2015

TRANSLOCATION AND TELEMETRY TRACKING OF LAKE STURGEON IN THE MENOMINEE RIVER, MI / WI

Jeremy G. Olach
Michigan Technological University

Follow this and additional works at: https://digitalcommons.mtu.edu/etds
Part of the Biology Commons, and the Ecology and Evolutionary Biology Commons

TRANSLOCATION AND TELEMETRY TRACKING OF LAKE STURGEON IN THE MENOMINEE RIVER, MI / WI

By

Jeremy G. Olach

A THESIS

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

In Biological Sciences

MICHIGAN TECHNOLOGICAL UNIVERSITY

2015

This thesis has been approved in partial fulfillment of the requirements for the Degree of MASTER OF SCIENCE in Biological Sciences.

Department of Biological Sciences

Thesis Advisor:	*Nancy Auer*
Committee Member:	*Ed Baker*
Committee Member:	*Casey J. Huckins*
Committee Member:	*Ann Maclean*
Department Chair:	*Chandrashehkar P. Joshi*

To my parents, my love, and my children

Table of Contents

List of Figures

List of Tables

Preface

This thesis was a written collaboration. Dr. Nancy Auer provided strong guidance for the writing of Chapter 3 of this thesis, editing, and the layout of the experimental design of the data sampling. I completed all data collection, GIS analysis, statistical analysis, and figure creation.

1. Acknowledgements

So many people have contributed to this happening. First, I would like to thank WE Energies & the Mitigation and Enhancement Fund for their funding for this project. I would like to thank my advisor, Dr. Nancy Auer, for giving me this opportunity to work on such a great project, for her guidance, her patience, her resourcefulness, and for constantly challenging me to be a better scientist. I would like to thank Mike Donofrio, WDNR & Dr. Ed Baker, MDNR for their advice, insights, and expertise in the field. Thank you to Dr. Casey Huckins, for all the talks, support, and advice given to me over the years. Thank you to Dr. Ann McLean, for showing me the wonders of GIS with patience and understanding. Thanks go to my field assistants, Jason Skoog and Aaron Garceau for both being smart, hardworking, and dependable workers, and great people with which to spend a lot of time on a river. Thank you to Dr. Janice Glime for assistance with aquatic macrophyte identifications and wonderful conversation. Thank you to Patty, Emily, and Jeff, for all the work they do for the Biology Department and have done for me. I would also like to thank Nancy, Bonnie, and the Graduate School for tuition support throughout this project.

Thank you to Vemco, Inc, Bedford, Nova Scotia, Canada, for graciously loaning a portable receiver for both study years. Additional thanks go to Northwoods Adventures, Iron Mountain, MI for shuttle service and information on the river. A special thank you goes to Sturgeon Falls Dam operator, Gerry Gerard, whose conversations and knowledge of the river proved to be not only immensely enjoyable but also an invaluable asset; I also would also like to thank Gerry for sharing his wonderful photos of spawning sturgeon. I would like to thank my fellow graduate students, including but not limited to: Emily, Cameron, Miles, Jamie, Tony, Brian, Tim, Barb, Alex, Ashley, Steph, Marty – whose collective input and encouragement has helped me from start to finish.

I would be amiss without thanking my family. I would like to thank my mom, for instilling in me the value of education and hard work. Thank you to my Aunt Jeannie for her unwavering encouragement and support in everything I do. I would like to thank my passed father and grandfathers for developing within me their love of fish, the water, and the woods. Last but certainly not least, I thank my love Nicole, for pushing me forward when I need it and standing beside me through it all.

2. Abstract

The Menominee River is a Michigan-Wisconsin boundary water historically traversed by lake sturgeon (*Acipenser fulvescens*), but now contains fragmented populations between hydroelectric dams. Though fish passage is currently being implemented on the lower dams, it is unclear whether sturgeon given access to historic spawning grounds would use them. In 2012 and 2013, a total of 15 pre-spawning sturgeon were captured, implanted with sonic transmitters and translocated upstream over two hydroelectric dams to the stretch below the historic spawning site of Sturgeon Falls. Sturgeon were then tracked via five stationary receivers from April 2012 until August 2013, and with a portable receiver April to September 2012 and May to August 2013. Abiotic habitat features, including water depths, temperatures, present substrate particle classes, dissolved oxygen, and light intensities near the river bottom, and biotic features including invertebrate sampling and vegetation mapping were also collected. Within 2 weeks of translocation, seven of the study sturgeon were detected near the historic spawning site, where sturgeon spawning behavior was observed both study years. Within 48 hours of translocation, the remaining 8 study sturgeon all migrated at least 10 rkm upstream, near two other potential spawning sites within the study area. Habitat measurements suggest that the study stretch contains suitable habitat for year-0, juvenile, and adult lake sturgeon. In-stream vegetation appeared to create a barrier to sturgeon movement in 2012, but did not in 2013 when observed vegetation was at half the coverage as the previous year. This study has found that if pre-spawning sturgeon from an impounded stretch of river are given access to historic upstream spawning habitat, they will migrate to this habitat. Sturgeon spawning activity near Sturgeon Falls Dam was observed in both study years.

3. Main Body[1]

3.1 Introduction

Dams have been erected on rivers to control flow and to produce electricity (Harford & McLaughlin, 2007). However, many species of fish are adversely affected by dams (Auer, 1996; Bartel et al., 2009; Ferguson et al., 2009; etc.). These barriers to fish migration can alter river temperatures, flows, and substrates, often forming reservoirs. In the Laurentian Great Lakes, over 40% of all river systems have some form of man-made obstruction (Liermann et al., 2012). The Menominee River is one such system in which hydroelectric dams fragment a historic population of lake sturgeon, *Acipenser fulvescens*.

The Menominee River is a Michigan-Wisconsin boundary water meandering 152 river kilometers (rkm) from its source at the confluence of the Brule and Michigamme Rivers (Figure 3.1). Historically, in the Menominee River, lake sturgeon spawned at a natural barrier known as Sturgeon Falls (Theumler, 1985) 115 rkm from the river's mouth, which is currently the site of a hydroelectric dam. The system below the historic Sturgeon Falls site is fragmented by five more hydroelectric dams which form impounded stretches of river. Below the White Rapids and the Grand Rapids Dams dwell naturally-reproducing populations of lake sturgeons (Theumler, 1988). Access to the stretch below Sturgeon Falls is currently barred to these sturgeons by the Chalk Hills Dam 39 rkm downstream from Sturgeon Falls and the White Rapids Dam 3 rkm downstream from the Chalk Hills Dam. It has been estimated that 27% of the Menominee River's suitable spawning habitat lies between the Chalks Hills Dam and Sturgeon Falls Dam (Daughtery et al, 2008).

For most lake sturgeon, the river habitat is used for spawning by adults and as a nursery for larval and early juvenile stages. Post-spawning adults in most barrier-free populations of lake sturgeons leave the river, often rapidly (Auer, 1999). After reaching age-1, the juveniles migrate out of the river and into a lake environment, though often into different habitats than those used by adults (Smith & King, 2005). Once out of the river, the juvenile fish will wander in lakes, or larger rivers if no lakes are accessible, as they grow for 15-20 years and become sexually mature, at which point the fish will return, with very high site fidelity, to the river to spawn. For an impounded fish, movement is restricted. While the movements of juvenile and adult lake sturgeons in free-flowing river settings have been studied in the Sturgeon River, MI (Auer, 1999;

[1] Portions of the material in this chapter are intended for publication.

Holtgren & Auer, 2006), the Peshtigo River, WI (Benson et al., 2005; Caroffino et al., 2009), and the Manistee River, MI (Mann et al., 2004), very few studies have tracked movement within impounded systems (the Menominee R. - Kornelly, 2005; Theumler, 1988; the Kettle River, MN - Borkholder et al. 2001), or described the habitat specifically used by the different life stages there in (the Ottawa R., Ottawa, Canada - Haxton, 2011). Research has shown juvenile sturgeon seek out sand or gravel substrates on the Wolf River, WI (Kempinger, 1996), the Manistee River, MI (Mann et al., 2011), the Upper Black River & Black Lake, MI (Smith & King, 2005), and hatchery raised lake sturgeon from Wolf River stock (Peake, 1999). Juveniles were observed in the Wolf River & connecting Lake Winnebago in areas free of vegetation (Kempinger, 1996), and juvenile lake sturgeon have been found in varying depth ranges from 0.6-3.0 m in the Manistee River, MI (Mann et al., 2011), to 5.4-13.4 m in Black Lake, MI (Smith & King, 2005), to >13 m in the Winnepeg River, Canada (Barth et al., 2009).

It has been suggested that the migration made from non-spawning habitats to spawning sites, generally in natal rivers, may have importance to lake sturgeon in allowing time for gonad maturation (Auer, 1996). Under the direction of the Stage 2 Remedial Action Plan for the Lower Menominee River Area of Concern, fish passage is currently being implemented to allow both upstream and downstream movement through the two dams closest to the mouth of the Menominee (Figure 3.1), the Upper and Lower Scott Dams (also known as the Park Mills Dam and Menominee Dam, respectively) (Uvaas & Baker, 2011). For sturgeon that may eventually have access to a historic spawn reach, it was unclear whether they would in fact use such a site. This study focused on addressing whether pre-spawning adult lake sturgeon, if moved around the White Rapids and Chalk Hills Dams and released within the historical spawning stretch of river, would migrate upstream and utilize the spawning area near the historic Sturgeon Falls site. Additionally, macrobenthic invertebrate samples and abiotic measurements of depth, temperature, dissolved oxygen, and present particle size classes were collected at fish locations, and vegetation mapping for the navigable study area was collected to help identify if suitable conditions were available in the river for lake sturgeon.

$H_0$1: Translocated pre-spawning condition lake sturgeon will not migrate further upstream toward the historic spawning site at Sturgeon Falls.

$H_0$2: There is no consistent pattern in movement of post-spawning sturgeon.

$H_0$3: Lake sturgeon do not show habitat or location preference post-spawning.

3.2 Study Area

The Menominee River flows into Green Bay in Lake Michigan and has an average width of 144 m, alkaline water (Theumler, 1985) and is stained light brown (Priegel, 1973). The study area includes the 39 rkm stretch of river from Sturgeon Falls Dam to the Chalk Hills Dam (Figure 3.2 & Table 3.1). Historically, lake sturgeons were found as far upstream as Sturgeon Falls (Theumler, 1997). Construction of wooden dams at the sites of the Lower and Upper Scott Dams was completed in 1862 and 1879 respectively, with the current structures being completed in the 1920s, barring access of the upper Menominee River from lake sturgeon returning from Lake Michigan (Kornely, 1988). From Sturgeon Falls to Chalk Hills Dam, no sturgeons were captured during Wisconsin Department of Natural Resources (WDNR) boat electroshocking surveys in 1971, 1972, or 1980 (Kornely, 1988). The WDNR stocked juvenile sturgeon into this reach of the river from 1982-1986 (Theumler, 1988) and then began a new stocking program in 1994 (Kornely, 2005). Since then, little population assessment has been attempted in this stretch. A 1999 electrofishing survey was unable to capture any lake sturgeon; however, in a 2003 survey, three juvenile sturgeons were recovered (50.8 to 78 cm Total Length) (Kornely, 2005). Some downstream movement of lake sturgeon over or through dams does happen (Theumler, 1985), but no upstream movement is possible above the White Rapids Dam. Therefore, any non-tagged fish observed within the study area originated from stock released into this section of river by the WDNR, or are the progeny of these stocked fish.

3.3 Methods

Pre-spawning adult lake sturgeons were collected below the White Rapids Dam in spring of 2012 and 2013, and additionally below the Grand Rapids Dam in 2013 (Figure 3.1). The sturgeons were captured via boat mounted pulsed DC electrofishing units operated by MDNR and WDNR. All captured sturgeon were scanned for the presence of a Passive Integrated Transponder (PIT) tag, or were implanted with one if none were not detected, and then measured for Total Length (TL) (cm), fork length (cm), and girth (cm) by the electrofishing crews. Determination of gender was then attempted, with fish being classified as either pre-spawning female, milt-producing male, or of undetermined gender which were returned to the river. Suspected mature, pre-spawning sturgeon were held in a large holding tub next to the White Rapids Dam, where surgeries were performed by WDNR personnel. Sexual maturity was confirmed during surgery via observation of mature gonadal tissue or presence of ripe eggs. Non-ripe sturgeon were sutured and returned to the river below the White Rapids Dam after time to recover. Sexually ripe fish were implanted with a Vemco V16 69-kHz coded ping transmitter. After successful implantation, the fish were sutured and transported to a temporary holding tub set in the back of a MDNR vehicle. Fish were then transported upstream and released above the Chalk Hills Dam, at either Release Site A or Release Site B (Figure 3.2). Electrofishing attempts continued in 2012 until twelve lake sturgeon, four females and eight males, were obtained. In 2013, only three pre-spawning male sturgeon were caught and attempts continued until no new ripe conditioned fish were found.

Prior to acquisition of lake sturgeon in April 2012, five Vemco VR2W stationary receivers were placed in the Menominee River, four within the study area and one just downstream of the study area (Figure 3.2). The stationary receivers were tethered to either a tree at the water's edge or to a road bridge support via chains or cable, and were placed in at least 1.5 meters of water to avoid detection by those involved in recreational activity.

From these receivers, detections were periodically uploaded on site to a laptop computer via a connection using Vemco's VUE software and a Bluetooth USB adapter. In addition to the five stationary receivers, a VR100 portable receiver was used to detect and locate tagged lake sturgeons. For the purposes of this study, it was assumed that all sturgeon spawning in the Menominee River concluded by the end of May in 2012 and the end of June in 2013, when water temperatures reached ~20°C . The threshold of 20°C was used based upon reported observed spawning ranges below 20°C in the Lower St. Clair River, MI (Nichols et al., 2003), the Manistee River, MI, (Chiotti et al., 2008), the St. Lawrence River, USA / Canada (Johnson et al., 2006) and its tributary the Des Prairies River, Quebec, Canada (LaHaye et al.,1992),\, and the Sturgeon River, MI (Auer, 1996a).

Tracking expeditions were performed with a 16' jon-boat and 25 horsepower outboard engine, and as well as from shore. Tracking occurred during daylight hours each week for 14 of the 20 weeks from 4 May to 15 September in 2012, and 10 of the 12 weeks from 20 May to 3 August in 2013. These trips occurred when scheduling and weather allowed. In both years areas of the river were inaccessible due to low flow, lack of access, or presence of rapids forming barriers to the boat. The Menominee River is a rocky river with many areas of high flow and shallow depths. For the entire 39 rkm stretch, only 5 boat launches exist, with two of them occurring in and at the top of the Chalk Hills Flowage in the lower quarter of the study area. Shore tracking was also limited due to numerous multi-rkm stretches of river passing through completely uninhabited and undeveloped tracts of forest. In both years, a 1.8 rkm stretch just upstream of Pemene Falls was completely inaccessible, due to rapids, harsh terrain, and no access roads within the small stretch. Certain areas of the river were inaccessible beneath certain threshold discharges. For example, the stretch below Faithhorn to the top of Quiver Falls was not traversable when river discharge was below ~43 m^3/s, so that for over half of the summer in 2012 we were unable track here; similarly, the very top of the study area between the SFD receiver and the Sturgeon Falls Dam not accessible below 28 m^3/s, which occurred during periods in both 2012 & 2013.

Upon fish detection, an omnidirectional microphone was replaced with a pole-mounted directional microphone. When possible, we drifted downstream past the sturgeon and approached it as we pushed back upstream to ensure maximum maneuverability. The pole mounted microphone was slowly rotated back and forth in a sweeping like motion, scanning for sound. When a ping was detected, the pole was then spun around and the direction of the strongest individual ping was noted and then approached. A decibel reading of 80 - 90+ was sought before a location would be entered and the location and time was marked via the GPS logging function. The highest observed individual ping of 104 dB occurred with the directional microphone angled downward at a 45 angle to the water surface in 1.5 m depth water. A reading of 80-90 dB was calculated to be within 10 m of the sturgeon's actual location.

After recording GPS coordinates, a D-framed 38.5cm wide by 35 cm tall 1-mm mesh drift net on a small sled-like base was deployed to sample macroinvertebrates. All invertebrate samples were labeled and preserved in 95% ethanol, and classified in the lab using Macke et al., 1980 and Merritt & Cummins, 1996. This net remained in place to collect for 30 minutes during which time various physical habitat measurements were taken. Depth of location (m) and surface temperature (°C) were collected with a Humminbird depth finder. A 15.4 x 15.4 cm mini-Ponar was used to collect substrate for particle size class using a modified Cummins scale (Cummins, 1962), and also for additional macroinvertebrate sampling. When mini-Ponar sampling was unsuccessful or impossible, wooden pole strikes on the river bottom were used to estimate

substrate particle class by feel and sound. Water temperature (°C) at river bottom was collected in 2012 via a HOBO data and collected in 2013 via a ProODO Dissolved Oxygen meter. Weather observations of air temperature (°C), relative cloud cover, and precipitation were recorded. Flows were determined from one of the two USGS gauging stations located within the study area, station 04065722 Menominee River near Vulcan, MI and station 04066003 Menominee River below Pemene Creek near Pembine, WI, from data downloaded from http://www.usgs.gov/ . In 2012, light penetration at the river bottom was recorded via a HOBO data logger, recorded in LUX. The HOBO meter and a PAR meter were also used side-by-side in a number of light level conditions in the laboratory in order to relate the awkward unit of illuminance to the more relatable unit of Photosynthetically Active Radiation (PAR). From 10 July to 15 September transect depth data was collected when possible. Eight transects were made, 10m apart, with one occurring at the location point, four upstream of the location and three downstream. Depth was recorded at the approximate one-quarter, halfway, & three-quarter points of each transect. In 2013, dissolved oxygen measurements (mg O_2/ ml H_2O) were attained via a ProODO Dissolved Oxygen meter.

To determine overall year to year differences in river temperature, data from the USGS gauging station 04067500, Menominee River near McAllister, WI, was used. This gauging station is ~50 rkm downstream from the study area, 4.6 rkm below the Grand Rapids Dam; while temperatures here are presumably not the same as those within the study area, overall trends in temperature are applicable.

All data was entered into Microsoft Excel and then imported into a Geographic Information System (GIS) database using ESRI's ArcMap 10.1/10.2. This data was then superimposed over high-resolution satellite images downloaded from public domain USGS data. Additional data and shapefiles were downloaded from the Michigan Department of Technology, Management and Budget's geographic library webpage. Satellite ortho images were mosaicked together using ERDAS Imagine, and then imported into ArcMap.

Vegetation mapping occurred in late July and August in both study years. At the approximate peak vegetation density, the full extent of the navigable river study area was surveyed for submerged aquatic macrophytes. Plant specimens were collected, pressed, and identified to species when possible using Fassett,1957 & Muencher, 1944. With the mobile GPS application Gaia for spatial reference, vegetation extent was marked on Google Maps sheets. The marked sheets were then scanned into digital form and after some image processing the files were ready for import into ArcMap. Reference marks on the scanned image rasters were georeferenced to the corresponding landmarks on the satellite ortho photos, resulting in an accurate georeference with very little distortion. The rasters were then converted to polygon shapefiles and all non-vegetation reference marks were eliminated. Individual vegetation

polygons were altered to match a river outline polygon to ensure no area outside of the river outline was incorrectly included.

ArcMap was additionally used for the creation of maps, and also for analysis of sturgeon location associations with proximity to river features, including islands, tributaries, and rapids. Buffers of 100 m around these features were created and then cut to the river outline, allowing calculations of in-river area around these features. All sturgeon location GPS coordinates and all gathered location data for each point were also imported into ArcMap, permitting accurate spatial analysis between locations and between locations and physical river features .

Statistical analyses were done using JMP Pro 10.0.2.

Two stationary receivers, one near Sturgeon Falls Dam (SFD) and one near Faithhorn (FH), were found to have potentially missed data. On 1 August 2012, the SFD receiver was completely surrounded by very dense submerged aquatic macrophytes. The receiver contained zero new detections in the 19 days since data had last been downloaded. On 9 August, additional chain was added and the receiver was moved further out into the river past the edge of the vegetation. It is uncertain when the vegetation overcame the receiver. On 14 September 2012, on the last tracking trip of the year, the Faithhorn receiver was discovered on the shore of the river, still attached to its chain and still functioning, but out of the water and so contained no new detections since its last download over a month prior on 10 August 2012.

3.4 Results

Sturgeon Movements

In 2012, twelve adult pre-spawning lake sturgeon were captured below the White Rapids Dam, four females and eight males (1.22 to 1.56 m TL) (Table 3.2). Eight of these sturgeon, three females and five males, were released into the Chalk Hills Flowage (CHF) just north of the CHF stationary receiver at Release Site A, 2.6 rkm upstream from the Chalk Hills Dam (Figure 3.2), on 23 April. The remaining four sturgeon, one female and three males, were released at the boat launch in Faithhorn, MI, in the upper third of the study area Release Site B, 28.6 rkm upstream from the Chalk Hills Dam (Figure 3.2), on 26 April. In 2013, three male prespawning sturgeon (1.21 to 1.33 m TL) were captured; all three were released into the Chalk Hills Flowage at Release Site A on 20 May.

Upstream movement displayed in 2012 by the twelve study lake sturgeon was prompt. Within three days of their release, all eight fish released into the CHF had moved 10.14 rkm upstream from the release site. By 3 May 2012 three males had swum nearly the length of the study area (36.5 rkm) to be detected by the stationary receiver near Sturgeon Falls Dam (Appendix A) All four of the sturgeon in the released at the FH boat launch were detected near the SFD receiver 10.25 rkm upstream, on 27 April 2012, the next day. On 8 May 2012, during a period of increased flow (Figure 3.3) three untagged adult sturgeon were observed exhibiting spawning behavior in shallow water just downstream of the Sturgeon Falls Dam. One male, 2-M-FH, was detected moving from SFD to the CHF and then back again to SFD within an 8-day period in mid-May of 2012 (Appendix A), traveling ~73 rkm in this time.

In 2013, the three tagged and translocated males moved upstream and were detected at the Highway Z (HWZ) receiver (10.14 rkm) within two days of release. For a full month, little movement was detected by these fish, and their presence in the 1.5 rkm above HWZ was confirmed with portable receiver detections on 7 and 14 June. In late June, two of these males, Fish 13-M-CHF and Fish 15-M-CHF, traveled upstream, passing by FH and arriving at SFD from 21-22 June (Appendix A). In 2013, spawning activity, involving 3-4 sturgeon, was observed at SFD on 20 May while attempting to detect fish using a portable receiver from shore. The behavior was observed right against a rocky shore, ~5-10 m downstream of the far hydroelectric turbine in very fast, turbulent water. The portable receiver made no detections from the attempts, though the proximity to the dam and the very fast water likely blocked any signal that may have been detectable. Photographs of this spawning activity were taken later that day by the dam operator (Figure 3.4). Three tagged males were detected by the receiver near the Sturgeon Falls Dam the day before and/or the day of the witnessed spawning activity.

During both years, four fish moved downstream through or over the Chalks Hills Dam. In early July of 2012, heavy rainstorms passed over the Menominee River watershed, causing the waters to rise dramatically from ~31.1 CMS on 3 July to nearly 113.3 CMS on 7 July (Figure 3.3). Fish 6-M-CHF & 12-F-CHF were detected first above the Chalk Hills Dam at the CHF receiver and then below at the BCHD receiver over the course of this mid-summer flow increase (Appendix A). In 2013, Fish 13-M-CHF, released into the CHF on 15 May, was detected in the CHF while river flow was approximately 68 CMS on 28 June. The next day, this fish was detected by the BCHD receiver while river flow was near 90.6 CMS. The only other fish detected by the BCHD receiver in 2013 was a female from 2012, Fish 10-F-CHF. The last time this female was detected within the study area was at the CHF receiver on 3 July at approximately 62.3 CMS while the flow was dropping to around 51 CMS. Flow began to increase again, and on 8 July this female was detected by the BCHD receiver during rising waters, ~62.3 CMS. After being detected below the Chalk Hills Dam, each of the four sturgeon went in and out of the BCHD receiver's range, indicating that each sturgeon survived the trip downstream. Interestingly, three of the four sturgeon to migrate downstream beyond the Chalk Hills Dam were never detected above Pemene Falls, while all but one sturgeon to be detected near the FH receiver or above remained in the upper half of the study reach until the end of the study, with the exception to each observation being the same study sturgeon, Fish 13-M-CHF.

Movement over the White Rapids Dam may have also occurred. The female, Fish 12-F-CHF, and the male, Fish 6-M-CHF, which were both first detected below the Chalk Hills Dam in July of 2012, were detected regularly by the BCHD receiver until April 2013. It was during the rising near-flood waters in late April (Figures 3.5 & 3.6) that each was last detected. A tracking attempt made in the 2 rkm below the White Rapids Dam on 18 July 2013 ended with no sturgeon detections, though in non-high waters this was a shallow stretch of river that would not be favorable habitat for the sturgeon based upon low water depth.

Movements and movement distances varied for all tagged sturgeon; of the 15 sturgeon, only one sturgeon was detected at all five stationary receiver locations, therefore traveling over 39 rkm in and just below the study area. Six of the tagged sturgeon were detected at all four receivers within the study area, and so had traveled at least 36.5 rkm of the study area. Three tagged sturgeon were only detected at the upper two receivers, two were only detected at the lower two receivers within the study area, and the remaining three tagged sturgeon were detected by the lower two receivers within the study area as well as the receiver below the study area. Detections at stationary receivers were averaged for each fish per stationary per 24-hour period; in 2012, the average number of stationary 24hr detections per fish was 54.4 (range 9 to 149), and 58.3 stationary 24hr detections per fish (range 3 to 165) in 2013 (Table 3.3).

Every study fish was detected near at least 2 stationary receivers; from this movement rates for the fish could be calculated (Table 3.4). The average number of stationary to stationary receiver movements was 7.4 ± 5.9 (range 1 – 20, n= 15 fish). The maximum observed movement rate upstream was 2.63 km/hr (10.25 km in 3.9hrs), and the maximum observed downstream movement rate was 3.18 km/hr (16.14km in 5.07 hrs). Of the 111 stationary-to-stationary receiver movements, 57% occurred in <24 hours.

To look at the differences in movement based upon seasonality, the year was divided into two 'seasons', summer from May until October, and winter from November until April. No movement between stationary receivers occurred during the winter period, with the exception of the initial post-translocation movement of the 2012 study sturgeon occurring in the final week of April, 2012. Fish 3-M-FH and Fish 5-M-FH, were detected nearly every day at the SFD receiver from 20 October 2012 to 27 April 2013. Similarly, Fish 6-M-CHF and Fish 12-F-CHF were also detected nearly daily on the BCHD receiver from 10 October 2012 until 11 April 2013, though this is perhaps to be expected, as the section of river between the Chalk Hills Dam and White Rapids Dam is only ~4 rkm long. At both the FH and HWZ receivers, no activity was detected from late-October 2012 until late-April 2013 (Figure 3.7). The CHF stationary receiver did not detect any tagged sturgeon from late October 2012 until mid-May 2013.

Using the portable receiver, a total of 44 fish locations occurred between 14 June and 15 September of 2012, and 53 between 6 June and 3 August of 2013. Each fish was located with a portable receiver at least twice, with three sturgeon being located ten or more times. Using both stationary receiver and portable receiver detections, total distances covered for each sturgeon were determined (Table 3.3). Total distance covered by individual sturgeon ranged from 9.7 to 36.8 rkm (mean of 19.37 ± 12.75, n=12) in 2012 and from 2.08 to 38.76 rkm (mean of 17.55 ± 11.72, n=13) in 2013 (of the 39.6 rkm stretch between the Sturgeon Falls Dam and the Chalk Hills Dam), and was not significantly different between years (T=0.37, $T_{0.05(2),23}$ = 2.069). In both study years, male sturgeon total distances (mean of 23.7 rkm in 2012, 19.1 rkm in 2013) did not differ significantly from female sturgeon total distances (mean of 10.8 rkm in 2012, 12.3 rkm in 2013) (T_{2012} = 1.81, $T_{0.05(2),11}$=2.201; T_{2013} = 0.878, $T_{0.05(2),11}$ = 2.201).

Some individual sturgeon locations occurred regularly in certain areas of the river. The ~2 rkm stretch between the Pemene boat launch and the Highway Z crossing yielded four locations in 2012 and ten in 2013 (Figure 3.8) in two different areas. The 0.75 rkm immediately above HWZ had an average observed depth ~1.75 m and a bottom of sand/gravel/pea gravel with some cobble and boulders; submerged aquatic macrophytes were present in bands and patches along each shore line. The second area was in the main channel of the river just downstream of the Pemene Boat launch, along the downstream edge of a small island. Of the five locations made in a 72 m stretch, four of them were of 2013 male Fish 14-M-CHF.

Some sturgeon detections did occur in the vicinity of stream features (Figure 3.9, Tables 3.5 & 3.6) In the study area there are 51 islands, ranging in size from 65.4 m^2 – 1.03 km^2 (average island size of 35,888 m^2). In 2012, 14 of 44 sturgeon locations occurred within 100 m of an island, and in 2013, 15 of 53 locations were withing 100 m of an island. The area contained within 100 m of islands was 1.96 km^2, 32% of the 6.11 km^2 study area. Nine sets of rapids occurred in the studied area, including Quiver and Pemene Falls (Figure 3.2). Only one sturgeon location in 2012 occurred within 100 m of rapids; approximately 0.24 km^2, 3.9% of the 6.11 km^2 study area. In 2012, 36 tributary mouths, ranging from year-round flowing to small intermittent streams, were mapped. In 2012, 3 of 44 sturgeon locations occurred within 100 m of a tributary mouth, and in 2013, 7 of 53 sturgeon locations were within 100 m of a tributary mouth. The area captured within 100 m of the tributary mouths was 0.49 km^2, 8.0% of the 6.11 km^2 study area.

