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## Demographic and Reproductive Status of Lake Sturgeon in the Muskegon River System, Michigan

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DEMOGRAPHIC AND REPRODUCTIVE STATUS OF LAKE STURGEON IN THE  
MUSKEGON RIVER SYSTEM, MICHIGAN

Alex C. Wieten

A Thesis Submitted to the Graduate Faculty of

GRAND VALLEY STATE UNIVERSITY

In

Partial Fulfillment of the Requirements

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## ABSTRACT

My study focused on a threatened population of lake sturgeon (*Acipenser fulvescens*) in the Muskegon River system, Michigan. I assessed the condition, growth and population dynamics of lake sturgeon and compared them to nearby populations using a length-weight relationship and the von Bertalanffy growth model. I also estimated the abundance of adult lake sturgeon in the Muskegon River system during the spawning run using closed-population models, analyzed movements of adult lake sturgeon during their spawning migrations using ultrasonic telemetry in 2011, and verified reproductive success by capturing larvae with drift nets in 2010 and 2011. The capture of adult lake sturgeon was performed using boat electrofishing and large-mesh gill netting in the spring, and juvenile lake sturgeon were captured using small-mesh gill netting in the fall. From 2008 to 2011, 141 individual lake sturgeon (24.9 – 191.0 cm total length; 0.05-59.50 kg weight) were captured. Of these, 116 lake sturgeon were aged using pectoral fin rays, representing 24 age cohorts. The weight-length relationship for captured lake sturgeon, where W is weight (kg) and TL is total length (cm), is  $\log_{10}(W) = -6.13 + 3.42 \cdot \log_{10}(TL)$  and the von Bertalanffy growth model is  $TL = 177.62 (1 - e^{-0.0985(t-1.0035)})$ , where t is age. Compared to nearby systems, a 100-cm individual from the Muskegon system tended to weigh less (average: -0.98 kg), and individuals age 23-27 years tended to be longer at age (average: +18.0 cm). Abundances were estimated for the 2009 and 2010 spawning migrations, which were 46 (95% CI: 37-67) and 39 (95% CI: 27-67) individuals, respectively. Successful reproduction in the Muskegon River was confirmed by the capture of 16 larval lake sturgeon in 2010 and 2 individuals in 2011. Consistent

with other studies, the onset of larval drift was at a water temperature of 16 °C. The number of larvae drifting downstream appeared to become heavily diluted with increasing distance downstream of a known spawning site. Overall, my results suggest the Muskegon River supports a small (in terms of annual population numbers), healthy (in terms of individual growth rates and proportion of individuals less than age 5), naturally-reproducing population of lake sturgeon. Nevertheless, the small size of the annual spawning run suggests the population should continue to be protected and be the focus of restoration.

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## CHAPTER 1

### INTRODUCTION

#### *History of Lake Sturgeon*

Lake sturgeon (*Acipenser fulvescens*), the largest fish species in the Great Lakes, once flourished but now have declined to less than 1% of their historical abundance (Tody, 1974; Auer, 1996; Hay-Chmielewski and Whelan, 1997). Lake sturgeon is the only species of sturgeon native to the Laurentian Great Lakes and is unique in its ability to grow over 110 kg and live over 150 years (Scott and Crossman, 1973; Kempinger, 1996). Currently, lake sturgeon is listed as a threatened species in much of its native range, including Michigan, and is thus protected from commercial fishing and under strict regulation in the few locations where recreational angling is allowed (Baker, 2006).

Of the 95 sites known to have supported healthy spawning populations of lake sturgeon in the Great Lakes basin, 43 populations have been extirpated (Holey et al., 2000). Historically, the status of lake sturgeon in the Great Lakes has been ignored due to low numbers and lack of reproduction during the 20<sup>th</sup> century (Auer, 1999). The lack of interest in this species led to an absence of information concerning the overall condition and abundance of individual lake sturgeon stocks. Today, interest in restoring lake sturgeon stocks is rising, but restoration of the species is hindered by this lack of basic life history information.

Factors such as public interest, the relicensing of hydropower facilities, and a lack of basic biological knowledge of the species have recently sparked interest in lake sturgeon research. In order to implement effective recovery strategies, management agencies of the Great Lakes need to understand the historical as well as the present-day distributions of lake sturgeon, population abundance and reproductive patterns, and habitat requirements for all life stages (Holey et al., 2000; Hayes and Caroffino, In Press). Recent interest regarding lake sturgeon has led to the creation of multiple rehabilitation strategies that stress the importance of gaining an understanding of current spawning stock size and population dynamics of individual lake sturgeon populations (Hay-Chmielewski and Whelan, 1997; Holey et al. 2000; Hayes and Caroffino, In Press).

### *The Decline*

Overfishing and habitat loss are primarily responsible for the decline of lake sturgeon in the Great Lakes region. In the 19<sup>th</sup> century, lake sturgeon was harvested as by-catch because it was considered a nuisance by early fisherman (Baker, 1980). Once fisherman realized the commercial value of lake sturgeon, adults were harvested in great numbers, leading to sharp population declines (Harkness and Dymond, 1961). This was followed by habitat degradation from logging, agriculture, and the construction of dams, which in turn limit access to the higher gradient portions of rivers with suitable spawning habitat (Houston, 1987; Hay-Chmielewski and Whelan, 1997; Baker, 2006). By limiting access to high gradient portions of river, dams also may prevent proper gonad maturation by limiting migration distance, leading to reduced spawning success (Auer, 1996).

### *Life History Dynamics*

Lake sturgeon has shown an inability to quickly rebound after protection from commercial and recreational harvest due to its slow maturation and low reproductive frequency. Lake sturgeon exhibit late sexual maturity; as a result, males require up to 14-16 years and females up to 24-26 years to reach reproductive age (Priegel and Wirth, 1971; Scott and Crossman, 1973). In addition, mature lake sturgeon spawn intermittently, with males every 1-3 years and females every 3-7 years (Auer, 1996; Smith and Baker, 2005; Forsythe et al., 2012). The combination of these reproductive traits lead to small spawning runs even in robust populations (Priegel and Wirth, 1971), and thus make it hard to reestablish healthy populations (Baker, 2006). However, once established, these life history characteristics can allow populations to deal with environmental variability by decreasing the chances of mating with the same individual each year (Forsythe et al., 2012).

In the spring, adult lake sturgeon in most systems migrate great distances upriver to spawn and afterwards return back to the Great Lakes (Auer, 1996; Lallaman et al., 2008). However, lake sturgeon also can remain in riverine environments for long periods of time or even their entire life (Threader and Brosseau, 1986; Lyons and Kempinger, 1992; Borkholder, et al., 2002). Lake sturgeon have been found to use factors such as river temperature, lunar period, and river discharge to cue spawning migrations (Fortin et al., 1993; Auer, 1996; Bruch and Binkowski, 2002; Lallaman et al., 2008; Forsythe et al., 2012) to their natal rivers (Homola et al., In Press). Since rivers are complex systems and vary in factors such as accessible length, habitat and discharge, I suspect that movement patterns of adult lake sturgeon will vary among systems. Thus, a better understanding of

movement patterns and key habitats in each unique system will help managers develop specific restoration plans.

Much is unknown regarding what factors hinder production during early life stages of lake sturgeon, which may limit recruitment especially in large river systems. The low level of reproducing fish typical in most remnant populations leads to very few drifting larvae (Auer and Baker, 2002; Smith and King, 2005). Previous studies show larval drift can be highly variable among years and cues, such as water temperature and time of day, dictate larval drift dynamics (Auer and Baker, 2002; Smith and King, 2005; Caroffino et al., 2010). Assessing larval drift dynamics in unique populations is important for measuring recruitment into the population and for identifying factors limiting survival of newly hatched lake sturgeon (Smith and King, 2005). Following larval drift, age-0 lake sturgeon leave their natal river in the fall to take up residence in lentic environments (Kempinger, 1996; Holtgren and Auer, 2004; Benson et al., 2005; Smith and King, 2005). Altenritter (2010) found that juvenile lake sturgeon occupy various habitats in Muskegon Lake for multiple years before immigrating to Lake Michigan. However, the dynamics of larval lake sturgeon moving downstream from Muskegon River to Muskegon Lake is still not understood.

### *The Muskegon River System*

Extensive logging occurred in the Muskegon River basin from the late 1880's to early 1920's. The logging led to intensive habitat alteration from scour, erosion, and channelization, resulting in increased river temperatures, altered flow regimes, and higher bed loads that degraded spawning habitat (O'Neal, 1997; Alexander, 2006). In addition,

the construction of Newaygo Dam in 1900 blocked upstream passage of lake sturgeon to the only high gradient portions of the Muskegon River with suitable spawning habitat (Peterson and Vecsei, 2004; Alexander, 2006). Although Newaygo Dam was demolished in 1968, upstream migration continues to be blocked by Croton Dam, which is located 75-km upstream from Muskegon Lake. Currently, the portion of river between the former Newaygo Dam and Croton Dam is the only section of the river with suitable spawning habitat for lake sturgeon (Scott and Crossman, 1983; O'Neal, 1997; Altenritter, 2010).

Downstream of the available spawning habitats in the Muskegon River, lake sturgeon encounter further pressures in Muskegon Lake and Lake Michigan. For example, lake sturgeon leaving the Muskegon system and emigrating to Lake Michigan faced commercial harvest until the fishery was closed in 1970 (Peterson et al., 2007). Moreover, Muskegon Lake has a history of anthropogenic disturbance and was listed as an Area of Concern due to impairments from industry and urbanization (Carter et al., 2006; Steinman et al., 2008). Additionally, age-0 and juvenile lake sturgeon likely faced entrainment by a power plant in Muskegon Lake, but measures have been taken to reduce entrainment. In addition, since the implementation of the Clean Water Act in 1973, great strides have been made to improve the water quality and habitat of Muskegon Lake (Evans, 1992; Carter et al., 2006; Steinman et al., 2008; Nelson, 2011).

