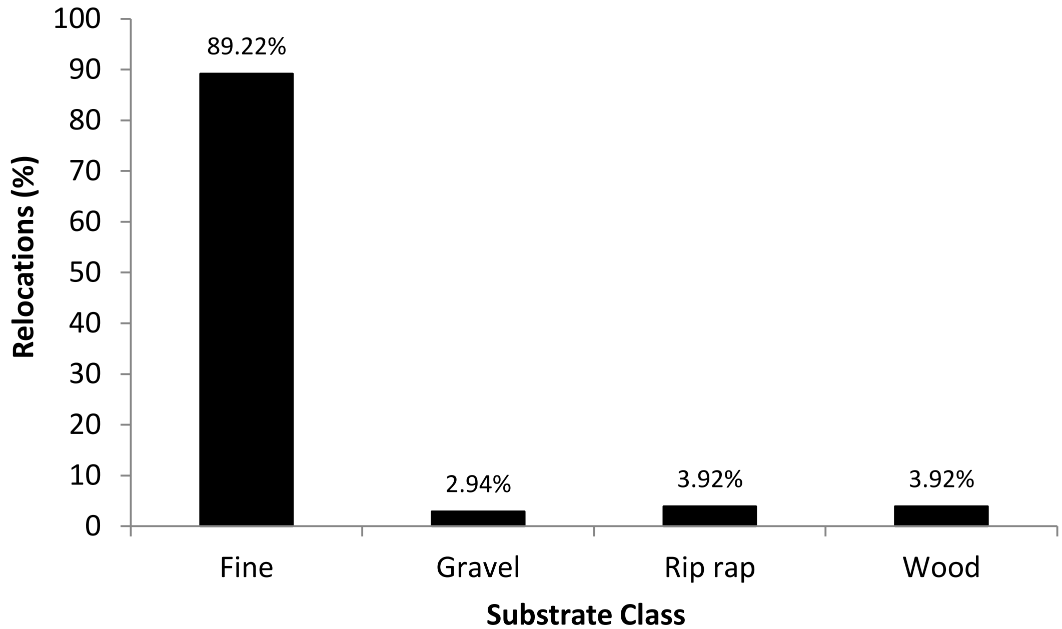

Figure 22. Percentage of sub-adult Lake Sturgeon relocations (N = 102) within the lower Wolf River by substrate class. Eighteen different fish were relocated multiple times over the course of the study that occurred from August 2013 to June 2015.

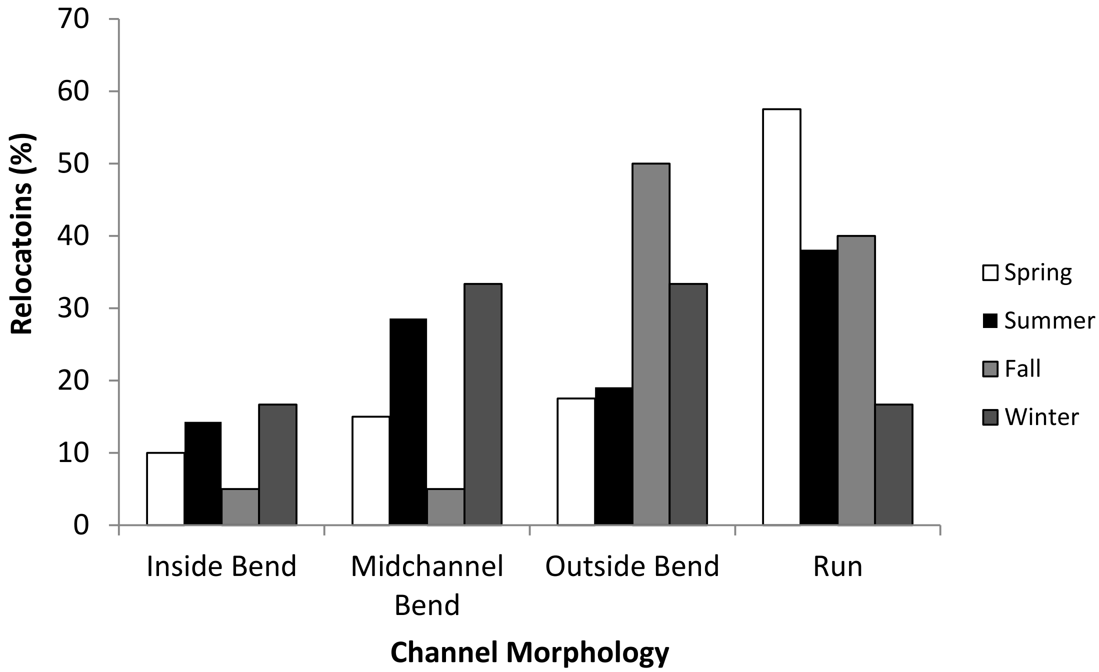

Figure 23. Percentage of total relocations (N = 102) by channel morphology type within season for sub-adult Lake Sturgeon in the lower Wolf River. Eighteen different fish were relocated multiple times over the course of the study that spanned from August 2013 to June 2015.