Sturgeon were often located near the large bend downstream of HWZ, where the river's flow direction changes from south to west (Figure 3.9). In 2012, nine sturgeon locations (four different sturgeon) and in 2013 five locations (two different sturgeon) occurred in the ~2 rkm stretch. All locations in this area happened on the Wisconsin side of the river in 1.2 to 2.4 m of water. Substrate here consisted of sand, gravel, and pea gravel, with some cobble occurring. In at least two different locations, the sturgeon appeared to be resting near or under docked pontoon boats. Interactions with landowners revealed that both sub-adult and adult lake sturgeon are regularly seen and caught here on hook and line.

The most concentrated grouping of locations observed during the study period occurred in a stretch of river beginning 2.3 rkm south of the Sturgeon Falls Dam. In just shy of 1 rkm, twelve sturgeon locations occurred during the study period, with nine of these in a 120 m stretch. This was the common spot to find 2012 female Fish 1-F-CHF (Appendix A); four of the five 2012 locations and five of the seven in 2013 mark her positions. This is the only area of the river to have three sturgeon located at the same time in <100 m of river. The area had very little vegetation in either year; location depth here varied from 2.1 to 3.6 m, with sand/gravel/pea gravel substrate and some boulders and cobble present.

Abiotic Characteristics at Sturgeon Location Sites

Sturgeon location sites showed strong associations with particular substrate particle size classes (Figure 3.10). Gravel was the most common in 2012, its presence was found at 74% of fish locations, and second most common in 2013 at 88.3%. Sand was the next most common particle size class in 2012 at 65.1%, but was most common in 2013, occurring at 90.7% of fish location sites. Pea gravel was present at 65.1% of all location sites in both study years. Cobble was found at 32.5% and 48.8% in 2012 and 2013 respectively, and all other substrate classes

were detected <33% each of the study years. No sturgeon detections occurred within vegetation, and in 2012 a single sturgeon detection occurred over muddy substrate.

Average depth in sturgeon location area measurements were recorded and was collected at 20 sturgeon locations in 2012 (Table 3.6). The average depth for the 30 m upstream and 40 m downstream from sturgeon locations ranged from 1.12 to 2.67 m, with individual depth readings in these areas ranging from 0.3 to 5.2 m; no significant difference was found between males and females (T=-1.59, $T_{0.05(2),20}$ = 2.086). Dissolved oxygen readings were measured for all locations between 4 July and 3 August of 2013, at a total of 30 separate sturgeon locations. The average amount of dissolved oxygen over this period was 8 mg/ml, with a range of 7 to 9 mg/ml. All samples were at least 88% saturated.

Surface water temperatures at locations in 2012 ranged from 17.2 to 27.8 °C, with an average of 24.0 ± 2.2°C; in 2013 the range was from 13.9 to 27.8°C, with an average of 20.7 ± 4.04°C (Figures 3.12 & 3.13). There was never a difference of more than one degree Celsius between surface and benthic temperature readings in either year. River temperatures measured at sturgeon locations in 2012 (mean = 24.35 °C , n = 42) were significantly different from those measured in 2013 (mean = 21.07 °C , n = 53) (t = 5.02, $t_{0.05(2).93}$ = 1.986). Temperatures were not significantly different at sturgeon locations sites in 2012 between upper half of the study stretch (mean = 24.45 °C, n = 21) and lower half of the study stretch locations (mean = 23.95°C, n = 21) (t = 1.50, $t_{0.05(2),40}$ = 2.021), but were significantly different in 2013 between upper stretch (mean= 22.29 °C, n = 38) and lower study stretch location sites (mean = 17.97 °C, n = 15)(t = 4.12, $t_{0.05(2),51}$ = 2.008).

Light measurements made side-by-side with the HOBO and the PAR meter were plotted out for 5 light level conditions (Figure 3.14). Light intensity was measured at 43 fish locations in 2012, and averaged 2098 ± 325 Lux (~100 PAR), and ranged from 0 to 8905 Lux (~0-250 PAR) over 16 June to 15 September (Figures 3.15, 3.16, & 3.17). Light measurements from the boat, made just before and after deployment into the river, averaged 81015 ± 8723 Lux, and ranged from 8456 to 203912 Lux (~320-2000 PAR) . A lux value of zero (0) is the complete absence of light; light measurements from above the river when paired with their corresponding near river bottom measurements were always at least an order of magnitude greater, if not much more.

Biotic Characteristics at Sturgeon Location Sites

Invertebrate sampling occurred at 91 of the 97 fish locations. Arthropod class collected in mini-ponar samples and drift net samples include Insecta, Amphipoda, Decapoda, and Arachnida; mollusk classes included both Gastropoda and Bivalvia (Figure 3.18). In both study

years, insects were the most ubiquitous class, occurring at 87.8% of location surveys in 2012, and 93.0% of location surveys in 2013. Bivalves were found at 36.6% of location surveys in 2012 and 51.2% of location surveys in 2013. Gastropods were also common in both years, occurring in 53.6% of location surveys in 2012 and 39.5% of location surveys in 2013. All other classes occurred in <10% of samples collected.

All aquatic invertebrates were identified to one of 20 taxonomic groups, with two additional categories, Cone-Shelled Gastropods and Terrestrials (Figure 3.19). Most invertebrates were identified to family only, unless genus or species was possible. Trichoptera were the most commonly present group of invertebrates (60.9% of location surveys in 2012, 86.0% of location surveys in 2013) followed by Ephemeroptera (43.9% of location surveys in 2012, 51.1% of location surveys in 2013) and Chironomidae (24.4% of location surveys in 2012, 53.5% of location surveys in 2013)(Appendix D). Freshwater limpets belonging to the family Ancylidae (36.6% of location surveys in 2012, 27.9% of location surveys in 2013), Sphaeriid clams (24.4% of location surveys in 2012, 30.2% of location surveys in 2013), Zebra mussels (*Dreissena polymorpha*) (14.6% of location surveys in 2012, 25.6% of location surveys in 2013), and cone-shelled gastropods (26.8% of location surveys in 2012, 20.9% of location surveys in 2013) were also commonly present (Appendix D). In 2012, Notonectidae was found in 19.5% of location surveys, but was not found at all in 2013. All other groups were found at <10% of location survey sites in either 2012 or 2013.

A total of twelve species of submerged aquatic macrophytes were observed in 2012, and 11 species were seen in 2013 (Table 3.8), with the study site-wide dominant species being wild celery, *Valisnaria americana*. Approximately 4 rkm of the study area was inaccessible for vegetation mapping in 2012 due to too low flows or unsafe boating conditions due to falls or rapids, while approximately 2.75 rkm was not mapped in 2013; this ~1.25rkm difference occurred because of higher river flows in 2013 compared to 2012 (Figures 3.3 & 3.5) allowing access to more river area in 2013. In 2012, the mapped vegetation covered at least 412 acres of the 1510.9 acre study area (1.67 of 6.11 km^2), 27.3% of the area. In 2013, only 195 acres (0.79 km^2) of vegetation was mapped, 12.9% of the river area. The large amount of in-stream vegetation in 2012 covered a half kilometer stretch of river in the Sturgeon Bend Park area (Figure 3.20), from shore to shore with the only breaks from the coverage coming in the numerous massive boulders peppering the area (Appendix E), with similar stretches of vegetation in the main and minor channels around Grand Island (Figure 3.21). No sturgeon movement was recorded across these densely vegetated areas. In 2013, with the vegetation at a fraction of its extent in the previous year, movement across both these areas occurred (Appendix A).

3.5 Discussion

Sturgeon Movements

The null hypothesis $H_0 1$, that translocated pre-spawning condition lake sturgeon will not migrate further upstream toward the historic spawning site at Sturgeon Falls, was rejected. The movements of the 15 sturgeon translocated in 2012 & 2013 support the hypothesis that pre-spawning sturgeon will migrate upstream towards historic spawning habitat if given access. Seven of the fifteen sturgeon were detected at the top of the study area near the historic spawning site of Sturgeon Falls within 2 weeks of translocation, a migration of over 30 rkm for three of these sturgeons. In 2012, these seven sturgeon were detected near SFD days before and after observations of spawning activity were made on 8 May. In 2013, spawning activity was observed at the Sturgeon Falls Dam on 20 May, but no sturgeon with a transmitter could be detected, likely due to fast turbulent waters blocking any sound that may have been there. Some male sturgeon are known to occasionally spawn in consecutive years in warmer bodies of water such as the Wolf River in Wisconsin (Bruch & Binkowski, 2002) or the Lake Huron tributary Black River in Michigan (Smith & Baker, 2011), while in colder bodies of water, such as the Lake Superior tributary Sturgeon River, back to back spawning years have not been observed (Auer, 1999). Three of the male sturgeon translocated in 2012 were detected at the SFD stationary receiver the day before or the day of the spawning observations, so it is possible one or more of these sturgeon were involved in the observed behavior. The other eight sturgeon in this study all migrated upstream 10.14 rkm from Release Site A in the CHF to the HWZ receiver, the nearest stationary receiver downstream of Pemene Falls and Quiver Falls, two other possible spawning sites within the study area. Rapid upstream migration by pre-spawning surgeon post-translocation has also been observed in the Winnipeg River, Manitoba, Canada, where tagged lake sturgeon travelled 18.7 rkm upstream in an average of 3.85 days post-translocation (McDougall et al., 2013).

For freely-ranging sturgeon, post-spawning adults migrate back downstream exiting the river and returning to the lake environment from which they came (Auer, 1999; Bruch & Binkowski, 2002). Over the course of this study, four of the fifteen fish migrated downstream past the Chalk Hills Dam. Interestingly, three of the four sturgeon to migrate downstream beyond the dam were never detected above Pemene Falls, while all but one sturgeon to be detected at FH receiver or above remained in the upper half of the study reach until the end of the study. Interestingly, the exception to both these observations was 13-M-CHF. Through a communication between the dam operator Wisconsin Energy and the WDNR, it was revealed that for every 11.3 CMS over 56.6, the Chalk Hills Dam spillway gates open 0.3 m. As all migrations

downstream were accompanied by flow increases large enough to require the dam be opened up further, it is possible that the time of season may be what is prompting downstream migration, and that the increased flow opening the gate allows for such movement.

The null hypothesis H02, that there is no consistent pattern in movement of post-spawning sturgeon, was not rejected. Locations of tagged lake sturgeon occurred throughout the study area, though were conspicuously absent in the Sturgeon Bend Park area and all but the upper stretch of the Chalk Hills Flowage. This was surprising, as it was suspected that the sturgeon would frequent the deeper, slower waters of the flowage which assumedly resembles more closely their natural lake habitat over the riverine habitat that covers most of the study area. In spite of no locations occurring in the lower CHF, movement of study sturgeon through the CHF did occur regularly as based upon stationary receiver detections at the CHF stationary receiver located near the midpoint of the CHF.

The weather in the Menominee River watershed, and in particular the winters of 2011-2012 and 2012-2013, directly and indirectly influenced the lake sturgeon movement, the river itself, and the effectiveness at which the various tasks involved in this study were performed. The winter of 2011-2012 was mild, with less than average snowfall and an early snowmelt. This was reflected in the USGS river flows recorded at gauging station 04066003 (Figure 3.3). In 2012, spring flow crested in early May, with a single ~113 CMS river surge occurring around 4 July. Flow was generally well below median for the time period. In the spring of 2013, heavy snows from the winter combined with a late thaw and ample spring rain resulted in a large river surge. On 4 May 2013, the river crested in the study area at a flow of 433 CMS (Figure 3.5), and nearly reached flood stage levels (Figure 3.6). Flows remained above median well into June, and for the rest of the study period flow was above median more often than not, with multiple 85+ CMS spates. The Sturgeon Falls Dam operator described a large numbers of logs, trees, and other woody debris moving through the river during the spring high waters of 2013. The in-river topography in many sections of the river was noticeably different; in 2012, the river could be traveled upstream all the way from the Faithhorn boat launch to the bottom of the large island at SFD in ~22.5 CMS. This same journey was barely possible in 2013 with 28+ CMS in the 16 foot jon boat, likely due to the movement of bottom substrates during the suspected river scour which occurred during April of 2013.

Spring flows seemed to influence the effectiveness at which pre-spawning sturgeon were collected. The spring of 2012 was a low-flow warm spring for the Menominee River; the pre-spawning sturgeon congregated in staging areas downstream of the fast flowing headwaters, or in the case of an impounded reach of river, below the upper hydroelectric dam. Flow levels were manageable to work in as the water temperature increased to ~9°C; sturgeon have been observed spawning at similar temperatures in the nearby systems of the Sturgeon River, MI

(Auer, 1996a) and the Wolf and Upper Fox Rivers, WI (Bruch & Binkowski,2002). Twelve prespawning sturgeon were found among the over 100 sturgeon captured. In the second year of the study, the unusually high flow in the spring of 2013 caused numerous problems. Firstly, the high waters made sampling for pre-spawning sturgeon impossible until discharge receded to below 200 CMS. By this time, many sturgeons may have already spawned, taking advantage of the high flow. A further possible complication of the increased flow is that it may have created new temporary spawning habitat. Instead of spawning at the top of an impounded reach, below hydroelectric turbines or spillways where water flow rate would usually be the fastest, the sturgeon likely had many sites where they could spawn. Only three prespawning fish were collected and translocated in 2013, in spite of increased time spent sampling and expanding the number of sampling sites.

The third null hypothesis, lake sturgeon do not show habitat or location preference post-spawning for such features as islands, rapids, or tributary mouths, was also not rejected. While sturgeon locations did occur within the vicinity of certain river features, it does not appear that there was selection preference (Table 3.6) In 2012 and 2013, 29 of 97 locations (30%) happened in the proximity of islands; this includes 32% of the study area. For rapids, 1 of 97 locations (1%) occurred in the 3.9% of the study area which was within 100 m of rapids. Similarly, 10 of 97 locations (10%) occurred within the 8% of the study area which was within 100 m of a tributary mouth. With % occurrences of locations so similar to the % area for each of the respective feature buffers, it does not seem that the sturgeon are selectively associating with these features.

Abiotic Characteristics at Sturgeon Location Sites

Mini-ponar samples taken in this study showed similar particle sizes similar to those found for both adult and juvenile lake sturgeon in the Grasse River in New York (Trested et al., 2011), age-0 sturgeon in the Manistee River in Michigan (Mann et al., 2011), and juvenile sturgeon in the Menominee River (Kornelly, 2005). Sand was present at most sturgeon location sites, suggesting ample habitat for age-0 sturgeon, which has been indicated to be selected by sturgeon from Lake Winnebago, WI both in the field (Kempinger, 1996) and in a laboratory setting (Peake, 1999).

The maximum observed surface water temperature on the Menominee River was 27.8°C in both years but temperatures in deep water were not sampled; there are no records of lake sturgeon occurring in such high water temperatures to be found in the literature. Observed depths in sturgeon location areas ranged from near 0.3 to 5.7 m, nowhere near the maximum depth observed in the study area of ~10 m.

Light intensity readings were made just above the river substrate; assuming that detected sturgeons were near the bottom and not elsewhere in the water column, light readings suggest that sturgeon prefer less light or deeper water. Half (50%) of light readings were between 0 (no light) and 1250 Lux, (~0-4 PAR) and 29% of light reading were between 0 and 500 Lux (~0-1) (Figure 3.15).

The water was well oxygenated at all fish location sites where dissolved oxygen levels were measured in 2013, with saturation levels ranging from 88.8 to 100%.

Biotic Characteristics at Sturgeon Location Sites

Observed taxa of invertebrates at sturgeon locations were also found to be consumed by both adult and juvenile lake sturgeon (Benson et al., 2005; Chiasson et al., 1997; Harkness, 1923; Kempinger, 1996; Nilo et al,. 2006). Trichopterans were by the far the most commonly present group of invertebrates, with most specimens collected being non-armored species. In Lake Nipigon, Canada, Harkness 1923 found Chironomids, Spaerids, Ephemeropterans, and Gastropods to be main food sources of lake sturgeon, but that also Trichopterans and other alternate foods were consumed when found in their habitats in abundance. All of these taxonomic groups were found to be present in the Menominee River at lake sturgeon locations. Supporting previous findings suggesting that lake sturgeon avoid zebra mussels (McCabe et al., 2006), live zebra mussels were observed at only 20% of all location sites, with their shells making up a majority of the substrate at some locations. Zebra mussels were only observed at sturgeon locations within the 10 rkm below the Sturgeon Falls Dam. Unionid clams and their shells were commonly seen in the shallows of the Meniominee River, however none were collected in mini-Ponar samples at any sturgeon location.

Lake sturgeon habitat selection and presence of in-stream vegetation is not well studied. Kempinger (1996) noted an absence of vegetation in habitats which contained juvenile sturgeon. While some fish locations occurred in the vicinity of vegetation, at no time did a fish location occur within the outlines of the vegetation mapping when the vegetation was present. A single location was made in 2012, near the south-to-west bend downstream of HWZ, several weeks prior to vegetation mapping and the vegetation reaching its full extent (Figure 3.9). This aversion to vegetation is also supported by the vegetation blocks in 2012 in SBP and around Grand Island, and the consequent lack of movement by study sturgeon through these areas. In 2013, with these areas no longer dominated by vegetation due to increased flows, sturgeon passage both upstream and downstream occurred (Appendix A). The difference in vegetation between the two years is likely a combined effect of warmer temperatures and greater flows in 2013 than in 2012 (Figures 3.3 & 3.5), warmer temperatures in 2012 than in 2013 (Figure 3.22), and a suspected

river bottom scour which may have occurred in 2013 during a flood event in late April (Figures 3.5 & 3.6). It is likely that a year in which low flows and higher river temperatures occur, dense vegetation which can block sturgeon movement will develop.

Stocking of lake sturgeon has occurred in this section of the river since the early 1980's, and many un-tagged sturgeon from previous year classes were observed. Implementation of fish passage over the White Rapids and Chalk Hills Dams would add ~43 rkm to the possible upstream migration to spawning grounds, perhaps allowing more time for gamete maturation and therefore spawning success, augmenting the population which currently dwells within this stretch of the river.

3.6 Conclusions

In conclusion, this study has found that pre-spawning sturgeon from an impounded stretch of river when given access to historic upstream spawning habitat migrated upstream to this habitat, presumably to use it. Sturgeon spawning activity near Sturgeon Falls Dam was observed in both study years. In this study, sturgeon were located in proximity of in-stream features such as islands and tributary mouths, but not at higher rates then these features occurred at proportionally within the study area. Within the boundaries of the study area, appropriate water depths and substrate types were observed to support both juvenile and adult lake sturgeon. Numerous taxa of aquatic invertebrates known to be fed on by lake sturgeon were observed at sturgeon location sites, suggesting that appropriate food sources for sturgeon were readily found. Observed river temperatures suggest that lake sturgeon may be tolerant to higher temperatures, but temperatures near the bottom were not collected in both years. Tagged lake sturgeon were found generally in water with less light, suggesting they select for lower light levels within the river. The presence of thick in-stream vegetation appeared to block sturgeon movement in 2012, whereas no block in movement occurred in 2013 when in-stream vegetation coverage in this area was halved. In addition to those sturgeon used in this translocation study, numerous un-tagged sturgeon ranging from ~0.5 m subadults to 1.2+ m adults were also observed within the study area, supporting the findings that this section of the river will open up new habitat, both for spawning and non-spawning access, should fish passage be implemented.

3.7 Limitations & Recommendations

Of the 15 lake sturgeon tagged for this study, five were never detected at the Faithhorn access point or higher or on the instream recievers. Three of these five sturgeon were detected with a portable receive in the 2 rkm above the Highway Z receiver, however whether any of these five sturgeon travelled further upstream is unknown. Future Investigations should include stationary receivers placed between Quiver and Pemene Falls to establish upstream movement and whether these falls are used as spawning sites. Evidence of spawning in these regions would increase the value of protecting this reach and allowing sturgeon passage to these sites. Additionally, this area contains one of the two regions of heavy vegetation shown to discourage sturgeon movement in 2012. For the Menominee River investigating the connection between vegetation and movements of sturgeon and flows is imperative to management and fishing regulations for this system.

Measurements of depth and light at location where sturgeon were detected suggest that these fish selected for water with less light and utilized a range of depths. Future work should incorporate transmitters which record depth and/or temperature data to determine diurnal movements and where in the water column the fish actually are. These types of data collection would provide critical information on temperature selection and tolerance as we detected fish in water at upper limits of 27.8°C.

Use of mapping using side-scan sonar would enhance depth data by giving accurate bottom profiles of sturgeon location sites. The use of GIS in this study allowed for spatial analysis of sturgeon location relative to obvious features such as islands and tributary mouths, and the incorporation of sonar mapping would allow for analysis of association with in-stream features such as thalwegs, submerged boulders or pools. Sidescan sonar can also be used to identify substrate types and therefore possible prey organisms.

In both 2012 and 2013, spawning activity was observed in the vicinity of the Sturgeon Falls Dam. While a stationary receiver downstream confirmed tagged sturgeon were in the vicinity, we were not able to gather data on whether fish successfully spawned. With two of the four females and nine of the eleven males remaining in the study area at the end of the two year study period, it is likely that these sturgeon will spawn prior to transmitter battery expiration. One way to determine if spawning is successful is to collect sturgeon eggs using devices placed in river prior to spawning at potential sites, or to conduct drift sampling below such sites. The Menominee River is a fast flowing, regulated river (dam operation impacts flows) and this makes working in the river in spring, usually a time of high flow, dangerous and unpredictable. Discharge within the study area was often variable and changed rapidly. The river’s discharge is

controlled by numerous hydroelectric dams. As dam gates were opened or closed, river depth would rise or fall as much as 0.3m, so extreme caution was needed. Additionally, the river responded to rains quickly, in particular from large thunderstorm systems that regularly passed through the watershed. In both study years heavy rains in early July resulted in the flow increases which coincided with downstream movement of sturgeon through the Chalk Hills Dam. These increases in flow did allow us to track the area between Quiver Falls and the Faithhorn stationary receiver, and the upper 0.5 rkm below the Sturgeon Falls Dam. A survey of the river during late summer low flows may provide insight into where nets could be placed to collect drifting larvae in spring, especially if coupled with information on possible spawning at the Quiver or Pemene Falls sites, helping narrow the region needed to be sampled.

Unlike small rivers in which sturgeon are known to spawn, as the Sturgeon River, Baraga Co., Michigan, or the Upper Black River, Michigan, where successful egg collection and larval drift netting methodology has developed, the Menominee River is a larger, wider river. The Sturgeon River has an average width in spawning areas of 30-40 m and an average depth of 0.25 m (Auer, 1999). The Upper Black has an average yearly discharge of 6.4 m^3/s (Smith & Baker, 2005), yet the Menominee River dwarfs each system having anaverage width of 144m within the study area and an average yearly discharge of 113 m^3/s at the mouth (Priegel, 1977). In the Sturgeon River, spawning generally occurs when discharge is between 22.5-33 m^3/s (Auer, 1999); during this two year study spawning activity was observed in the Menominee River when flows within study area were at ~100 m^3/s, levels of discharge which inhibited placement of egg collection devices. While successful egg collection has occurred in the large, deep Huron-Erie corridor, this occurred on and near artificially created spawning grounds in a well mapped river.

In this study, we had on loan 5 stationary receivers from the WDNR to cover the 39 rkm stretch. Additional stationary receivers would help to establish small-scale movement patterns. Active tracking of sturgeon with a handheld receiver may also be enhanced with a watercraft able to access parts of the river a small aluminum craft with a propped tiller outboard cannot, such as an inflatable zodiac-type craft or use of a boat with a jet-propelled outboard engine.

3.8 Bibliography

Auer, N.A. 1996a. Response of spawning lake sturgeon to change in hydroelectric facility operation. Transactions of the American Fisheries Society. Vol. 125 pp. 66–77.

Auer, N.A. 1996b. Importance of habitat and migration to sturgeons with emphasis on lake sturgeon. Can. J. Fish. Aquat. Sci. Vol. 53 (Suppl. 1) 152-160.

Auer, N.A. 1999. Population characteristics and movements of lake sturgeon in the Sturgeon River and Lake Superior. Journal of Great Lakes Research. Vol. 25 pp. 282-293.

Barth, C.C., Peake, S.J., Allen, P.J., and Anderson, W.G. 2009. Habitat utilization of juvenile lake sturgeon, *Acipenser fulvescens*, in a large Canadian river. Journal of Applied Ichthyology. Vol. 25 Supplement 2 pp. 18-26.

Bartel, R., Wiśniewolski, W., and Prus, P.2007. Impact of the Włocławek Dam on migratory fish in the Vistula River. Archives of Polish Fisheries. Vol. 15(2)pp.141-156.

Benson, A.C., Sutton, T.M., Elliot, R.F., and Meronek, T.G. 2005. Seasonal movement patterns and habitat preferences of Age-0 lake sturgeon in the lower Peshtigo River, Wisconsin. Transactions of the American Fisheries Society. Vol.134 pp. 1400-1409.

Borkholder, B.D., Morse, S.D., Weaver, H.T., Hugill, R.A., Linder, A.T., Schwarzkopf, L.M., Perrault, T.E., Zacher, M.J., and Frank, J.A. 2001. Evidence of a year-round resident population of lake sturgeon in the Kettle River, Minnesota, based on radiotelemetry and tagging. N.A. Journal of Fisheries Management. Vol. 22 pp. 888-894.

Bruch, R.M. and Binkowski, F.P. 2002. Spawning behavior of lake sturgeon (Acipencer fulvescens). Journal of Applied Ichthyology. Vol. 18 pp. 570-579.

Carrofino, D.C., Sutton, T.M., and Lindberg, M.S. 2009. Abundance and movement patterns of age-0 juvenile lake sturgeon in the Peshtigo River, Wisconsin. Environmental Biology of Fish. Vol. 86. Pp. 411-422.

Chiasson, W.B., Noakes, D.L.G. and Beamish, F.W.H. 1997. Habitat, benthis prey, and distribution of juvenile lake sturgeon (*Acipenser fulvescens*) in northern Ontario rivers. Canadian Journal of Fisheries and Aquatic Sciences. Vol. 54.12 pp. 2866-2871.

Chiotti, J.A., Holtgren, J.M., Auer, N.A., & Ogren, S.A. 2008. Lake sturgeon spawning habitat in the Big Manistee River, Michigan. North American Journal of Fisheries Management. Vol. 28 pp. 1009-1019.

Cummins, K.W. 1962. An Evaluation of Some Techniques for the Collection and Analysis of Benthic Samples with Special Emphasis on Lotic Waters. American Midland Naturalist. Vol. 67(2) pp. 477-504

Daugherty, D.J., Sutton, T.M., and Elliot, R.F. 2009 Suitability Modeling of Lake Sturgeon Habitat in Five Northern Lake Michigan Tributaries: Implications for Population Rehabilitation. Restoration Ecology. Vol. 17(2), pp. 245-257.

Fasset, N. 1957. Manual of Aquatic Plants, with revision appendix by Eugene C. Ogden.

Ferguson, J.W., Healey, M., Dugan, P., and Barlow, C. 2011. Potential effects of dams on migratory fish in the Mekong: Lessons from Salmon in the Fraser and Columbia Rivers. Environmental Management. Vol. 47. Pp. 141-159.

Harford, W.J and McLaughlin, R.L. 2007. Understanding uncertainty in the effect of low-head dams. Ecological Applications, Vol. 17(6) pp. 1783–1796.

Harkness, W.J.K. 1923. The rate of growth and the food of the lake sturgeon (*Acipenser rubicundus* Le Sueur). University of Toronto Studies. No. 18 pp 14-42.

Haxton, T. 2011. Depth selectivity and spatial distribution of juvenile lake sturgeon in a large, fragmented river. Journal of Applied Ichthiology. Vol. 27(Suppl. 2) pp. 45-52.

Holtgren, J.M., and Auer, N.A. 2004. Movement and habitat of juvenile lake sturgeon (Acipenser fulvescens) in the Sturgeon River/Portage Lake System, Michigan. Journal of Freshwater Ecology. Vol. 19 pp. 419-432.

Johnson, J.H., LaPan, S.R., Klindt, R.M. & Schiavone, A. 2006. Lake sturgeon spawning on artificial habitat in the St. Lawrence River. Journal of Applied Ichthyology. Vol. 22 pp. 465-470.

Kempinger, J.J. 1996. Habitat, growth, and food of young lake sturgeons in the Lake Winnebago system, Wisconsin. North American Journal of Fisheries Managaement. Vol. 16.1 pp 102-114.

Kornely, G.W. 1988. Lake sturgeon creel survey of the Menominee River Wisconsin-Michigan boundary water, 1981-1984. Wisconsin Department of Natural Resources Fish Management Report 134.

Kornely, G.W. 2005. A Survey of Lake Sturgeon Status and Stocking Success In the Menominee River below Sturgeon Falls. Final Report to the Wilderness Shores Implementation Team.

LaHaye, M., Branchaud, A., Gendron, M., Verdon, R., & Fortin, R. 1992. Reproduction, early life history, and characteristics of the spawning grounds of the lake sturgeon (*Acipenser fulvescens*) in Des Prairies and L'Assomption rivers, near Motreal, Quebec. Canadian Journal of Zoology. Vol. 70, pp. 1681-1689.

Liermann, C.R., Nilsson, C., Robertson, J., and Ng, R.Y. 2012. Implications of dam obstruction for global freshwater fish diversity. Bioscience. Vol. 62(4) pp.539-548.

Macke, G.L., White, D.S., and Zdeba, T.W. 1980. A guide to freshwater mollusks of the Laurentian Great Lakes, with special emphasis on the Genus Pisidium.