### *Research Objectives*

Information about the current spawning stock size of remnant populations of lake sturgeon is critical for the successful rehabilitation of the species (Hay-Chmielewski and

Whelan, 1997; Holey et al., 2000; Hayes and Caroffino, In Press). While population estimates have been determined for certain stocks (e.g., Peterson et al., 2002; Peterson and Vecsei, 2004; McLeod, 2008; Lallaman et al., 2008; Dieterman et al., 2010, Bauman et al., 2011; Trested et al., 2011), most lake sturgeon populations remain unstudied. However, the unique life history of individual lake sturgeon population necessitates long-term monitoring of population dynamics in different systems (Houston, 1987). Along with the need for population-specific monitoring, few studies have examined reproductive movements and larval drift dynamics in large river systems (Auer and Baker, 2002; Smith and King, 2005; Lallaman et al., 2008; Boase et al., 2011). Identifying the factors that influence lake sturgeon reproductive patterns and larval drift will aid in the development of rehabilitation plans to protect lake sturgeon at their most vulnerable life stages.

As part of a monitoring effort in the lower Muskegon River and Muskegon Lake (hereafter Muskegon system), I studied the population characteristics of a remnant population of lake sturgeon. My primary objectives were to: 1) characterize individual growth, condition, and age structure of lake sturgeon in the Muskegon system, 2) estimate the annual number of adults present during the spawning run in the lower Muskegon River, 3) examine the distribution and residency of adult lake sturgeon in the Muskegon River system during the spawning run using ultrasonic telemetry, and 4) evaluate spawning success by sampling larval lake sturgeon drift downstream of known spawning sites.

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## CHAPTER 2

### AGE, GROWTH, AND ABUNDANCE OF LAKE STURGEON IN THE MUSKEGON RIVER, MICHIGAN, USA

#### ABSTRACT

The lake sturgeon (*Acipenser fulvescens*) is a large, slowly maturing species that is threatened throughout much of its native range due to habitat loss and overfishing. This study focused on a remnant population of lake sturgeon in the Muskegon River system. Biological data (age, weight, total length) were collected on adult lake sturgeon using boat electrofishing and large-mesh gill netting in the spring and on juvenile lake sturgeon with small-mesh gill netting in the fall. From 2008 to 2011, 141 individual lake sturgeon (24.9 – 191.0 cm total length; 0.05-59.50 kg weight) were captured. Of these, 116 lake sturgeon were aged using pectoral fin rays, representing 24 age cohorts. The weight-length relationship for captured lake sturgeon was  $\log_{10}(W) = -6.13 + 3.42 \cdot \log_{10}(TL)$  and the von Bertalanffy growth model was  $TL = 177.62 (1 - e^{-0.0985(t-1.0035)})$ , where W was wet weight (g), TL was total length (cm), and t was age (years). Compared to nearby systems, 100-cm individuals (predicted weight = 5.2 kg) from the Muskegon system tended to weigh 0.98 kg less and individuals age 23-27 years tended to be longer. Using program CAPTURE, abundances of adults present during the spawning run were estimated for the 2009 and 2010 spawning migrations, which were 46 (95% CI: 37-67) and 39 (95% CI: 27-67) individuals, respectively. I found a naturally reproducing

population of lake sturgeon in the Muskegon River system with a recent increase in year class strength, suggesting a small but slowly recovering population of lake sturgeon.

## INTRODUCTION

Lake sturgeon (*Acipenser fulvescens*), the only species of sturgeon native to the Laurentian Great Lakes, once flourished throughout the region but encountered a steady decrease in population abundance since the late 1800s (Harkness and Dymond, 1961; Hay-Chmielewski and Whelan, 1997). There are many reasons for the decline of lake sturgeon populations such as overharvest, logging and agriculture-induced habitat destruction, and the construction of dams on spawning rivers (Houston, 1987; Hay-Chmielewski and Whelan, 1997; Baker, 2006). Unique life characteristics, such as late sexual maturity and periodic spawning, decrease the ability of populations to quickly rebound (Priegel and Wirth, 1971; Smith and Baker, 2005). Lake sturgeon exhibit late sexual maturity; male's usually mature in 14-16 years while females can take 20 years or more to mature (Priegel and Wirth, 1971; Auer, 1996). Lake sturgeon have been found to travel great distances upriver to spawn and return back to the Great Lakes after spawning (Auer, 1996).

Information regarding individual population characteristics on the few remaining populations of lake sturgeon will allow better management decisions to be made basin wide. Basic biological information is still missing on a few remaining individual lake sturgeon populations (Holey et al., 2000). In addition, although population assessments have occurred throughout the Great Lakes basin (Peterson et al., 2002; Lallaman et al., 2008; Trested and Isely, 2011; Bauman et al., 2011), few studies have examined lake sturgeon population dynamics in drowned river mouth systems (Holtgren and Auer, 2004; Lallaman et al., 2008).

The lower Muskegon River watershed, in north-central Michigan, is known to support a remnant population of lake sturgeon (Hay-Chmielewski and Whelan, 1997; O'Neal, 1997; Peterson and Vecsei, 2004); however, its current population characteristics have not been well documented. I suspect that historic changes in the system such as the removal of dams, habitat enhancement since the implementation of the clean water act, and the closure of the lake sturgeon fishery in Lake Michigan have increased the spawning population of lake sturgeon in the Muskegon River. The objective of this study was to provide managers with key biological information on the remnant lake sturgeon population inhabiting the Muskegon River and Muskegon Lake, specifically assessing individual growth, condition, age structure, and annual abundance of adults during the spawning run in the lower Muskegon River system.

## METHODS AND MATERIALS

### *Study area*

The Muskegon River Watershed, located in the west-central portion of Michigan's Lower Peninsula, is a drowned river mouth system, consisting of a tributary (Muskegon River) that flows into a lake (Muskegon Lake) that is connected directly to Lake Michigan (Albert et al., 2005; Jude et al., 2005). Muskegon Lake has a surface area of 17 km<sup>2</sup> and a maximum depth of 23 m (Steinman et al., 2008; Fig. 2.1).

Muskegon Lake has a history of anthropogenic disturbance; however, recent studies document improvements in water quality and benthic fauna of the lake (Carter et al., 2006; Steinman et al., 2008; Nelson, 2011). Muskegon Lake has been found to provide nursery habitat for juvenile lake sturgeon as they migrate from the Muskegon River after hatching to Lake Michigan (Altenritter, 2010).

The main stem of the Muskegon River is 348 km, yet only 75 km are accessible for upstream migration of fish from Lake Michigan due to Croton Dam (O'Neal, 1997; Fig. 2.1). In the Muskegon River system, extensive logging occurred from the late 1880s to early 1920s, leading to intensive habitat degradation from scour, erosion, and channelization (O'Neal, 1997; Alexander, 2006). In addition, the Newaygo Dam (54.7 km upstream from Muskegon Lake) blocked upstream passage of lake sturgeon from 1900 to 1968 (O'Neal, 1997). My study focused on the lower 75 km of river below Croton Dam in Newaygo and Muskegon counties.

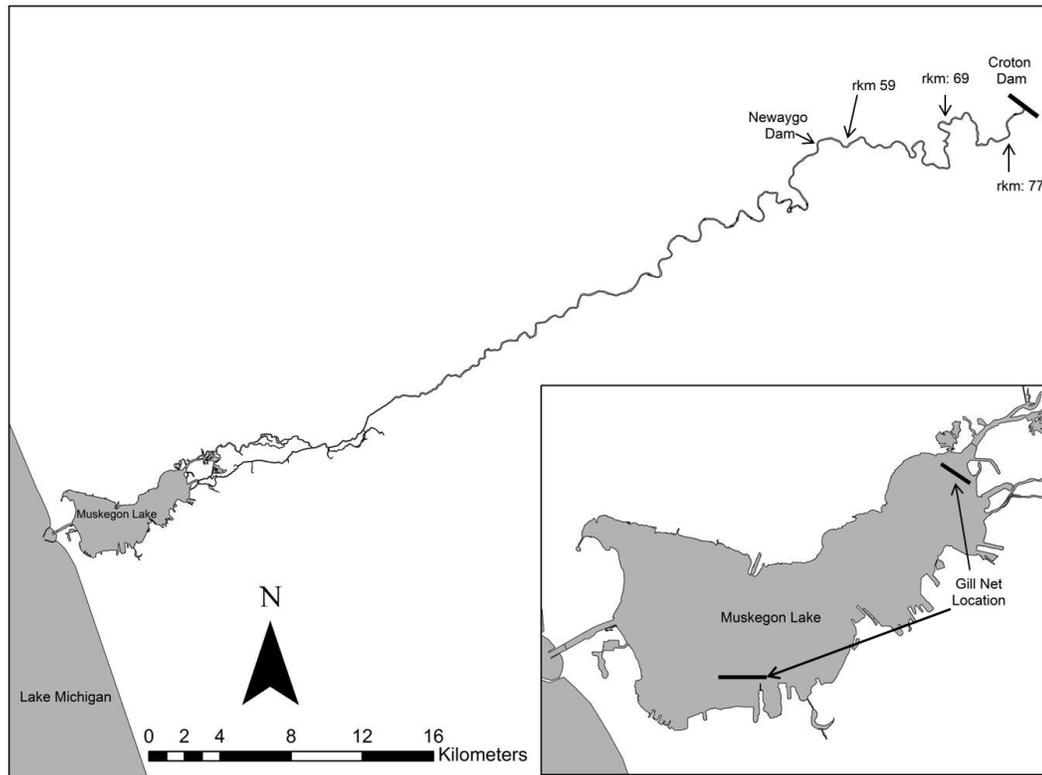


Figure 2.1. Map of lower Muskegon River below Croton Dam with inset map of Muskegon Lake showing gill netting locations in Muskegon Lake.

### *Fish capture and sampling*

Adult lake sturgeon capture occurred exclusively during the spring due to the movement of fish out of the system post-spawn, limiting my accessibility to capture fish other times of the year. Lake sturgeon were captured using gill nets and boat electroshocking during their spring spawning migrations as they entered the Muskegon River system. Two to five large-mesh gill nets (length = 100 m, height = 2 m, stretch mesh = 25.4 or 30.5 cm) were set at dusk and retrieved the following dawn for durations  $\leq 12$  hours near the mouth of the Muskegon River in Muskegon Lake. Nets were set perpendicular to the flow of the river on the east end of Muskegon Lake and secured to the bottom using crab-style anchors (Fig. 2.1).

