# Assessing Passage of Lake Sturgeon (*Acipenser fulvescens*) through Cheatham and Old Hickory Dams, Cumberland River, Tennessee

by

John Eric Ganus

A Thesis Submitted in Partial Fulfillment
of the Requirements for the Degree of
Master of Science in Biology

Middle Tennessee State University
August 2016

Dr. Dennis M. Mullen, Chair

Dr. Brian T. Miller

Dr. Vincent Cobb

# ACKNOWLEDGEMENTS

I would like to thank my wife Laura for her unwavering support throughout this process.  This work was funded through the Tennessee Wildlife Resources Agency's State Wildlife Grant Program.  It's with great appreciation for his professionalism and dedication to teaching and mentoring of me and others that I mention the late Dr. George W. Benz.  I would like to thank Dave McKinney, Don Hubbs, David Simms, Allen Pyburn, Bobby Brown, Sue Lanier, Tracey Porter, Lynn Barrett and Jason Henegar (Tennessee Wildlife Resources Agency) for technical expertise and assistance throughout the entire project.  A special thanks to Phil Bettoli (Tennessee Technology University) for his technical assistance and training with surgical procedures and protocols.  I would like to recognize the USACE Nashville Water Department Section for assistance with operations at Old Hickory Dam.

# ABSTRACT

While lake sturgeon stocking began in 2006 in the Cumberland River system, reservoir specific data is needed to assess restoration efforts as well as provide information to support sturgeon management decisions. The purpose of this study was to (1) assess dam passage and emigration rates of tagged hatchery-reared juvenile lake sturgeon through Cheatham and Old Hickory locks and dams, (2) estimate reservoir section use and movement by tagged hatchery-reared juvenile lake sturgeon within Cheatham Lake, and (3) estimate the minimum annual stocking rate for Cheatham Reservoir. Percent downstream passage of tagged lake sturgeon through Cheatham Lock and Dam (CLD) was 32% (n=11) in 2011 and 9% (n=3) in 2012. Percent upstream passage of tagged lake sturgeon through Old Hickory Lock and Dam (OHLD) was 32% (n=11) in 2011 and 28% (n=9) in 2012. The total emigration rate for Cheatham Lake was 68% in 2011 and was 38% in 2012. Upstream movement was high for each cohort as 75% (n = 25) in 2011 and 81 % (n = 26) in 2012 of tagged lake sturgeon moved upstream to a position just below OHLD within 5 days post-stocking. Average upstream distance traveled post-stocking was 25.2 river km (rkm) and downstream was 3.6 rkm for 2011. Average upstream distance traveled post-stocking was 35.6 rkm and downstream was 16.1 rkm for 2012. The estimated minimum annual stocking rates would be 1,770, 2,456 and 48,778 at 0%, 1% and 10% emigration rates when applied equally over 40 years of stocking.

TABLE OF CONTENTS

LIST OF TABLES ........................................................................ v

LIST OF FIGURES ........................................................................ vi

INTRODUCTION ........................................................................ 1

STUDY AREA ........................................................................ 4

MATERIALS AND METHODS ........................................................................ 6

General Overview of Study Methods ........................................................................ 6

Sturgeon Production ........................................................................ 6

Sturgeon Tagging Protocols ........................................................................ 6

Telemetry ........................................................................ 8

Data Analysis ........................................................................ 9

RESULTS ........................................................................ 15

DISCUSSION ........................................................................ 24

REFERENCES ........................................................................ 28

LIST OF TABLES

Page

Table 1. Parameters used for estimating annual lake sturgeon stocking rate for Cheatham Lake ……….……………….…………………………….…….… 13

Table 2. Tag to body mass ratio (tag/bm) for juvenile lake sturgeon tagged with acoustic and dummy tags for 2010 and 2011 cohorts ……….……….…… 16

Table 3. Tag detections representing 34 tagged fish from receiver stations S1 (Barkley Reservoir) and S4 (Old Hickory Reservoir) showing downstream (S1) and upstream (S4) movements by month through Cheatham and Old Hickory Dams ………………………………..……………………..….. 17

Table 4. Percent section use semiannually and annually in Cheatham Lake for each cohort in 2011 2012. Section usage was calculated as a percentage of time that a tagged lake sturgeon occupied each section …………….…….….. 19

Table 5. Section use and movement was plotted from relocation data by year, depth and distance traveled in Cheatham Reservoir …………..…………………... 20

# LIST OF FIGURES

Page

Figure 1. Study area for the assessment of dam passage of lake sturgeon, *Acipenser fulvescens*, in the Cumberland River. Upper right: general location (box) of the study area. Lower: location of Cumberland River system dams and tributaries important to the study and locations of submersible receiver (S1-4) stations within the system. Star indicates location of sturgeon release (Shelby Bottoms boat ramp). The lower study boundary was located at river km 216 (S-1) and the upper study boundary was located at Cumberland rkm 423 (S-4) …………………..…... 5

Figure 2. Study area for section usage of lake sturgeon, *Acipenser fulvescens*, in Cheatham Reservoir. Upper right: general location (box) of the study area. Star indicates location of sturgeon release (Shelby Bottoms boat ramp). Cheatham Reservoir was divided into three approximately equal sections. Section 1 consisted of that portion of the reservoir from 312.2 upstream to Old Hickory Lock and Dam (rkm 347.6). Section 2 consisted of that portion of the reservoir from rkm 275.2 upstream to rkm 312.2. Section 3 consisted of that portion of the reservoir from Cheatham Reservoir Lock and Dam (rkm 239.3) upstream to rkm 275.2 ………..……….……… 11

Figure 3. Number of adult lake sturgeon at age 40 from initial stocking and reproduction after 40 years with various reproduction and emigration rates applied …… 22

# INTRODUCTION

The lake sturgeon, *Acipenser fulvescens,* is listed as extinct, endangered, threatened, vulnerable or a species of special concern in 20 U.S. states (Pikitch et al. 2005). By 1995, a general consensus that the species was only represented in Tennessee waters by a few fish prompted the formation of a cooperative restoration effort (now known as the Southeastern Lake Sturgeon Working Group; SELSWG 2014), originally involving participation by the Tennessee Wildlife Resources Agency (TWRA), the Tennessee Aquarium and its Southeast Aquatic Research Institute (now operating as the Tennessee Aquarium Conservation Institute), the U.S. Fish and Wildlife Service (USFWS), the Tennessee Valley Authority, the U.S. Geological Service, Tennessee Tech University, the University of Tennessee, the World Wildlife Fund, and the Wisconsin Department of Natural Resources (WDNR). Through that effort and since 1998, lake sturgeon eggs collected and fertilized in Wisconsin have been reared in Tennessee, Georgia and Mississippi for stocking in Tennessee. Continuing restoration efforts have resulted in 141,972 sturgeon (as of 2015) stocked into the Tennessee River system and 32,226 sturgeon (as of 2015) stocked into the Cumberland River system. Lake sturgeon stocking began in 2000 and 2006 in the Tennessee River and Cumberland River systems, respectively and sturgeon are now routinely reported by anglers in each system (TWRA unpublished data). As sturgeon restoration unfolds in Tennessee, reservoir specific data are needed to assess restoration efforts as well as provide information to support sturgeon management decisions.