Mann, K.A., Holtgren, J.M., Auer, N.A., and Ogren, S.A. 2004. Comparing size, movement, and habitat selection of wild and streamside-reared lake sturgeon. North American Journal of Fisheries Management. Vol. 31 pp. 305-314.

McCabe, D.J., Beekey, M.A., Mazloff, A., and Marsden, J.E. 2006. Negative effect of zebra mussels on foraging and habitat use by lake sturgeon (*Acipencer fulvescens*). Aquativ Conservations: Marine and Freshwater Ecosystems. Vol. 16 pp. 493-500.

McDougall, C.A., Hrenchuk, C.L., Anderson, W.G., and Peake, S.J. 2013. The rapid upstream migration of pre-spawn lake sturgeon following trap-and-transport over a hydroelectric generating station. North American Journal of Fisheries Management, Vol. 33 pp. 1236-1242.

Merritt, R.W. and Cummins, K.W. 1996. An Introduction to the Aquatic Insects of North America, 3rd Edition.

Muencher, W. 1944. Aquatic Plants of the United States.

Nichols, S.J., Kennedy, G., Crawford, E., Allen, J., French, J. III, Black, G., Blouin, M., Hickey, J., Chernyak, S., Haas, R. & Tomas, M. 2003. Assessment of Lake Sturgeon (*Acipenser fulvescens*) in the Lower St. Clair River, Michigan. Journal of Great Lakes Research. Vol. 29 pp. 383-391.

Nilo, P., Tremblay, S., Bolon, A., Dodson, J.,Dumont, P., and Fortin, R. 2006. Feeding ecology of juvenile lake sturgeon in the St. Lawrence River system. Transactions of the American Fisheries Society. Vol. 135.4 pp. 1044-1055.

Peake, S. 1999. Substrate preference of juvenile hatchery-reared lake sturgeon, *Acipenser fulvescens*. Environmental Biology of Fishes. Vol. 56 pp. 367-374.

Priegel, G.R. 1973. Lake sturgeon management on the Menominee River. Wisconsin Department of Natural Resources, Technical Bulletin Number 67.

Smith, K.M. and King, D.K. 2005. Movement and habitat use of yearling and juvenile lake sturgeon in Black Lake, Michigan. Transactions of the American Fisheries Society. Vol. 134 pp. 1159-1172.

Smith, K.M., and Baker, E.A. 2011. Characteristics of spawning lake sturgeon in the Upper Black River, Michigan. North American Journal of Fisheries Management. Vol. 25.1 pp. 301-307.

Theumler, T.F. 1985. The Lake sturgeon, *Acipenser fulvescens*, in the Menominee River, Wisconsin-Michigan. Environmental Biology of Fishes. Vol. 14(1), pp. 73-78.

Theumler, T.F. 1988. Movements of Young Lake Sturgeons Stocked in the Menominee River, Wisconsin. American Fisheries Society Symposium 5. pp. 104-109.

Theumler, T.F. 1997. Lake sturgeon management in the Menominee River, a Wisconsin-Michigan boundary water. Environmental Biology of Fishes. Vol. 48 pp. 311-317.

Trested, D.G., Chan, M.W., Bridges, W.C., and Isely, J.J. 2011. Seasonal movement and mesohabitat usage of adult and juvenile lake sturgeon in the Grasse River, New York. Transactions of the American Fisheries Society. Vol. 140 pp. 1006-1014.

Uvaas,B. and Baker,S. 2011. Stage 2 Remedial Action Plan for the Lower Menominee River A-rea of Concern.

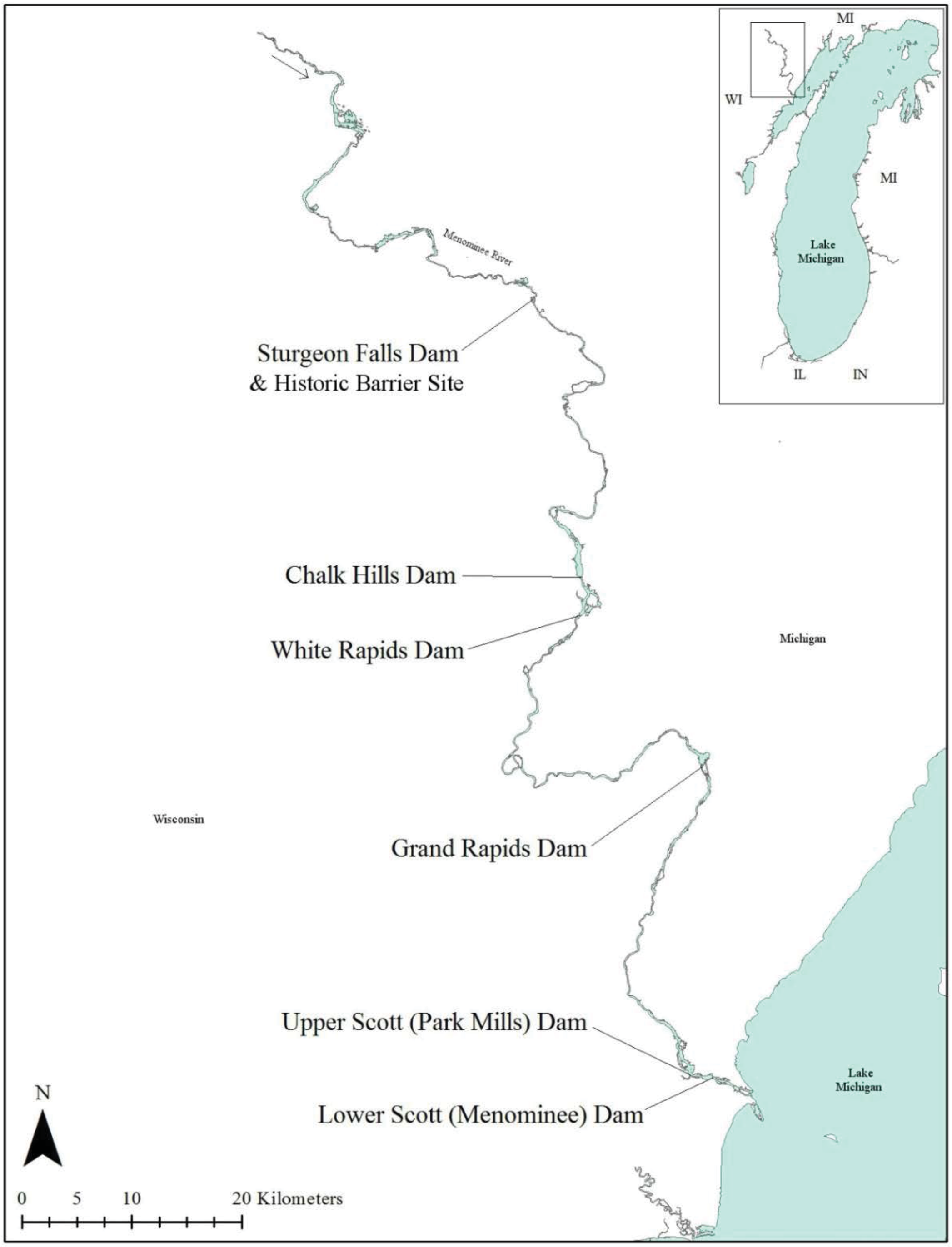


Figure 3.1: Map of the Menominee River, MI/WI with six most downstream dams identified.

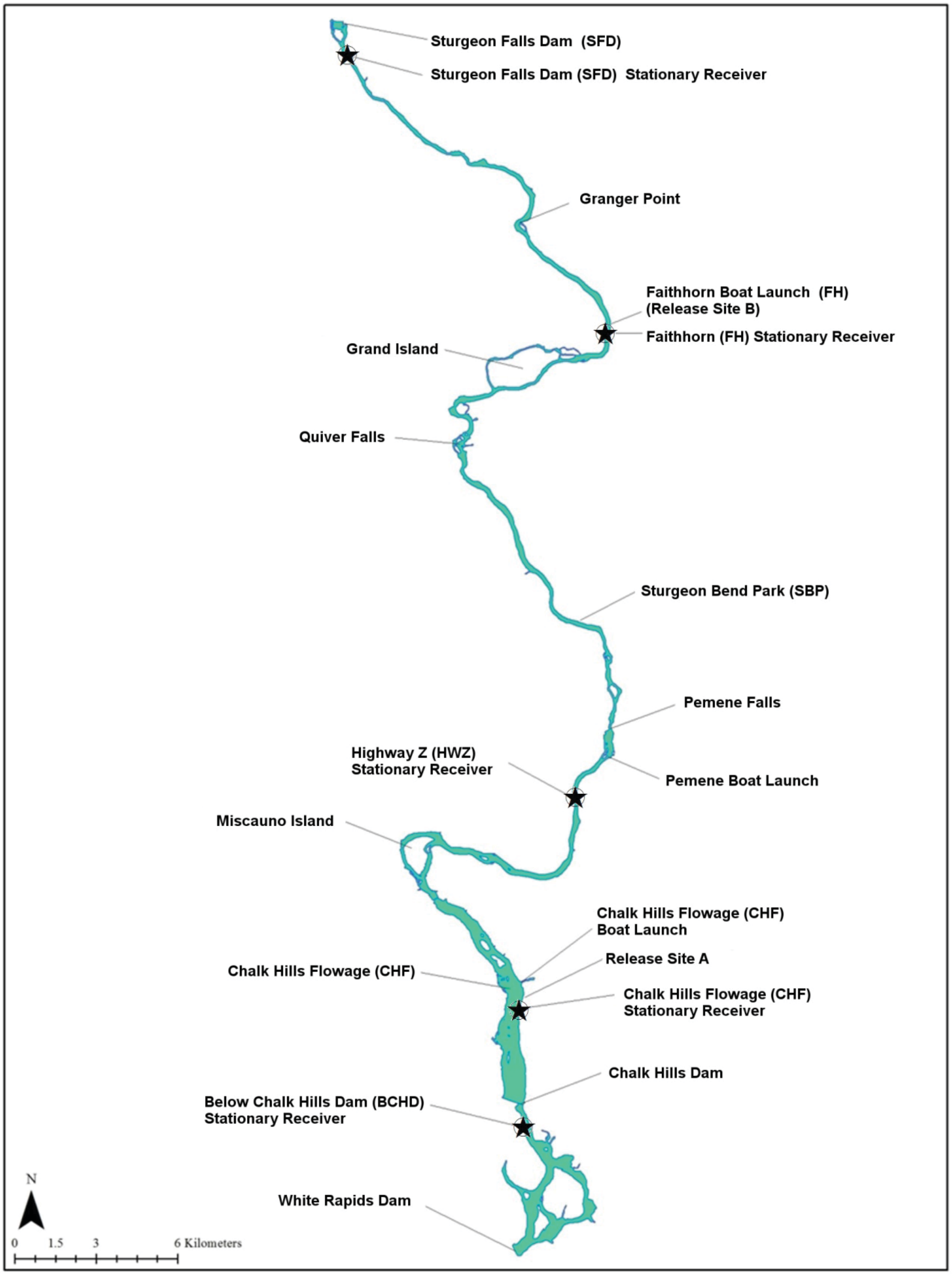


Figure 3.2: Map of the study area, White Rapids Dam to Sturgeon Falls Dam Menominee River, MI/WI

Table 3.1: Site Abbreviations

Abbreviation	Site Description	rKm from Mouth
BCHD	Below Chalk Hills Dam	85
CHF	Chalk Hills Flowage	89
FH	Faithhorn	114
HWZ	Highway Z crossing	100
SBP	Sturgeon Bend Park Campground and Public Access	106
SFD	Sturgeon Falls Dam	125

Table 3.2 : Overview of all study sturgeon

Fish #	Gender	Total Length (m)	Release Date	PIT tag #	Vemco Tag ID	Release Site
1-F-FH	Female	1.46	4/26/2012	4549621C77	30788	FH
2-M-FH	Male	1.22	4/26/2012	4179247F1E	30789	FH
3-M-FH	Male	1.24	4/26/2012	985121024812575	30790	FH
4-M-CHF	Male	1.24	4/23/2012	422F480A33	30791	CHF
5-M-FH	Male	--	4/26/2012	985161001200106	30792	FH
6-M-CHF	Male	1.23	4/23/2012	422618072F	30793	CHF
7-M-CHF	Male	1.22	4/23/2012	985121024803825	30794	CHF
8-M-CHF	Male	1.36	4/23/2012	45497C107B	30795	CHF
9-F-CHF	Female	1.35	4/23/2012	985161000703501	30796	CHF
10-F-CHF	Female	1.34	4/23/2012	900118001505203	30797	CHF
11-M-CHF	Male	1.24	4/23/2012	4226236124	30798	CHF
12-F-CHF	Female	1.56	4/23/2012	46184B4D75	30799	CHF
13-M-CHF	Male	1.21	5/20/2013	42302F1930	28384	CHF
14-M-CHF	Male	1.28	5/20/2013	4226161C3C	28386	CHF
15-M-CHF	Male	1.33	5/20/2013	985121024823917	28388	CHF

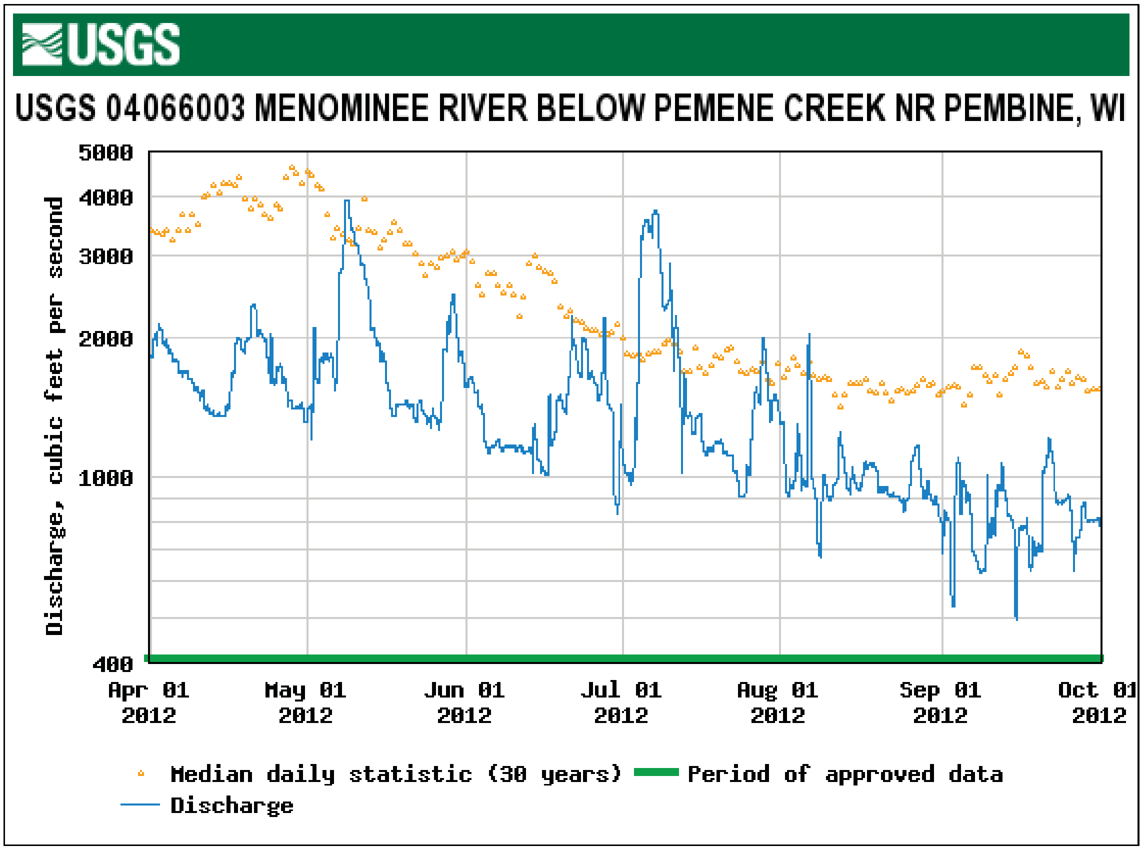


Figure 3.3: Discharge at USGS station 04066003, Menominee River below Pemene Creek near Pembine, WI, for April to October 2012.

Figure 3.4: Photographs of sturgeon spawning behavior occurring 20 May 2013 at Sturgeon Falls Dam, courtesy of Gerry Gerard. See Appendix F for documentation of permission for use.

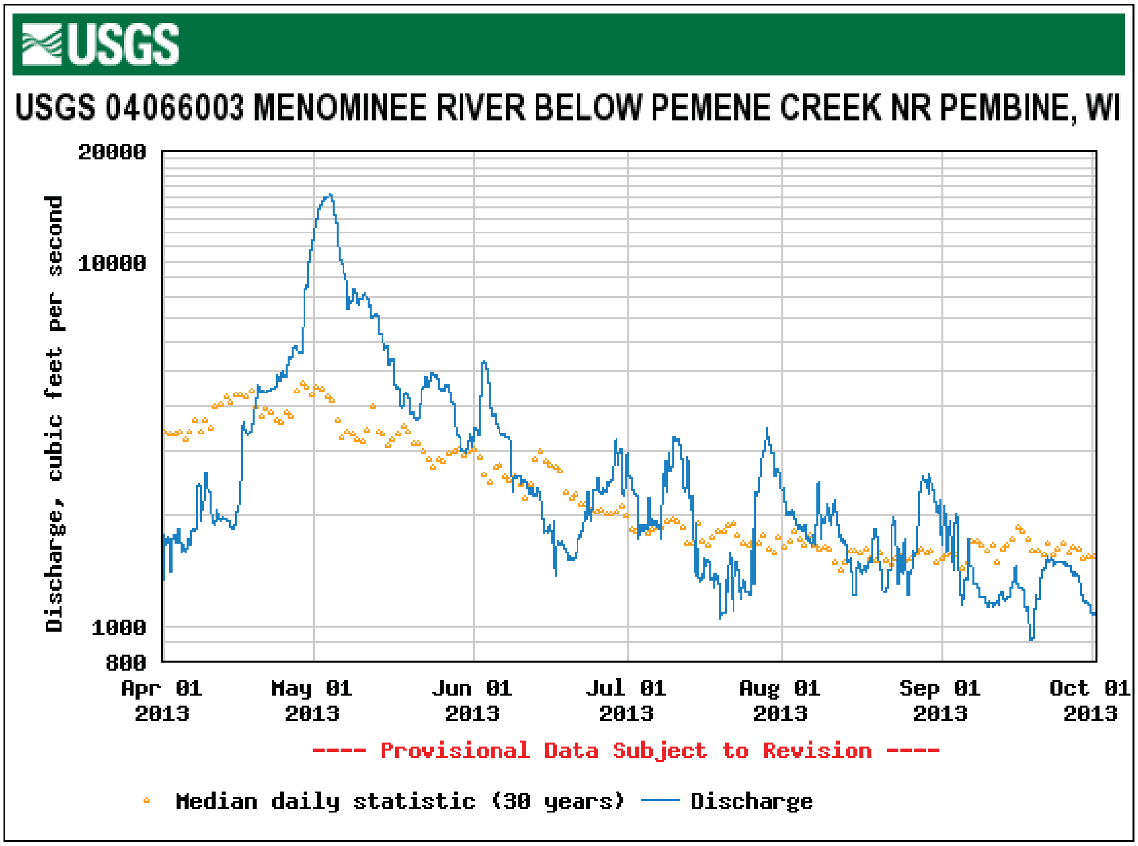


Figure 3.5: Discharge at USGS station 04066003, Menominee River below Pemene Creek near Pembine, WI, for April to October 2013.

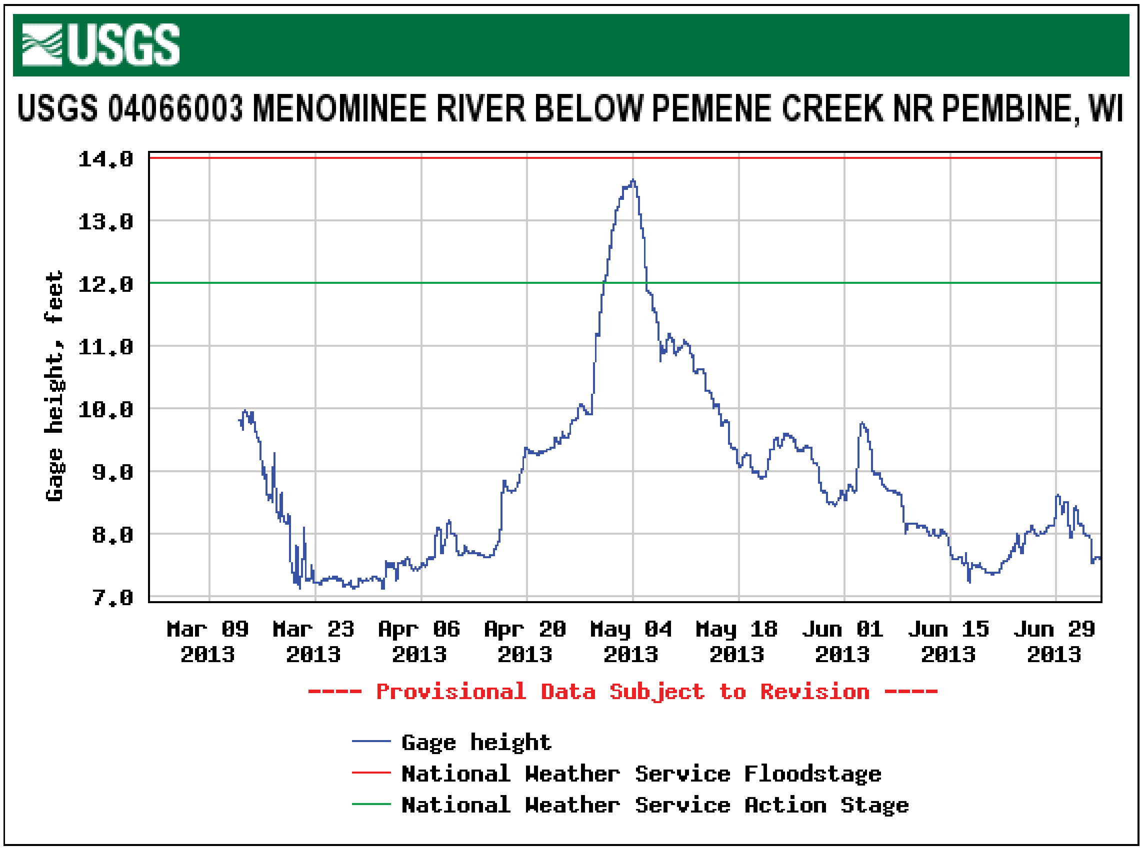


Figure 3.6: River gage height on the Menominee River at the USGS gauging station near Pembine, WI from 01 March to 30 June of 2013.

Table 3.3: Overview of detections and total distance covered (out of a maximum 39.63rkm) for each study year

Sturgeon #	# of Handheld Detections		# of Stationary Detection Days		Total Distance Covered (rkm)	
	2012	**2013**	**2012**	**2013**	**2012**	**2013**
1-F-FH	4	7	11	10	10.25	13.25
2-M-FH	2	3	49	50	36.53	10.77
3-M-FH	3	5	83	165	10.25	2.08
4-M-CHF	4	5	26	33	36.51	13.81
5-M-FH	3	3	102	139	9.7	16.53
6-M-CHF	2	0	149	100	12.37	-
7-M-CHF	1	4	9	4	36.51	10.92
8-M-CHF	4	4	27	22	36.83	14.14
9-F-CHF	5	5	41	26	10.12	11.24
10-F-CHF	7	0	27	80	10.12	12.37
11-M-CHF	6	5	26	26	10.60	36.51
12-F-CHF	3	0	103	95	12.65	-
13-M-CHF	-	2	-	85	-	38.76
14-M-CHF	-	4	-	3	-	11.31
15-M-CHF	-	6	-	37	-	36.51
Avg. All	3.7	3.5	54.4	58.3	19.37	17.55
Avg. Females	4.75	3	45.5	52.8	10.8	12.3
Avg. Males	3.12	3.73	58.9	60.4	23.7	19.1

Table 3.4: : Overview of sturgeon movements between stationary receivers

Sturgeon #	# of Movements	Movements <24hrs	Fastest Rate Upstream (km/hr)	Fastest Rate Downstream (km/hr)
1-F-FH	3	1	0.5 (10.25 km in 20.52 hrs)	-
2-M-FH	18	13	1.96 (10.25 km in 5.22hrs)	3.18 (16.14 km in 5.07 hrs)
3-M-FH	2	1	1.69 (10.25 km in 6.07 hrs)	-
4-M-CHF	9	3	1.71 (10.25 km in 5.98 hrs)	2.34 (10.25 km in 4.37 hrs)
5-M-FH	1	0	0.35 (10.25km in 29.02 hrs)	-
6-M-CHF	7	5	1.86 (10.12 km in 5.43 hrs)	2.31 (10.12 km in 4.37 hrs)
7-M-CHF	4	2	2.22 (10.25 km in 4.62 hrs)	0.39 (10.25 km in 26.33 hrs)
8-M-CHF	8	4	2.63 (10.25 km in 3.9 hrs)	1.54 (10.25 km in 6.65 hrs)
9-F-CHF	20	10	1.86 (10.12 km in 5.45 hrs)	2.79 (10.12 km in 3.63 hrs)
10-F-CHF	13	9	2.18 (10.12 km in 4.65 hrs)	2.06 (10.12 km in 4.9 hrs)
11-M-CHF	9	3	0.73 (10.25 km in 14.07 hrs)	0.44 (10.12 km in 23.12 hrs)
12-F-CHF	3	3	1.59 (10.12 km in 6.38 hrs)	1.90 (10.12 km in 5.32 hrs)
13-M-CHF	9	7	1.78 (10.12 km in 5.67 hrs)	2.01 (10.12 km in 5.02 hrs)
14-M-CHF	1	0	0.31 (10.12 km in 32.15 hrs)	-
15-M-CHF	4	2	1.26 (10.12 km in 8.02 hrs)	-

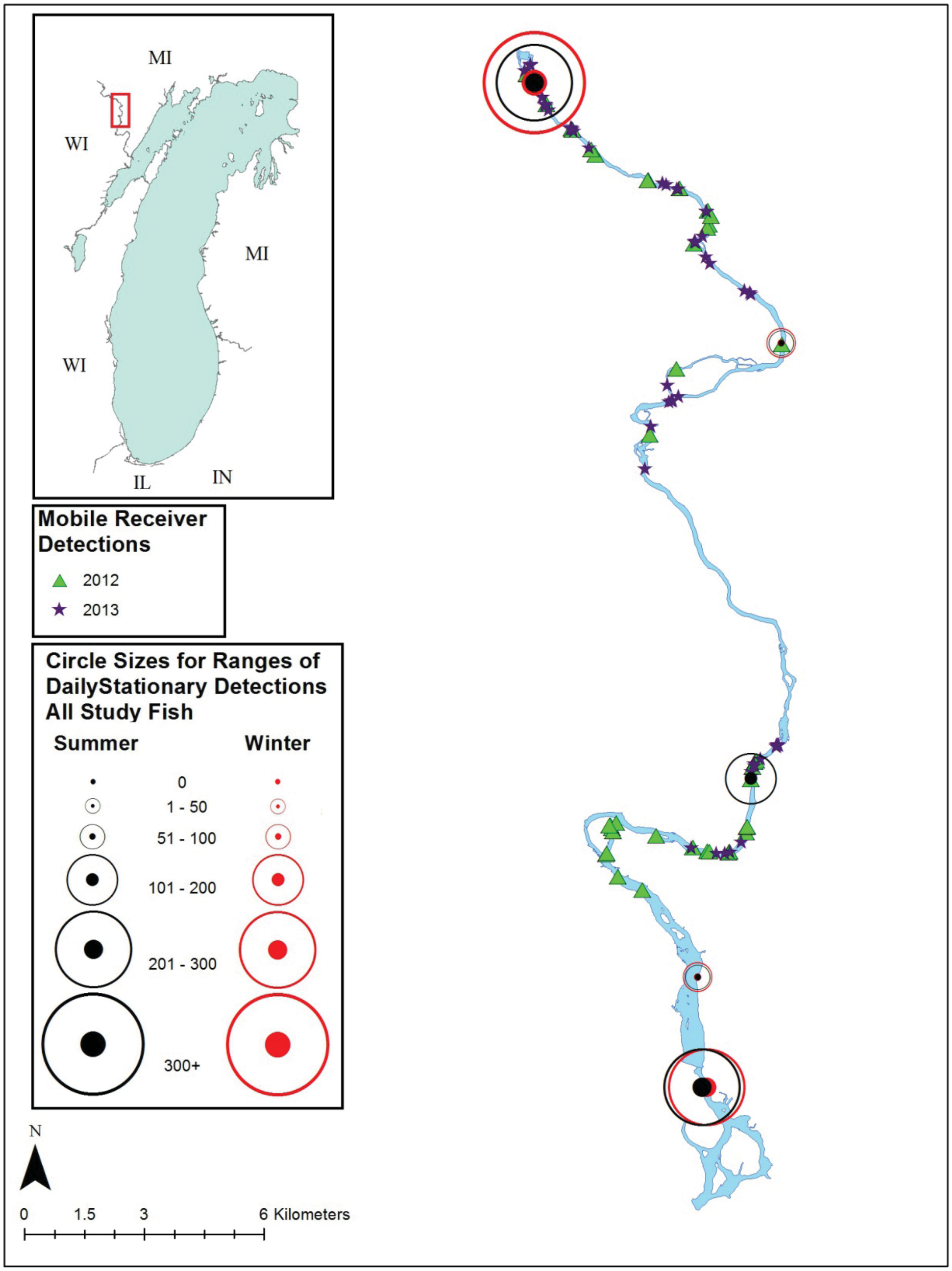


Figure 3.7: All sturgeon detections, stationary and handheld, separated by season in the Menominee River, MI/WI, White Rapids to Sturgeon Falls Dam in 2012 and 2013.