As adult lake sturgeon moved upstream from Muskegon Lake to the Muskegon River during their spring spawning migration, boat electrofishing was used to capture fish. Electrofishing was conducted in the downstream direction using a Smith-Root 5.0 Generator Powered Pulsator Electrofisher using direct current at 15 pulses per second. The boat was launched at one of two access sites (river km: 77 or 69) and concluded downstream (river km: 59; Fig. 2.1). Sampling trips occurred during daylight hours and began when water temperatures in the river were above 8 °C or when fish were visually observed in the river. Sampling was conducted once per week until fish were not observed for two weeks, which was assumed to indicate fish had finished spawning and were emigrating from the river. This section of river was sampled based on previous work documenting lake sturgeon spawning activity (Altenritter, 2010). Although the study design was effective for capturing fish near the known spawning site, some unknown portion of fish likely were missed by focusing on a 10-18 km reach of river.

Juvenile lake sturgeon (i.e., individuals < 100 cm TL) were targeted using small-mesh gill nets (length = 100 m, height = 2 m, stretch mesh = 7.5 cm) in Muskegon Lake during the fall season. Juvenile lake sturgeon were sampled 2-4 times per week with sampling beginning when water temperature in the lake were less than 20 °C. When water temperatures were 12-20 °C, nets were fished for approximately 2 hours per set with 2-3 sets at and before dawn. At temperatures below 12 °C, nets were set at dusk and retrieved the following morning. Nets were set at two main locations in Muskegon Lake known from previous studies to harbor juvenile lake sturgeon: the area where the Muskegon River enters Muskegon Lake and the west end of the lake at the deepest location (Fig. 2.1; Altenritter, 2010).

When a lake sturgeon was captured, it was immediately placed in an on-board holding tank. All lake sturgeon were measured for total length (to the nearest 0.1 cm) and weight (to the nearest g). A 12.5 × 2.07 mm passive integrated transponder (PIT) tag (125 kHz; TX1411SSL; Biomark, Inc.) was inserted behind the fourth dorsal scute of each lake sturgeon for unique identification (if not previously tagged). A 1-cm section of the right pectoral fin ray was taken from individuals greater than 30 cm for aging. Fish were allowed to recuperate in the holding tank until operculum beats returned to pre-handling rates before being released at the capture site.

To age lake sturgeon, pectoral fin ray sections were dried for at least one month, sectioned to 0.5 mm using a diamond blade Isomet saw, mounted on glass slides, and annuli were counted using an Olympus Model SZX16 stereo microscope. Three individual readers examined the rays, and an age was not used unless all three readers

agreed. I did not analyze sex in this study due to few fish readily expressing gametes and lacking clear external sex characteristics.

### *Data analysis*

Catch per unit effort (CPUE) of lake sturgeon for gill netting was calculated as the number of individuals captured per hour of nets fished. CPUE for electrofishing was calculated as the number of lake sturgeon captured per electrofishing trip. To estimate growth of fish at age, I fit the von Bertalanffy growth model in R version 2.13.2 (R Development Core Team, 2011) using original captures only. The equation used was  $L_t = L_\infty(1 - e^{-K(t-t_0)})$ , where  $L_t$  is the length at age  $t$ ,  $L_\infty$  is the theoretical maximum length that an individual in the population can attain,  $K$  is the growth constant for the population, and  $t_0$  is the theoretical time at which the length is zero (Guy and Brown, 2007). To assess for growth between seasons, all fish were assumed to be born in the spring of the assigned year class, therefore six months were added to the age of the fish caught in the fall. The standard weight-length relation ( $W=aL^b$ ) was used to assess condition of fish, where  $W$  is weight (kg),  $a$  is a constant,  $L$  is total length (cm), and  $b$  is an exponent that describes the curve of the relationship (Pope and Kruse, 2007). I estimated  $a$  and  $b$  using linear regression of  $\log_{10}$ -transformed data (Pope and Kruse, 2007). Lake sturgeon age structure was assessed by using age-frequency histograms. Pooled data were used for age structure analysis over all four years, and data were assessed by year class.

To assess the number of adults present during the spawning run, I used mark-recapture of lake sturgeon in Muskegon Lake and the Muskegon River using closed-

population models in program CAPTURE (Otis et al., 1978; White et al., 1978; Rexstad and Burnham, 1991). Various study designs have been used to estimate the number of lake sturgeon spawning in a given system (Peterson et al., 2002; Lallaman et al., 2008), although I acknowledge that my study design may include fish that are not actually spawning, my estimate will give an estimate of the abundance of adults present in the Muskegon River system during the spring spawning run. Each set of large-mesh gill nets and each day of electroshocking was a capture event. Critical assumptions include that all adults captured in gill nets migrate upriver to spawn and all lake sturgeon that spawn in river are vulnerable to capture in the area where I conducted electrofishing surveys. The model selection tool within the program was used to select the appropriate model out of the eight models tested in program CAPTURE ( $M_0$ ,  $M_b$ ,  $M_t$ ,  $M_h$ ,  $M_{th}$ ,  $M_{bh}$ ,  $M_{tb}$ ,  $M_{tbh}$ ). Model  $M_0$  assumes equal probability of capture among all individuals over each sampling period, model  $M_b$  allows for trap response, model  $M_t$  assumes time varying probability in capture, and model  $M_h$  allows for heterogeneity in capture probability among all individuals (Pollock et al., 1991). Models  $M_{th}$  and  $M_{tb}$  both assume time varying capture probability but also incorporate individual heterogeneity in capture probability and trap response, respectively. Model  $M_{bh}$  account for trap response and individual heterogeneity in capture probability, while model  $M_{tbh}$  also incorporates time varying capture probability (Pollock et al., 1991).

## RESULTS

A total of 141 individual lake sturgeon were caught during my study along with 38 recaptures from April 18, 2008 to October 28, 2011 (Table 2.1). Included in this total is one unmarked fish found dead of an unknown cause in the Muskegon River during the spawning run in 2009 and a juvenile fish captured during a separate study using nighttime electrofishing in Muskegon Lake during 2009. Of the 141 individual lake sturgeon captured, 4 adults and 6 juveniles were recaptured in multiple years of the study. I recaptured 13 of the 24 marked lake sturgeon from a previous study on the Muskegon River system that took place in 2002 and 2003 (Peterson and Vecsei, 2004).

The size of lake sturgeon captured with small-mesh gill nets averaged 59.4 cm TL and 1.12 kg, with large-mesh gill nets averaged 139.8 cm and 18.81 kg, and with boat electroshocking averaged 153.2 cm and 26.14 kg (Table 2.1). The slope of the length-weight relationship for the combined four years of data of all individual lake sturgeon was significantly different from zero ( $P < 0.001$ ; Fig. 2.2).

I aged 116 of the 141 individuals that were captured during the study. Age of fish ranged from 0 to 37 years (average: 9.7). Due to deterioration and poor quality of some of the pectoral rays, I was unable to age 11 juveniles (TL: range = 39.0-88.5 cm; mean = 51.3 cm) and 14 adults (TL: range = 106.6-191.0 cm; mean = 169.7). The largest year classes represented in my study were 1993, 1999, 2007, 2008 and 2009 (Fig. 2.3). Using the von Bertalanffy growth model, the estimated parameters were:  $L_{\infty} = 177.62$  cm (SE = 4.85;  $P < 0.001$ ),  $K = 0.099$  year<sup>-1</sup> (SE = 0.002;  $P < 0.001$ ),  $t_0 = 1.004$  years (SE = 0.23;  $P < 0.001$ ; Fig. 2.4); each parameter was significantly different from zero.

Table 2.1. Total number of lake sturgeon caught, effort (hours, gill netting; sampling days, electrofishing), range of total length (TL; cm), range of weight (W; kg), and catch per unit effort (CPUE) of lake sturgeon captured using large-mesh gill nets (stretch mesh = 25.4 or 30.5 cm), boat electrofishing, and small-mesh gill nets (stretch mesh = 7.5 cm) in the Muskegon River system during 2008-2011.

| Yr   | Large-Mesh Gill Net |    |                 |               |             | Electroshocking |    |                 |               |              | Small-Mesh Gill Net |    |                |                  |             |
|------|---------------------|----|-----------------|---------------|-------------|-----------------|----|-----------------|---------------|--------------|---------------------|----|----------------|------------------|-------------|
|      | Effort (hrs)        | #  | TL (cm)         | W (kg)        | CPUE (#/hr) | Effort (day)    | #  | TL (cm)         | W (kg)        | CPUE (#/day) | Effort (hrs)        | #  | TL (cm)        | W (g)            | CPUE (#/hr) |
| 2008 | 458                 | 1  | 149.0           | ---           | 0.002       | 8               | 7  | 121.0-<br>180.5 | 8.5-<br>36.0  | 0.88         | 869                 | 2  | 39.0-<br>78.0  | 188.1-<br>2270.0 | 0.002       |
| 2009 | 488                 | 15 | 103.5-<br>152.5 | 5.0-<br>31.0  | 0.031       | 11              | 34 | 122.2-<br>181.0 | 10.0-<br>41.0 | 3.09         | 647                 | 11 | 24.9-<br>86.7  | 218.3-<br>3400.0 | 0.017       |
| 2010 | 984                 | 12 | 124.5-<br>157.5 | 14.0-<br>20.0 | 0.012       | 6               | 14 | 136.0-<br>191.0 | 13.6-<br>59.5 | 2.33         | 657                 | 33 | 31.3-<br>106.6 | 90.0-<br>6500.0  | 0.050       |
| 2011 | 1107                | 15 | 98.2-<br>180.0  | 5.0-<br>40.5  | 0.014       | 6               | 2  | 160.2-<br>180.0 | 24.0-<br>55.0 | 0.33         | 153                 | 31 | 25.2-<br>84.6  | 47.0-<br>2600.0  | 0.202       |

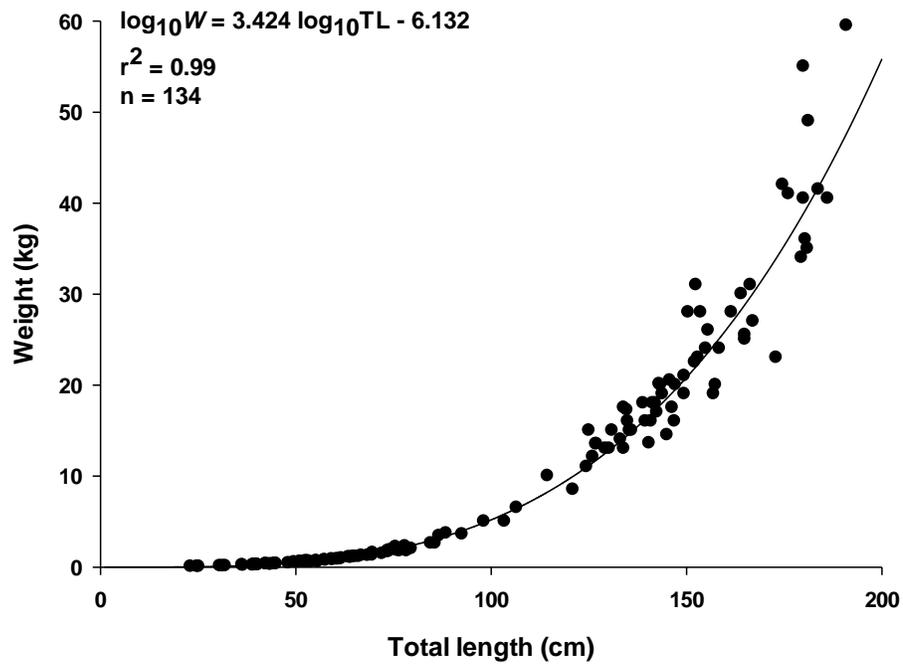


Figure 2.2. Length-weight relationship of lake sturgeon captured in the Muskegon River and Muskegon Lake during 2008-2010. The solid line represents the estimated length-weight function.