An important aspect of lake sturgeon management in Tennessee is the ability and propensity of sturgeon to move throughout the state's impounded river systems, including the ability of sturgeon to pass through locks and dams. Several preliminary studies of lake sturgeon river use, dispersal, and dam passage have been conducted in the Tennessee River system (e.g., Martin and Layzer 2001; Huddleston 2006; Collier et al. 2011); however, to date, no studies have been completed in the Cumberland River system. In the Tennessee River system, studies indicate that stocked juvenile lake sturgeon show a general propensity to disperse downriver by way of dam passage (Collier et al. 2011). This tendency and ability have important potential management implications regarding temporal stock size as it pertains to Minimum Viable Population levels (MVP; Schueller and Hayes 2011). And while studies of lake sturgeon (e.g., Knights et al. 2002) and other sturgeons (e.g., North et al. 1993) outside of Tennessee have generally garnered similar results (i.e., that juvenile lake sturgeon have a greater propensity to disperse downriver than upriver), lake sturgeon movements have been portrayed as being complex and variable according to fish size (Smith and King 2005). In addition, the percentage of an overall sturgeon stock that moves downstream and the rate of movement seem variable amongst species and river systems (e.g., cf. information in North et al. 1993; Martin and Layzer 2001; Knights et al. 2002; Haxton 2003; Huddleston 2006; Collier et al. 2011). Thus, with data lacking regarding lake sturgeon movement within the Cumberland River system, the objectives of this study are to: (1) assess dam passage and emigration rates of tagged hatchery-reared juvenile lake sturgeon through Cheatham and Old Hickory locks and dams (2) estimate reservoir section use and movement by tagged hatchery-reared juvenile lake sturgeon within Cheatham Lake, and (3) estimate the minimum annual stocking rate for Cheatham Reservoir

# STUDY AREA

The study area comprised a 207-km stretch of the Cumberland River from river km (rkm) 216 (henceforth referred to as the lower study boundary) to rkm 423 (henceforth referred to as the upper study boundary), as well as a section of the Harpeth River extending 3.2 km from the confluence with the Cumberland River and an 11.3 km section of the Stones River extending from the J. Piercy Priest Dam to the confluence with the Cumberland River (Figure 1). In addition, several small streams (each entirely within Tennessee) empty into the aforementioned waters. Two dams exist in the primary study area: Cheatham Dam (located at Cumberland rkm 239.3) and Old Hickory Dam (located at Cumberland rkm 347.6) (Figure 1). Waters just below Cheatham Dam comprise Lake Barkley (a 23.3 km river stretch with 33.3 ha surface area at full pool is within the study area), waters between Cheatham Dam and Old Hickory Dam comprise Cheatham Lake (a 113.5 km river stretch with 9105.3 ha surface area at full pool is within the study area), and waters just above Old Hickory Dam comprise Old Hickory Lake (within the study area a 75.3 km river stretch and 633.7 ha surface area at full pool within the study area) (Figure1). Cheatham and Old Hickory dams are multi-purpose facilities operated and maintained by the U.S. Army Corps of Engineers (USACE) for navigation activities, hydropower production, flood damage management, water supply purposes, water quality control, and recreation activities. As such, each dam possesses a navigation lock operated by the USACE. Cheatham and Old Hickory dams are considered to be low head hydro and high head mainstream navigation projects, respectively.

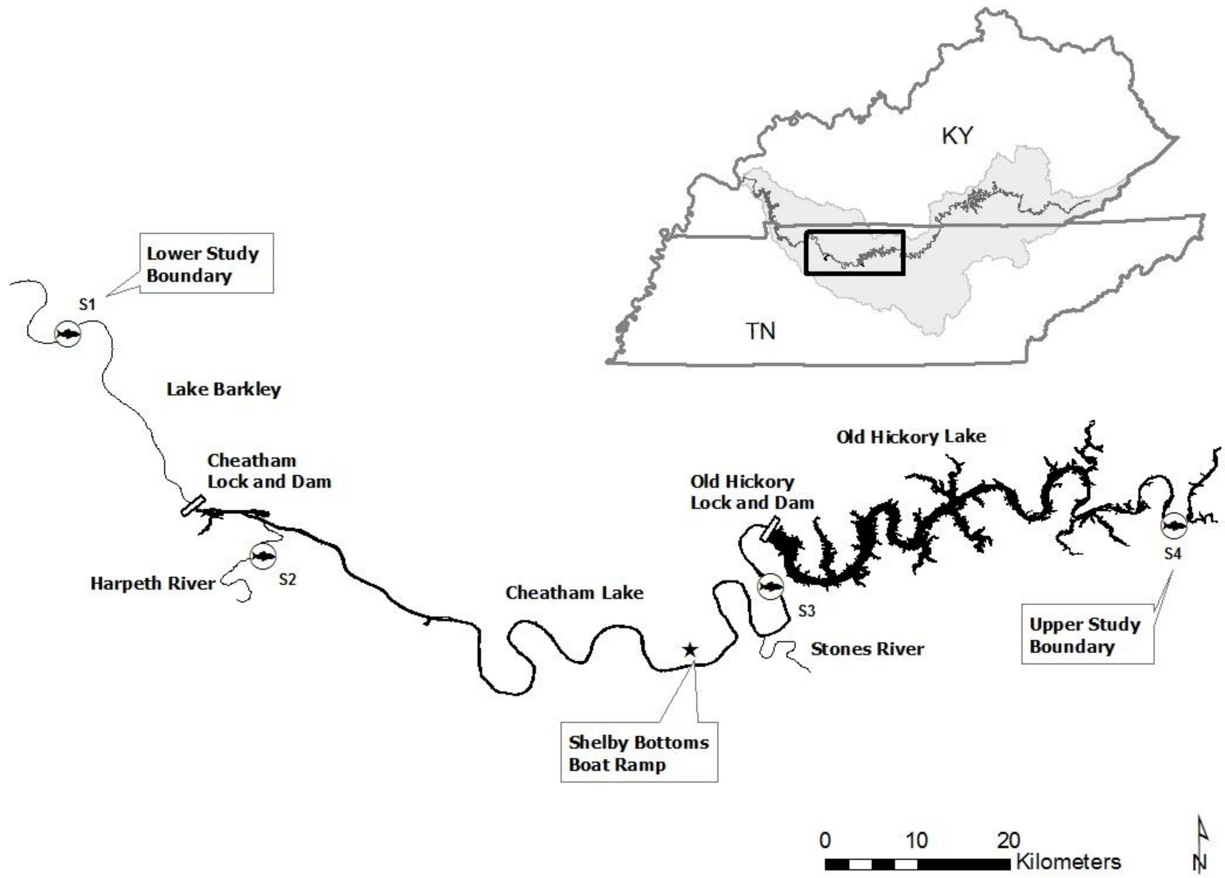


Figure 1**.** Study area for the assessment of dam passage of lake sturgeon, *Acipenser fulvescens*, in the Cumberland River. Upper right: general location (box) of the study area. Lower: location of Cumberland River system dams and tributaries important to the study and locations of submersible receiver (S1-4) stations within the system. Star indicates location of sturgeon release (Shelby Bottoms boat ramp). The lower study boundary was located at river km 216 (S-1) and the upper study boundary was located at Cumberland rkm 423 (S-4).

# MATERIALS AND METHODS

*General Overview of Study Methods.* Annual sturgeon movements within the study area were assessed using hatchery-raised juvenile lake sturgeon implanted with acoustic tags. A minimum size for all lake sturgeon was selected to mitigate for impacts from tag weight (in water), volume, and dimension (Jepsen et al. 2005; Cooke et al. 2011). Tagged hatchery reared sturgeon were monitored using active and passive telemetry methods.

*Sturgeon Production*. Lake sturgeon used in this study originated from the Wisconsin River, Wisconsin. Fertilized sturgeon eggs were obtained in cooperation with the WDNR and USFWS for use as part of the Tennessee lake sturgeon recovery efforts. Lake sturgeon were raised at TWRA fish hatcheries in Gallatin and Springfield, Tennessee; husbandry of sturgeon fry and fingerlings followed guidelines in the USFWS report FDS 2006-003, "Genoa National Fish Hatchery Lake Sturgeon Culture Standard Operating Procedures." Fingerling sturgeon were fed a combination of Starter™ and Soft Moist™ feeds (both made by Rangen, Inc., Buhl, ID) until they reached the minimum tagging size of 610 mm total length (TL) and 1362 g total weight.