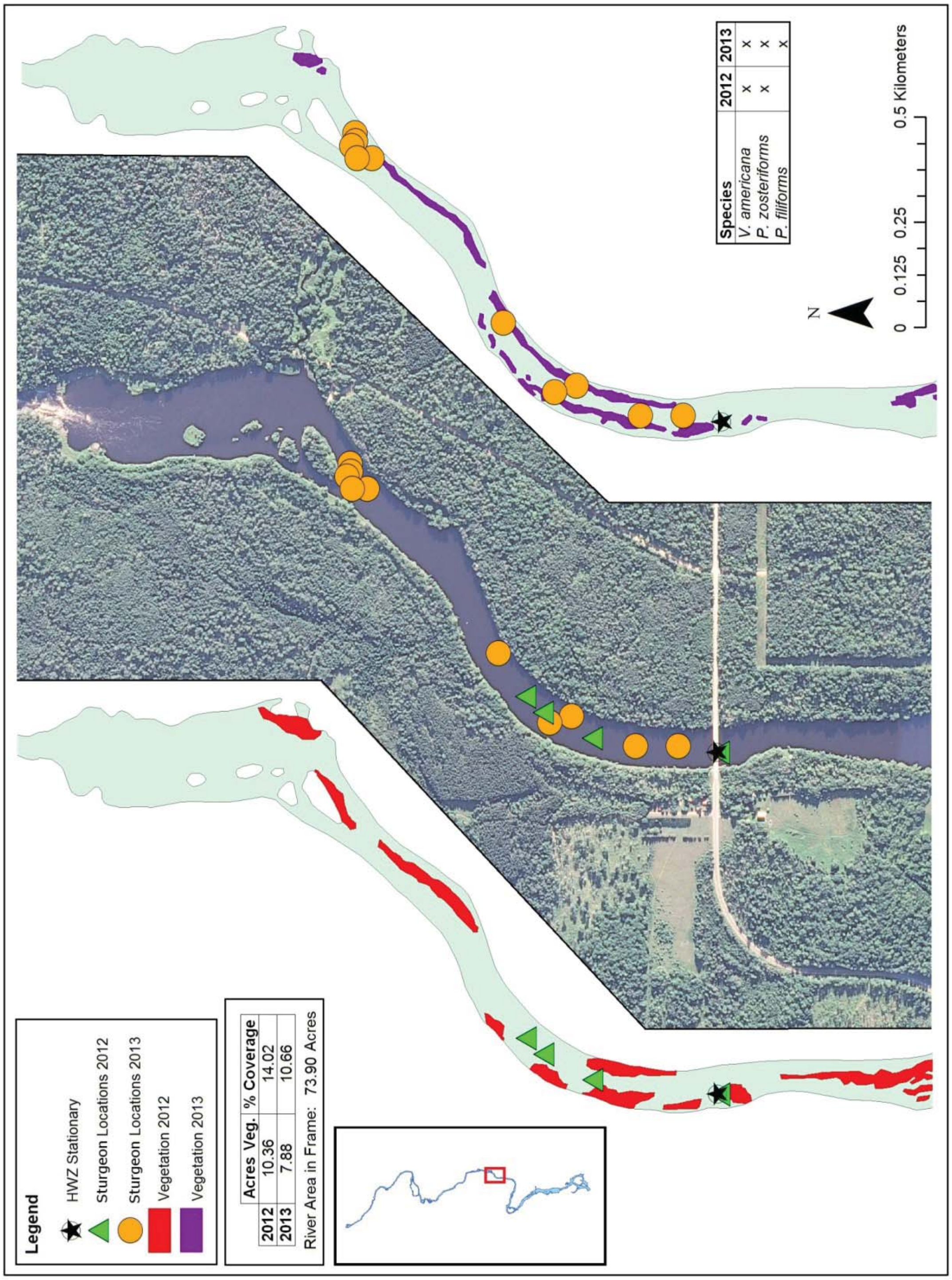


Figure 3.8: Submerged aquatic vegetation and handheld sturgeon detections plotted for the river stretch containing Pemene Falls in the Menominee River, MI/WI in 2012 & 2013.

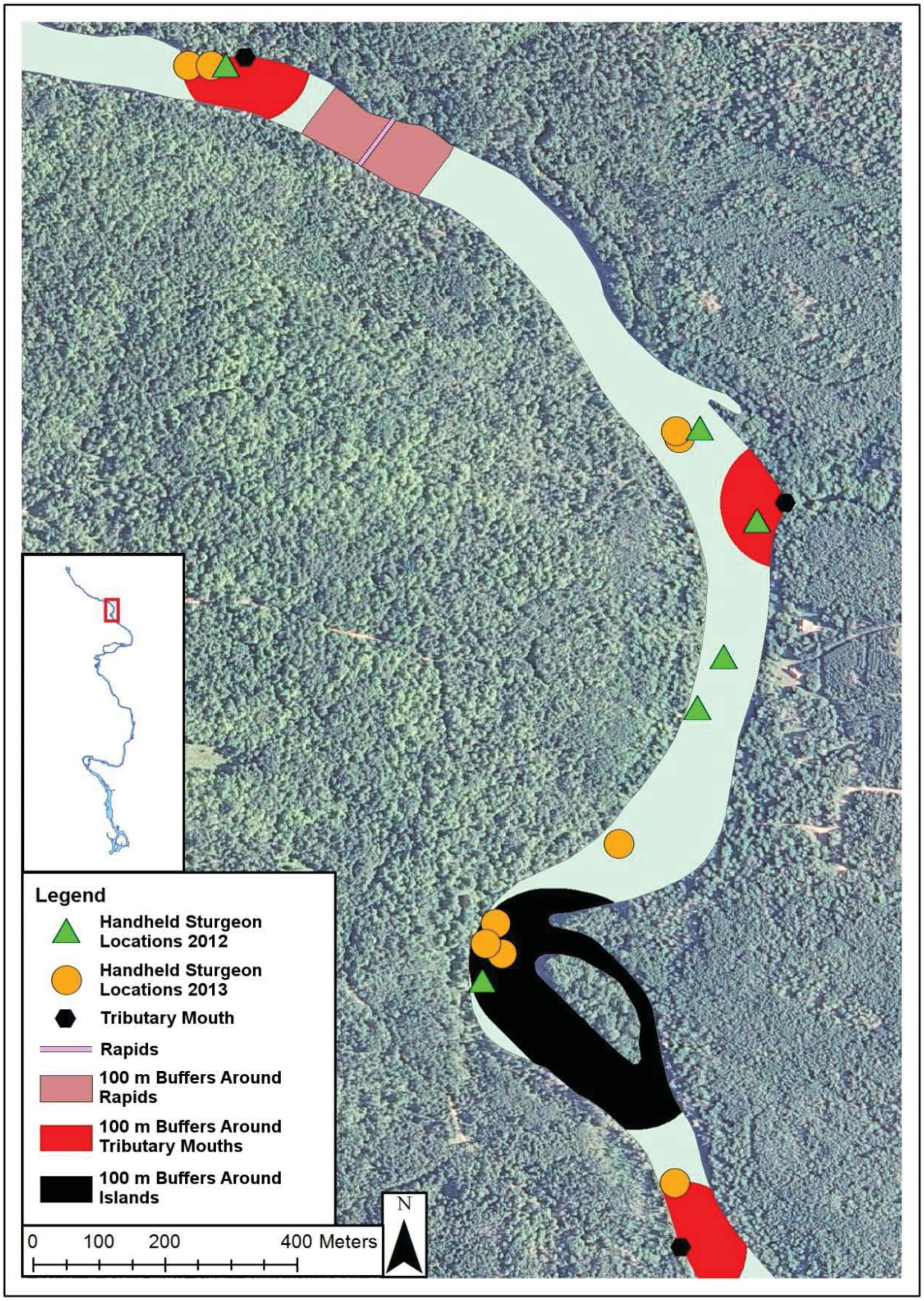


Figure 3.9: Example of different buffers and stream features with sturgeon locations for 2012 & 2013 mapped for the small stretch just above and containing Granger Point, Menominee River, MI/WI.

Table 3.5: Overview of sturgeon locations occurring near islands, rapids, and tributary mouths for 2012, 2013, females only, males only, and all detections.

	Total Individual Sturgeon found near Islands	# of Sturgeon Locations <100 m From an Island	Total Individual Sturgeon Found Near Rapids	# of Sturgeon Locations <100 m From a Rapid	Total Individual Sturgeon Found Near Tributary Mouths	# of Sturgeon Locations <100 m From a Tributary Mouth
2012	9 of 12	14	1 of 12	1	3 of 12	3
2013	11 of 15	15	0 of 15	0	5 of 12	7
Females	4 of 4	8	0 of 4	0	2 of 4	2
Males	10 of 11	21	1 of 11	1	4 of 11	8
All	14 of 15	29	1 of 15	1	6 of 15	10

Table 3.6: Areas of buffers around islands, rapids, and tributary mouths, and total detections occurring within each buffer.

	Area (km^2)	% of Study Area Covered	# of Total Detections in Area
TOTAL Study Area	6.114	100	97 of 97
<100m of an Island	1.958	32.0	29 of 97
<100m of a Rapid	0.239	3.9	1 of 97
<100m of a Tributary Mouth	0.492	8.0	10 of 97

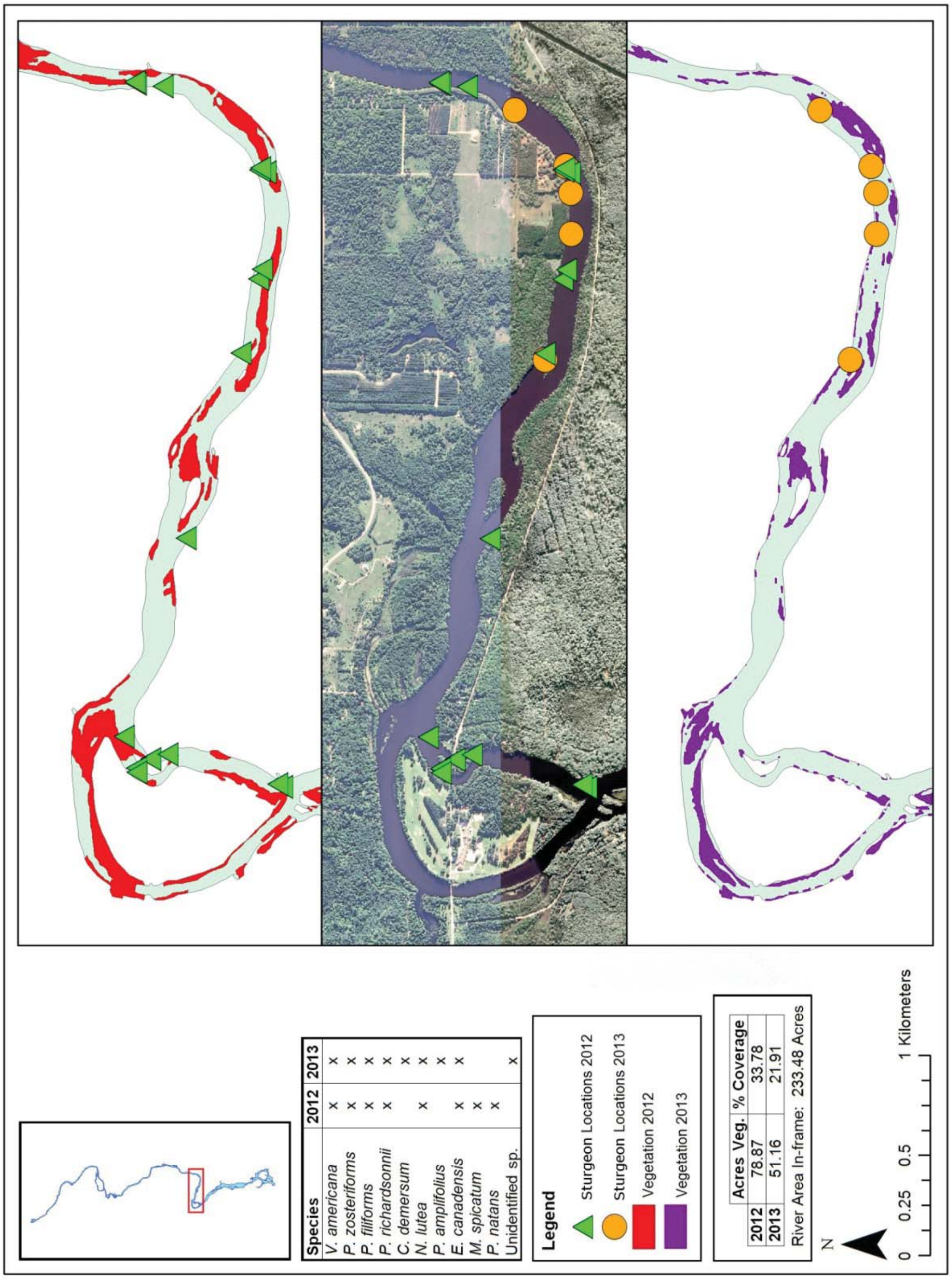


Figure 3.10: Submerged aquatic vegetation and handheld sturgeon locations plotted for the river stretch containing Miscauno Island and upstream in the Menominee River, MI/WI in 2012 & 2013.

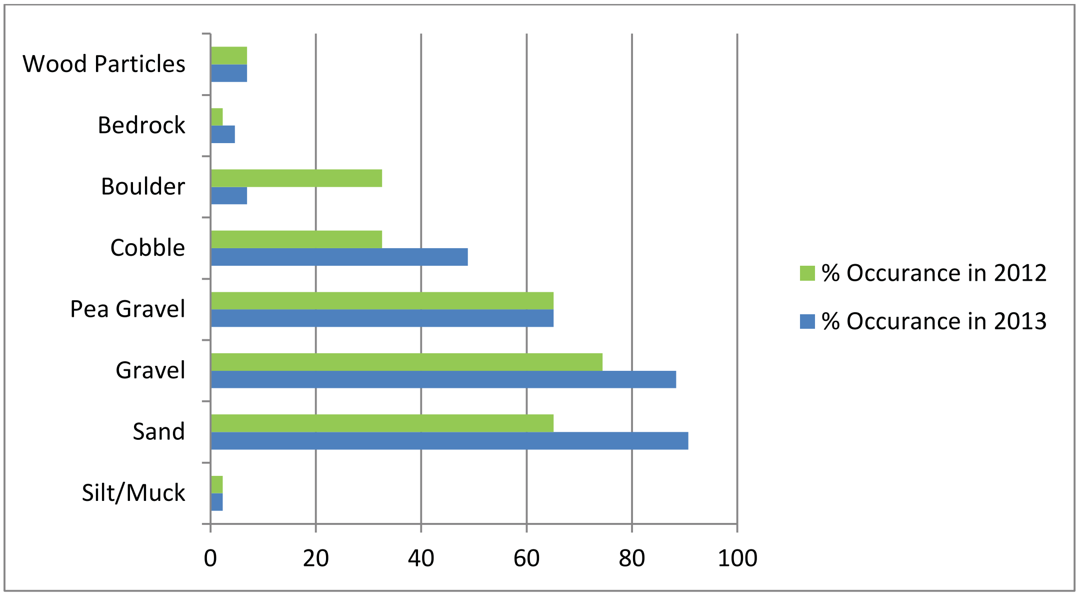


Figure 3.11: Substrate particle size and bottom type presence/absence in terms of percent occurrence at sturgeon locations in the Menominee River, MI/WI in 2012 & 2013

Table 3.7 List of handheld receiver detections from 2012 with average depth in location area

Date	Fish #(s)	Average Depth in Location Area (m)	Range of Depth Measured in Location Area (m)
July 10	4-M-CHF	1.41	0.9 – 1.8
July 10	11-M-CHF	1.97	1.2 – 2.4
July 11	10-F-CHFv	1.89	1.2 – 2.4
July 12	1-F-FH	1.92	0.6 – 2.4
July 12	2-M-FH & 8-M-CHF	1.17	0.3 – 1.8
July 18	11-M-CHF	1.59	0.6 – 1.8
July 18	9-F-CHF	2.17	1.5 – 2.4
July 18	10-F-CHF	2.55	1.8 – 3.3
July 19	10-F-CHF	1.78	0.9 – 2.4
July 19	9-F-CHF	1.85	0.9 – 2.7
July 24	4-M-CHF	1.38	0.3 – 2.4
July 24	8-M-CHF	2.67	0.9 – 5.2
July 24	1-F-FH	2.06	0.9 – 3.3
July 24	5-M-FH	1.69	1.2 – 1.8
July 24	2-M-FH	1.12	0.6 – 1.5
August 1	10-F-CHF	1.71	1.2 – 2.1
August 9	11-M-CHF	2.00	0.9 – 3.6
August 10	1-F-FH & 3-M-FH	2.18	0.6 – 4.3
August 10	8-M-CHF	1.83	1.8 – 2.4
August 15	11-M-CHF	2.26	2.1 – 3.0
	All fish	1.86	1.02 - 2.5
	Females	2.05	1.07 – 2.81
	Males	1.77	0.95 – 2.67

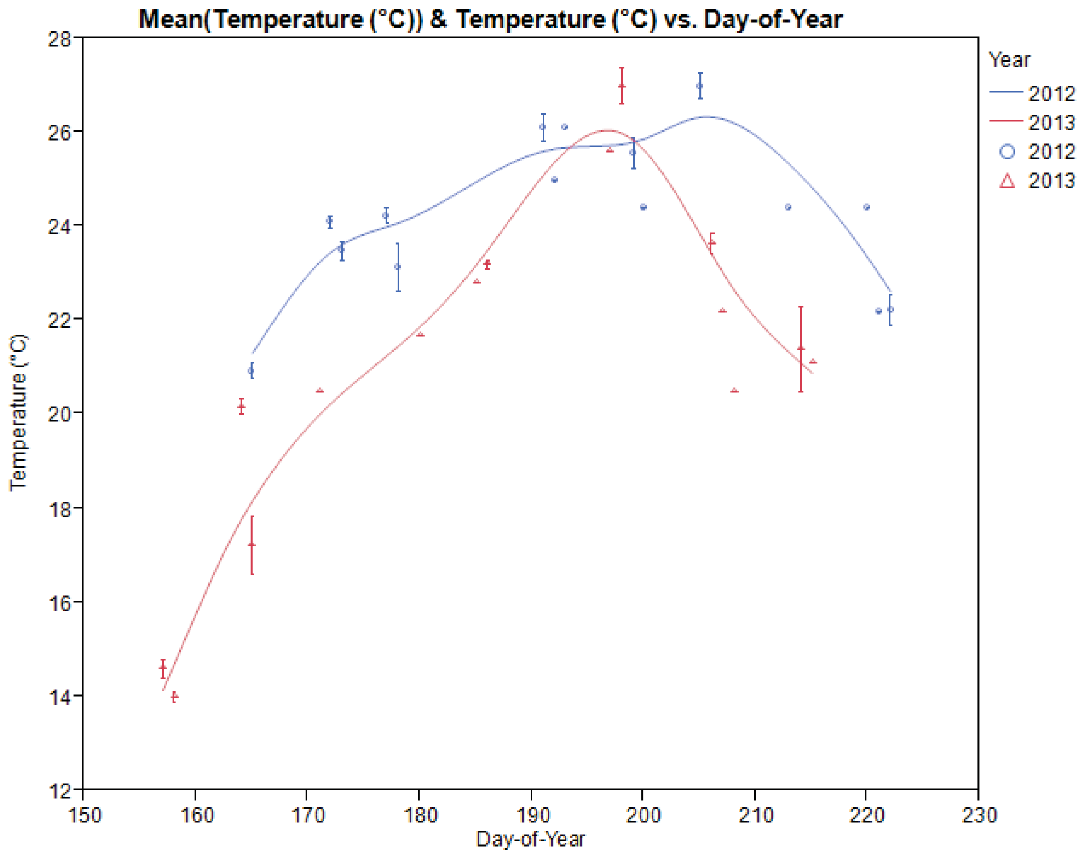


Figure 3.12: Surface water temperatures (°C) recorded at sturgeon location sites in the Menominee River, MI/WI in 2012 & 2013.

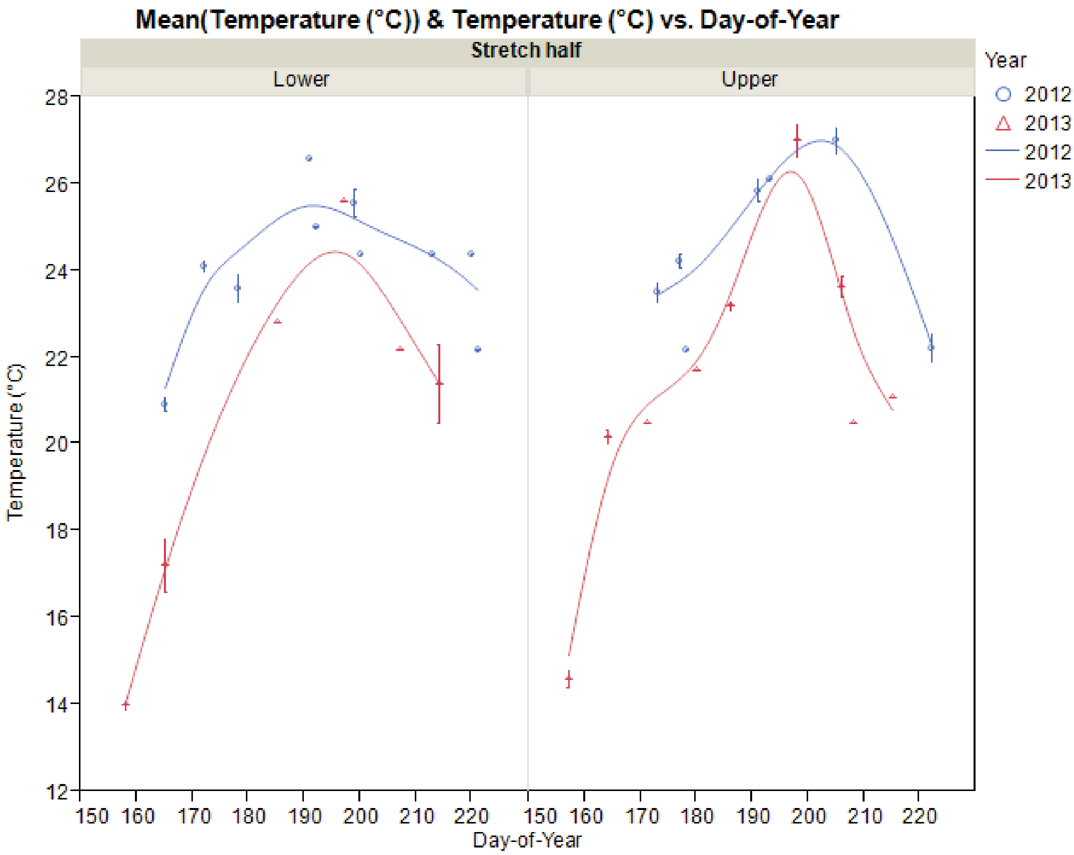


Figure 3.13: Surface water temperatures (°C) recorded at sturgeon location sites in 2012 & 2013, separated by upper half of study area locations and lower half of study area locations in the Menominee River, MI/WI in 2012 & 2013

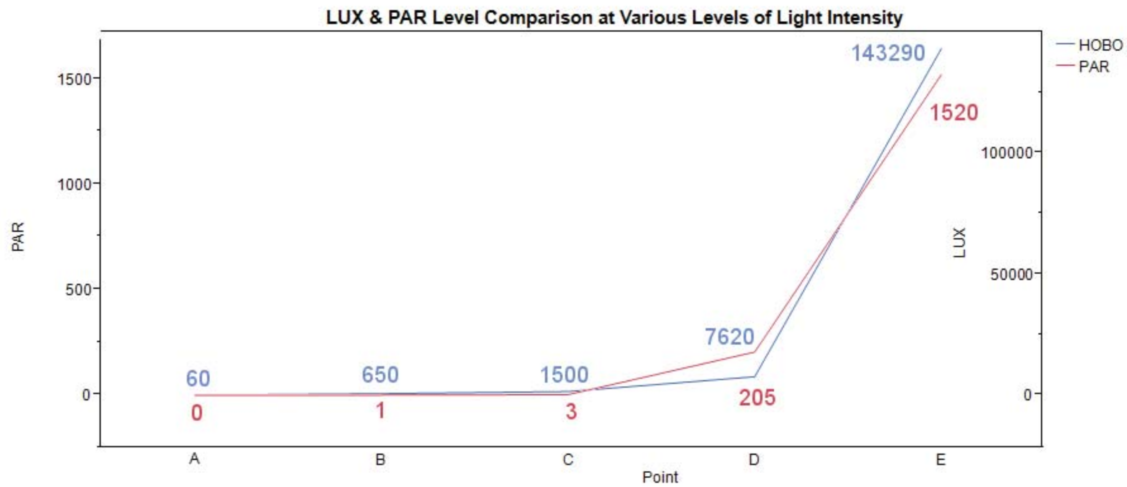


Figure 3.14: Comparison of light reading made side-by-side with a the HOBO light meter (LUX) and a PAR meter. Point A was made in nearly no-light, point B in very low light, point C in low room light, point D in bright room light, and point E outside on a very bright, sunny day.

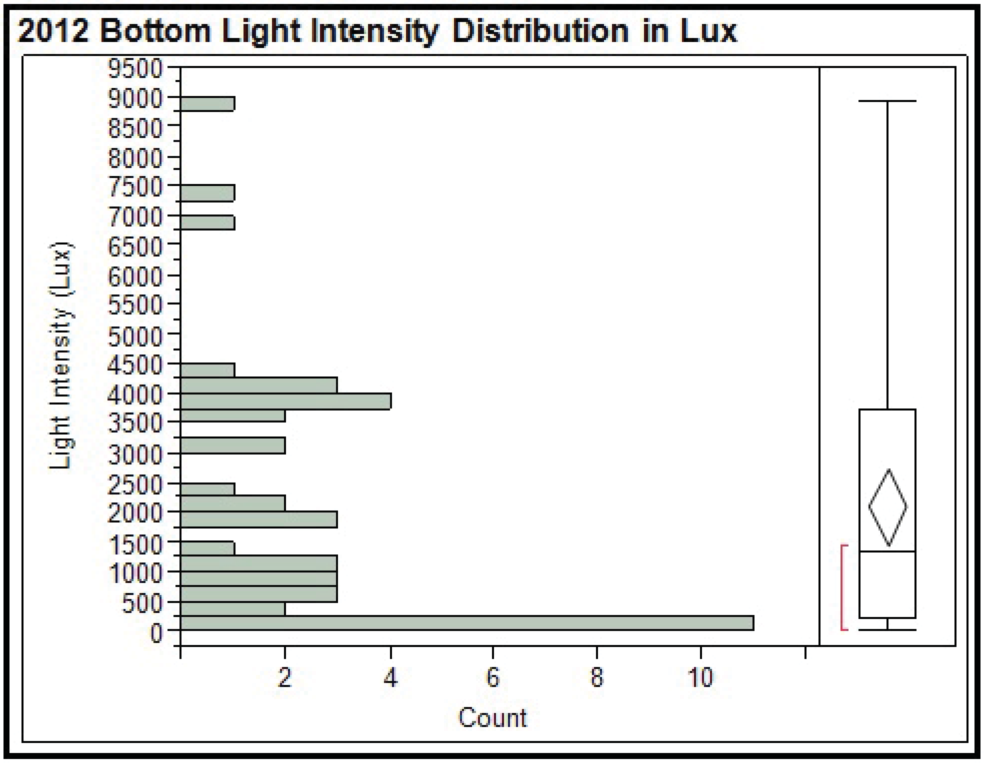


Figure 3.15: Distribution of light intensity readings in Lux near bottom at sturgeon location sites in 2012 with attached quantile box plot in the Menominee River, MI/WI.

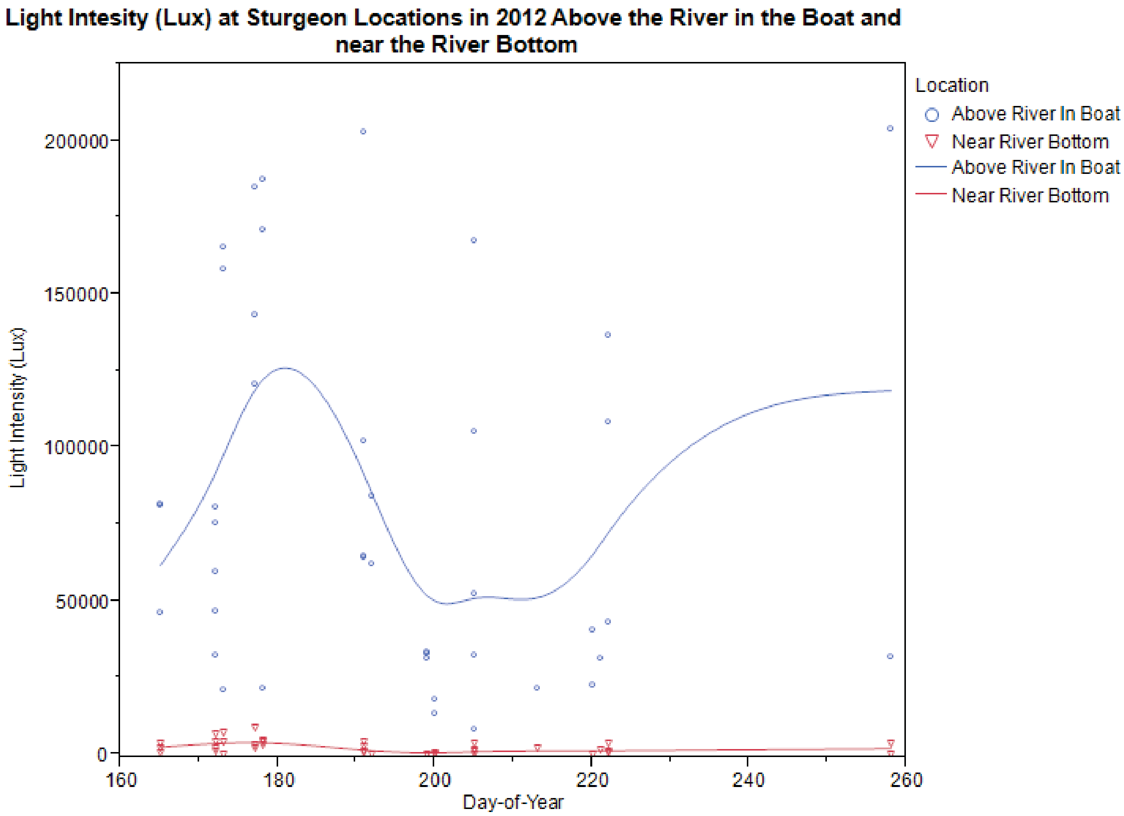


Figure 3.16: Light intensity (Lux) at sturgeon locations in 2012 above the river in the boat and near the river bottom in the Menominee River, MI/WI. Zero (0) Lux is the complete absence of light, while direct sunlight on a clear day results in values over 150000 Lux.