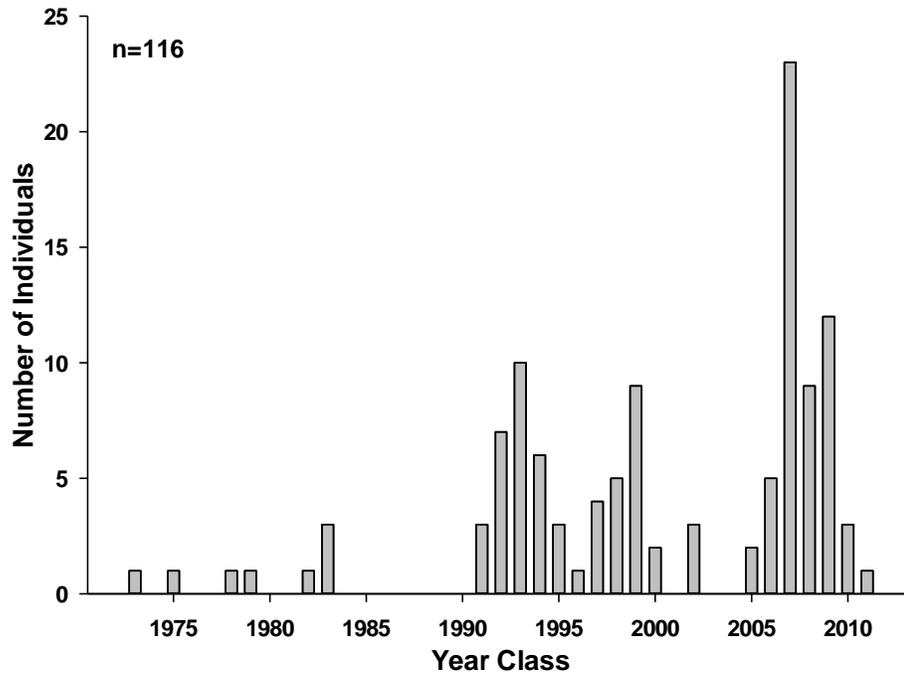


Figure 2.3. Age structure of lake sturgeon captured in the Muskegon River and Muskegon Lake during 2008-2011.

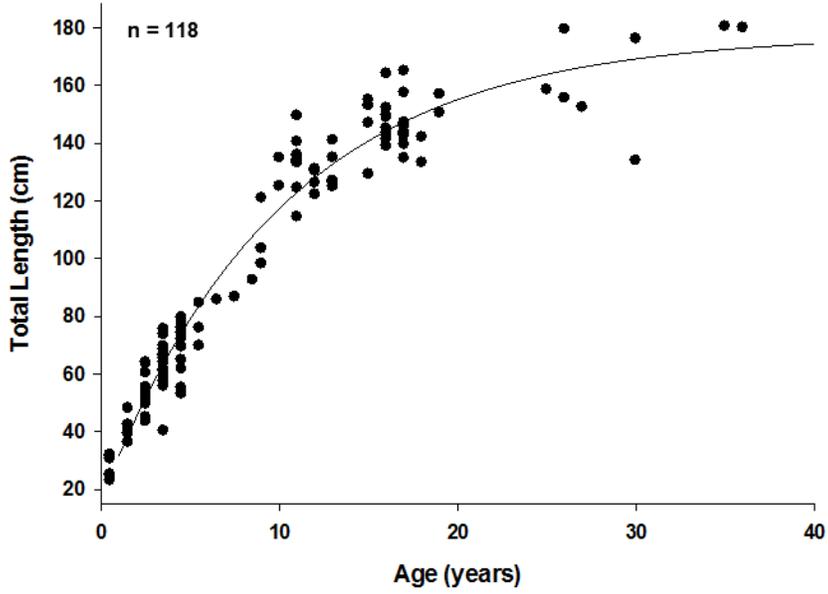


Figure 2.4. The total length and age of lake sturgeon captured in the Muskegon River and Muskegon Lake during 2008-2011. The solid line represents the estimated von Bertalanffy growth curve.

During 2008 and 2011, I did not recapture any adult lake sturgeon, precluding me from estimating the annual spawning run abundance (Table 2.2). In 2009, 31 individual PIT-tagged adult lake sturgeon were handled, which included 18 recaptures (i.e., an individual fish could be recaptured more than once, but not more than one time per sampling event; Table 2.2). Using 2009 capture histories, the best-fit model based on the chi-square goodness of fit test was model  $M_h$ , which generated a spawning run abundance estimate of 46 individuals (Table 2.2). In 2010, 19 individual adult lake sturgeon were handled, which included 6 recaptures. The best-fit model for 2010 based on the chi-square goodness of fit test was again  $M_h$ , providing an abundance estimate of annual spawning run size of 39 individuals (Table 2.2).

Table 2.2. Number of adult lake sturgeon captured, number of recapture, number of sampling events, and estimate of adult lake sturgeon present during the spawning run (including 95% confidence intervals) in the Muskegon River system. Spawning run estimates were made using Program CAPTURE.

| Year | Captures | Recaptures | Spawning run estimate<br>(95% CI) |
|------|----------|------------|-----------------------------------|
| 2008 | 8        | 0          | ---                               |
| 2009 | 31       | 18         | 46 (37-67)                        |
| 2010 | 19       | 6          | 39 (27-67)                        |
| 2011 | 13       | 0          | ---                               |

## DISCUSSION

My study suggests that the Muskegon River supports a small but naturally reproducing population of lake sturgeon with recent increases in recruitment. Although lake sturgeon in the Muskegon system tended to weigh less at length (within 1.5 kg for a 100-cm individual) and be longer at age (within 25 cm for a 23-27 year old fish), the condition of lake sturgeon in the Muskegon River system was still relatively similar to nearby populations (Table 2.3). Based on the weight-length relationship, I estimated that a 100-cm lake sturgeon from the Muskegon River population weighs 5.20 kg. In addition, I estimated using the von Bertalanffy model that an individual age 23-27 years from the Muskegon population would be 160.8 cm total length. Nevertheless, comparisons among studies can be problematic because each sampling protocol (with respect to gear type, habitat, and time of year) used to study lake sturgeon may select for certain size classes, which could affect the results of growth models (Trested and Isely, 2011). In my study, I tried to sample multiple life stages with the use of three sampling techniques. I was not able to analyze sex differences due to the difficulty of determining sex in non-gravid lake sturgeon, which accounted for the majority of the fish I captured, but I suspect that sex differences did not have a large influence on my results given the good fit of the length-weight relationship and the von Bertalanffy growth model.

Currently only three populations of lake sturgeon in Michigan are considered healthy enough to support harvest (i.e., Black Lake, Lake St. Clair, and Detroit River; Hayes and Caroffino, In Press). These large populations contain large recent year classes with multiple year classes over 20 years of age represented (Thomas

Table 2.3. Mean weights of lake sturgeon at 100 cm total length, and mean total length of lake sturgeon aged at 23-27 years from the Muskegon River system and nearby systems.

| Population                         | Source                    | Weight<br>(kg) | Total length<br>(cm) |
|------------------------------------|---------------------------|----------------|----------------------|
| Lake Wisconsin, Wisconsin          | Fortin et al.<br>(1996)   | 5.73           | 149.1                |
| Upper Black River,<br>Michigan     | Smith and Baker<br>(2005) | 6.39           | 141.0                |
| St. Marys River, Michigan          | Bauman et al.<br>(2011)   | 6.00           | 138.2                |
| Manistee River system,<br>Michigan | Lallaman et al.<br>(2008) | 6.60           | --                   |
| Muskegon River system,<br>Michigan | Present study             | 5.20           | 160.8                |

and Haas, 2002; Smith and King, 2005). My aging technique may potentially bias age estimates towards younger fish because older fish may be more likely to have deteriorated fin rays that cannot be aged, and none of the fish I aged were over 37 years. However, only seven of the 25 fish that I could not age weighed more than the oldest fish I aged, suggesting that the age distribution of the lake sturgeon sampled is not strongly biased. Although a method was derived to correct for aging errors of lake sturgeon (Bruch et al., 2009), this correction is likely not transferable among systems due to the unique growth of fish in each system (Trested and Isely, 2011). Although there are few representatives of older year classes in the Muskegon population, there have been recent larger year classes, suggesting recent increases in survival and recruitment leading positive population growth.

I attribute the apparent increase in survival and recruitment to multiple factors. First, Newaygo Dam limited lake sturgeon movement to the lower 54.5 km of the river from 1900 to 1968, denying fish access to the portion of river with the highest gradient and suitable spawning substrates (O'Neal, 1997). Currently, lake sturgeon are observed spawning above this aforementioned site. In 1970, the commercial fishery was closed along the east shore of Lake Michigan, putting a halt to the large yearly harvest of lake sturgeon since the 1800's. Along with these changes, the diversion of wastewater from industry and municipalities since the implementation of the Clean Water Act in 1973 and efforts to clean-up contaminated sediments have increased the suitability of Muskegon Lake as juvenile nursery habitat by creating a more suitable food base and better habitat (Carter et al., 2006; Steinman et al., 2008; Altenritter, 2010). In addition, Croton Dam was switched from operating on a peaking regime to generate electricity to a "run of the

river” regime in 1994, allowing for more natural flow and temperature during the spawning period of lake sturgeon (Godby et al., 2007).