*Sturgeon Tagging Protocols.* Surgical procedures described by Wagner et al. (2011) were used to implant acoustic transmitter tags (CT-82-2-I, Sonotronics, Inc., Tucson, AZ). Before surgery, all instruments, acoustic tags, and non-functioning (dummy) tags (Sonotronics, Inc.) were disinfected in a chlorohexadrine solution and rinsed with sterile saline. Tricaine methanesulfonate (MS-222) was used to anesthetize fish prior to surgical procedures. For anesthesia, two tubs were used (one for narcosis induction, one for maintenance dosing during surgery) with oxygen induction and water replacement from flowing raceways. Narcosis was induced using 75 ppm MS-222 in the narcosis tub until stage 4 anesthesia (Summerfelt and Smith 1990) was observed. Subsequently, fish were measured (TL, mm), weighed (g), PIT tagged (HPT12, 12.5mm, 134 kHz ISO FDXB; BIOMARK, Boise, ID), and scanned for identification assurance purposes. Sturgeon were positioned for surgery by placing them ventral side up in a surgical trough lined with a clean plastic sheet. A Nalgene® tube was inserted into the mouth and anesthetic was pumped across the gills using a recirculating system from the maintenance dosing tub underneath the surgical trough. A surgical incision approximately 4.5 cm in length along the midline on the ventral surface anterior to the pelvic girdle accommodated acoustic tag (n = 70 sturgeon total; 35 tagged in 2011 and 2012) and dummy tag (n = 10 sturgeon tagged in 2011and 2012) insertion. Surgical incisions were closed with 3 interrupted sutures (surgeon's knots) using sterile, absorbable 1-0 or 2-0 Monocryl® suture and reverse-cutting needles. Sturgeon were monitored for tag retention and mortality in a partitioned raceway post-surgery (Cooke et al. 2011). Short-term tag retention and post-tagging mortality was assessed at 60 days post-tagging using all sturgeon implanted with an acoustic tag as well as all sturgeon implanted with a dummy tag. Long-term tag retention and post-tagging mortality was assessed for a 14-month period post-tagging using sturgeon implanted with a dummy tag. Prior to release, sturgeon with acoustic transmitters were measured (TL, mm), weighed (g), scanned for PIT tag identification, and tested regarding acoustic tag operation. All sturgeon releases took place at Shelby Bottoms boat ramp, Cumberland rkm 310 (Figure 1).

*Telemetry*. Active tracking of tagged hatchery-reared juvenile lake sturgeon occurred at a minimum of once every three months (quarterly), avoiding days when spill gates were open at Old Hickory Dam. Tracking efforts in Cheatham Reservoir began 5 m below Old Hickory Dam and ended 50 m above Cheatham Dam. The Stones and the Harpeth rivers were monitored from each river's confluence with the Cumberland River to a point 3.2 km upstream. An ultrasonic receiver (USR-80, Sonotronics, Inc.) and a towed omnidirectional hydrophone (TH-2, Sonotronics, Inc.) were used for boat-based tracking efforts. The omnidirectional hydrophone was suspended from a stainless steel hanger towed parallel to the boat. The hydrophone was taped to a 4.54 kg finned downrigger weight suspended 30.5 cm below the water's surface on a coated steel cable. As sturgeon were detected, the omnidirectional hydrophone was replaced with a directional hydrophone (DH-4, Sonotronics, Inc.) to more accurately estimate their location. A combination fish finder and GPS unit (798ci HD SI, Humminbird, Eufaula, AL) was used to locate (latitude, longitude) sturgeon identified through hydrophone detection and to estimate bottom depth where detected sturgeon were located.

Passive sturgeon tracking was accomplished using archival submersible ultrasonic receivers (SURs) (SUR-1 and SUR-3, Sonotronics, Inc., Tucson, AZ) deployed in a descending paired linear array in the main river channel of the Cumberland River at 3 locations (Figure 1): S1 (216 rkm; lower study boundary in Barkley Reservoir), S3 (336 rkm; below Old Hickory Dam in Cheatham Reservoir), and S4 (423 rkm; upper study boundary Old Hickory Reservoir). In addition, a single SUR (S2) was deployed at rkm 3.2 of the Harpeth River (Figure 1). Default settings were used on SURs (1 s channel delay, 1 s scan delay, 15 channel scan span) to scan individual frequencies every 46 s.

Recorded detections from acoustically tagged lake sturgeon were archived on SURs for later processing. Downloading data from SURs was scheduled to occur every 7 months or as time and water conditions permitted. Mooring and recovery of SURs followed Bettoli et al. (2010).

Field testing of tracking equipment (SUR maximum detection distance, SUR detection interval rate and directional hydrophone detection distance) was conducted in the Cumberland River (rkm 175) to assess the detection range of SURs. Kessel et al. (2014) defined detection range as "the relationship between detection probability and the distance between the receiver and tag". Detection range is influenced by water temperature, turbidity, turbulence and substrate (Kessel et al. 2014; Medwin and Clay 1998). Efforts revealed that a SUR suspended vertically, 0.6 m above the bottom (bottom depth ca. 3.7 m) had a maximum detection distance of 150 m (tested at 50 m intervals). A study transmitter deployed at a depth of ca. 3.7 m, 150 m away for 30 min. had a detection interval rate of 1 to 12 min. A transmitter deployed on the bottom (bottom depth ca. 3.7 m) in the Cumberland River (rkm 175) was detected from a maximum distance of 200 m by the study hydrophone (tested at 50 m intervals).

*Data Analysis.* Dam passage was determined by analyzing detections recorded on SURs deployed upstream of Old Hickory and downstream of Cheatham locks and dams. A recording of a specific transmitted frequency and interval was considered as a detection. The recorded data from SURs were downloaded as text files into SURsoft data processing software (Sonotronics, Inc., Tucson, AZ). Detections were analyzed with an interval tolerance of 5 ms from a preconfigured tag list. Processed files were saved as excel files and further analyzed to verify detections as valid. Detections were considered valid if they meet the following criteria (Pincock 2012); if on any day (1) three consecutive detections were recorded in a six hour period, or (2) two separate pairs of detections were recorded in a six hour period, and (3) with each successive detection maintaining an interval rate of 1 to 30 minutes between detections.

Emigration rates for 2011 and 2012 of tagged hatchery-reared juvenile lake sturgeon from Cheatham Reservoir were assessed at a biannual and annual rate. Emigration rates were estimated by the calculation as follows:

$$\text{Emigration Rate (ER)} = X_{NP} / X_{SC} * 100,$$

where $X_{NP}$ (not present) represents the number of sturgeon detected from SUR data (S1 and S4) and $X_{SC}$ (stocked cohort) represents the number of tagged sturgeon stocked each year.

Cheatham Reservoir section use was assessed semiannually and annually by plotting location data from each tagged sturgeon from 2011 and 2012. Semiannual section usage was assessed from January through June (period 1) and July through December (period 2). Cheatham Reservoir was divided into three approximately equal sections (Figure 2). Section 1 consisted of that portion of the reservoir from 312.2 upstream to Old Hickory Lock and Dam (rkm 347.6). Section 2 consisted of that portion of the reservoir from rkm 275.2 upstream to rkm 312.2. Section 3 consisted of that portion of the reservoir from Cheatham Reservoir Lock and Dam (rkm 239.3) upstream to rkm 275.2. Section use was calculated as a percentage of time that a tagged lake sturgeon occupied each section.