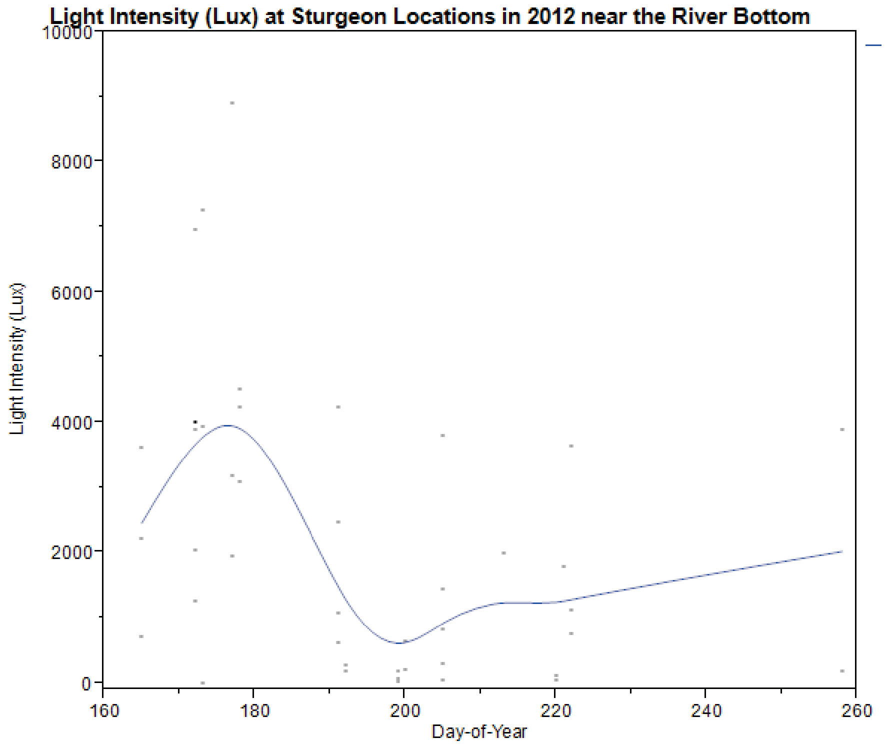


Figure 3.17: Light Intensity (Lux) near the river bottom at Sturgeon Locations in the Menominee River, MI/WI in 2012.

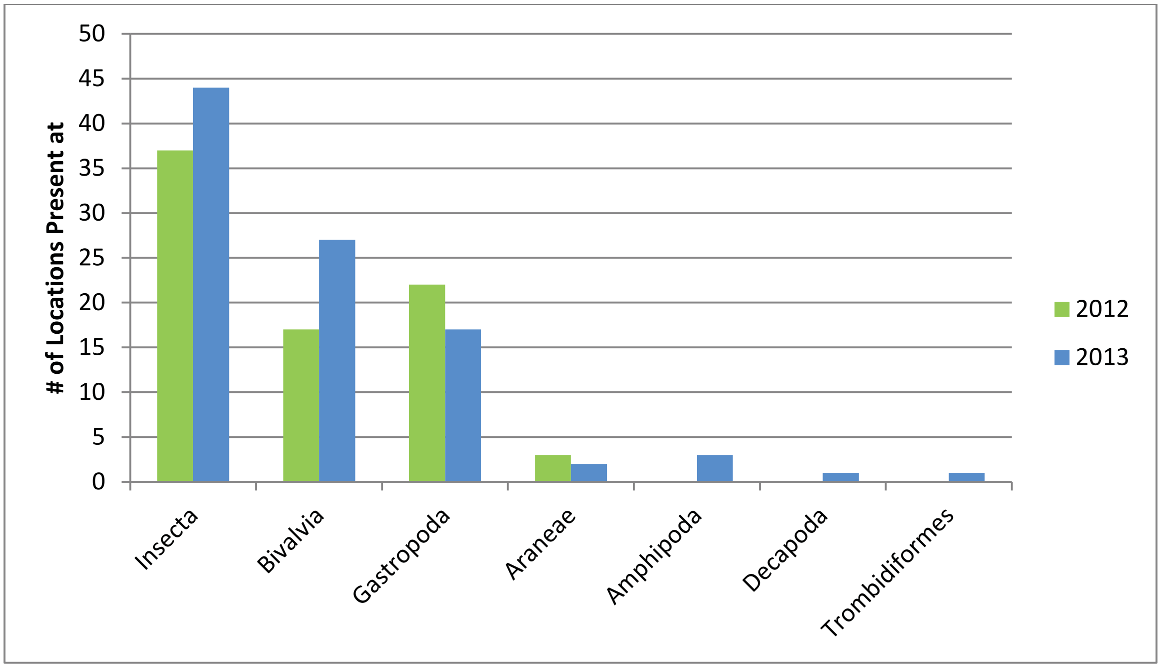


Figure 3.18: Invertebrate orders present at sturgeon locations in the Menominee River, MI/WI, Chalk Hills to Sturgeon Falls Dam in 2012 & 2013 (n_{2012}=45, n_{2013}=53).

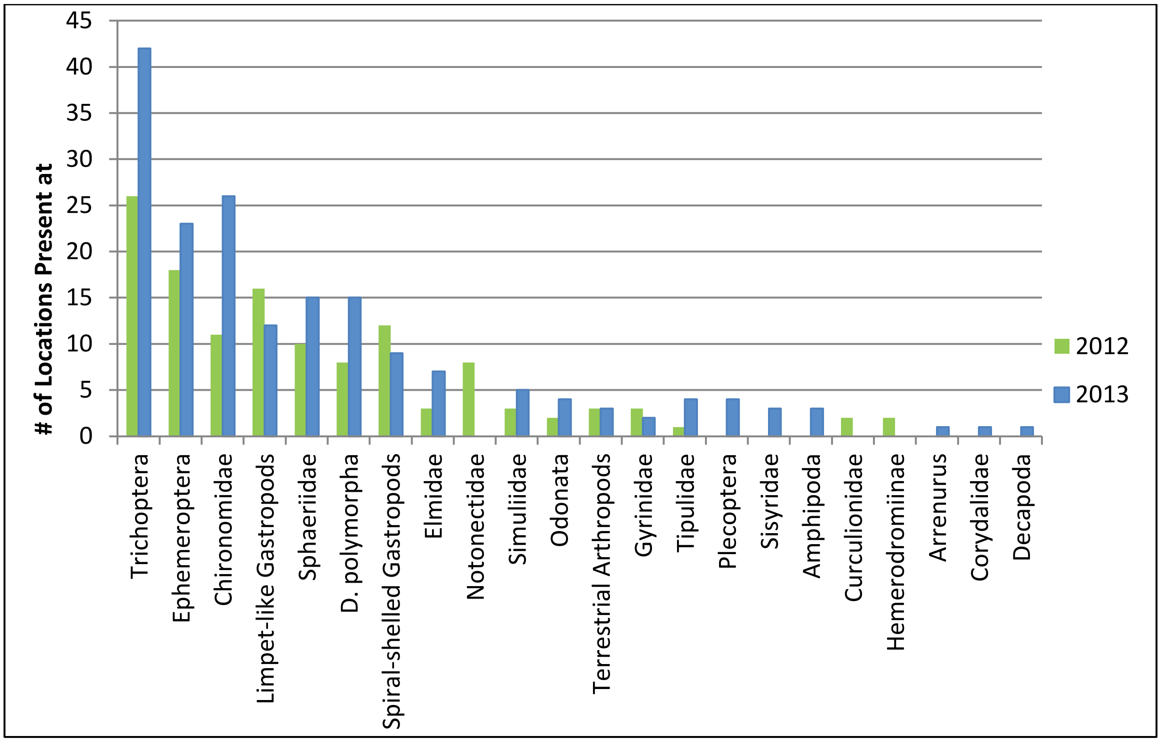


Figure 3.19: Invertebrates to lowest identified taxon present at sturgeon locations in the Menominee River, MI/WI, Chalk Hills to Sturgeon Falls Dam in 2012 & 2013 (n_{2012}=45, n_{2013}=53).

Table 3.8: Submerged aquatic macrophytes present in 2012 & 2013 with relative abundances

Species	Common name	Stretches found 2012	Stretches found 2013	Usual Relative Abundance
Vallisneria americana	Wild Celery	All	All	Primarily dominant
Potamogeton zosteriforms	Flat-Stemmed Pondweed	All	Above FH to CHF	Secondarily dominant
Potamogeton filiforms	Slender-Leaved Pondweed	Above SBP to Misc. I.	Grand I. to Misc. I.	Uncommon
Potamogeton richardsonnii	Richardson's Pondweed	Just below SFD; CHF	Above Quiver to CHF	Common where present
Ceratophyllum demersum	Coontail	CHF to above Misc. I.	CHF to above Misc. I.	Common where present
Nuphar lutea	Yellow Pond Lily	CHF to above Misc. I.	CHF to above Misc. I.	Common where present
Potamogeton amplifolius	Broad-Leafed Pondweed	CHF to above Misc. I.	CHF to above Misc. I.	Uncommon
Nymphaea odorata	American White Water Lily	CHF to above Misc. I.	CHF to above Misc. I.	Uncommon
Elodea canadensis	Canadian Waterweed	CHF to above Misc. I.	CHF to above Misc. I.	Common where present
Myriophyllum spicatum	Eurasian Watermilfoil	CHF to above Misc. I.	CHF	Uncommon
Potamogeton natans	Floating Brownleaf	All	Not found	Rare
Potamogeton berchtoldii	Pondweed	Just below SFD	Not found	Rare
Unidentified species	-	Not found	Grand I. area	Uncommon

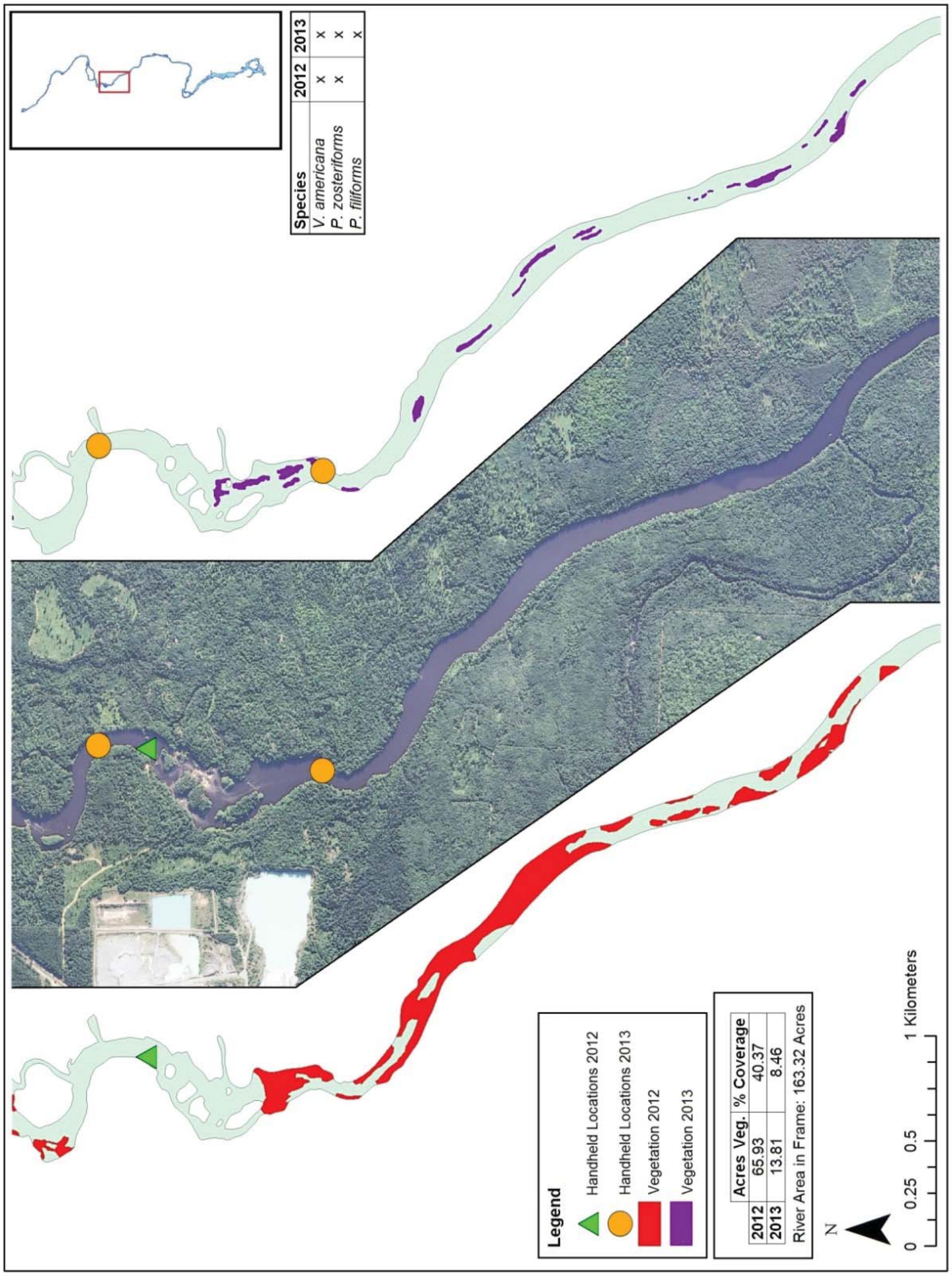
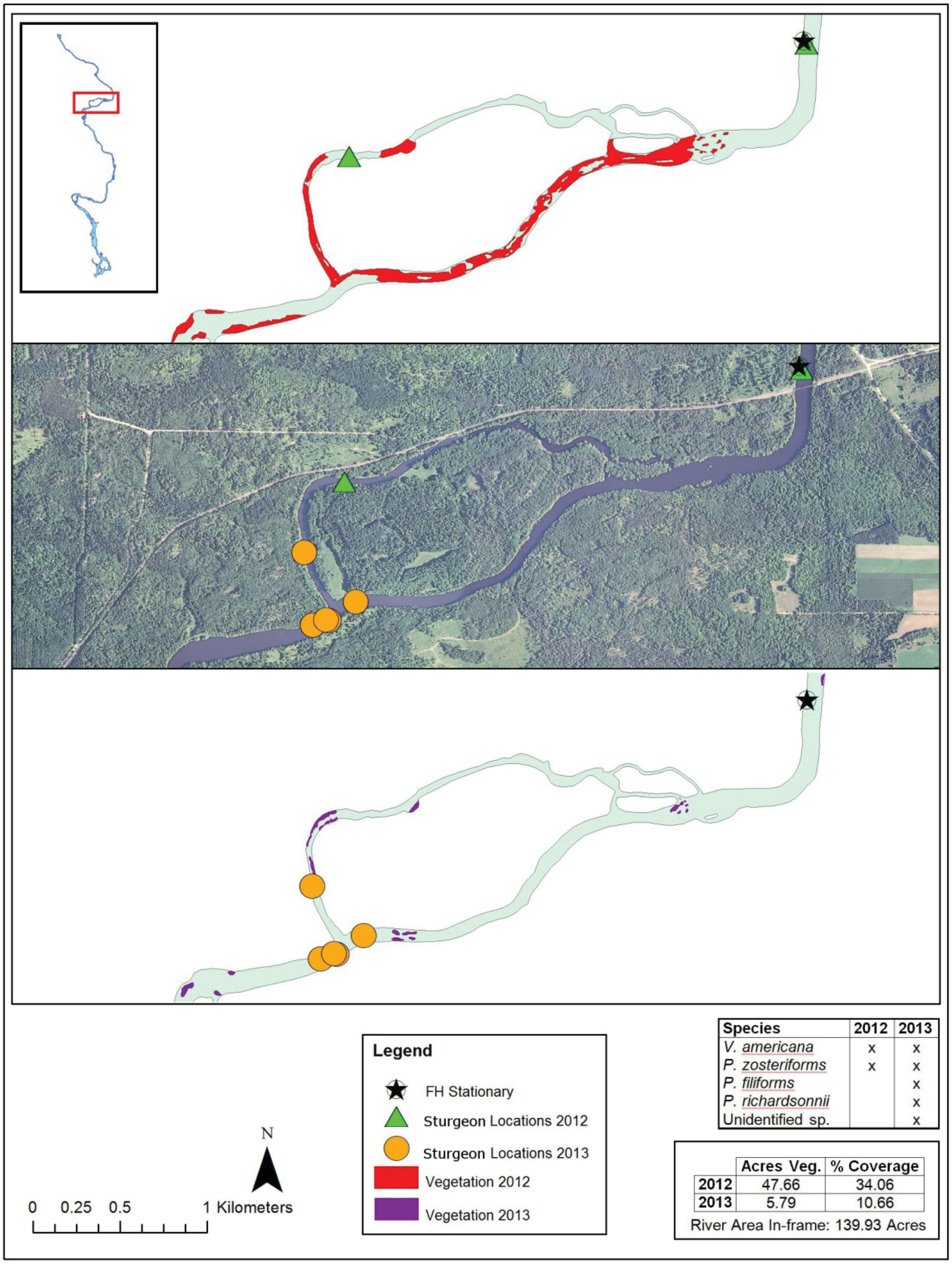


Figure 3.20: Submerged aquatic vegetation and handheld sturgeon locations plotted for the river stretch containing Quiver Falls and SBP in the Menominee River, MI/WI in 2012 & 2013.



Species	2012	2013
V. americana	x	x
P. zosteriforms	x	x
P. filiforms		x
P. richardsonnii		x
Unidentified sp.		x

	Acres Veg.	% Coverage
2012	47.66	34.06
2013	5.79	10.66

River Area In-frame: 139.93 Acres

Figure 3.21: Submerged aquatic vegetation and handheld sturgeon locations plotted for the river stretch containing Grand Island in the Menominee River, MI/WI in 2012 & 2013.

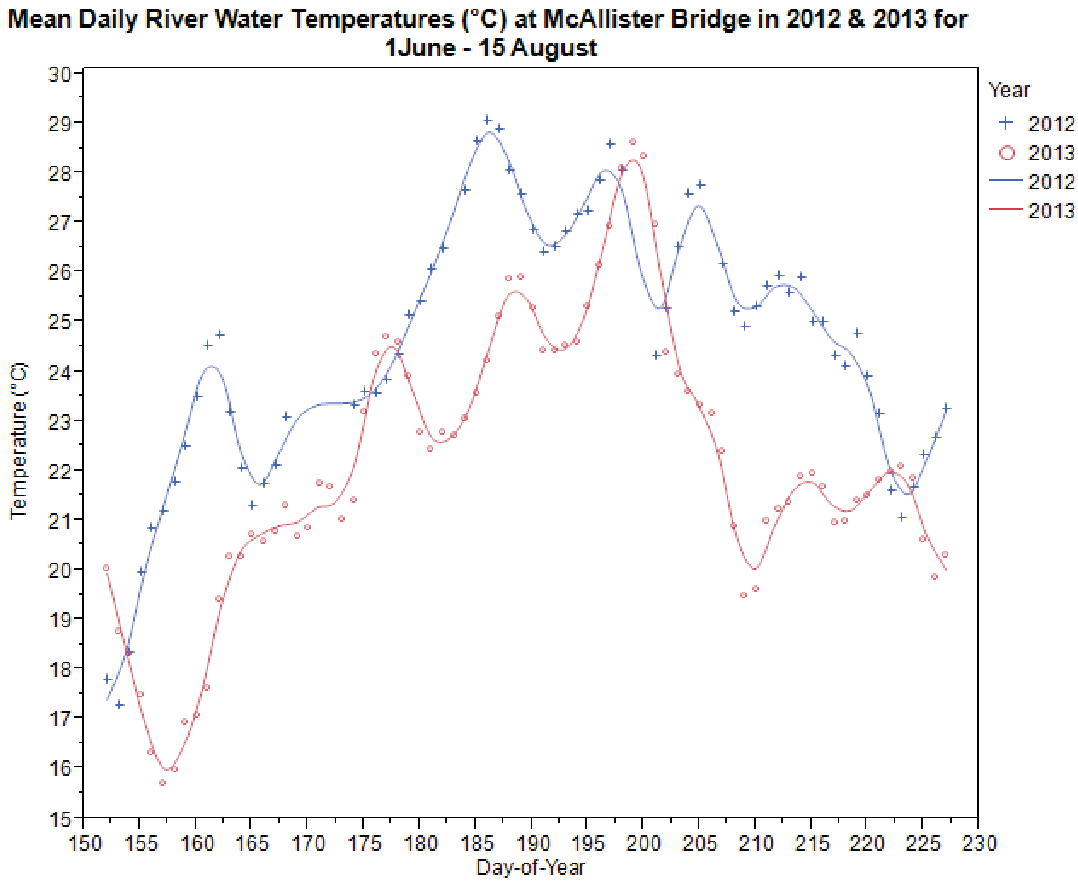


Figure 3.22: In-stream Temperatures plotted for the Menominee River, MI/WI, in 2012 & 2013 from the USGS temperature gauge located as Macaalister bridge, WI

Appendix A: Movement and location overview figures for each study lake sturgeon

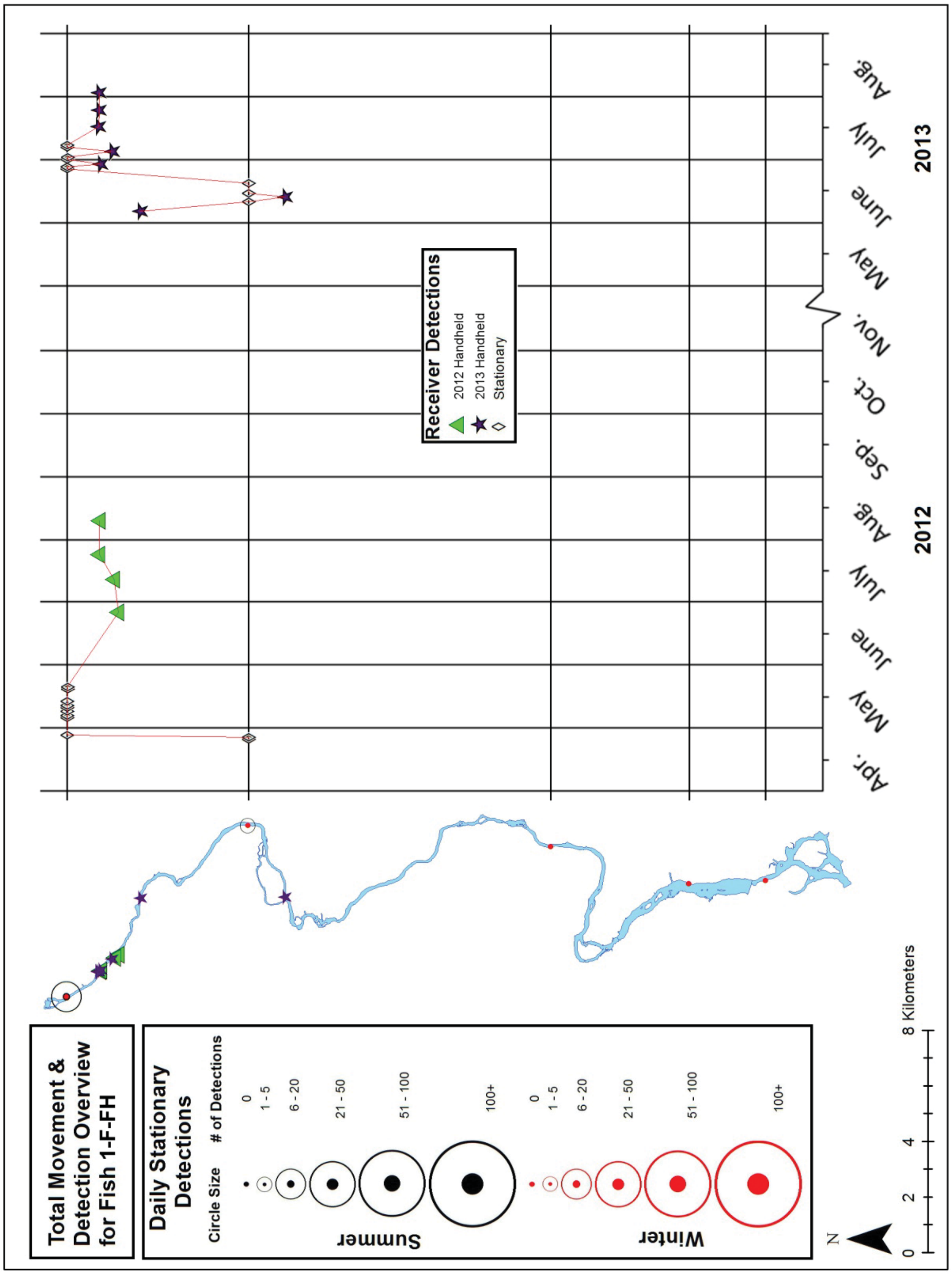


Figure A1: Overview of detections and movements for female Fish 1-F-FH in the Menominee River, MI/WI.

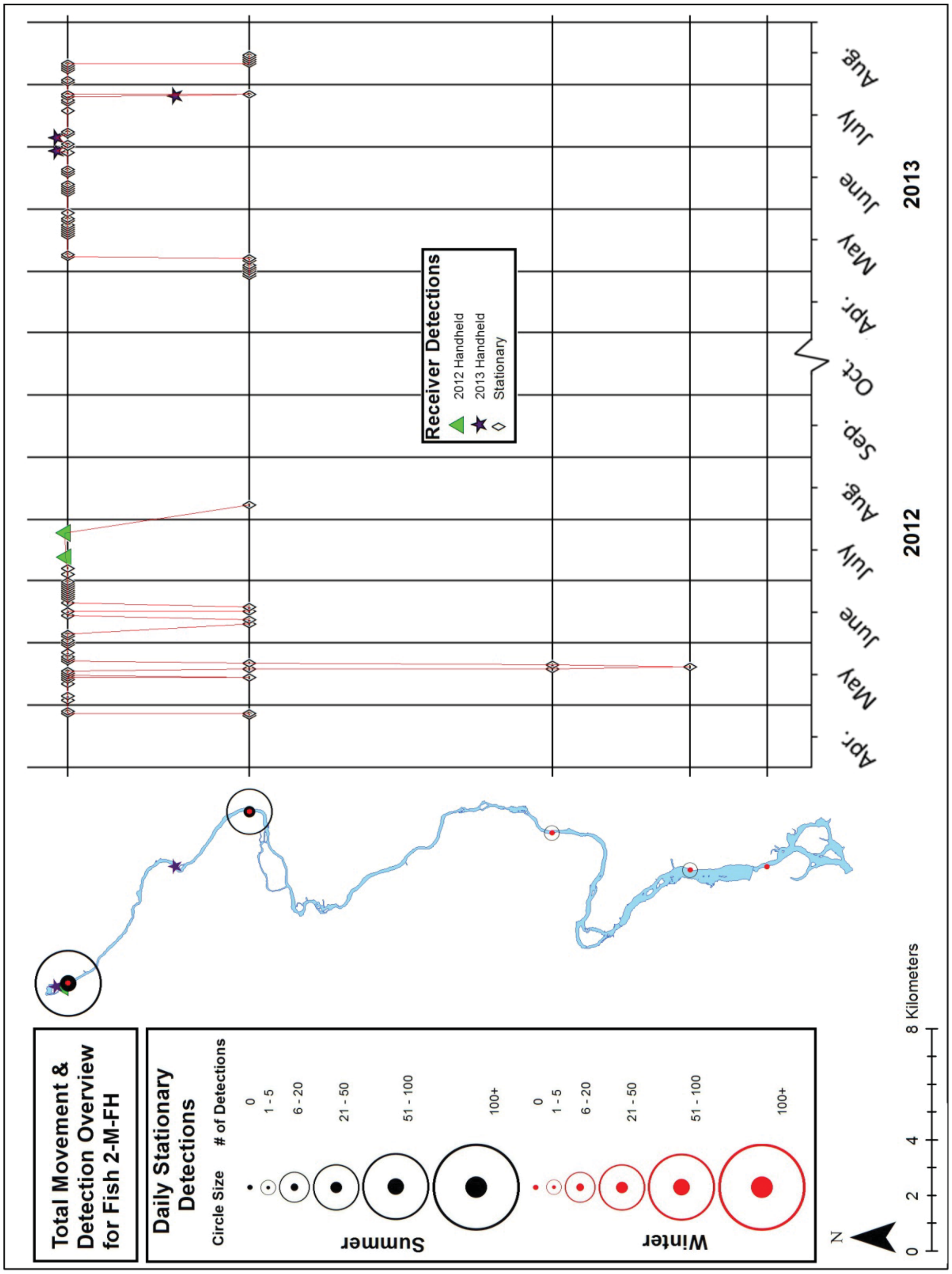


Figure A2: Overview of detections and movements for male Fish 2-M-FH in the Menominee River, MI/WI.