My spawning run abundance estimates were within the confidence intervals of estimates made for the nearby population of lake sturgeon in the Manistee River system from 2001 to 2004 (Lallaman et al., 2008). The Manistee population faced many of the same historical anthropogenic disturbances as the Muskegon population and appears to be in the same current state (Lallaman et al., 2008). However, I caution that my estimates may over or under estimate the spawning run size if assumptions of statistical model were not met. The best fit model in both years of spawning run estimates was model  $M_h$ , which allows for heterogeneity in capture probability among all individuals. Although this model may account for heterogeneity in capture probability associated with the size selectivity of my sampling regime (e.g., only three fish captured in large-mesh gill nets were >160 cm) and heterogeneity associated the timing and duration of male and female lake sturgeon in the system during the spawning run, bias in my estimates of the spawning run is unknown. For instance, male lake sturgeon may spend more time in the upper river waiting for additional ripe females during the spawning season, thus allowing these fish a longer period to be recaptured (Bruch and Binkowskik, 2002). Studies have shown that lake sturgeon may inhabit the lower system (i.e., Muskegon Lake in our study) that are not “spawners,” and my sampling regime included these fish in my estimates, which could overestimate the spawning run size (Rusak and Mosindy, 1997; Lallaman et al., 2008). Both juvenile and adult lake sturgeon inhabit Muskegon Lake in the spring. By not examining gonad maturation of each fish, I may have included some fish that were not mature in my estimates of the spawning run size.

Overall, I found a small number of adult lake sturgeon returned to the lower Muskegon River during the spring spawning run in each year from 2008 to 2011. The capture of multiple year classes with recent increases in production of lake sturgeon in Muskegon Lake strongly suggests that successful reproduction is occurring in the Muskegon River. I suspect that closure of the commercial fishery, the removal of Newaygo Dam, improvements in water quality post Clean Water Act, and the implication of “run of the river” flow regime by Croton Dam have all helped increase the suitability of the system for lake sturgeon. Given the depressed status of the Muskegon River lake sturgeon population, efforts to protect all life stages should be continued. Population monitoring is needed to evaluate recruitment and better estimate the abundance with more sophisticated approaches (e.g., open-population models). If increases in the spawning run size are not observed as the large year classes of young fish mature, then additions to the population (via streamside rearing; Holtgren et al., 2007) may be appropriate to help restore this population to a viable size of mature spawning fish.

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## CHAPTER 3

### ADULT LAKE STURGEON MOVEMENT AND REPRODUCTIVE STATUS IN THE MUSKEGON RIVER SYSTEM, MICHIGAN

#### ABSTRACT

Lake sturgeon populations throughout the Great Lakes remain depressed, and the dynamics of many of those populations are unknown. Management and restoration of lake sturgeon populations are hampered by the dearth of data on reproductive characteristics and movement patterns, which may be unique for each population. I investigated adult lake sturgeon movement and reproductive dynamics of a remnant population inhabiting the lower Muskegon River, Michigan. Twenty-six adult lake sturgeon were captured using large-mesh gill netting and boat electrofishing between 2010 and 2011. Adult lake sturgeon ranged from 98.2 to 191.0 cm in total length, 5.0 to 59.5 kg in weight, and 9 to 36 years in age. Spawning was observed in both years, and successful reproduction was confirmed by the capture of 16 larval lake sturgeon in 2010 and 2 in 2011. Movement patterns of five adult lake sturgeon were monitored during their spawning migration in 2011. I found that not all fish in Muskegon Lake migrated upstream to spawn and temperature cues appeared to initiate spawning movements. Additionally, consistent with other studies, lake sturgeon larvae hatched at a water temperature of 16 °C. The number of larval lake sturgeon captured in the drift was lower further downstream from a known spawning site, which was likely due to a dilution effect. My results suggest lake sturgeon are reproducing in the Muskegon River.

## INTRODUCTION

Adult lake sturgeon (*Acipenser fulvescens*) in most systems connected to the Great Lakes travel great distances upstream to spawn and return to the Great Lakes after spawning (Auer, 1996; Lallaman et al., 2008). In some streams with open access to lakes, lake sturgeon remain in the river throughout the year (Threader and Brosseau, 1986; Lyons and Kempinger, 1992). The complex migrations and the environmental variables that influence these migrations remain unstudied in many systems. Lake sturgeon use water temperature changes, lunar phases, and rivers discharge as a cue for spawning migrations (Fortin et al., 1993; Auer, 1996; Bruch and Binkowski, 2002; Lallaman et al., 2008; Forsythe et al., 2012). It is important to understand the characteristics of spawning migrations and to identify critical habitat in spawning tributaries to develop more effective management strategies.

Most populations of lake sturgeon in the Great Lakes remain severely depressed and may be unable to maintain their current abundance without rehabilitation. Although commercial fishing for lake sturgeon has been closed since the 1970s and recreational harvest is strictly regulated, a lack of knowledge of this species has minimized rehabilitation successes (Auer, 1996; Hayes and Caroffino, In Press). Since the 1980s, concern by state and federal agencies, as well as general interest from the public in the protection and enhancement of lake sturgeon populations has increased. In order to proceed effectively, it is essential for management agencies throughout the Great Lakes to understand the reproductive dynamics (i.e., spawning locations, frequencies, and biotic and abiotic factors that influence success) and habitat requirements for all life stages of the species.

Restoration plans for lake sturgeon have repeatedly emphasized the need for understanding the early life stages that limit recruitment (Hay-Chmielewski and Whelan, 1997; Hayes and Caroffino, In Press). Still, very few studies have focused on larval lake sturgeon due to the rarity of viable spawning populations and the difficulty associated with sampling drifting larvae (Auer and Baker, 2002; Smith and King, 2005). Previous studies on larval lake sturgeon dynamics in wadeable river systems have shown that larvae hatch at water temperatures around 16 °C, larval drift often occurs in a “plug” (i.e., concentrated group) that becomes diluted as they drift downstream, and larval drift density is greatest near the stream bottom (Auer and Baker, 2002; Smith and King, 2005). In addition, the larval drift distribution can vary annually within the same stream across the width of a stream, with distance downstream from a spawning site, and temporally over a diel cycle (Auer and Baker, 2002; Smith and King, 2005). Recent research was focused on wadeable river systems (Auer and Baker, 2002; Smith and King, 2005; Duong et al., 2011), while less is known about larval lake sturgeon drift in non-wadeable river systems such as the Muskegon River.

The Muskegon River system in Michigan’s Lower Peninsula is known to support a small but naturally reproducing population of lake sturgeon (Peterson and Vecsei, 2004; Altenritter, 2010; Chapter 2). During a previous study on the Muskegon River system in 2002 and 2003, the movements of adult lake sturgeon were monitored during their spawning runs leading to the discovery of a single suspected spawning site (Peterson and Vecsei, 2004). In addition, larval drift sampling confirmed that successful reproduction occurred in 2002 and 2009 (Peterson and Vecsei, 2004; Altenritter, 2010). Furthermore, juvenile lake sturgeon have been found to utilize Muskegon Lake as nursery habitat

during their juvenile life stage (Altenritter, 2010). Nevertheless, reproductive dynamics of this population are not well understood, and continued monitoring of this population is required to aid in rehabilitation. Thus, the goal of my study was to: 1) assess the spatial distribution of adult lake sturgeon spatial distribution in the Muskegon River during the spring spawning run, and 2) subsequently evaluating evidence of reproductive success via the capture of drifting larvae.

## METHODS AND MATERIALS

### *Study Site*

The Muskegon River mainstem is 348 km; however, fish migrating from Lake Michigan currently only have access to the lower 75 km of river due to Croton Dam (O'Neal, 1997). In addition, from 1900 to 1968, the Newaygo Dam limited fish movement to the lower 58 km of river. The highest gradient portion of the stream occurs from Croton Dam to Newaygo where water velocities are high and bottom substrate is composed of large amounts of gravel and cobble (Fig. 3.1; O'Neal, 1997). Downstream from the city of Newaygo to Muskegon Lake, water velocities are moderate and bottom substrates are composed of mostly sand (O'Neal, 1997). Before the Muskegon River enters Lake Michigan, it flows into Muskegon Lake, a drowned river mouth lake. Muskegon Lake has a surface area of 17 km<sup>2</sup> and maximum depth of 23 m (Steinman et al., 2008). The Muskegon River enters Muskegon Lake from the east and exits via a dredged navigational channel on the west (Fig. 3.1).

### *Adult Sampling*

Adult lake sturgeon were captured using large-mesh gill nets (length = 100 m, height = 2 m, stretch mesh = 25.4 or 30.5 cm) during spring spawning migrations as fish entered the Muskegon River from Muskegon Lake in 2010 and 2011. Two to five large-mesh gill nets were set at dusk and retrieved the following dawn for durations  $\leq$  12 hours near the mouth of the Muskegon River in Muskegon Lake (Chapter 2). Nets were set perpendicular to the flow of the river on the east end of Muskegon Lake and secured to the bottom using crab-style anchors (Fig. 3.1).