Movements for tagged lake sturgeon in Cheatham Reservoir was limited to those sturgeon not detected on SUR 1 and 4 and that were detected during both semiannual and

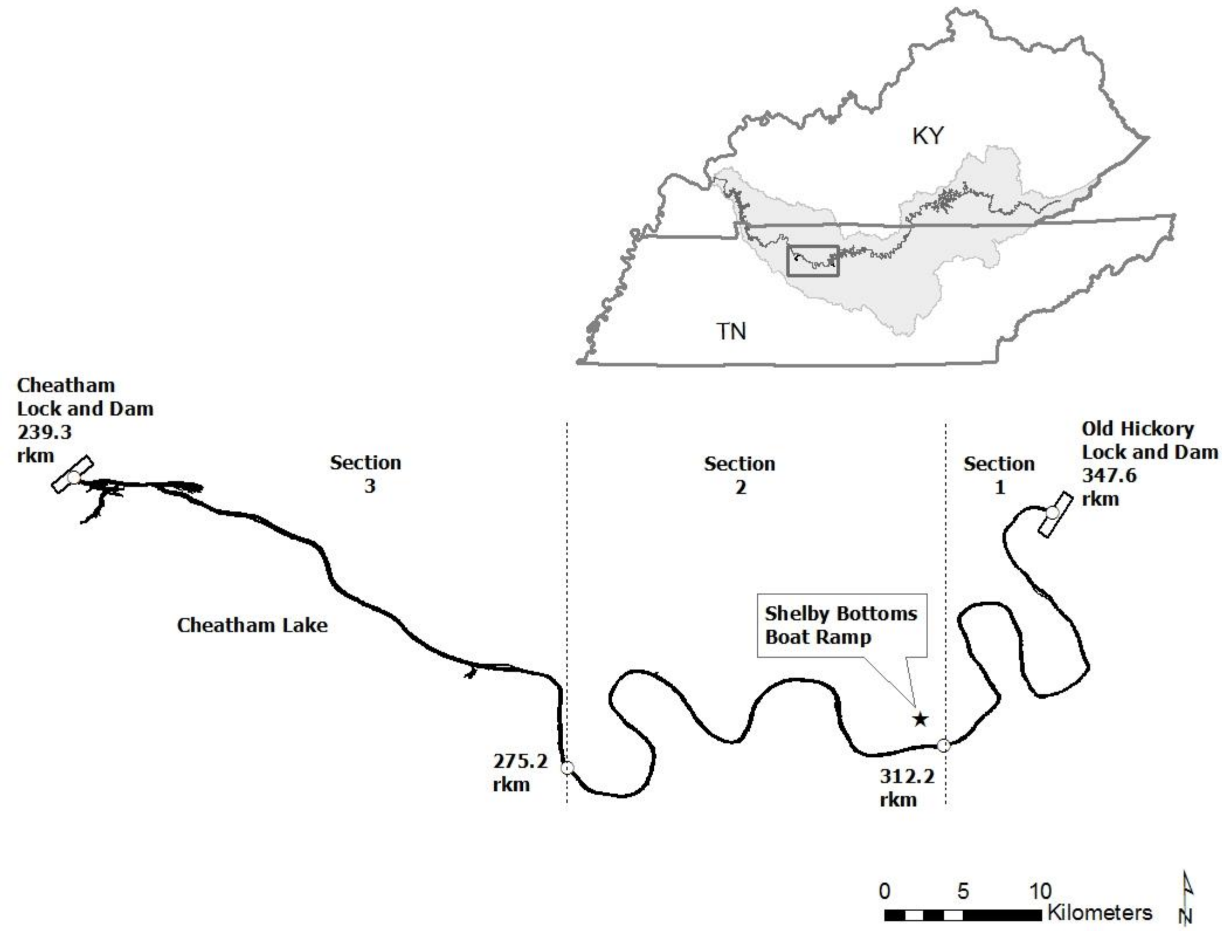


Figure 2. Study area for section usage of lake sturgeon, *Acipenser fulvescens*, in Cheatham Reservoir. Upper right: general location (box) of the study area. Star indicates location of sturgeon release (Shelby Bottoms boat ramp). Cheatham Reservoir was divided into three approximately equal sections. Section 1 consisted of that portion of the reservoir from 312.2 upstream to Old Hickory Lock and Dam (rkm 347.6). Section 2 consisted of that portion of the reservoir from rkm 275.2 upstream to rkm 312.2. Section 3 consisted of that portion of the reservoir from Cheatham Reservoir Lock and Dam (rkm 239.3) upstream to rkm 275.2.

annual periods. Average depth and a range of depths were calculated from location data from 2011 and 2012. Estimates of movements were calculated as linear distance traveled (km) between successive locations, range was calculated as the maximum and minimum distance [km] traveled between all relocations for a specific tagged fish and average distance traveled was calculated for each individual tagged fish. Average distance traveled post-stocking was calculated from the initial stocking site to the first relocation of each tagged sturgeon during the first quarter tracking period. Distance between relocations points where measure from the center of the main river channel when distances where greater than 300 m. ArcGIS 10.3 (Environmental Systems Research Institute, Redlands, CA) was used for all spatial analysis.

Matrix projection models (Leslie 1945; Caswell 2000; Heppell et al. 2000) were used to create simple life tables to be used to estimate the minimum annual stocking rate for necessary for Cheatham Reservoir. Demographic data (age specific mortality, growth and fecundity) was used along with varying estimates of emigration rates (0.0, 0.01, and 0.10) and varying spawning fractions (0.10, 0.15 and 0.20) to estimate the annual stocking rate necessary to achieve an adult population of 750 individuals after 40 years. An age-0 (fingerling) lake sturgeon was used as the beginning point for all model simulations. Mortality rates were derived from Bruch et al. (2006), Caroffino et al. (2010), Crossman et al. (2009), Shaw et al. (2012), and Wendel and Frank (2012), and female age at maturity and fecundity rates were derived from Bruch et al. (2006). Weight specific fecundity estimates were determined from the fecundity to weight equations calculated from Lake Winnebago, Wisconsin (Bruch et al. 2006). Mean weight estimates at different ages were derived from Bruch et al. (2006) and TWRA (unpublished data)

Table 1.  Parameters used for estimating annual lake sturgeon stocking rate for Cheatham Lake.

| Parameters | Values |
|---|---|
| Larval Mortality | 95% |
| Fingerling Mortality (Age 0-1) | 60% |
| Yearling Mortality (Age 1-9) | 20% |
| Adult Mortality (10+) | 5% |
| Female age at Maturity | 20 |
| Fecundity Equation | f = 16640w - 150683 |
| Weight values (lbs) for; 20, 30, 40 and 50 year old fish | 50, 60, 70 & 80 |
| Percent Yearly Spawning (Females) | 10%, 15% & 20% |
| Emigration Rate | 0%, .01% & .10 |
| Target Adult Population (Age 20 – 40) | 750 |

and used for all estimates (Table 1). Although only a 10% spawning fraction of adult female lake sturgeon has been reported (Shaw et al. 2012), an additional spawning fraction of 15% and 20% was used to estimate reproduction for all model parameters. All models were created in Microsoft Excel (2010).

# RESULTS

Thirty four (2010 cohort; mean TL = 672 ± 32 mm, mean mass = 1881 ± 361 g) and thirty two (2011 cohort; mean TL = 729 ± 23 mm, mean mass = 2016 ± 270 g) acoustic transmitter tagged sturgeon were released into the Cumberland River in January of 2011 and 2012, respectively. Ten juvenile lake sturgeon from the 2010 (mean TL = 671 ± 26 mm, mean mass = 1892 ± 256 g) and 2011 (mean TL = 725 ± 28 mm, mean mass = 1964 ± 264 g) cohorts were tagged with dummy (non-functioning) tags and kept at the TWRA fish hatcheries in Gallatin, Tennessee.