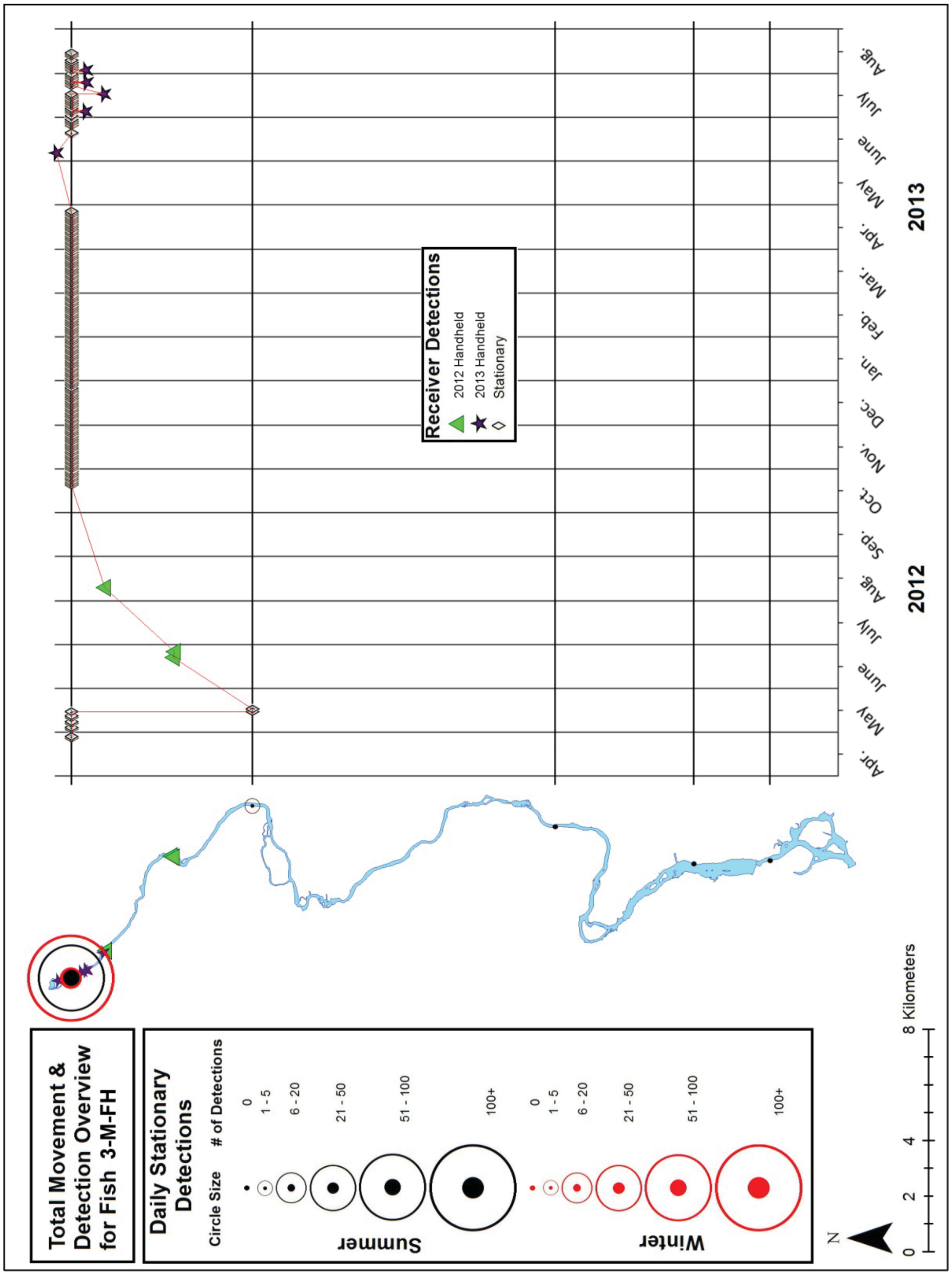


Figure A3: Overview of detections and movements for male Fish 3-M-FH in the Menominee River, MI/WI.

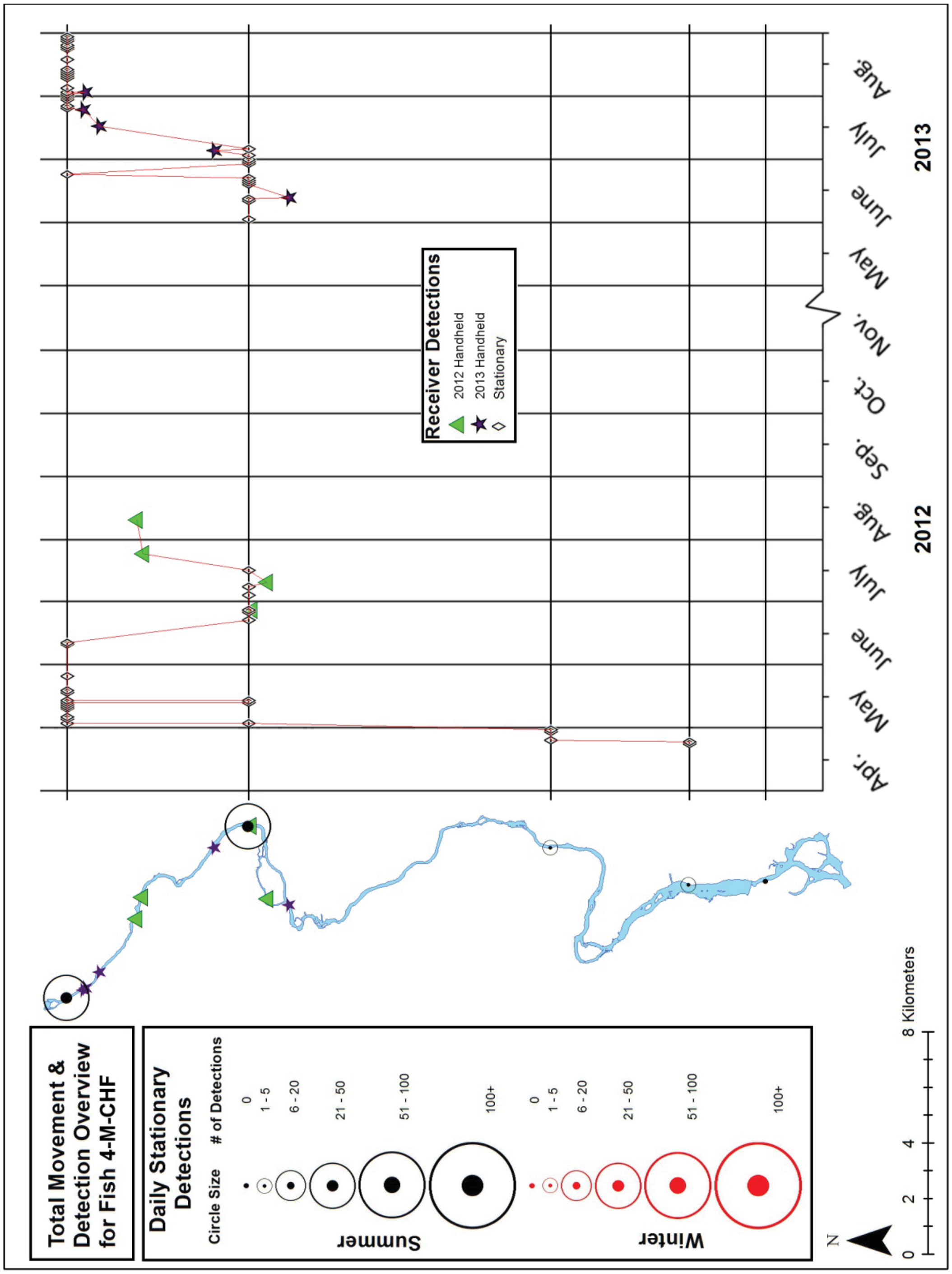


Figure A4: Overview of detections and movements for male Fish 4-M-CHF in the Menominee River, MI/WI.

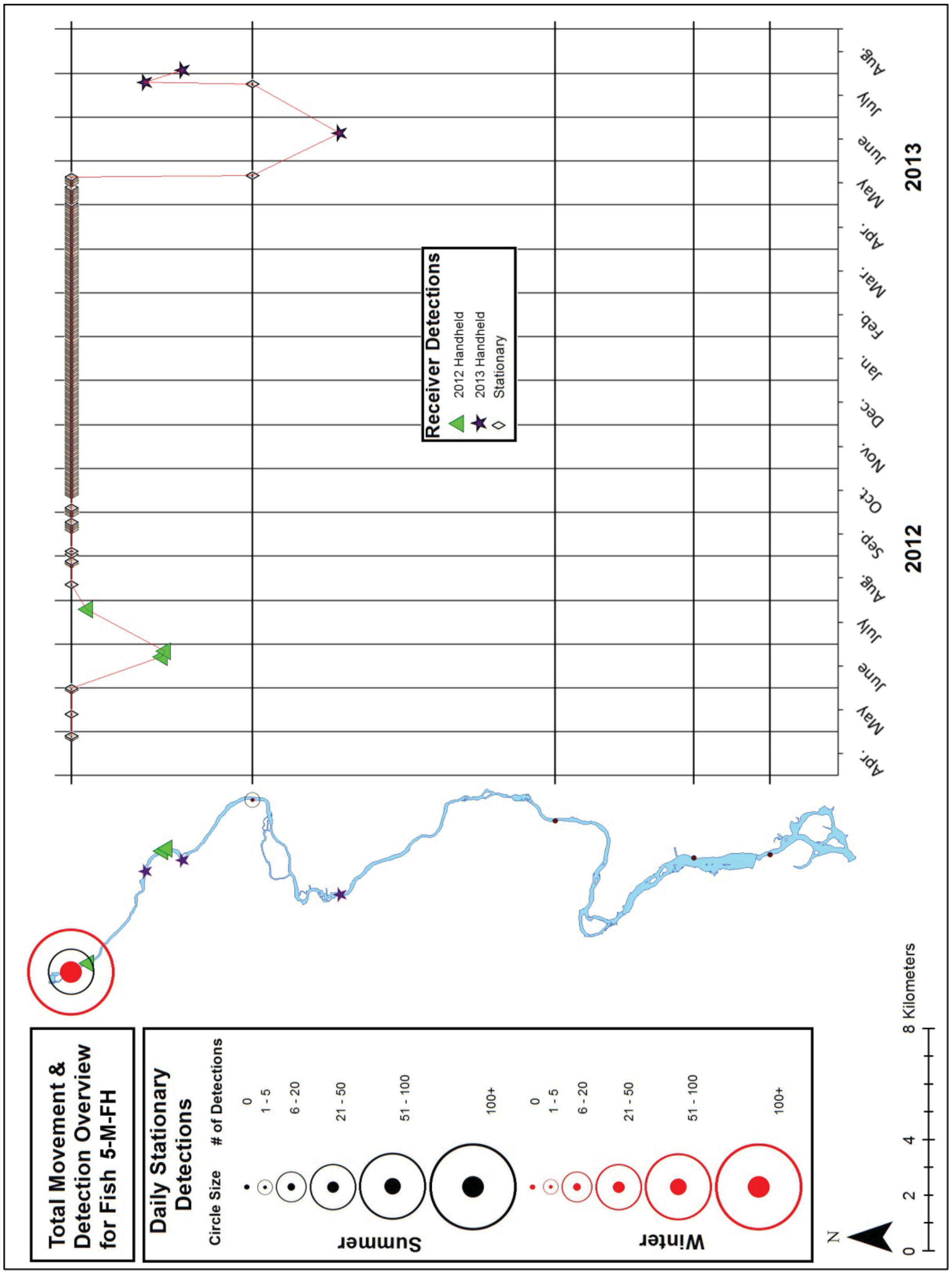


Figure A5: Overview of detections and movements for male Fish 5-M-FH in the Menominee River, MI/WI.

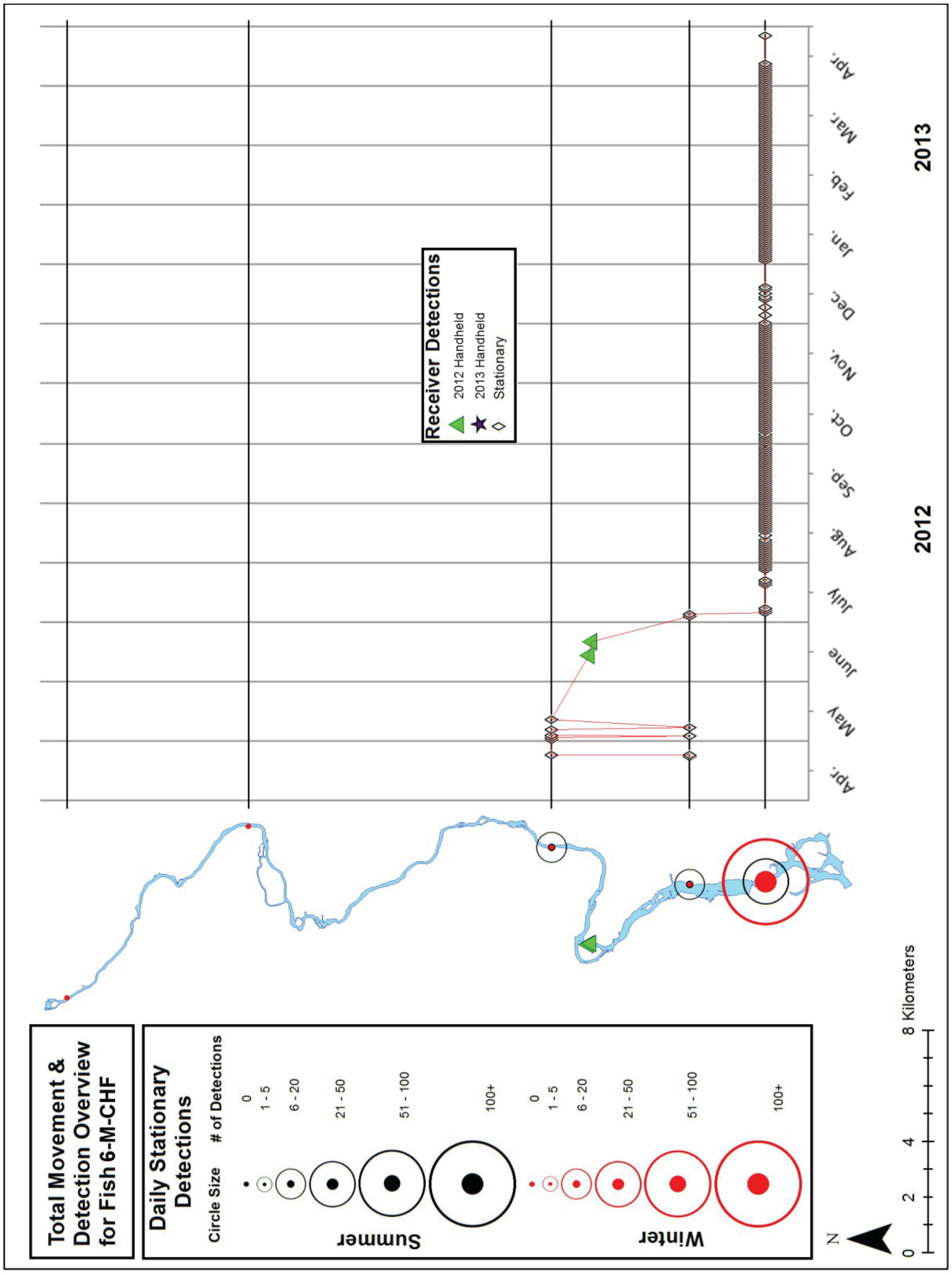


Figure A6: Overview of detections and movements for male Fish 6-M-CHF in the Menominee River, MI/WI.

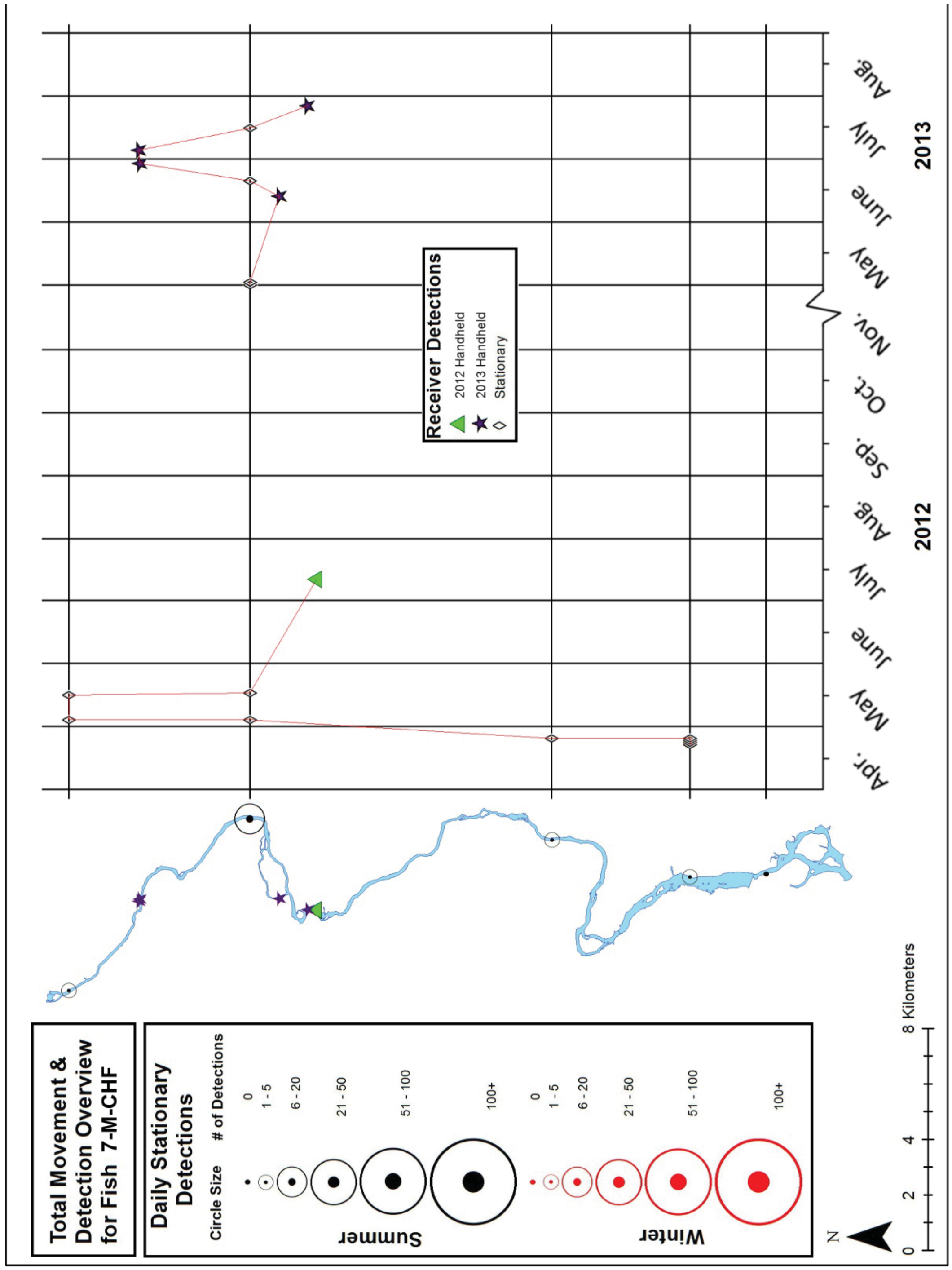


Figure A7: Overview of detections and movements for male Fish 7-M-CHF in the Menominee River, MI/WI.

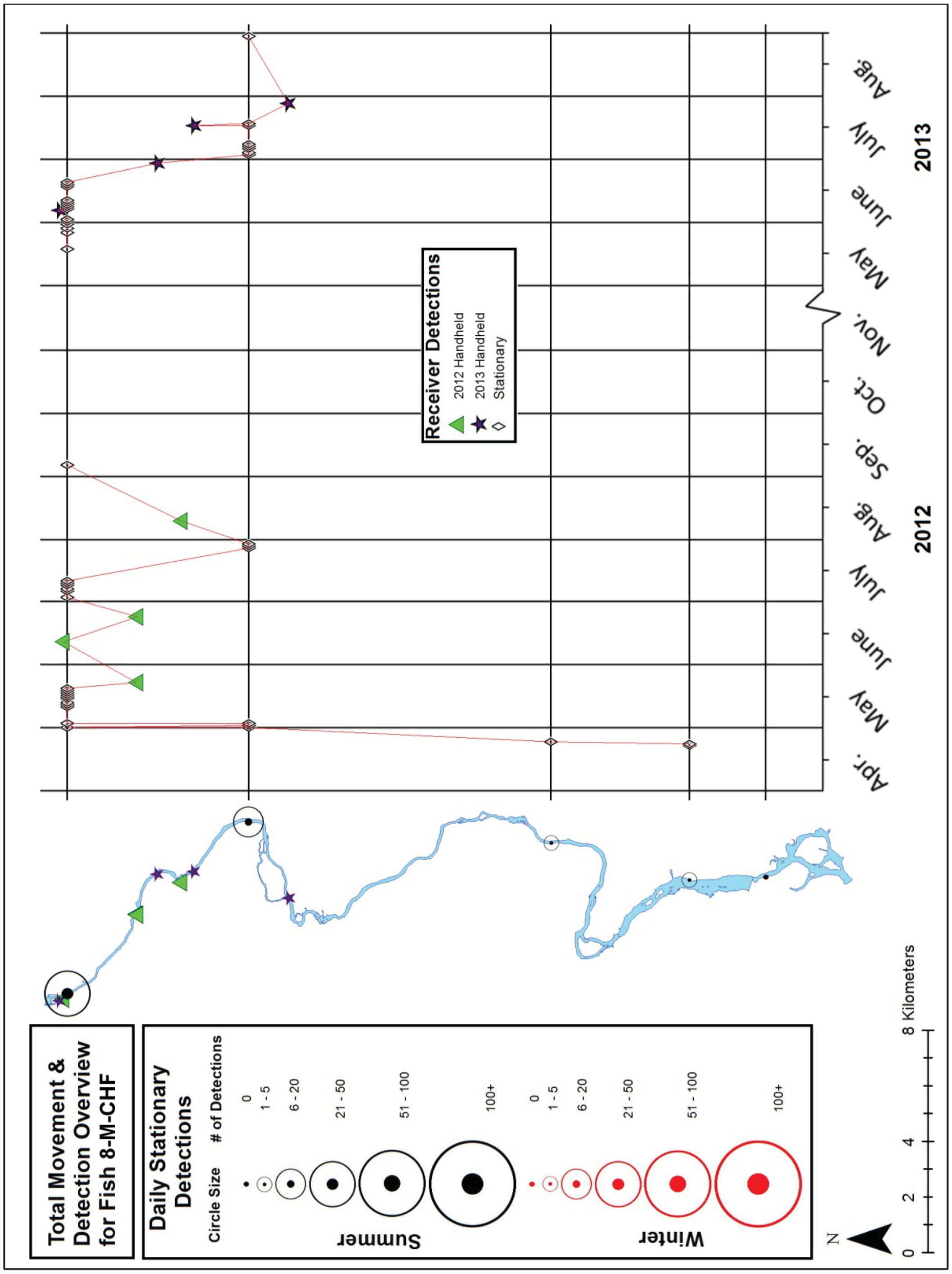


Figure A8: Overview of detections and movements for male Fish 8-M-CHF in the Menominee River, MI/WI.

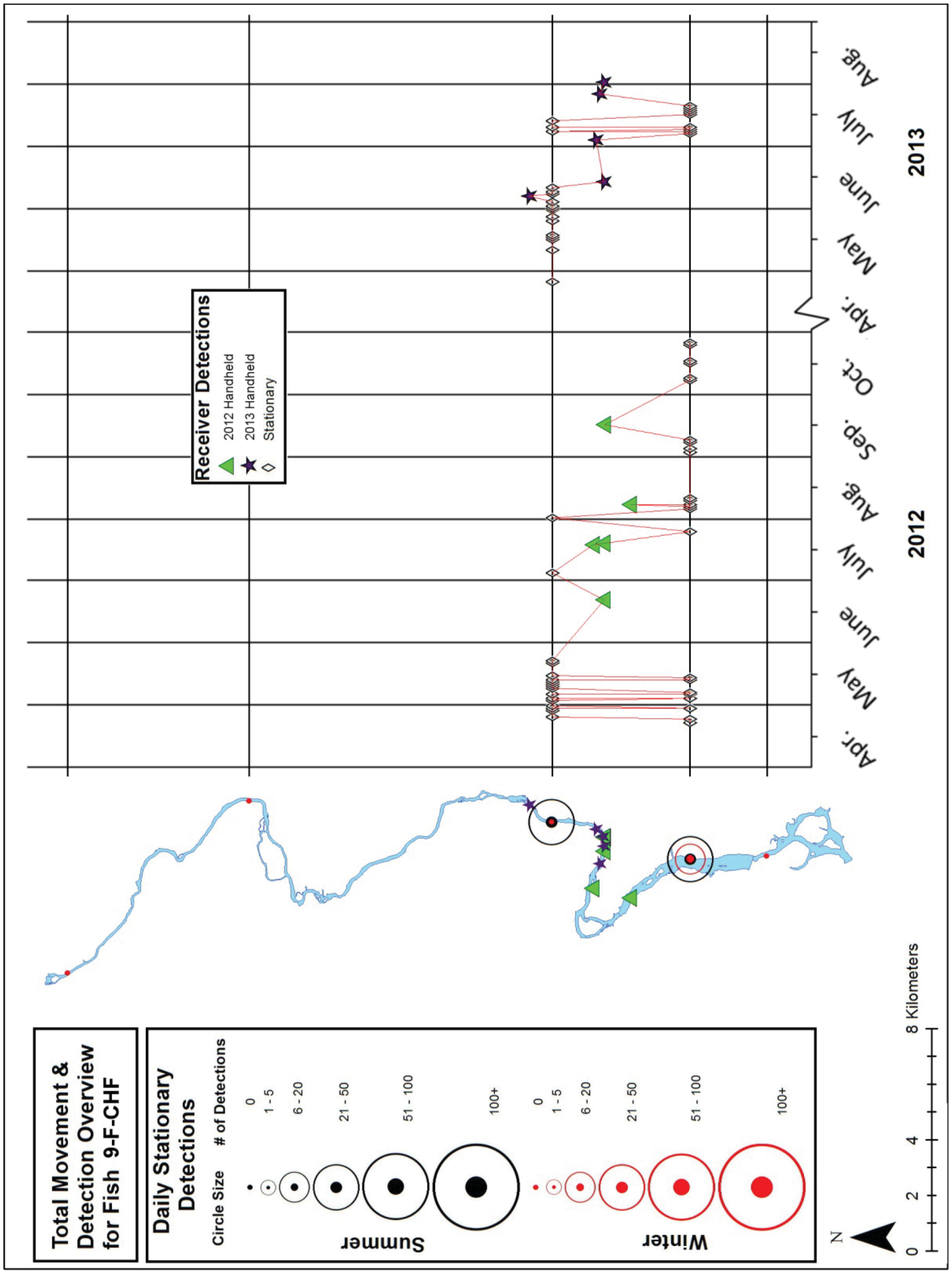


Figure A9: Overview of detections and movements for female Fish 9-F-CHF in the Menominee River, MI/WI.