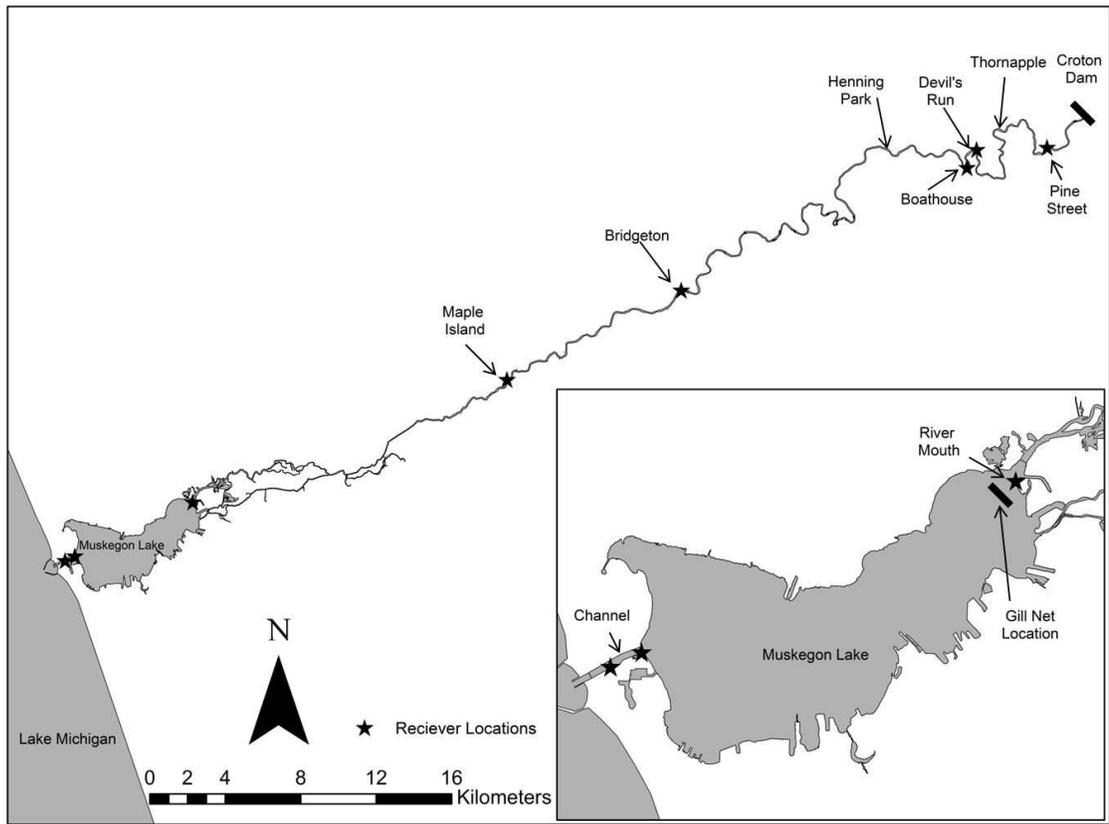


Figure 3.1. Map of the Muskegon River system including submerged ultrasonic receiver locations (★), launches used for boat electroshocking surveys in the river, and location of gill net surveys in the lake. Croton Dam is the first upstream barrier to fish passage, blocking all upstream movements.

Once adult lake sturgeon entered the Muskegon River during the spring spawning migration, I used boat electrofishing to capture fish (Chapter 2). The boat was launched at one of two access sites (Thornapple or Pine Street) and concluded downstream at Henning Park (Fig. 3.1). Previous work showed spawning activity occurred in this section of the river (e.g., Peterson and Vecsei, 2004; Altenritter, 2010). In addition, sampling upstream from Croton to Pine Street was inaccessible due to low water levels not suitable for the boat electrofisher. Sampling trips were conducted during daylight hours and began when water temperatures in the river exceeded 8 °C. Sampling continued at least once per week (weather permitting) until fish were not observed for two weeks, which was assumed to indicate the spawning in the river was complete.

When a lake sturgeon was captured, it was immediately placed into an on-board holding tank. All lake sturgeon caught were measured for total length (to the nearest 0.1 cm) and weight (to the nearest g). A 12.5 × 2.07 mm passive integrated transponder (PIT) tag (125 kHz; TX1411SSL; Biomark, Inc.) was inserted behind the fourth dorsal scute of each lake sturgeon for unique identification if not already present. A 1-cm section of the right pectoral fin was taken from individuals greater than 30-cm for age determination (Chapter 2). Fish were released at the capture site.

### *Tag Implantation*

A subsample of five adult lake sturgeon captured from large-mesh gill nets in 2011 were each surgically implanted with a ultrasonic transmitter (Sonotronics model CT-05-48-I; frequency = 69 kHz). Transmitters weighed 12 g (79 mm × 15.6 mm) and had an estimated active battery life of 4 years. The weight of a transmitter did not exceed

2% of a fish's body weight (e.g., Nielsen, 1992). Surgical implantation of transmitters followed the procedure described by Smith and King (2005). Transmitters were implanted by making a 2-cm incision ventrally in the body cavity posterior to the pectoral fins. The transmitter was then placed into the body cavity, followed by an injection of oxytetracycline (0.05 mL/kg body weight) to prevent infection. The incision was subsequently closed using a simple interrupted suture pattern with drops of Nexabond glue placed on suture knots. Following surgery, each fish was held until normal respiration and movements were observed before being released at the approximate location of capture.

#### *Ultrasonic Telemetry*

Submerged ultrasonic receivers (Sonotronics SUR-3BT) were deployed to monitor lake sturgeon residency time and location in the Muskegon River and Muskegon Lake. Receivers were deployed to continuously monitor movement of adult lake sturgeon during the 2011 spring spawning run (15 March – 12 July 2011). Although there is a loss of spatial resolution when using submerged ultrasonic receivers that passively detect fish compared to active manual tracking, the advantage is that fish can be continuously monitored, which is not possible with manual tracking. The spatial scale of Muskegon Lake and the Muskegon River would make it difficult to manually track each fish every day. I estimated tag detection in the river with a test that entailed floating an active tag submerged near the bottom of a receiver at multiple distances in the river channel. I found the SUR picked up the transmitter easily across the channel during tests. In addition, an overall efficiency rate of the SUR's was calculated by taking the total

number of hits on the receivers divided by the total number of hits plus the missed hits (i.e., missed hits occurred when a fish was picked up at both the upstream and downstream receiver but skipped a receiver).

I placed a total of seven receivers throughout the system (Fig. 3.1). Receivers were placed at locations where the channel narrowed and deepened to obtain the best possible hydrophone reception. Three receivers were placed in the upper river portion (boathouse [rkm: 64] and above) of the study site (2 km downstream of Croton Dam denoted Pine Street [rkm: 77], just above the suspected spawning grounds at Devils Run [rkm: 66], and just below the spawning grounds at Boathouse Pool [rkm: 64]) and two receivers were placed in the lower river above Muskegon Lake (denoted Bridgeton [rkm: 36] and Maple Island [rkm: 23; Fig. 3.1]). During the study, a high-flow ( $>250 \text{ m}^3 \text{ s}^{-1}$ ) event disabled the receiver at Devil's Run on 30 April 2011. Because I suspected most fish were out of the upper river when the receiver was disabled, I moved the receiver downstream to the mouth of the Muskegon River on 6 May 2011 (rkm: 0; Fig. 3.1). The last two receivers were placed in the channel to Lake Michigan to detect fish entering and exiting Muskegon Lake; one was placed in the west end near Lake Michigan and one in the east end near Muskegon Lake (Fig. 3.1).

### *Larval Drift Sampling*

I began larval drift sampling when water temperatures near the suspected spawning site reached 10 °C. Larval drift sampling for lake sturgeon was conducted 3-5 days per week. D-shaped drift nets (1600- $\mu\text{m}$  mesh) were used to capture drifting larvae. Four nets were set per night in 2010, and 4-7 nets were set per night depending on the

discharge in 2011. Drift nets were placed approximately 1-m apart in the main flow of the current. The cod end of each net was emptied into a container and immediately replaced every hour. Captured larval lake sturgeon were enumerated, measured, and released in the field. Drift sampling was conducted from 21:00 hours to 01:00 hours; if lake sturgeon larvae were captured in this period, then sampling continued until 03:00 hours each night (weather permitting). The volume of water sampled by each drift net was measured using a flow meter (General Oceanics Model 2030) attached to the mouth of the drift net. I measured depth, water temperature, and dissolved oxygen concentration using an YSI 6600V2 Sonde (Yellow Springs, Ohio, USA) each time nets were tended (hourly).

Larval drift sampling was conducted at three sites; the first site was approximately 500-m downstream from a known spawning site (i.e., “boathouse pool”), the second location was approximately 1.5-km downstream of the known spawning site, and the last site was at Henning Park (6-km downstream of the known spawning site; Fig. 3.1). Sampling was conducted at the upstream site until larval lake sturgeon were first captured, at which point the sampling site was rotated every sampling event. The purpose of sampling further downstream was to assess whether additional lake sturgeon spawning was occurring downstream of the known spawning site; however, to guard against downstream dilution of larvae, I initially focused sampling nearest the known spawning site to increase the probability of capturing larval lake sturgeon.

## RESULTS

### *Adult Capture*

During 2010 and 2011, I captured 19 and 17 unique adult lake sturgeon, respectively. Fish ranged from 98.2 to 191.0 cm in TL and 5.0 to 59.5 kg in weight. Twenty-three lake sturgeon were caught with gill nets and 13 were caught via boat electrofishing. Using pectoral fin samples ( $n=29$ ), lake sturgeon ages were determined to be between 9 and 36 years (see Chapter 2). Three adult lake sturgeon that I captured were recaptured from a previous study on Muskegon Lake in 2002 and 2003 (Peterson and Vecsei, 2004) and four were recaptured from a previous study in 2008 and 2009 (Altenritter, 2010). Lake sturgeon were observed in spawning congregations in the river approximately 2-km upstream of the known spawning site on 22 April 2010 at water temperatures of 11.5° C and on 12 May 2011 at water temperatures of 13.7° C.

### *Adult Movement*

Of the 17 adult lake sturgeon captured in Muskegon Lake in 2011, 5 were implanted with ultrasonic transmitters (Table 3.1). Between 24 March and 12 June, a total of 25 locations were recorded on submerged ultrasonic receivers (Fig. 3.2). Lake sturgeon were recorded in the river from 7 April to 6 June while the water temperature in the river during this period ranged from 3.0 to 18.0 °C (Fig. 3.2A). Fish were recorded above Boathouse Pool from 5 May to 17 May while water temperature during this period ranged from 9.8 to 13.9 °C (Fig. 3.2A). Of the five fish tagged, three were recorded above Boathouse Pool (Fish 101, 105, 107; Fig. 3.2B). Of the two fish not recorded

Table 3.1. Characteristics of adult lake sturgeon implanted with ultrasonic tags in 2011 in the Muskegon River, Michigan. All fish were captured and tagged in Muskegon Lake.

| Tag ID | Total       |             |                 |      |             |                          | Number of Locations |
|--------|-------------|-------------|-----------------|------|-------------|--------------------------|---------------------|
|        | Length (cm) | Weight (kg) | Age (years)     | Sex  | Date Tagged | Last Location (date)     |                     |
| 101    | 143.1       | 20.1        | 17              | Unk. | 3/31/2011   | Channel<br>5/22/2011     | 4                   |
| 103    | 126.1       | 12.1        | 13              | Male | 4/25/2011   | Channel<br>6/6/2011      | 5                   |
| 105    | 167.1       | 27.0        | 28 <sup>a</sup> | Unk. | 4/14/2011   | Channel<br>6/6/2011      | 11                  |
| 107    | 147.2       | 20.0        | 17              | Unk. | 3/22/2011   | Maple Island<br>6/6/2011 | 7                   |
| 109    | 150.5       | 28.0        | 19              | Male | 3/30/11     | Channel<br>6/12/2011     | 3                   |

<sup>a</sup>Age of fish was estimated with von Bertalanffy growth model (Chapter 2).