Short-term tag retention was 100% with no post-tagging mortality observed at 60 days from both acoustic and dummy tagged cohorts from 2010 and 2011. Long-term tag retention was 100% with no post-tagging mortality observed for a 14-month period for lake sturgeon surgically implanted with dummy tags. The mean tag/bm ratio in air (mass of the tag as a percentage of the fish's body mass) for fish tagged in 2010 with acoustic and dummy tags was 1.04% and 1.02%, respectively (Table 2). The mean tag/bm ratio in air (mass of the tag as a percentage of the fish's body mass) for fish tagged in 2011 with acoustic and dummy tags was 0.96% and 0.98%, respectively (Table 2).

A total of 20,470 valid detections representing 34 tagged fish that were logged on SUR arrays downstream of Cheatham Lock and Dam (CLD) and upstream of Old Hickory Lock and Dam (OHLD) (Table 3). Multiple or paired detections were recorded annually from tagged fish throughout both tagging years. Percent downstream passage of tagged lake sturgeon through CLD was 32% (n=11) in 2011 and 9% (n=3) in 2012. Percent upstream passage of tagged lake sturgeon through OHLD was 32% (n=11) in

Table 2. Tag to body mass ratio (tag/bm) for juvenile lake sturgeon tagged with acoustic and dummy tags for 2010 and 2011 cohorts.

| Year | Description | Number of Tagged Fish | Range (%) | Mean (%) |
|---|---|---|---|---|
| 2010 | Acoustic | 35 | 0.70 - 1.39 | 1.04 |
| | Dummy | 10 | 0.85 - 1.27 | 1.02 |
| 2011 | Acoustic | 35 | 0.69 - 1.16 | 0.96 |
| | Dummy | 10 | 0.76 - 1.14 | 0.98 |

Table 3. Tag detections representing 34 tagged fish from receiver stations S1 (Barkley Reservoir) and S4 (Old Hickory Reservoir) showing downstream (S1) and upstream (S4) movements by month through Cheatham and Old Hickory Dams.

| Year | Monthly Detections | SUR Station | Tag Number | Percent Passage |
|---|---|---|---|---|
| **2011** | | **S1** | | 11 (32%)[a] |
| | January | | 4, 13 | |
| | February | | 3, 24, 15 | |
| | March | | 10 | |
| | April | | 5, 35 | |
| | May | | 7 | |
| | October | | 29 | |
| | November | | 33 | |
| | | **S4** | | 11 (32%)[a] |
| | April | | 8, 32, 39 | |
| | May | | 19, 26, 34 | |
| | June | | 9, 11, 14, 22 | |
| | October | | 17 | |
| | | | | 22 (65%)[b] |
| **2012** | | **S1** | | 3 (9%)[a] |
| | February | | 170, 184 | |
| | December | | 182 | |
| | | **S4** | | 9 (28%)[a] |
| | February | | 171, 180, 191 | |
| | March | | 200 | |
| | May | | 167, 174, 183, 189 | |
| | June | | 197 | |
| | | | | 12 (38%)[b] |

[a] Percent tag detections from receiver stations

[b] Total tag detections from receiver stations by year

2011 and 28% (n=9) in 2012. The total emigration rate for Cheatham Lake for the 2011 was 68% and was 38% for the 2012. The fastest downstream movement detected by an SUR array through a dam (CLD) was 4 days with a total distance traveled of 94 rkm in 2011. The fastest upstream movement detected by an SUR array through a dam (OHLD) was 11 days with a total distance traveled of 113 rkm in 2012.

Upstream passage through CLD and downstream passage through OHLD by the same fish was detected during both 2011 and 2012. In 2011, the first detection of fish 10 was on 12 February below OHLD. The fish moved downstream and was detected again below CLD on 28 March 2011. The next detection of fish 10 was on 12 May 2011 below OHLD and then again above OHLD on 17 June 2011. From 31 January through 17 June 2011 (138 days), fish 10 travelled 347 rkm, passing down and upstream of CLD and upstream of OHLD. Fish 171 was first detected on 1 February 2012 below OHLD. The fish was then detected upstream above OHLD on 11 February 2012. The next detection of fish 171 was on 22 June 2012 below OHLD, and then below CLD on 14 December 2012. Thus, fish 171 traveled 320 rkm in 320 days, from 27 January through 14 December 2012 passing up and downstream of OHLD and downstream of CLD.

Location data from 22 tagged fish (9 for 2011 and 13 for 2012) were used to assess section use by juvenile lake sturgeon (Tables 4 and 5). Location data was plotted by year, section, depth and distance traveled in Cheatham Reservoir. Upstream movement was high for each cohort as 75% (n = 25) in 2011 and 81% (n = 26) in 2012 of tagged lake sturgeon moved upstream to a position just below OHLD within 5 days post-stocking. Average upstream distance traveled post-stocking was 25.2 rkm and downstream was 3.6 rkm for 2011. Average distance traveled post-stocking during 2012

Table 4. Percent section use semiannually and annually in Cheatham Lake for each cohort in 2011 2012. Section usage was calculated as a percentage of time that a tagged lake sturgeon occupied each section.

| Year | No. of Tagged Fish | No. of Detections | Section Use<br>Section 1 | <br>Section 2 | <br>Section 3 |
|---|---|---|---|---|---|
| 2011 | | | **Period 1** | | |
| | | 34 | 27 (79%) | 6 (18%) | 1 (3%) |
| | | | **Period 2** | | |
| | | 35 | 34 (97%) | 1 (3%) | 0 (0%) |
| | | | Combined | | |
| | 9 | 69 | 61 (88%) | 7 (10%) | 1 (1%) |
| 2012 | | | **Period 1** | | |
| | | 41 | 31 (76%) | 5 (12%) | 5 (12%) |
| | | | **Period 2** | | |
| | | 36 | 24 (67%) | 3 (8%) | 9 (25%) |
| | | | Combined | | |
| | 13 | 77 | 55 (71%) | 8 (10%) | 14 (18%) |

Table 5. Section use and movement was plotted from relocation data by year, depth and distance traveled in Cheatham Reservoir.