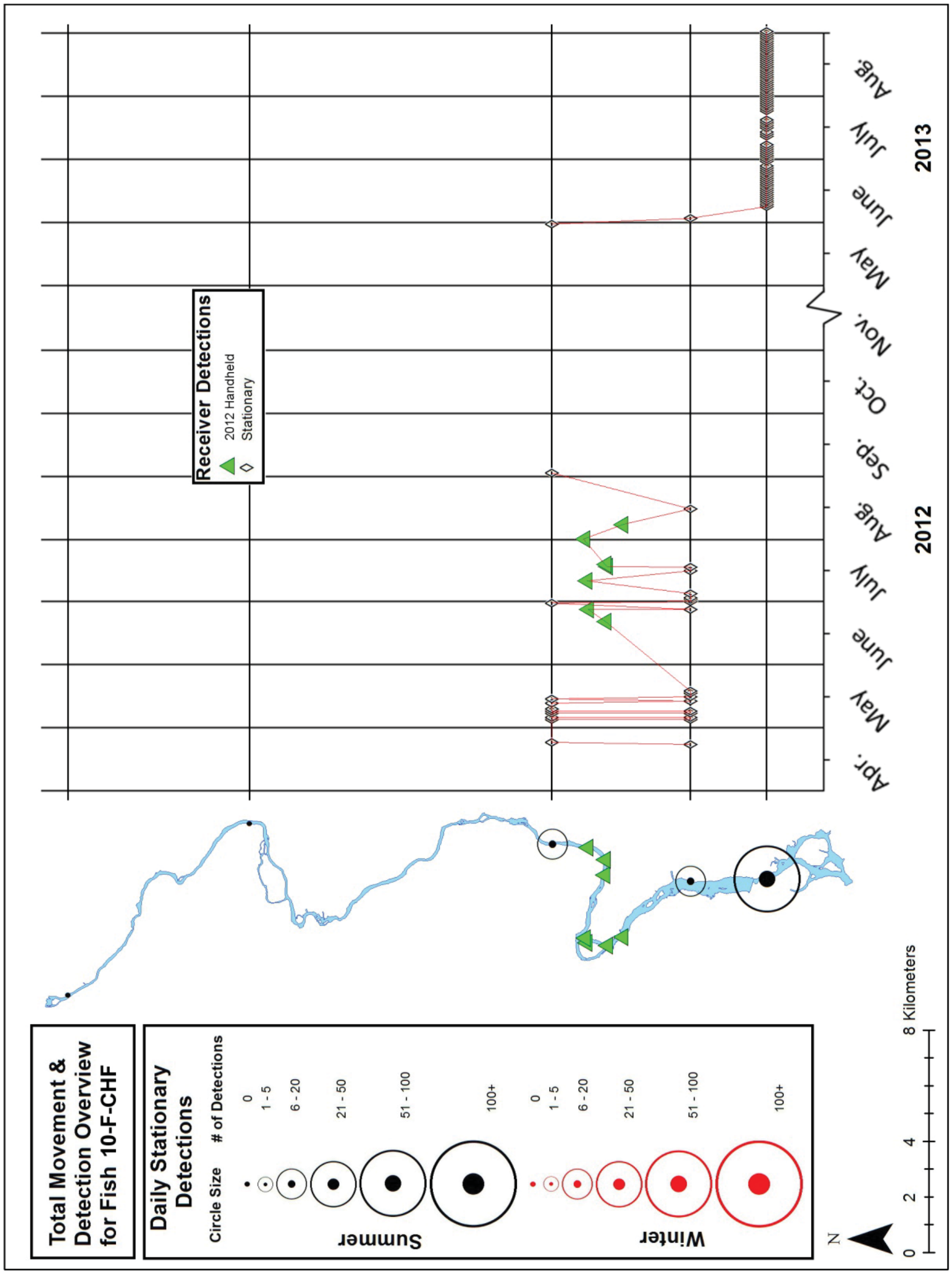


Figure A10: Overview of detections and movements for female Fish 10-F-CHF in the Menominee River, MI/WI.

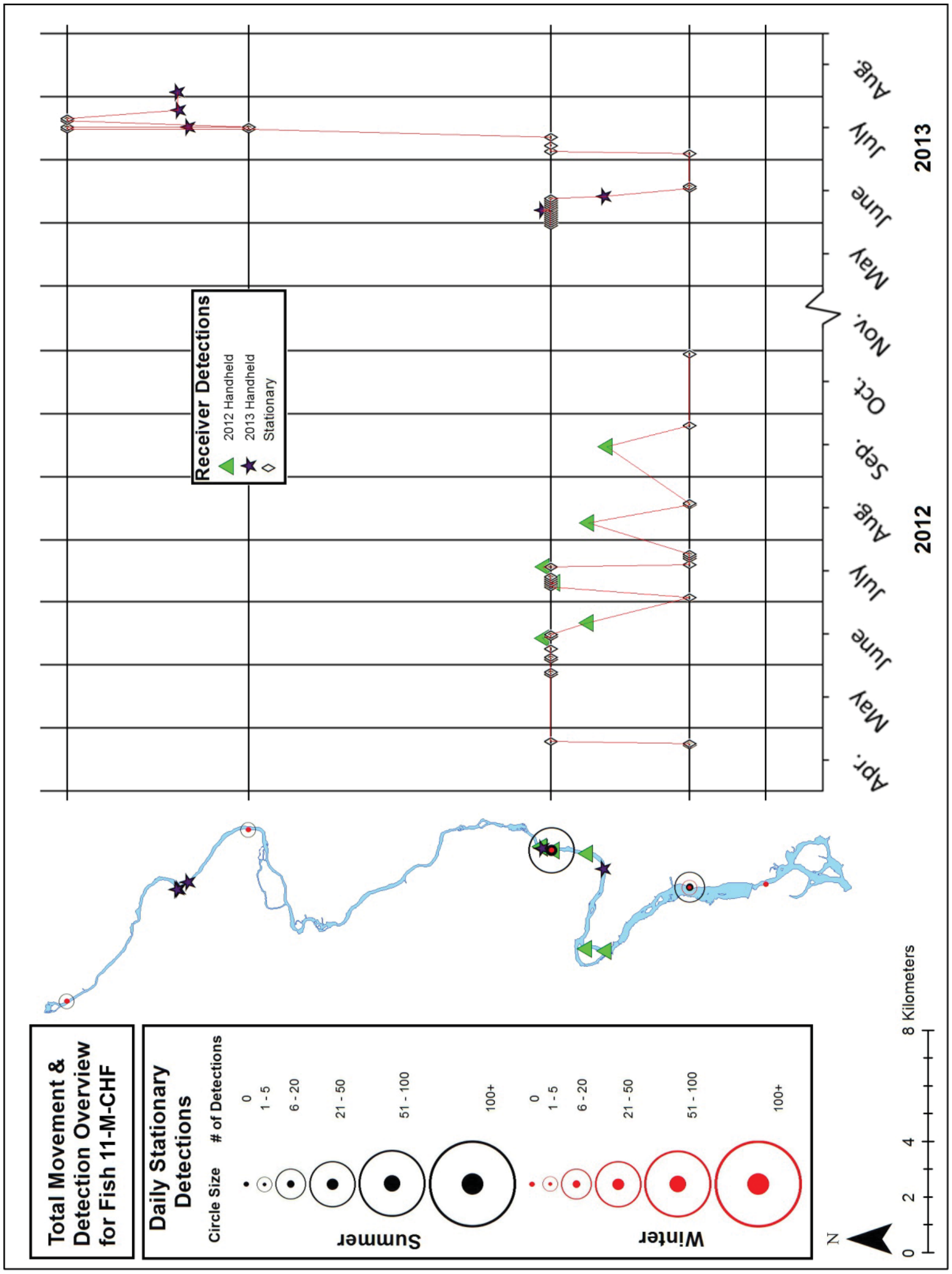


Figure A11: Overview of detections and movements for male Fish 11-M-CHF in the Menominee River, MI/WI.

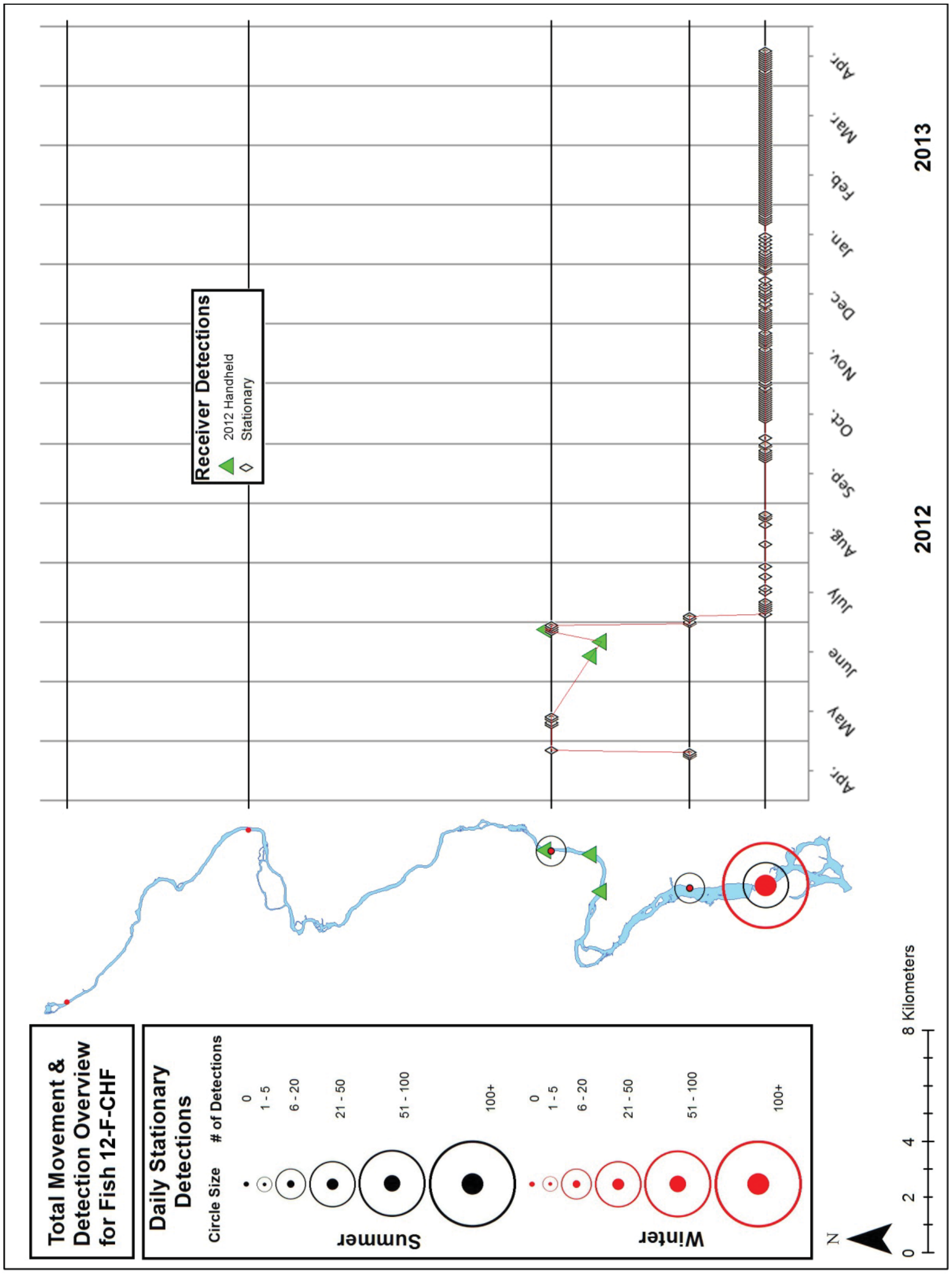


Figure A12: Overview of detections and movements for female Fish 12-F-CHF in the Menominee River, MI/WI.

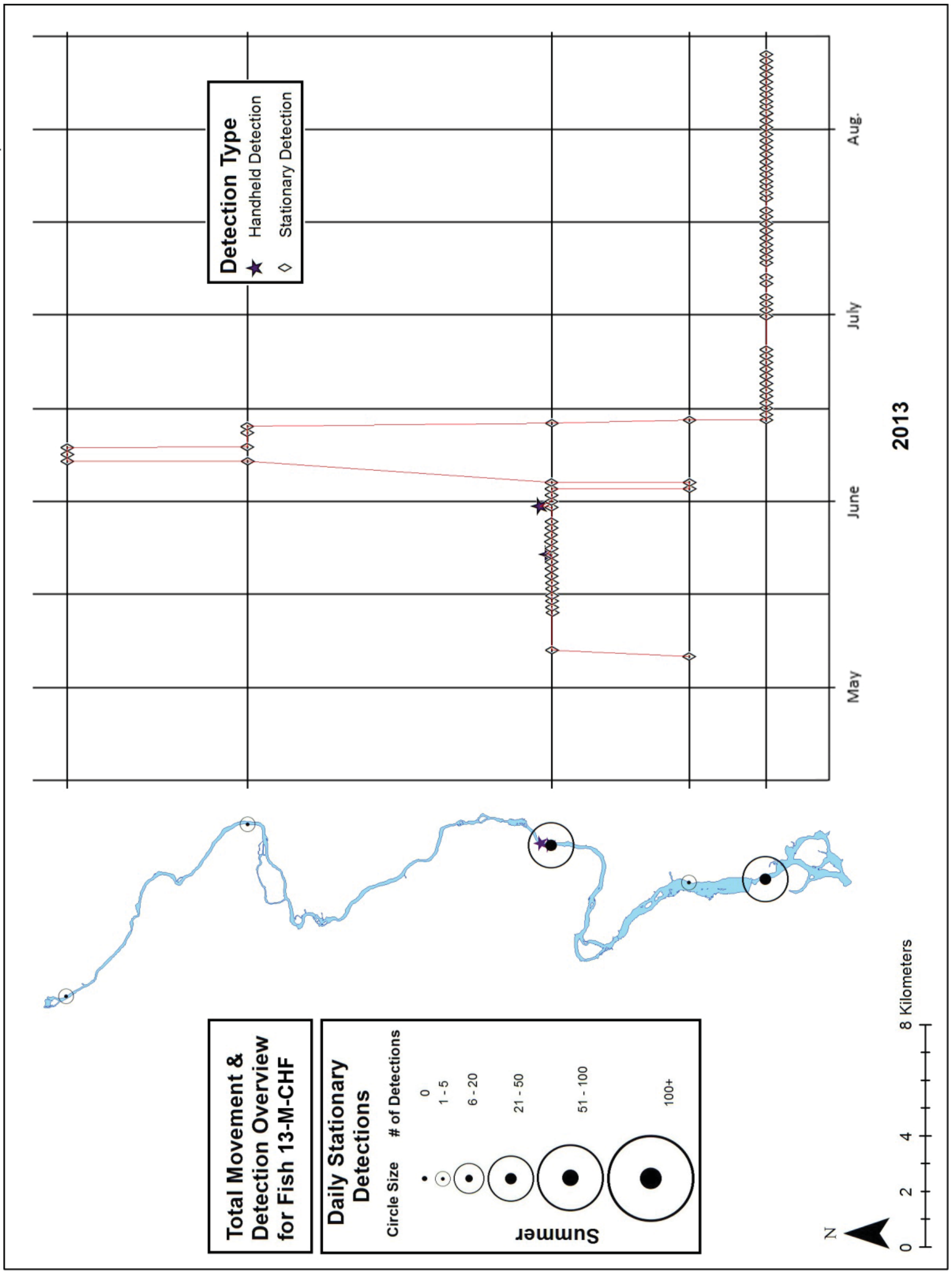


Figure A13: Overview of detections and movements for male Fish 13-M-CHF in the Menominee River, MI/WI.

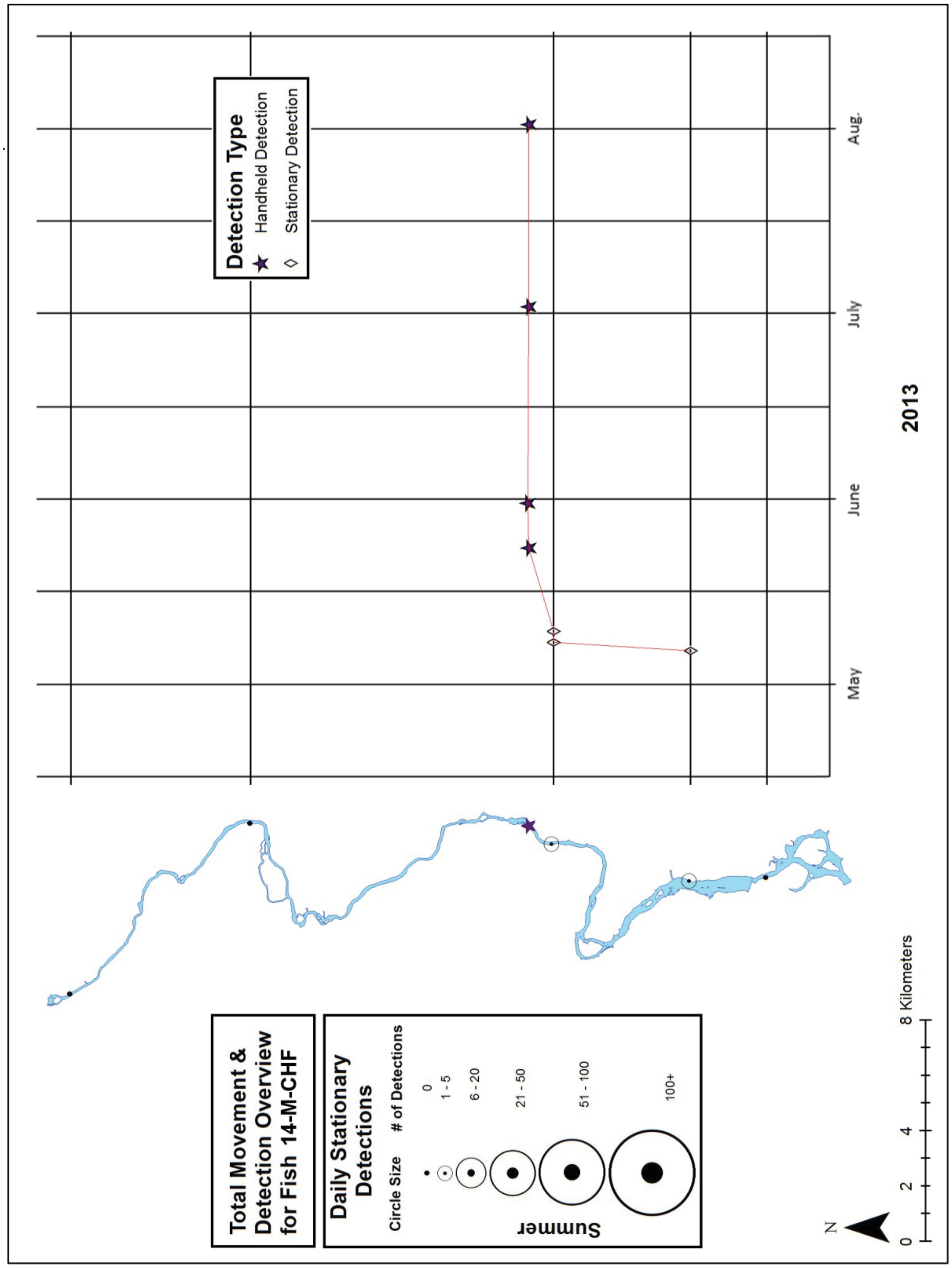


Figure A14: Overview of detections and movements for male Fish 14-M-CHF in the Menominee River, MI/WI.

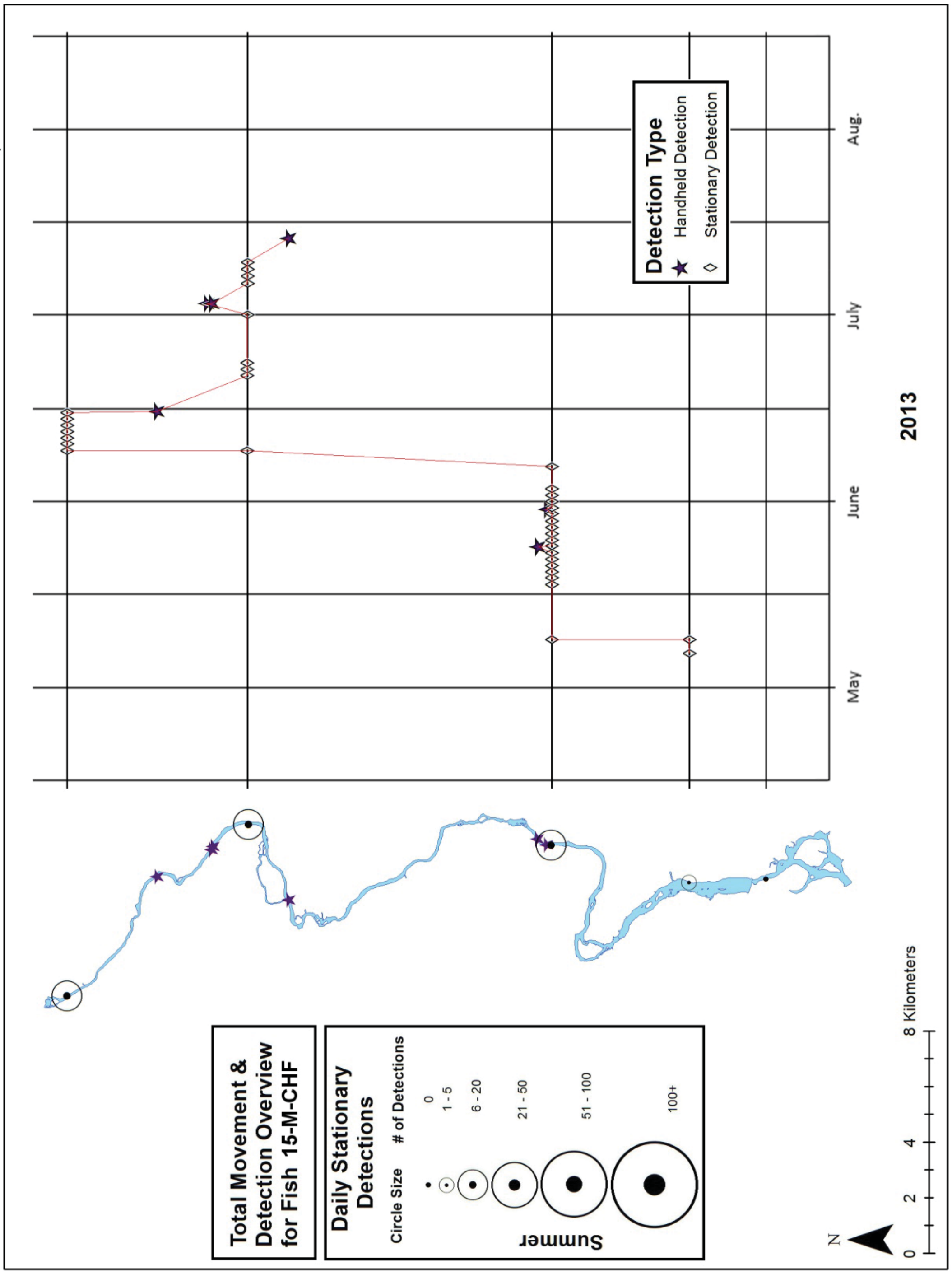


Figure A15: Overview of detections and movements for male Fish 15-M-CHF in the Menominee River, MI/WI.

Appendix B: Stationary and portable receiver tables

Table B1 : Handheld receiver (VR100) tracking effort in 2012

Date	Location	Time spent	# Fish Detected	Detected Fish
5/4	Above HWZ; in CHF; MI side of SFD	3 hours	0	
5/8	MI side of SFD	1 hour	0	
5/9	Upstream of HWZ, FH; WI side of SFD	2.25 hours	0	
5/16	At CHF receiver	0.25 hour	0	
5/23	Sturgeon Band Park (SBP) to Quiver Falls	2 hours	0	
5/24	HWZ to Miscauno I.	3 hours	4	6, 9, 10, 12
5/30	MI side of SFD; above HWZ	1 hour	1	11
5/31	SFD to FH	3.75 hours	6	1, 2, 3, 4, 5, 8
6/14	Pemene to Miscauno I.	3.5 hours	3	6, 11, 12
6/21	Pemene to Miscauno I.	4 hours	5	6, 9, 10, 11, 12
6/22	FH to downstream of SFD	2 hours	3	3, 5, 8
6/26	SFD to FH	4 hours	4	1, 2, 3, 5
6/27	FH to above Quiver; near HWZ	3 hours	4	4, 10, 11, 12
7/10	FH to Quiver; above HWZ	3.5 hours	3	4, 7, 11
7/11	CHF to Miscauno I.; SBP	5 hours	1	10
7/12	FH to just below SFD	3.5 hours	3	1, 2, 8
7/18	SBP; Pemene to Miscauno I.	4 Hours	3	9, 10, 11
7/19	Pemene to Miscauno I.	4.5 Hours	2	9, 10
7/24	FH to Island at SFD	4 hours	5	1, 2, 4, 5, 8
7/31	FH to above Quiver; SBP to Quiver	4.5 Hours	0	
8/1	Pemene to all around Miscauno I.	6 Hours	1	10
8/2	CHF to Miscauno I.	5 Hours	0	
8/8	CHF to Miscauno I.	3.5 hours	2	9, 10
8/9	Pemene to Miscauno I.	4.5 Hours	2	10, 11
8/10	FH to Island at SFD	4.5 hours	4	1, 3, 4, 8
9/14	FH & HWZ Receiver runs; SBP to Pemebonwon R	2 hours	0	
9/15	All of CHF; Miscauno I to riffles below HWZ	4.5 Hours	2	9, 11
10/15	SFD to USGS gauge site - from shore	0.5 Hours	0	
10/15	FH; Pemene to HWZ	0.5 hours	0	

Table B2 : Handheld receiver (VR100) tracking effort in 2013

Date	Location	Time spent	# Fish Detected	Detected Fish
5/20	SFD area(from shore)	0.5 hours	0	
6/6	FH to top	4 hours	3	1, 3, 8
6/7	Pemene to all around Miscauno I.	4.5 hours	5	10, 11, 13, 14, 15
6/13	FH to Nosepeak I.	2.5 hours	3	1, 3, 7
6/14	Pemene to all around Miscauno I.	5 hours	5	9, 11, 13, 14, 15
6/20	SBP to below Quiver	2 hours	1	5
6/28	FH to just above Quiver Falls	3 hours	0	
6/29	FH to top	5 hours	5	1, 2, 7, 8
7/4	FH to Nosepeak I.; Pemene to island upstream of Miscauno I.	4 hours	1	9
7/5	FH to top	5 hours	5	1, 2, 3, 4, 7
7/16	Pemene to Big bend below HWZ	2 hours	1	14
7/17	FH to top	7 hours	6	1, 3, 4, 8, 11, 15
7/18	White Rapids dam to first falls/rapids downstream	1 hour	0	
7/25	FH to all around SFD	6.5 hours	6	1, 2, 3, 4, 5, 11
7/26	Pemene to small island above Miscauno I.	1.5 hours	1	9
7/27	FH to just above Quiver Falls	3 hours	3	7, 8, 15
8/1	SBP to just below Quiver	2 hours	0	
8/2	HWZ to all around Miscauno I.	4 hours	2	9, 14
8/3	FH to all around SFD	6.5 hours	5	1, 3, 4, 5, 11

Table B3: Stationary receiver data retrievals in 2012

Date	SFD	FH	HWZ	CHF	BCHD
5/2	x	x	x	x	
5/4			x		
5/8				x	x
5/9	x	x	x		
5/16	x	x	x	x	
5/23	x	x		x	x
5/24			x		
5/30	x	x	x	x	x
6/13	x	x	x	x	
6/21			x		
6/22		x			
6/27		x	x		
7/10		x	x		
7/11				x	x
7/12	x				
7/31		x			x
8/1	x		x	x	
8/9			x	x	
8/10		x			
9/14	x	x	x		
9/15				x	x
10/15	x	x			
10/25		x	x	x	x

Table B4: Stationary receiver data retrievals in 2013

Date	SFD	FH	HWZ	CHF	BCHD
5/15				x	
6/6		x			
6/7	x		x		
6/13		x			
6/21				x	x
6/28	x	x			
7/4		x			
7/5	x				
7/6				x	x
7/16			x	x	x
7/17	x	x			
7/25	x	x			
7/26			x		
8/3	x	x			
8/30	x	x	x	x	x

Table B5: Final detections of study sturgeon in 2013

Fish #	Fish Gender	Release Site	Final Detection Site	Final Detection Date
1	Female	FH	1.5 rkm ↓SFD	August 3
2	Male	FH	FH	August 11
3	Male	FH	SFD	August 4
4	Male	CHF	SFD	August 5
5	Male	FH	3.5 rkm ↑FH	August 3
6	Male	CHF	BCHD	April 26
7	Male	CHF	0.3 rkm ↑Quiver Falls	July 27
8	Male	CHF	FH	August 30
9	Female	CHF	2.4 rkm ↓HWZ	August 2
10	Female	CHF	BCHD	August 30
11	Male	CHF	Granger Point	August 3
12	Female	CHF	BCHD	April 18
13	Male	CHF	BCHD	August 30
14	Male	CHF	1.1 rkm ↑HWZ	August 2
15	Male	CHF	3.5 rkm ↓FH	July 27

Table B6: Near-island detections of study sturgeon in 2012

Date	Fish #	Fish Gender	Island Name (If Known) or Island Description	Position Relative to Island	Distance to Island (m)
July 12	2	Male	Downstream of SFD	Downstream	56
July 24	2	Male	Downstream of SFD	Downstream	75
July 12	8	Male	Downstream of SFD	Downstream	76
August 10	8	Male	Island at Granger Point	Upstream	82
July 10	4	Male	Grand I.	Alongside	20
July 10	7	Male	Pemebonwon Islands	Upstream	104
June 21	12	Female	2 rkm upstream from Miscauno I.	Upstream	87
July 18	9	Female	1.2 rkm upstream from Miscauno I.	Downstream	95
August 1	10	Female	Miscauno Island	Alongside	70
July 11	10	Female	Small island next to Miscauno I.	Alongside	22
August 9	11	Male	Small island next to Miscauno I.	Alongside	31
June 14	6	Male	Small island next to Miscauno I.	Alongside	4
June 21	6	Male	Small island next to Miscauno I.	Alongside	23
Sept. 15	11	Male	Miscauno I.	Alongside	80
July 18	10	Female	Miscauno I.	Downstream	65

Table B7: Near-island detections of study sturgeon in 2013

Date	Fish #	Fish Gender	Island Name (If Known) or Island Description	Position Relative to Island	Distance to Island (m)
June 6	3	Male	Downstream of SFD	Alongside	29
June 29	2	Male	Downstream of SFD	Alongside	19
July 5	2	Male	Downstream of SFD	Alongside	18
June 6	8	Male	Downstream of SFD	Alongside	16
August 3	11	Male	Island at Granger Point	Upstream	83
August 3	5	Male	Island at Granger Point	Upstream	79
July 25	11	Male	Island at Granger Point	Upstream	51
July 17	11	Male	Island at Granger Point	Downstream	189
June 13	7	Male	Grand Island	Alongside	3
June 13	1	Female	Grand Island	Alongside	36
July 27	15	Male	Grand Island	Downstream	114
July 27	8	Male	Grand Island	Downstream	118
June 13	4	Male	Grand Island	Downstream	190
July 27	7	Male	Nose Peak Island	Downstream	193
June 7	14	Male	Islands at Pemene Falls	Alongside	31
June 14	14	Male	Islands at Pemene Falls	Alongside	25
July 16	14	Male	Islands at Pemene Falls	Alongside	14
August 2	14	Male	Islands at Pemene Falls	Downstream	32
June 7	9	Female	Islands at Pemene Falls	Downstream	64
July 26	9	Female	Island 2rkm upstream from Miscauno Island	Upstream	55