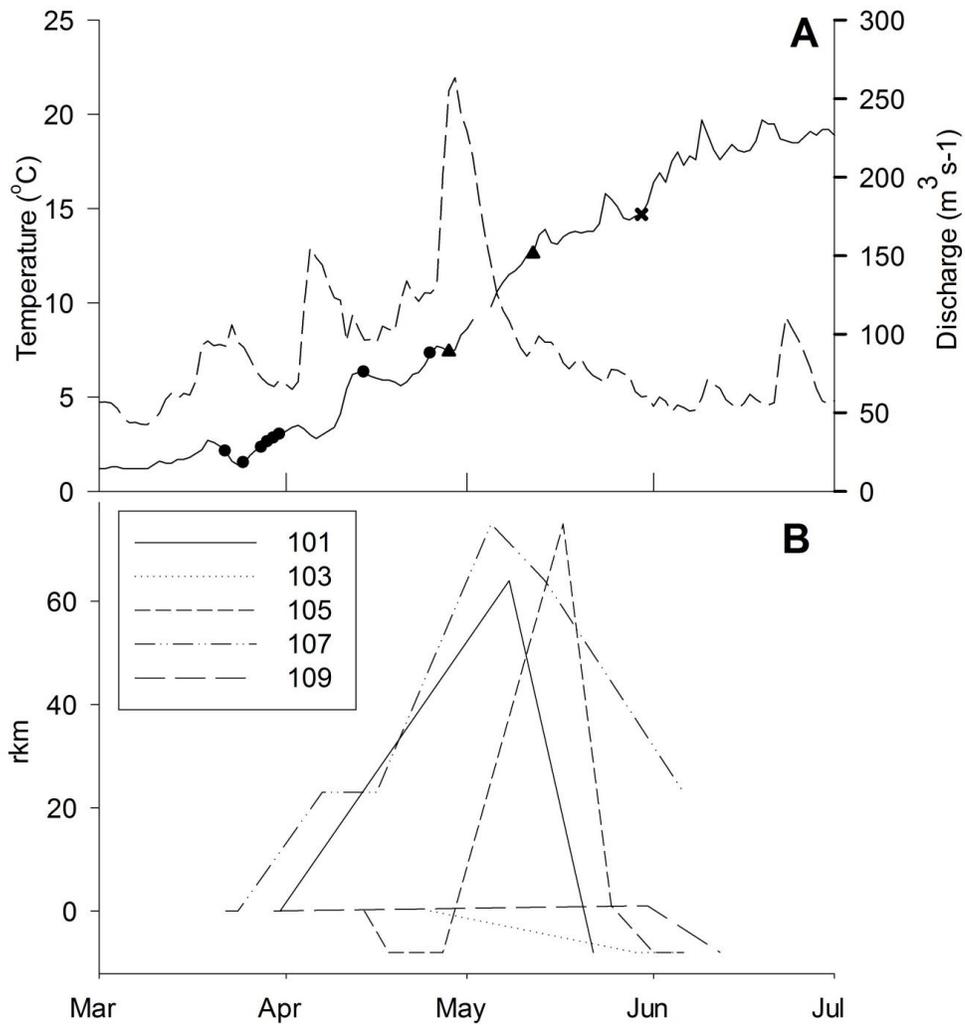


Figure 3.2. (A) Daily river discharge ( $\text{m}^3 \text{s}^{-1}$ ; dashed line) and water temperature ( $^{\circ}\text{C}$ ; solid line) in the Muskegon River at Croton Dam in 2011 including symbols representing capture of adults in Muskegon Lake ( $\bullet$ ), capture of adults in Muskegon River ( $\blacktriangle$ ), and capture of larvae in the river ( $\times$ ), and (B) locations of adult lake sturgeon implanted with transmitters represented by tag number. Ultrasonic receivers were placed at Pine Street [rkm: 77], Devils Run [rkm: 66], Boathouse Pool [rkm: 64], Bridgeton [rkm: 36], Maple Island [rkm: 23], River Mouth [rkm: 0], and two in the channel to Lake Michigan [rkm: -8].

above Boathouse Pool (Fish 103, 109; Fig. 3.2B), one was recorded as far as the river mouth (Fish 109; Fig. 3.2B) and the other was only recorded leaving the system in the channel to Lake Michigan (Fish 103; Fig. 3.2B). By the end of the study, I recorded four of the five fish leaving the system to enter Lake Michigan in the channel. Fish 107 (i.e., the fish that I did not detect leaving the system) was recorded as low as Maple Island, suggesting the fish was headed downstream to exit the system. However, fish 107 was not detected leaving, suggesting the fish stayed in the lower river system, stayed in Muskegon Lake, or avoided all the lower river receivers while exiting the system.

#### *Larval Drift Sampling*

In 2010, drift sampling occurred on 28 nights between 5 May and 13 June for a total of 525 hours (i.e., time nets were fished). Each net sampled an average volume of water of 78.84 m<sup>3</sup>/hr (SE = 1.90) and was set at an average depth of 0.79 m (SE = 0.13). Over this period, 16 larval lake sturgeon were caught in drift nets (TL range: 13-21.5 mm; mean = 16.47 mm). During larval sampling, water temperatures ranged from 10.5 to 20.4 °C, and larval lake sturgeon were captured when water temperatures ranged from 13.9 to 19.2 °C (Fig. 3.3). Larval lake sturgeon were captured between 21:00 and 01:00 hours (Fig. 3.4). All larvae were captured at the upstream sampling site, except for one that was captured at the middle site (i.e., 1.5-km downstream from known spawning site).

In 2011, drift sampling occurred on 19 nights between 10 May and 14 June for a total of 378 hours. Each net sampled an average volume of water of 88.89 m<sup>3</sup>/hr (SE = 4.84) and was set at an average depth of 0.70 m (SE = 0.16). Over this period, two larval lake sturgeon were caught in drift nets; both individuals were 20.0 mm TL. During larval

drift sampling, water temperatures ranged from 11.0 to 18.4 °C, and larval lake sturgeon were captured when water temperatures ranged from 16.8 to 17.0 °C (Fig. 3.2). Both larval lake sturgeon were captured between 23:00 and 00:00 hours at the most upstream sampling site.

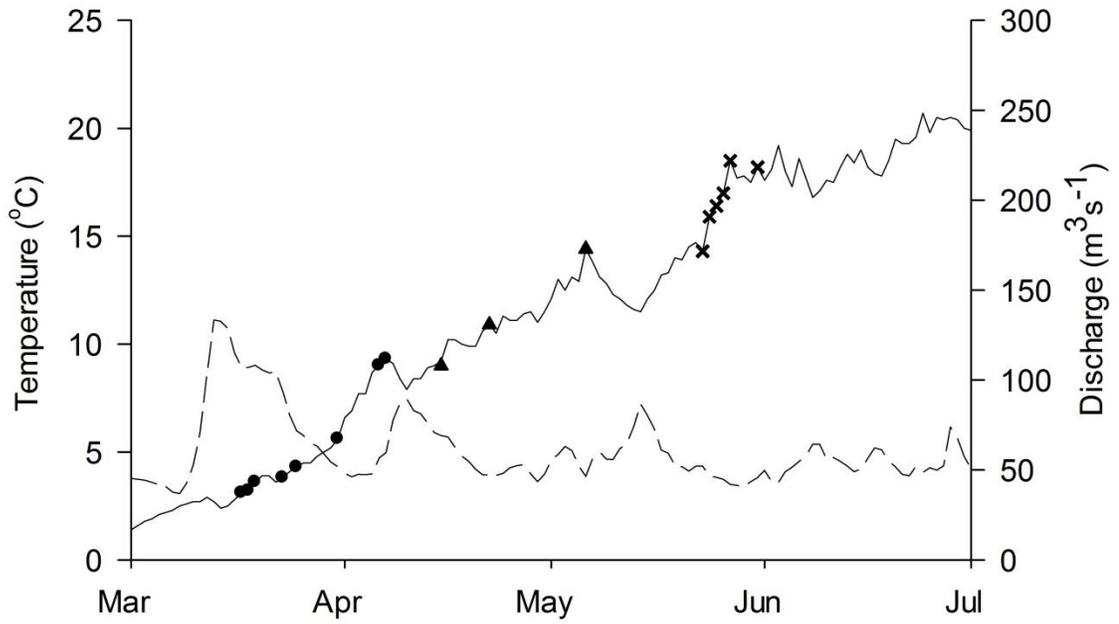


Figure 3.3. Daily river discharge ( $\text{m}^3 \text{s}^{-1}$ ; dashed line) and water temperature ( $^{\circ}\text{C}$ ; solid line) in the Muskegon River at Croton Dam in 2010 including symbols representing capture of adults in Muskegon lake ( $\bullet$ ), capture of adults in Muskegon River ( $\blacktriangle$ ), and capture of larvae in the river ( $\times$ ).