| | | | | Depth (m) | | Distance Traveled (km) | | |
|---|---|---|---|---|---|---|---|---|
| Year | Tag No. | Section Use | No. of Detections | Range | Mean | Range | Mean | Total |
| 2011 | 18 | 1 & 2 | 5 | 3.66 - 7.92 | 5.24 | 0.15 - 89.38 | 43.46 | 217.31 |
| | 20 | 1 | 5 | 3.96 - 8.23 | 5.18 | 0.32 - 36.27 | 14.47 | 72.34 |
| | 21 | 1 & 2 | 6 | 3.05 - 4.27 | 4.27 | 0.02 - 39.16 | 8.46 | 50.74 |
| | 23 | 1 | 4 | 3.66 - 4.88 | 4.34 | 4.18 - 22.92 | 13.63 | 54.51 |
| | 25 | 1 | 6 | 3.05 - 5.79 | 4.27 | 0.46 - 36.27 | 8.58 | 51.48 |
| | 28 | 1 | 6 | 5.49 - 7.62 | 6.3 | 0.29 - 27.08 | 9.90 | 59.39 |
| | 30 | 1 | 5 | 4.57 - 6.09 | 5.18 | 0.02 - 7.71 | 6.14 | 30.68 |
| | 36 | 1 | 5 | 3.96 - 6.71 | 4.94 | 0.04 - 33.20 | 11.18 | 55.90 |
| | 38 | 1 | 5 | 3.66 - 5.79 | 4.75 | 0.06 - 31.14 | 13.56 | 67.81 |
| 2012 | 169 | 1 | 7 | 2.74 - 6.40 | 4.05 | 0.01 - 35.85 | 5.23 | 36.63 |
| | 172 | 1 | 5 | 3.05 - 8.84 | 6.22 | 0.01 - 36.29 | 7.27 | 36.36 |
| | 173 | 1, 2 & 3 | 6 | 7.01 - 9.75 | 8.43 | 1.59 - 34.88 | 16.30 | 97.81 |
| | 176 | 1 | 5 | 3.05 - 8.84 | 6.16 | 0.01 - 35.34 | 7.26 | 36.31 |
| | 177 | 1 | 7 | 2.74 - 8.53 | 5.05 | 0.03 - 36.07 | 5.59 | 39.16 |
| | 179 | 1 & 3 | 7 | 2.74 - 9.14 | 7.14 | 0.08 - 95.38 | 19.99 | 139.91 |
| | 185 | 1 | 5 | 6.10 - .14 | 6.95 | 0.01 - 35.47 | 7.28 | 36.41 |
| | 187 | 1 | 7 | 2.13 - 8.84 | 4.75 | 0.02 - 35.68 | 5.25 | 36.78 |
| | 188 | 1 & 3 | 7 | 2.74 - 10.98 | 7.84 | 0.28 - 86.05 | 23.6 | 165.23 |
| | 192 | 1 & 2 | 6 | 3.05 - 8.84 | 6.15 | 0.82 - 52.25 | 19.87 | 119.21 |
| | 193 | 2 & 3 | 4 | 3.35 - 7.32 | 5.41 | 35.34 - 42.70 | 39.11 | 156.44 |
| | 194 | 1 | 5 | 3.05 - 8.23 | 5.79 | 0.11 - 29.87 | 7.32 | 36.59 |
| | 198 | 1 | 6 | 4.27 - 6.71 | 4.83 | 0.01 - 35.00 | 7.19 | 43.15 |

was 35.6 rkm upstream and 16.1 rkm downstream. Average depths for all relocations of tagged sturgeon were 4.95 m in 2011 and 6.37 m in 2012. For 2011, section usage was highest in section 1 for period 1 (79%) and period 2 (97%) with a total section usage of 88%. Total section usage was 10% for section 2 and 1% for section 3. The maximum and minimum distance traveled by tagged lake sturgeon during 2011 was 89.38 km and 0.02 km, respectively. For 2012, section usage was highest in section 1 for period 1 (76%) and period 2 (67%), with a total section usage of 71%. Total section usage was 10% for section 2 and 18% for section 3. The maximum and minimum distance traveled by tagged lake sturgeon in 2012 was 95.38 km and 0.01 km, respectively. Average distance traveled post-stocking was 22.88 km for 2011 and 34.02 km for 2012.

Minimum annual stocking rates necessary to reach an adult population of 750 fish (Welsh et al. 2010) were estimated from model parameters listed in Table 1. The estimated minimum annual stocking rate for lake sturgeon with zero emigration from Cheatham Lake was 1,770. The estimated minimum annual stocking rates would be 1,770, 2,456 and 48,778 at 0%, 1%, and 10% emigration rates when applied equally over 40 years of stocking. At minimum annual stocking rates of 1,770, 2,456 and 48,778 the estimated number of adult fish at age 20 was 57, 62 and 116 at a 0%, 1% and 10% emigration rate, respectively. The estimated number of adult fish at age 20 was 3,339, 2,887, and 692 at a 0%, 1%, and 10% emigration rates with 10% spawning fraction after 40 years at the minimum annual stocking rates (Figure 3). The estimated number of adult fish at age 20 increases to 6,618, 5,707, and 1,247 at a 0%, 1%, and 10% emigration rates with 20% spawning fraction after 40 years at the minimum stocking rates (Figure 3). At

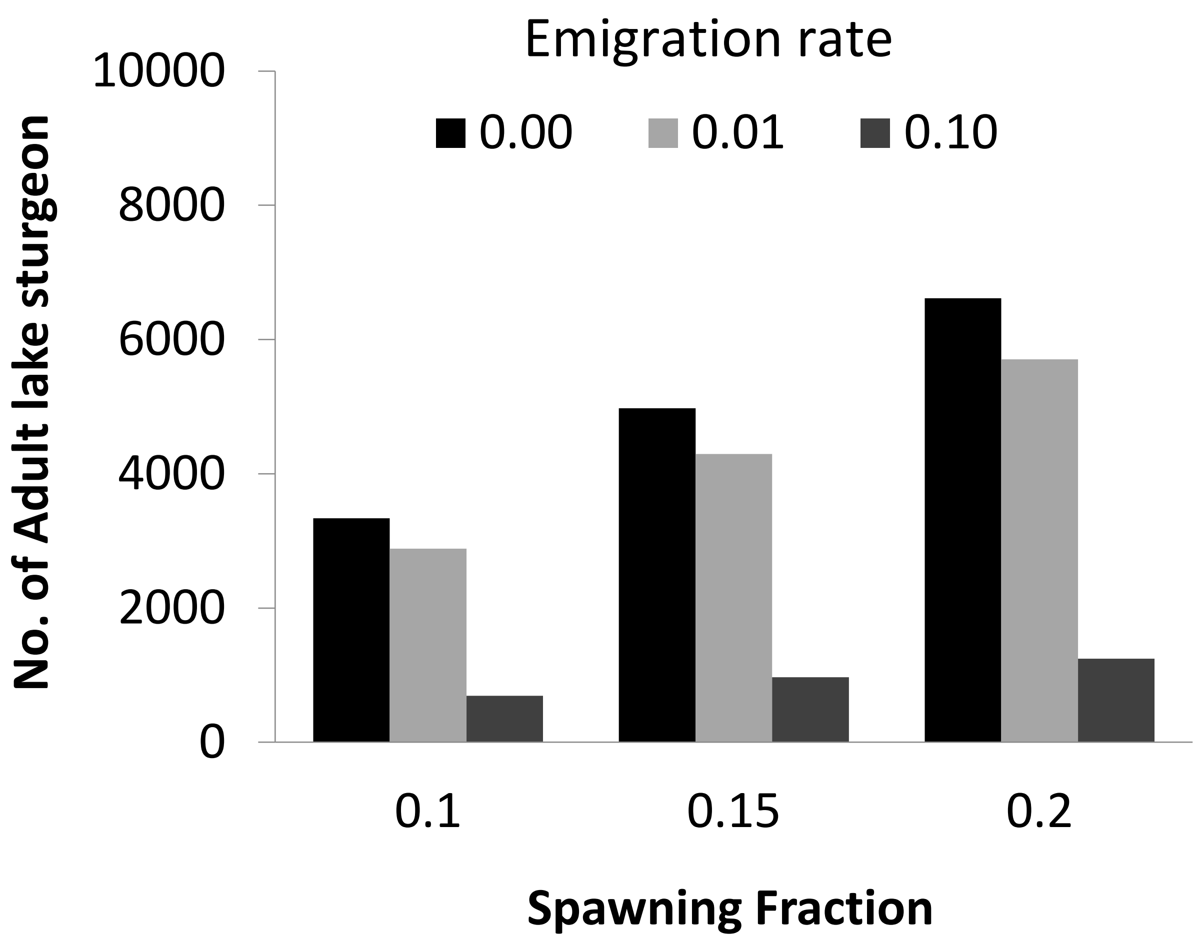


Figure 3. Number of adult lake sturgeon at age 40 from initial stocking and reproduction after 40 years with various reproduction and emigration rates applied.

the minimum stocking rate the estimated number of adult lake sturgeon after 40 years would increase 44%, with a 10% change in the spawning fraction (Figure 3).