Appendix C: Stationary to stationary fish movement tables

Table C1: Fish 1 stationary to stationary movements

Initial Date	Initial Time	Initial Receiver	Final Date	Final Time	Final Receiver	Distance (km)	Time (h)	Rate (km/hr)
4/27/12	0138	FH	4/27/12	2209	SFD	10.25	20.52	0.50
5/20/12	1927	SFD	6/11/13	0706	FH	10.25	1yr+	-
6/20/13	1824	FH	6/26/13	2059	SFD	10.25	146.58	0.07

Table C2: Fish 2 stationary to stationary movements

Initial Date	Initial Time	Initial Receiver	Final Date	Final Time	Final Receiver	Distance (km)	Time (h)	Rate (km/hr)
4/26/12	1558	FH	4/27/12	0128	SFD	10.25	9.50	1.08
5/14/12	1024	SFD	5/14/12	1419	FH	10.25	3.92	2.61
5/14/12	1844	FH	5/14/12	2357	SFD	10.25	5.22	1.96
5/17/12	1801	SFD	5/17/12	2320	FH	10.25	5.32	1.93
5/17/12	2324	FH	5/18/12	0428	HWZ	16.14	5.07	3.18
5/18/12	1445	HWZ	5/19/12	0132	CHF	10.12	8.78	1.15
5/19/12	1501	CHF	5/19/12	2331	HWZ	10.12	8.50	1.19
5/19/12	2349	HWZ	5/21/12	1534	FH	16.14	39.75	0.41
5/21/12	1547	FH	5/22/12	0708	SFD	10.25	15.35	0.67
6/9/12	1527	SFD	6/10/12	0153	FH	10.25	10.43	0.98
6/12/12	0949	FH	6/14/12	0009	SFD	10.25	38.33	0.27
6/15/12	2202	SFD	6/16/12	1816	FH	10.25	20.23	0.51
6/18/12	1432	FH	6/20/12	1146	SFD	10.25	45.23	0.23
7/7/12	0803	SFD	8/8/12	1818	FH	10.25	1mo+	-
5/6/13	1923	FH	6/9/13	1646	SFD	10.25	1mo+	-
7/25/13	0524	SFD	7/25/13	2330	FH	10.25	18.10	0.57
7/26/13	0206	FH	7/26/13	1835	SFD	10.25	16.48	0.62
8/11/13	0050	SFD	8/11/13	1607	FH	10.25	15.95	0.64

Table C3: Fish 3 stationary to stationary movements

Initial Date	Initial Time	Initial Receiver	Final Date	Final Time	Final Receiver	Distance (km)	Time (h)	Rate (km/hr)
5/14/12	2024	SFD	5/15/12	0228	FH	10.25	6.07	1.69
5/16/12	2336	FH	10/19/12	2022	SFD	10.25	1mo+	-

Table C4: Fish 4 stationary to stationary movements

Date	Initial Time	Receiver	Date	Final Time	Receiver	Distance (km)	Time (h)	Rate (km/hr)
4/24/12	1503	CHF	4/25/12	0105	HWZ	10.12	10.03	1.001
4/29/12	2257	HWZ	5/3/12	0702	FH	16.14	80.05	0.20
5/3/13	0710	FH	5/3/12	1420	SFD	10.25	31.17	0.33
5/12/12	2217	SFD	5/13/12	0239	FH	10.25	4.37	2.34
5/13/12	1958	FH	5/14/12	0157	SFD	10.25	5.98	1.71
6/10/12	2359	SFD	6/22/12	0032	FH	10.25	1week+	-
6/22/13	0446	FH	6/24/13	0101	SFD	10.25	44.25	0.23
6/24/13	1305	SFD	6/29/13	0346	FH	10.25	110.03	0.09
7/6/13	1344	FH	7/25/13	1913	SFD	10.25	1week+	-

Table C5: Fish 5 stationary to stationary movements

Initial Date	Initial Time	Initial Receiver	Final Date	Final Time	Final Receiver	Distance (km)	Time (h)	Rate (km/hr)
5/20/13	2221	SFD	5/22/13	0322	FH	10.25	29.02	0.35

Table C6: Fish 6 stationary to stationary movements

Date	Initial Time	Receiver	Date	Final Time	Receiver	Distance (km)	Time (h)	Rate (km/hr)
4/23/12	2219	CHF	4/24/12	0501	HWZ	10.12	6.7	1.51
5/3/12	2029	HWZ	5/4/12	0051	CHF	10.12	4.37	2.31
5/4/12	0731	CHF	5/4/12	1257	HWZ	10.12	5.43	1.86
5/6/12	1340	HWZ	5/7/12	0028	CHF	10.12	10.8	0.94
5/7/12	0928	CHF	5/7/12	2255	HWZ	10.12	13.45	0.75
5/12/12	0143	HWZ	7/4/12	1604	CHF	10.12	1mon+	-

Table C7: Fish 7 stationary to stationary movements

Date	Initial Time	Receiver	Date	Final Time	Receiver	Distance (km)	Time (h)	Rate (km/hr)
4/26/12	0104	CHF	4/26/12	0713	HWZ	10.12	6.15	1.64
4/26/12	0729	HWZ	5/4/12	0117	FH	16.14	1week+	-
5/4/12	0121	FH	5/4/12	0558	SFD	10.25	4.62	2.22
5/16/12	0046	SFD	5/17/12	0306	FH	10.25	26.33	0.39

Table C8: Fish 8 stationary to stationary movements

Date	Initial Time	Receiver	Date	Final Time	Receiver	Distance (km)	Time (h)	Rate (km/hr)
4/24/12	1501	CHF	4/25/12	344	HWZ	10.12	12.72	0.79
4/25/12	0356	HWZ	5/1/12	344	FH	16.14	119.8	0.13
5/1/12	0347	FH	5/1/12	859	SFD	10.25	5.2	1.97
5/1/12	1258	SFD	5/1/12	1937	FH	10.25	6.65	1.54
5/2/12	2212	FH	5/3/12	0206	SFD	10.25	3.9	2.63
7/11/12	1004	SFD	7/26/12	2248	FH	10.25	1wk+	-
7/29/12	0213	FH	9/6/12	0051	SFD	10.25	1mo+	-
6/19/13	2020	SFD	7/2/13	2327	FH	10.25	1wk+	-

Table C9: Fish 9 stationary to stationary movements

Date	Initial Time	Receiver	Date	Final Time	Receiver	Distance (km)	Time (h)	Rate (km/hr)
4/24/12	1602	CHF	4/24/12	2206	HWZ	10.12	6.07	1.67
4/29/12	0051	HWZ	4/29/12	0540	CHF	10.12	4.82	2.10
4/29/12	1335	CHF	4/29/12	1902	HWZ	10.12	5.45	1.86
5/3/12	1437	HWZ	5/3/12	2106	CHF	10.12	6.48	1.56
5/3/12	2231	CHF	5/4/12	0435	HWZ	10.12	6.07	1.67
5/5/12	2119	HWZ	5/6/12	0131	CHF	10.12	4.2	2.41
5/7/12	1304	CHF	5/8/12	2305	HWZ	10.12	34.02	0.30
5/13/12	0910	HWZ	5/13/12	1423	CHF	10.12	5.22	1.94
5/14/12	0756	CHF	5/15/12	1401	HWZ	10.12	30.08	0.36
7/5/12	0118	HWZ	7/25/12	0151	CHF	10.12	1wk+	-
7/25/12	0614	CHF	8/1/12	0121	HWZ	10.12	163	0.06
8/1/12	1318	HWZ	8/6/12	0952	CHF	10.12	116.57	0.09
9/8/12	2005	CHF	10/10/12	0400	HWZ	10.12	1mo+	-
10/20/12	0346	HWZ	10/25/12	1227	CHF	10.12	128.41	0.08
10/26/12	1022	CHF	4/24/13	2250	HWZ	10.12	1mo+	-
6/11/13	1716	HWZ	7/7/13	1430	CHF	10.12	1mo+	-
7/7/13	2204	CHF	7/8/13	0845	HWZ	10.12	10.68	0.95
7/8/13	1557	HWZ	7/8/13	1934	CHF	10.12	3.62	2.79
7/10/13	0206	CHF	7/10/13	1545	HWZ	10.12	13.65	0.74
7/13/13	0919	HWZ	7/15/13	2254	CHF	10.12	61.58	0.16

Table C10: Fish 10 stationary to stationary movements

Initial Date	Initial Time	Initial Receiver	Final Date	Final Time	Final Receiver	Distance (km)	Time (h)	Rate (km/hr)
4/23/12	1651	CHF	4/23/12	2317	HWZ	10.12	6.43	1.57
5/5/12	0639	HWZ	5/5/12	1133	CHF	10.12	4.9	2.06
5/5/12	2258	CHF	5/6/12	0337	HWZ	10.12	4.65	2.18
5/7/12	2102	HWZ	5/8/12	0704	CHF	10.12	10.03	1.01
5/9/12	0023	CHF	5/9/12	1001	HWZ	10.12	9.63	1.05
5/13/12	1459	HWZ	5/14/12	0850	CHF	10.12	17.85	0.57
5/14/12	1127	CHF	5/15/12	1119	HWZ	10.12	23.87	0.42
5/15/12	1631	HWZ	5/16/12	1117	CHF	10.12	18.77	0.54
6/27/12	0326	CHF	6/30/12	0516	HWZ	10.12	73.83	0.14
6/30/12	1818	HWZ	7/1/12	0552	CHF	10.12	11.57	0.87
8/16/12	0655	CHF	9/1/12	1942	HWZ	10.12	1week+	-
5/31/13	1815	HWZ	6/2/13	2235	CHF	10.12	52.33	0.19

Table C11: Fish 11 stationary to stationary movements

Initial Date	Initial Time	Initial Receiver	Final Date	Final Time	Final Receiver	Distance (km)	Time (h)	Rate (km/hr)
4/23/12	2344	CHF	4/24/12	2013	HWZ	10.12	20.48	0.49
6/14/12	2258	HWZ	7/3/12	0604	CHF	10.12	1wk+	-
7/3/12	1636	CHF	7/8/12	0504	HWZ	10.12	108.47	0.09
7/18/12	1618	HWZ	7/19/12	1525	CHF	10.12	23.12	0.44
10/30/12	604	CHF	5/30/13	2021	HWZ	10.12	1mo+	-
6/13/13	420	HWZ	6/18/13	2220	CHF	10.12	138	0.07
7/4/13	1528	CHF	7/5/13	1422	HWZ	10.12	22.9	0.44
7/12/13	1756	HWZ	7/16/13	0231	FH	16.14	80.58	0.20
7/16/13	240	FH	7/16/13	1644	SFD	10.25	14.07	0.73

Table C12: Fish 12 stationary to stationary movements

Initial Date	Initial Time	Initial Receiver	Final Date	Final Time	Final Receiver	Distance (km)	Time (h)	Rate (km/hr)
4/25/12	1635	CHF	4/25/12	2258	HWZ	10.12	6.38	1.59
6/29/12	2042	HWZ	6/30/12	0201	CHF	10.12	5.32	1.9

Table C13: Fish 13 stationary to stationary movements

Initial Date	Initial Time	Initial Receiver	Final Date	Final Time	Final Receiver	Distance (km)	Time (h)	Rate (km/hr)
5/20/13	1423	CHF	5/21/13	0521	HWZ	10.12	12.97	0.78
6/16/13	2036	HWZ	6/17/13	0338	CHF	10.12	7.03	1.44
6/17/13	2206	CHF	6/18/13	0346	HWZ	10.12	5.67	1.78
6/18/13	0353	HWZ	6/20/13	2341	FH	16.14	67.8	0.24
6/21/13	0010	FH	6/21/13	1857	SFD	10.25	18.78	0.55
6/22/13	1900	SFD	6/23/13	0032	FH	10.25	5.53	1.85
6/25/13	2236	FH	6/27/13	2114	HWZ	16.14	36.63	0.44
6/27/13	2121	HWZ	6/28/13	0222	CHF	10.12	5.02	2.01

Table C14: Fish 14 stationary to stationary movements

Initial Date	Initial Time	Initial Receiver	Final Date	Final Time	Final Receiver	Distance (km)	Time (h)	Rate (km/hr)
5/20/13	1320	CHF	5/22/13	0329	HWZ	10.12	32.15	0.31

Table C15: Fish 15 stationary to stationary movements

Initial Date	Initial Time	Initial Receiver	Final Date	Final Time	Final Receiver	Distance (km)	Time (h)	Rate (km/hr)
5/22/13	0054	CHF	5/22/13	0855	HWZ	10.12	8.02	1.26
6/19/13	2243	HWZ	6/22/13	0236	FH	16.14	52.88	0.3
6/22/13	0256	FH	6/22/13	1803	SFD	10.25	15.12	0.68
6/28/13	0123	SFD	7/5/13	0205	FH	10.25	1week+	-

Appendix D: Invertebrate Maps

Figure D1: Location surveys with presence/absence of the three most commonly collected types of insects, Trichoptera, Ephemeroptera & Chironomidae, plotted for 2012 & 2013.

Figure D2: Location surveys with presence/absence of the three most commonly collected types of Mollusks, Sphaeridae, *Dreissena polymorpha*, & Spiral-shelled Gastropods, plotted for 2013 & 2013.

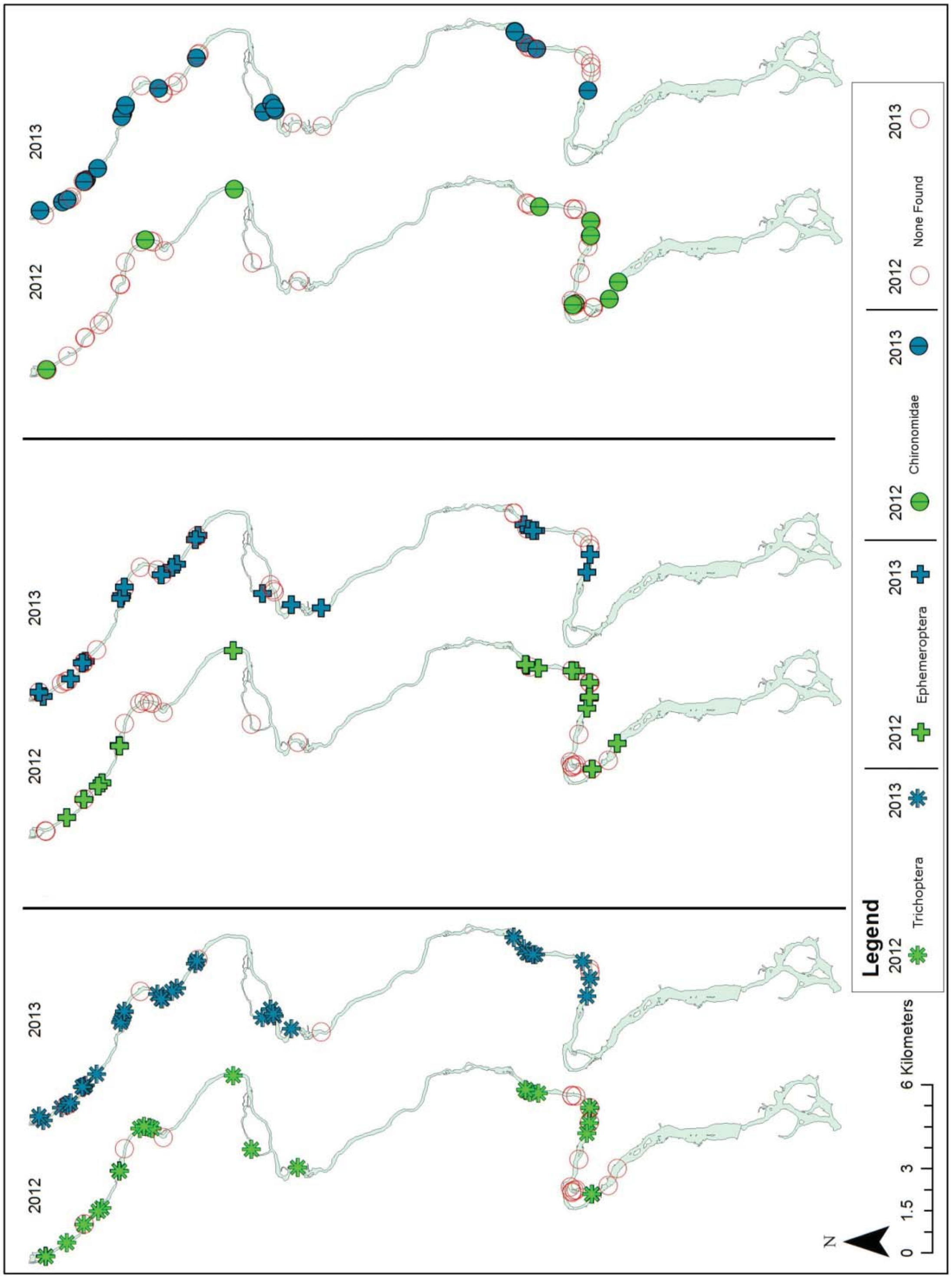


Figure D1: Location surveys with presence/absence of the three most commonly collected types of insects, Trichoptera, Ephemeroptera & Chironomidae, plotted for 2012 & 2013.

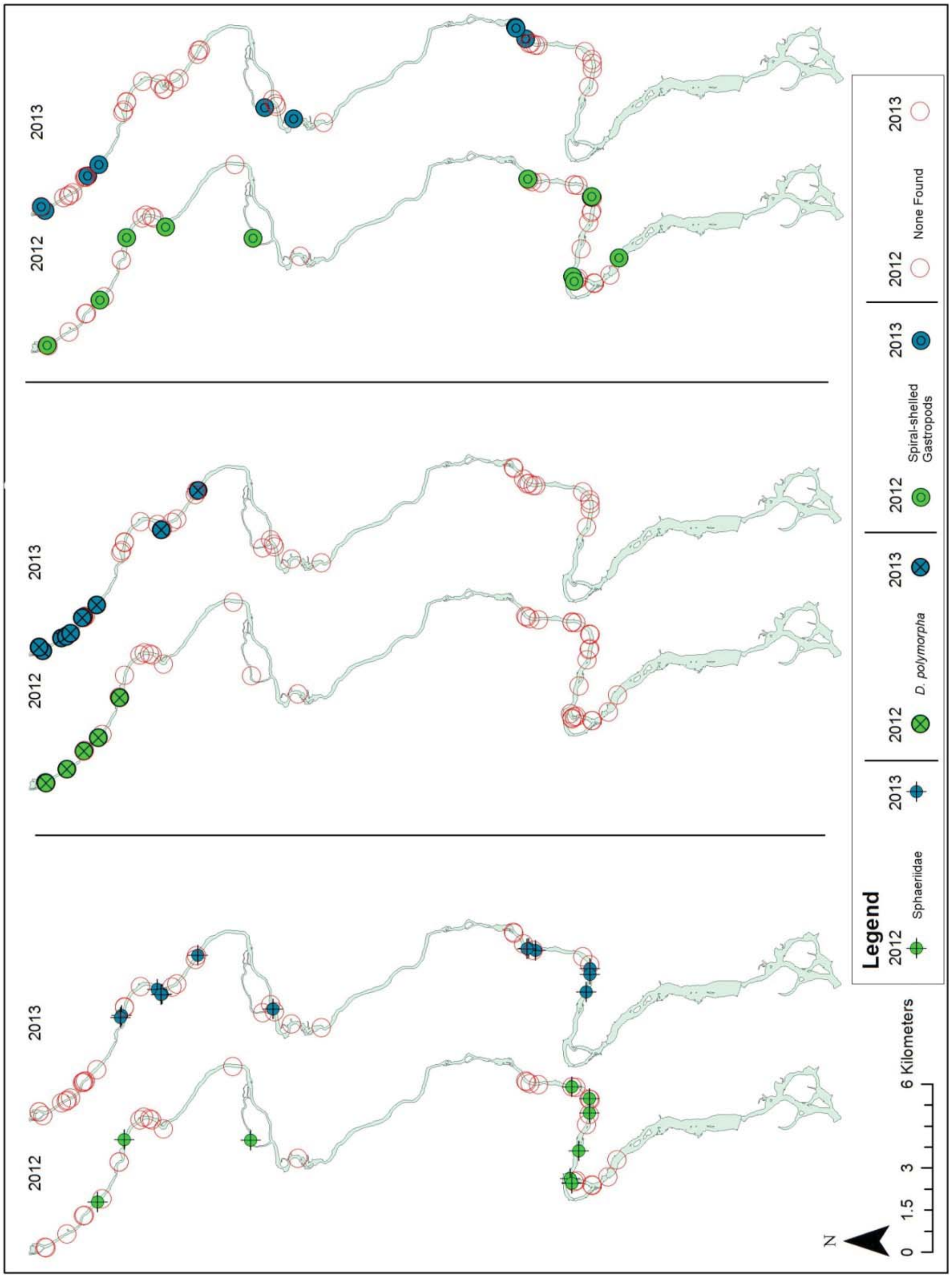


Figure D2: Location surveys with presence/absence of the three most commonly collected types of Mollusks, Sphaeridae, *Dreissena polymorpha*, & Spiral-shelled Gastropods, plotted for 2013 & 2013.

Appendix E: Vegetation

Figure E1: Submerged aquatic vegetation for the CHF in 2012 & 2013.

Figure E2: Photograph of a representative section of heavily vegetated river in July of 2012, with the stream-wide dominant species *Vallisneria americana* (Wild Celery) shown.

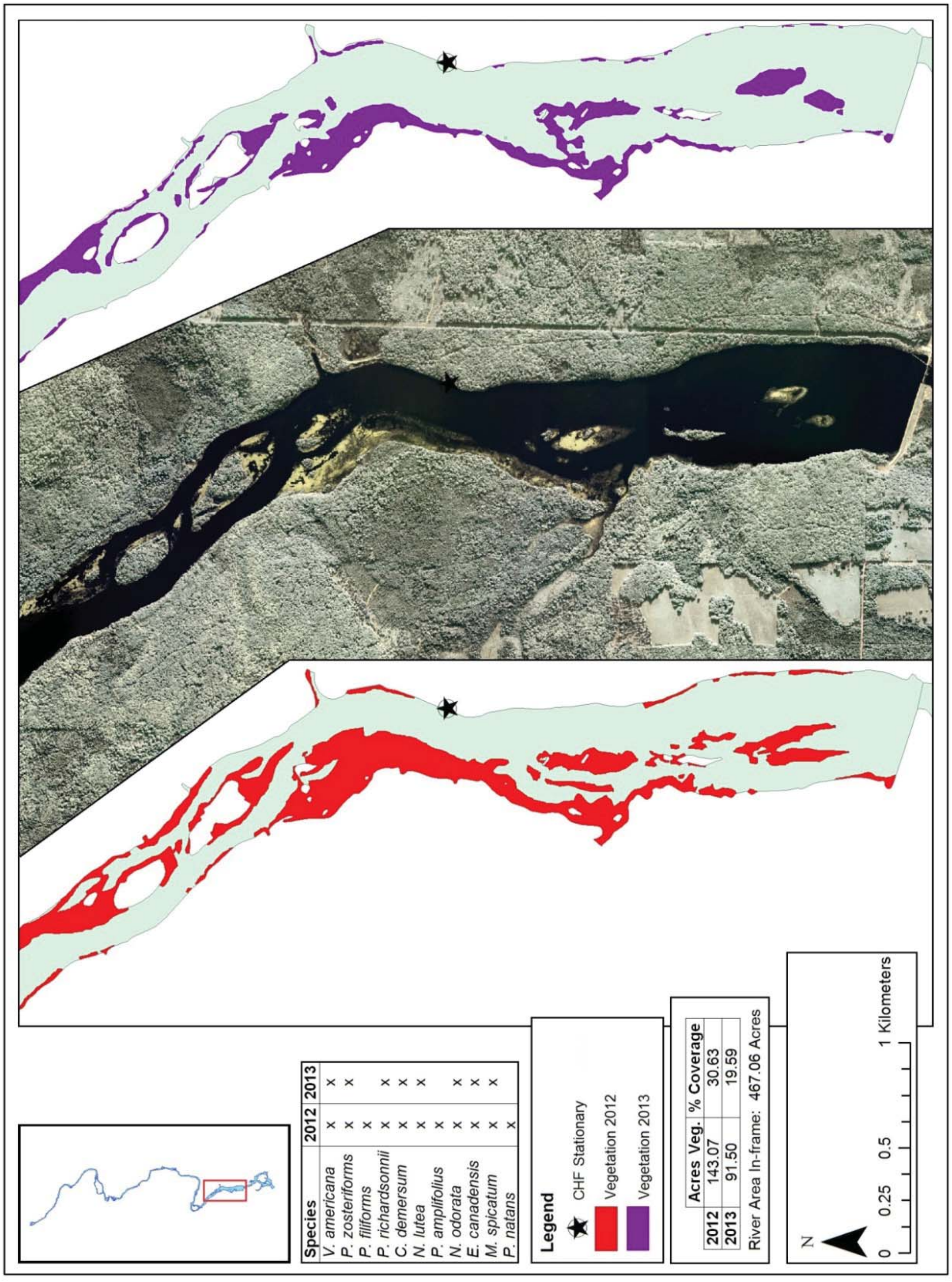


Figure E1: Submerged aquatic vegetation for the CHF in 2012 & 2013.

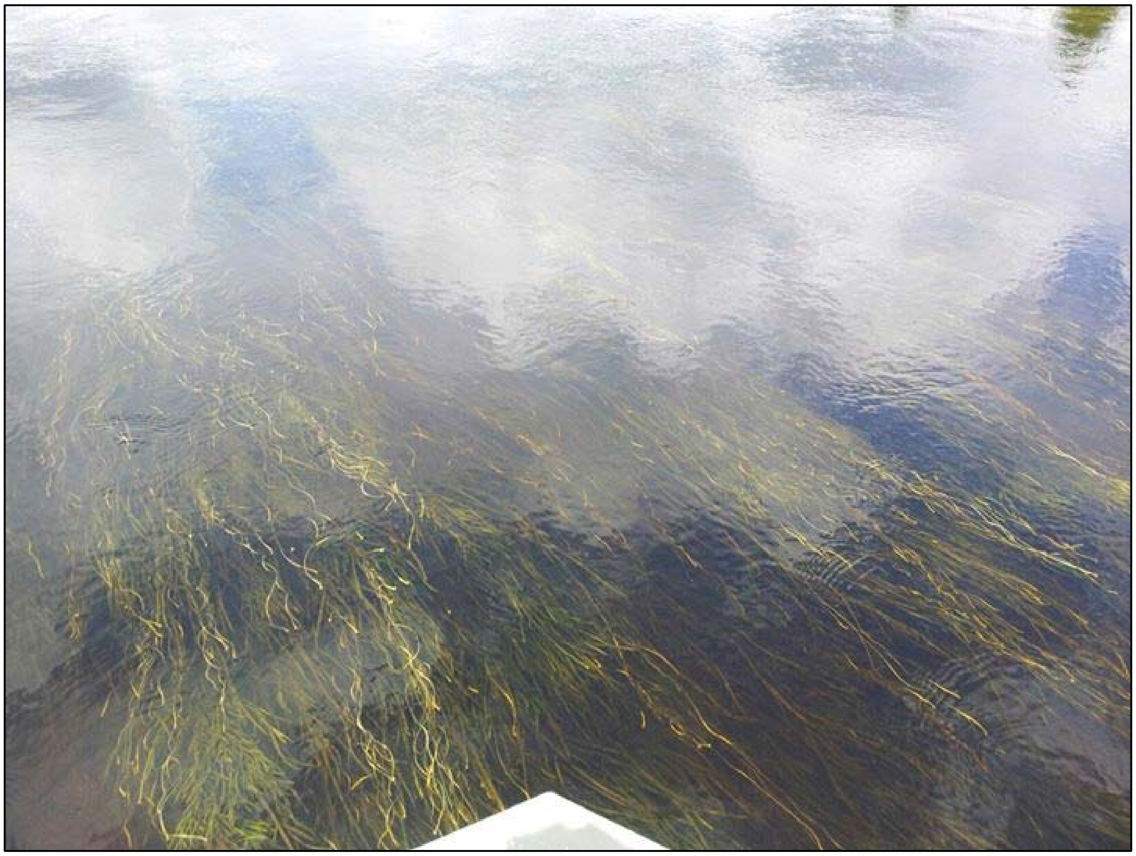


Figure E2: Photograph of a representative section of heavily vegetated river in July of 2012, with the stream-wide dominant species *Vallisneria americana* (Wild Celery) shown.

Appendix F: Documentation of permission to use photographs

Figure F1: Emailed permission statement from Gerald Girard

Statement of Permission to use your photograph

Inbox x

Jeremy Olach <jgolach@mtu.edu> Apr 2

to Gerald

Hi Gerry-

Sorry to bother you, but I have a favor to ask of you. I would like to use two of your pictures in my thesis, but to do so i need a written statement from you saying you are allowing it. This thesis will be published and available online, I wanted to make this clear before you give permission in case that is an issue for you. I hope all is well down in Norway and you continue to have more good sturgeon interactions. Take care, I hope to hear back from you soon.

...

Gerald Girard <ggirard3@norwaymi.com> Apr 7

to me

You have my permission to use my photographs. Gerald Girard

...