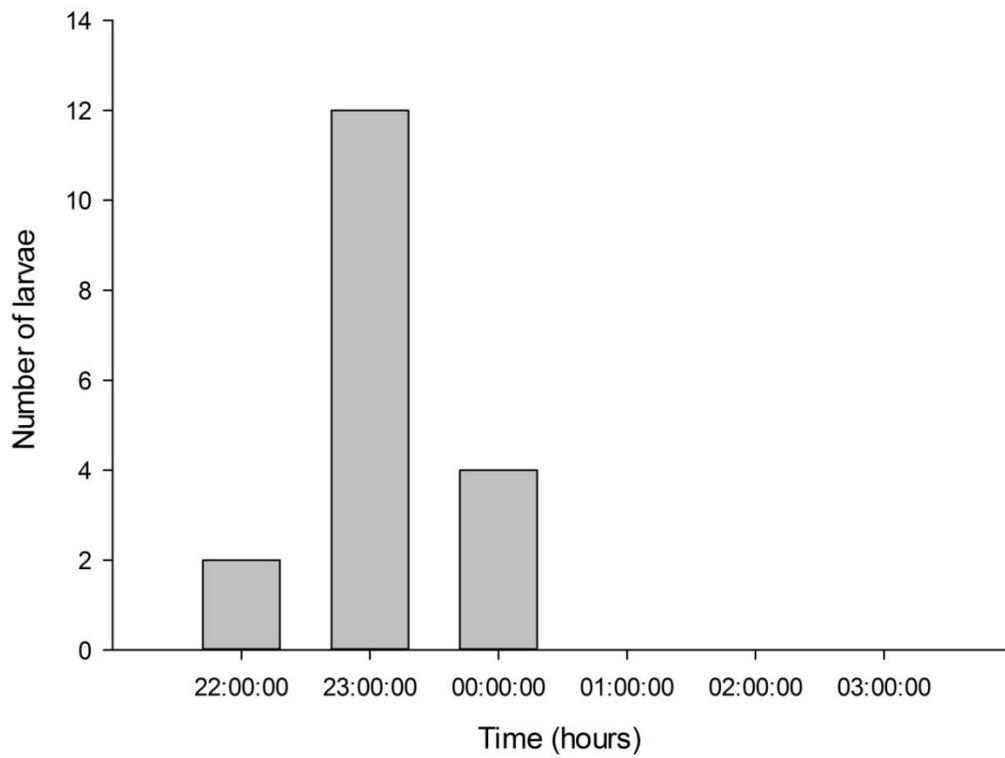


Figure 3.4. Total hourly catch of larval lake sturgeon during all sampling events in the Muskegon River, Michigan in 2010 and 2011.

## DISCUSSION

My objective was to determine the movement dynamics of adult lake sturgeon during their spawning runs throughout the Muskegon River system and the subsequent dynamics of larvae drifting downstream. I found that adult lake sturgeon are utilizing the Muskegon River during the spring to spawn and are returning to Lake Michigan. I also confirmed the location of a second spawning site. I observed successful reproduction of lake sturgeon in the Muskegon River based on the capture of larval lake sturgeon in 2010 and 2011.

Movement patterns of adult lake sturgeon in the Muskegon River were similar to other studies of spring spawning migrations in both the use of increasing water temperature to cue migrations and the timing of the spawning runs (Auer, 1999; Lallaman et al., 2008). In 2010 and 2011, I caught lake sturgeon on the first sampling attempt (via gill netting), which corresponded to lake temperatures of 3 and 6 °C, respectively. I suspect that lake sturgeon are inhabiting Muskegon Lake to stage sometime in the winter or early spring. During future surveys to sample lake sturgeon in Muskegon Lake, initiating gill netting earlier in the year will likely result in the capture of more lake sturgeon. Of the five fish I implanted with ultrasonic tags in Muskegon Lake, three were recorded in the Muskegon River. The behavior of fish entering the system but not migrating upstream is not uncommon and adult lake sturgeon in a nearby drowned river mouth system (Manistee River) also were observed to not all migrate upstream to spawn from the drowned river mouth lake (Lallaman et al., 2008).

Consistent with previous studies in the Muskegon River system, I found that migrating lake sturgeon staged at the mouth of the Muskegon River until water

temperatures reached 8-12 °C, at which point they began upstream movement (Peterson and Vecsei, 2004; Altenritter, 2010). Adult lake sturgeon were first caught via boat electrofishing and detected by receivers in the upper river (upstream of Henning Park; Fig. 3.1) during May at water temperatures of 9 °C. Previous studies have suggested that lake sturgeon begin arriving around spawning locations when water temperatures reach 8-14 °C (Rusak and Mosindy, 1997; McKinley et al., 1998; Lallaman et al., 2008), which was consistent with the fish I found inhabiting the portion of river near the spawning grounds upstream of Henning Park in the Muskegon River. I observed spawning activity occurring within the range of water temperatures (10-16 °C) reported in other studies (Kempinger, 1988; LaHaye et al., 1992; Rusak and Mosindy, 1997; Bruch and Binkowski, 2002; Chiotti et al., 2008).

All of my observations of fish in spawning congregations were at a single location. Previous studies on the Muskegon River focused on one suspected spawning location based on telemetry (Peterson and Vecsei, 2004), visual observations, and capture of adults in the river (Altenritter, 2010). In 2010 and 2011, I only captured and observed lake sturgeon in spawning congregations at a location approximately 2-km upstream of the previous documented spawning site. All fish captured and observed near the previous documented spawning site were observed to be alone, suggesting that although I did not see spawning occurring at this site, it may have occurred when I was not present. Altenritter (2010) proposed that additional spawning habitat was present, and I confirmed this by the observation of fish spawning at an additional site. Moreover, I suspect that more spawning areas may be available and further investigation of fish movement may provide insight into these locations. Below Croton Dam, 14 km of the Muskegon River

consists of moderate flow environment with gravel, cobble, and boulder substrates, with many sites suitable for lake sturgeon spawning (Ichthyological Associates, 1991; O'Neal, 1997). Altenritter (2010) proposed that it is apparent that few of these sites were being used, suggesting the number of adults in the Muskegon River spawning is more limiting than spawning site availability; my results support this suggestion.

Movement of fish downstream to Muskegon Lake and Lake Michigan in a short period (< 2 weeks) is a commonly observed pattern in most systems (Baker, 1980; Hay-Chmiewlewski, 1997; Auer, 1999; Lallaman et al., 2008). I did not find evidence of fish residing in the Muskegon River throughout the year as has been reported in other rivers (Lyons and Kempinger, 1992; Rusak and Mosindy, 1997; Boase et al., 2011). Although fish 107 was never detected after June 6, I suspect this fish either shed its tag or exited during the high-flow period without being detected due to the lack of additional receiver locations during the remainder of the study. Auer (1999) proposed that fish migrated out of rivers after spawning to avoid harsh conditions. I suspect similar harsh conditions occur in the Muskegon River, with fish avoiding high water temperatures, low flows, and high amounts of recreational traffic in the river. Of the four fish I tagged with ultrasonic transmitters that entered the river, only two individuals were detected at both the river mouth receiver and in the channel leaving to Lake Michigan, allowing residency time in Muskegon Lake to be estimated at 6 and 12 days. The fact that two of the four fish went by the receiver at the river mouth leads me to suspect that fish are either swimming by this receiver at a fast rate or are exiting the system through the South Branch of the river where I did not have a receiver (Fig. 3.1).

Although the tracking data in this study present new information on movement in the Muskegon River system, additional investigation is needed to further improve understanding of lake sturgeon movement patterns in this system. During the 2011 tracking season, a large flood occurred in April and May, causing receivers to lose reception strength due to the extremely high-water levels and the floodplain that was now accessible to fish (making it possible for fish to avoid detection by receivers). In addition, transmitters were programmed to emit a coded sequence once a minute for about 10 seconds to identify unique fish to the receivers. I acknowledge that some fish likely were missed due to the fish swimming by the receiver while the tag was not emitting its signal and due to the extremely high-flow period. Although receivers were tested and showed reception strength across the channel, I was not able to test this when the river was at peak flow. Overall, receivers detected fish 59% of the time fish swam by during my study (e.g., a fish was detected at an upstream receiver but not detected at the adjacent downstream receiver it would have had to swim by to get to its present location). Since the ultrasonic tags implanted in fish have a battery life of 4 years, future investigations of subsequent migrations of these fish will be able to track the movement, spawning patterns, and residency times of fish in the Muskegon system for 3 more years. In addition, an increase in the number of receivers around suspected spawning sites will help to identify the dates and times of congregation in certain areas (i.e., spawning activity).

Although the catch of larval lake sturgeon was low over this two-year study, I confirmed successful reproduction in both years of the study. My results were similar to previous studies that found larval drifting at water temperatures between 10 and 22 °C in

other streams (Auer and Baker, 2002; Smith and King, 2005; Benson et al., 2006) and between 14 and 16 °C in the Muskegon River (Altenritter, 2010). In addition, lake sturgeon are found to drift at night to avoid predation (Kempinger, 1988). I found peak larval drift occurred at 23:00 hours; this result is similar to that reported by Smith and King (2005) in the Black River, Michigan. Previous studies found catch of drifting larval lake sturgeon at downstream sampling sites decreased as distance from the spawning locations increased due to dilution (Auer and Baker, 2002; Smith and King, 2005). I suspect the overall low catch and the lack of capture of larval lake sturgeon at downstream sampling sites in my study were attributed to both low numbers of larval fish in the system and a dilution effect that was magnified by size of the Muskegon River. The Muskegon is a much larger river (average discharge at Croton Dam: 55.76 m<sup>3</sup>/s) than previously studied rivers such as the Black (average discharge at Black Lake: 6.4 m<sup>3</sup>/s) and Sturgeon rivers (average April and May discharge at Prickett Dam: 27.75 m<sup>3</sup>/s; Smith and Baker, 2002; Auer, 1999). Therefore, I suspect that pinpointing where eggs are being distributed each year and sampling just downstream of those locations would produce greater success sampling larval lake sturgeon in the Muskegon River.

In conclusion, I found a small number of adult lake sturgeon are utilizing at least two sites to spawn within the reach of the Muskegon River between Henning Park and Croton Dam and that successful reproduction of lake sturgeon is occurring. In order to restore this small remnant population of lake sturgeon, long-term protection of the lake sturgeon at all stages must continue. The small number of adult lake sturgeon captured each spring indicates the degraded status of the population. In addition, it appears that adult lake sturgeon stage in Muskegon Lake during the winter months before initiating

upstream spawning movements in the Muskegon River. This finding stresses the importance of drowned river mouth lakes to adult fish during their spring spawning migrations and additionally provides managers a period of time to sample adult fish before they migrate upstream. Future work using adult telemetry should be directed at pinpointing spawning areas and residency times within the river and lake. Knowing the spatial distribution of lake sturgeon within the system at certain times and temperatures will allow managers to protect areas of high use at times when lake sturgeon are present.

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