# DISCUSSION

Lake sturgeon populations in North American prior to mid-1990 were either below peak productivity levels or extirpated entirely from their home ranges (Pikitch et al. 2005; Haxton and Findley 2008). By the mid 1990's, most State agencies in cooperation with the U.S. Fish and Wildlife Service (USFWS) were creating regulatory, recovery, and reintroduction management plans (Auer 1996a). With any recovery plan, stocking is the major component and states that do not have spawning stocks need to develop partnerships with state and federal agencies that do have spawning stocks. Recent studies of lake sturgeon populations throughout its range have provided basic demographic information needed to quantify minimum stocking rates with an age-classified matrix projection model. However, in Tennessee specific information on migration through main stem impoundments was missing and needed to be investigated. Upstream or downstream passage of fish through CDL and OHLD can occur by way of turbines, spillway gates, and locks. The study design used herein did not focus on the specifics of each passage event, but only that passage occurred and at what rate. However, upstream passage through CDL and OHLD was restricted to locks because spillway gates were at least 1 m above the downstream water elevation for both years during this study. Nichols and Louder (1970) documented upstream lock passage of anadromous (American shad, alewife, blueback herring and striped bass) and resident (carp, longnose gar, and white catfish) fish species through dams on the Cape Fear River, North Carolina. Movement of sauger upstream through Pickwick Lock and Dam was detected by Pegg et al. (1997). Downstream passage and survival of juvenile and adult salmonids through turbines and spillway gates has been shown to occur on the Snake

River, Washington (Muir et al. 2001; Evans et al. 2008). Parsley et al. (2007) documented 69% downstream passage of white sturgeon through spillway gates at the Dalles Dam, Columbia River. Lake sturgeon had a 91 % survival rate and a 64% passage rate through bottom-draw regulating sluices at Slave Falls Generating Station on the Winnipeg River, Manitoba (McDougall et al. 2014). Simcox et al. (2015) documented 8% of all tagged paddlefish moved upstream through Miller Ferry and Claiborne Locks and Dams, Alabama River. Lake sturgeon emigration from Cheatham Reservoir occurred at a high annual rate in 2011 and 2012, 65% and 38% respectively. Although annual estimates of fish passage were not evaluated in relationship to discharge and/or lockage events, most passage occurred during high flows from January through June with 59% and 34% in 2011 and 2012, respectively. Zigler et al. (2004) found that both upstream and downstream passage of paddlefish increased with higher flows. Both CDL and OHLD have high annual lockage rates due to the high volume of recreational and commercial barge traffic on the Cumberland River. Average lockage rates from 2010 through 2014 were 1,829 and 2,557 at CDL and OHLD, respectively. During 2012 a total of 2,412 lock events occurred at OHLD with 1,370 of those being upstream lock events.

The abiotic and biotic factors affecting preferred habitat use, location, timing and spawning of lake sturgeon in Tennessee has yet to be identified. However, aggregate/riprap below OHLD is the presumed spawning area for lake sturgeon in Cheatham Reservoir. Spawning occurs in Wisconsin over riprap (>152 mm) in late April through early May during high flows (WIDNR 2000). Kempinger (1988) stated that large aggregate/riprap provided increase surface area for attachment and aided in concealment of fertilized sturgeon eggs from predators. Also, clean substrate and egg dispersal were evident at high flows (Chiotti et al. 2008). A water temperature range of 8.5$^{o}$C to 21.5$^{o}$C has been observed during spawning periods for lake sturgeon in Canada and the U.S. (Kempinger 1988; LaHaye et al. 1992; Auer 1996b). In this study, usage was higher in section 1 and could be the first indication that sturgeon preferred areas closer to OHLD in Cheatham Reservoir. A minimum base flow from OHLD of 53.6 $m^3/s$ in April and 138.8 $m^3/s$ in May (USACE 2016) could maintain the necessary minimum flows for spawning in future years. Lake sturgeon spawning has occurred at water velocities as low as 0.34 $m^3/s$ to 1.32 $m^3/s$ on average in the Big Manistee River, Wisconsin (Chiotti et al. 2008). Water flows below Prickett Dam of 7.5 $m^3/s$ to 59.2 $m^3/s$ are conducive to spawning on the Sturgeon River in Michigan (Auer 1996b). Drift of larval lake sturgeon occurs at distances from14 to 45 rkm below Prickett Dam on the Sturgeon River, Michigan (Auer and Baker 2002). Average discharge during June for OHLD from 2010 through 2012 ranged between 101.3 $m^3/s$ to 744.6 $m^3/s$ and could provide sufficient flow for larval drift.

Annual stocking and future populations estimates used in state recovery plans need to be guided by project goals and objectives. The advent of matrix models created by Leslie (1945) has allowed biologists to quantitatively estimate future populations with limited demographic data (Heppel et al. 2000). The key life history characteristics needed to create a simple age-classified matrix model is survival (e.g., young-of-year, yearling, juvenile and adult), age at maturity, mean annual fertility estimates, and reproductive rates (Caswell 2000). For example, VeLez-Espino and Koops (2009) used a stage-structured matrix population model to assess the recovery potential of lake sturgeon in Canada, and Heppell et al. (2000) used a simple age-classified matrix projection model for mammals in the United States. Using a 0.01% emigration rate, 10% spawning fraction, and a yearly stocking rate of 2,456, the estimated number of adult fish at age 20 after 40 years would be 2,887 adult lake sturgeon. This would represent a significant increase from the initial number of adults at 20 years (n=62). A stocking rate of 2,456 is probably a more realistic minimum stocking rate since a 0% and 10% emigration rate and a spawning fraction higher than 10% are probably unlikely. Although model projections are not always exact, the high number of adult fish suggests, that under model conditions a viable population of lake sturgeon can be obtained.

This project is a significant first step in characterizing the ability of lake sturgeon to migrate through USACE dams on the Cumberland River and adds to the current body of knowledge about lake sturgeon movements in highly regulated river systems. These migratory patterns may enhance model parameters that could shed light on within and between reservoir movements and allow for higher predictability of projection models. Also, substrate mapping will be a key component in identifying preferred habitat for young-of-year and juveniles that would assist in characterizing habitat suitability models in Cheatham Reservoir. Finally, movement patterns and the identification of essential habitat could assist biologists in creating management recommendation to the USACE on lockage and discharge rates that could aid upstream and downstream movement during key migration events.

# REFERENCES

Auer, N. A. 1996a. Importance of habitat and migration to sturgeons with emphasis on lake sturgeon. Canadian Journal of Fish Aquatic Sciences 53(Supplement 1):152–160.

Auer, N. A. 1996b. Response of spawning lake sturgeons to change in hydroelectric facility operation. Transactions of the American Fisheries Society 125:66–77.

Auer, N. A., and E. A. Baker. 2002. Duration and drift of larval lake sturgeon in the Sturgeon River, Michigan. Journal of Applied Ichthyology 18:557–564.

Bettoli, P. W., G. D. Scholten, and D. W. Hubbs. 2010. A system for anchoring submersible ultrasonic receivers in rivers.  North American Journal of Fisheries Management 30:989– 992.

Bruch, R. M., G. Miller, M. J. Hansen. 2006. Fecundity of lake sturgeon (*Acipenser fulvescens*, Rafinesque) in Lake Winnebago, Wisconsin, USA.  Journal of Applied Ichthyology 22:516-521.

Caswell, H. 2000. Matrix population models: construction, analysis and interpretation, Second edition. Sinauer, Sunderland, Massachusetts.

Collier, W. R., P. W. Bettoli, and G. D. Scholten. 2001. Dispersal and dam passage of sonic-tagged juvenile lake sturgeon in the Upper Tennessee River. Proceedings Annual Conference Southeastern Association Fish and Wildlife Agencies 65:143-147.

Cooke, S. J., C. M. Woodley, M. B. Eppard, R. S. Brown, and J. L. Nielsen. 2011. Advancing the surgical implantation of electronic tags in fish: a gap analysis and research agenda based on a review of trends in intracoelomic tagging effects studies. Reviews in Fish Biology and Fisheries 21:127-151.

Crossman, J. A., P. S. Forsythe, E. A. Baker, and K. T. Scribner. 2009. Overwinter survival of stocking age-0 lake sturgeon. Journal of Applied Ichthyology 25:516-521.

Caroffino, D. C., T. M. Sutton, R. F. Elliot, and M. C. Donofrio. 2010. Early life stage mortality rates of lake sturgeon in the Peshtigo River, Wisconsin. North American Journal of Fisheries Management 30:127-151.

Evans A. F., R. H. Wertheimer, C. T. Boggs, C. A. Peery and K. Collins. 2008. Transportation of steelhead kelts to increase iteroparity in the Columbia and Snake Rivers. North American Journal of Fisheries Management 28:1818–1827.

Haxton, T. 2003. Movement of lake sturgeon, *Acipenser fulvescens*, in a natural reach of the Ottawa River. The Canadian Field-Naturalist 117:541-545.

Haxton, T. J., and C. S. Findley. 2008. Variation in lake sturgeon (*Acipenser fulvescens*) abundance and growth among river reaches in a large regulated river. Canadian Journal of Fisheries and Aquatic Sciences 65:645–657.

Heppell, S. S., H. Caswell, and L. B. Crowder 2000. Life histories and elasticity Patterns: perturbation analysis for species with minimal demographic data author. Ecology 81:654-665.

Huddleston, M. D. 2006. Dispersal, persistence, and areas of core use of reintroduced juvenile lake sturgeon in the upper Tennessee River system. M. S. thesis, University of Tennessee, Knoxville, Tennessee. 147 pp.

Jepsen N., C. Schreck, S. Clements, and E. B. Thorstad. 2005. A brief discussion of the 2% tag/bodymass rule of thumb. In: Spedicato MT, Lembo G, Marmulla G (eds) Aquatic telemetry: advances and applications. FAO/COISPA, Rome, Italy, pp 225–260.

Kempinger, J. J. 1988. Spawning and early life history of lake sturgeon in the Lake Winnebago system, Wisconsin. Pages 110–122 in R. D. Hoyt, editor. 11th annual larval fish conference. American Fisheries Society, Symposium 5, Bethesda, Maryland.

Kessel, S. T., S. J. Cooke, M. R. Heupel, N. E. Hussey, C. A. Simpfendorfer, S. Vagle, and A. T. Fisk. 2014. A review of detection range testing in aquatic passive acoustic telemetry studies. Reviews in Fish Biology and Fisheries 24:199-218.

Knights, B. C., J. M. Vallazza, S. J. Zigler, and M. R. Dewey. 2002. Habitat and movement of lake sturgeon in the upper Mississippi River system, USA. Transactions of the American Fisheries Society 131:507–522.

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

Martin, R., and J. B. Layzer. 2001. Movements, habitat use, and survival of captive-reared lake sturgeon (*Acipenser fulvescens*) released into the upper Tennessee River system. M.S. thesis, Tennessee Technological University, Cookeville, Tennessee. 68 pp.

McDougall, C. A., W. G. Anderson, and S. J. Peake. 2014. Downstream passage of lake sturgeon through a hydroelectric generating station: route determination, survival, and fine-scale movements. North American Journal of Fisheries Management 34:546-558.

Medwin, H., and C. S. Clay. 1998. Fundamentals of acoustical oceanography. Academic Press, New York, pp. 712.

Muir, W. D., S. G. Smith, J. G. Williams, and B. P. Sandford. 2001. Survival of juvenile Salmonids passing through bypass systems turbines, and spillways with and without flow deflectors at Snake River dams. North American Journal of Fisheries Management 21:135-146.

Nichols P. R., and D. E. Louder. 1970. Upstream passage of anadromous fish through navigation locks and use of stream for spawning and nursery habitat in the Cape Fear River, N.C., 1962-66. United States Department of the Interior. U. S. Fish and Wildlife Service technical report No 352.

North, J. A., R. C. Beamesderfer, and T. A. Rien. 1993. Distribution and movements of white sturgeon in three lower Columbia River reservoirs. Northwest Science 67:105–111.

Pegg, M. A., P. W. Bettoli, and J. B. Layzer. 1997. Movement of saugers in the lower Tennessee River determined by radio telemetry, and implications for management. North American Journal of Fisheries Management 17: 763-768.

Pikitch, E. K., P. Doukakis, L. Lauck, P. Chakrabarty, and D. L. Erickson. 2005. Status, trends and management of sturgeon and paddlefish fisheries. Fish and Fisheries 6:233-265.

Pincock, D. G. 2012. False detections: what they are and how to remove them from detection data. Vemco, Halifax, Nova Scotia, Canada. Available: www.vemco.com/pdf/false_detections.pdf/. (DOC-004691 Version 03).

Parsley, M. J., C. D. Wright, B. K. van der Leeuw, E. E. Kofoot, C. A. Peery and M. L. Moser. 2007. White sturgeon (*Acipenser transmontanus*) passage at the Dalles Dam, Columbia. Journal of Applied Ichthyology. 23:627-635.

Schueller, A., and D. Hayes. 2011. Minimum viable population size for lake sturgeon using an individual based model of demographics and genetics. Canadian Journal of Fisheries and Aquatic Sciences 68:62–73.

Southeastern Lake Sturgeon Working Group (SELSWG). 2014. Management plan for restoration of the upper Tennessee River lake sturgeon population.

Shaw, S. L., S. R. Chipps, S. K. Windels, M. A. H. Webb, D. T. McLeod and D. W. Willis. 2012. Lake sturgeon population attributes and reproductive structure in the Namakan Reservoir, Minnesota and Ontario. Journal of Applied Ichthyology. 28:168-175.

Simcox, B. L., D. R. DeVries, and R. A. Wright. 2015. Migratory Characteristics and Passage of Paddlefish at Two Southeastern U.S. Lock-and-Dam Systems. Transactions of the American Fisheries Society 144:456-466.

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

Summerfelt, R. C., and L. S. Smith. 1990. Anesthesia, surgery, and related techniques. Pages 213-263 in C. B. Schreck and P. B. Moyle, editors. Methods for fish biology. American Fisheries Society, Bethesda, Maryland.

USACE (US Army Corp of Engineers). 2016. Old hickory lake master plan. NR 16-004, Nashville, TN.

Wagner, G. N., S. J. Cooke, R. S. Brown, and K. A. Deters. 2011. Surgical implantation techniques for electronic tags in fish. Reviews in Fish Biology and Fisheries 21:71-81.

Welsh, A., R. Elliott, K. Scribner, H. Quinlan, E. Baker, B. Eggold, J. Holtgren, C. Krueger, and B. May. 2010. Genetic guidelines for the stocking of lake sturgeon (*Acipenser fulvescens*) in the Great Lakes basin. Great Lakes Fishery Commission Miscellaneous Publication 2010-01.

Wisconsin Department of Natural Resources (WIDNR). 2000. Wisconsin's Lake Sturgeon Management Plan. Bureau of fisheries management and habitat protection. Available: www.dnr.wi.gov/topic/fishing/documents/sturgeon/lsturmplan_eversion.pdf/. (May 2005).

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