LAKE STURGEON REINTRODUCTION IN THE

COOSA RIVER SYSTEM, GEORGIA – ALABAMA

by

JUSTIN DAVID BEZOLD

Under direction of Douglas L. Peterson

ABSTRACT

Lake sturgeon were extirpated from the Coosa River System during the 1970's, after years of anthropogenic influence. In 2002, the GADNR began a long-term reintroduction program with the first annual stocking of lake sturgeon in the Coosa. From March 2004 to March 2007, I collected data on age, growth, and habitat use to assess reintroduction efforts. I also collected data on naïve and naturalized fish performance in a radio-telemetry study. Survival of stocked fish was low, but fish from each cohort have recruited to the juvenile population. Coosa lake sturgeon are in relatively good condition, but fish growth is slower compared to northern populations. Habitat use is consistent with previous reports, but summer water quality limits habitat availability in the Coosa. Naturalized lake sturgeon outperformed naïve fish in the telemetry study. The reintroduction is an initial success but many more years of data are required before complete success is determined.

Index word: reintroduction, lake sturgeon, Coosa River, native fish

LAKE STURGEON REINTRODUCTION IN THE

COOSA RIVER SYSTEM, GEORGIA – ALABAMA

by

Justin David Bezold

B.S., The University of Vermont, 2003

A Thesis Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE

ATHENS, GEORGIA

2007

LAKE STURGEON REINTRODUCTION IN THE

COOSA RIVER SYSTEM, GEORGIA – ALABAMA

by

Justin David Bezold

Major Professor: Douglas Peterson

Committee: James Peterson
John Maerz

Electronic Version Approved:

Maureen Grasso
Dean of the Graduate School
The University of Georgia
August 2007

DEDICATION

This thesis is dedicated to my parents, David and Linda Bezold, for guiding me through life and providing me with more knowledge than any university ever could, and to my siblings, Aby, Rosie, and Wini, for their support and comfort throughout my endeavors. Finally, thank you Orvis and Heidi for your unconditional love.

ACKNOWLEDGEMENTS

I would like to thank Doug Peterson for his guidance and the opportunity to advance my understanding of fisheries science. I would also like to thank James Peterson and John Maerz for their continued support and guidance throughout my process. A special thank you goes to David Higginbotham, for whom without I may have lost my sanity and never have eaten lunch. A very special thank you goes to all my fellow students and my technicians, who contributed to my success in innumerable ways.

TABLE OF CONTENTS

Page

CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

Lake sturgeon (*Acipenser fulvescens*) are one of the oldest, long-lived, and exploited fish in North American history (Auer 1999; Peterson et al. 2007). Similar in physical appearance to sharks, they display many primitive morphological characteristics including heterocercal tails, a cartilaginous skeleton, and body armoring (scutes) (Scott and Crossman 1973; Becker 1983). Despite their differences with modern fishes, lake sturgeon had existed in large numbers in their natural environment; however, during the westward expansion of settlers, lake sturgeon populations suffered precipitous declines due to anthropogenic influences, such as overfishing, pollution, and habitat destruction (Harkness and Dymond 1961; Priegel and Wirth 1971; Auer 2003). In northern reaches of their historic range, larger populations and early conservation measures allowed lake sturgeon to persist despite anthropogenic pressures (Bruch 1999; Peterson et al. 2007). However, in southern portions of their range, populations were smaller and environmental conditions more variable. As a result, habitat degradation and other anthropogenic influences caused the extirpation of the species in many systems (Etnier and Starnes 1993).

In northwestern Georgia, lake sturgeon were extirpated from the Coosa River sometime during the 1970's; the last specimen was documented in 1967 (Smith-Vaniz 1968; Dahlberg and Scott 1971). Since then, the major problems that contributed to this extirpation have been remedied through a ban on harvest, improved water quality as a result of the Clean Water Act of 1972, and better land-use practices (Johnson et al., 2002). Because of these improvements, the

Georgia Department of Natural Resources (GADNR) decided to reintroduce lake sturgeon to the Coosa River system beginning in 2002 with an initial stocking of 1,100 hatchery-reared fingerlings. Subsequent releases have been dependent on the number of fingerlings produced by the GADNR Summerville Fish Hatchery. Ultimately, the GADNR hopes to restore the Coosa River stock by re-establishing a self-sustaining population through a long-term stocking program (Beisser, GADNR personal communication).

Most southern lake sturgeon populations were extirpated before they could be studied; consequently, many key life history aspects of southern stocks remain unknown (Peterson et al. 2007). The GADNR reintroduction program presented a unique opportunity to examine life history traits and population dynamics of the species at the southern extreme of their historic range. In chapter two, I present (in manuscript style) primary research objectives; 1. investigating seasonal movements and habitat use, 2. post-stocking survival, 3. population abundance, and 4. annual growth of juvenile lake sturgeon in the Coosa River System. I present a second manuscript, chapter three, comparing the survival and post-stocking movements of naïve (stocked without river acclimation) and naturalized (>18 months post-stocking acclimation). Finally, I conclude with remarks on the relative success of the reintroduction program and methods for the potential improvement of the program.

Life History

The lake sturgeon is a large, long-lived, late maturing species with high fecundity (Harkness and Dymond 1961; Priegel and Wirth 1971). Adults may reach a TL in excess of 200 cm and weigh >45 kg (Harkness and Dymond 1961; Scott and Crossman 1973). The oldest recorded age of a lake sturgeon is 154 years (MacKay 1963), and many lake sturgeon older than 50 years have been documented (Priegel and Wirth 1971). Females typically spawn once every

4-7 years, whereas males spawn every 2nd or 3rd year (Harkness and Dymond 1961; Priegel and Wirth 1971; Scott and Crossman 1973; Becker 1983). Female lake sturgeon typically mature at 14 to 25 years and males at 12 to 20 years (Harkness and Dymond 1961; Priegel and Wirth 1971; Scott and Crossman 1973; Becker 1983; Etnier and Starnes 1993). Their late age at maturation also results in an unusually large size, and hence higher fecundity at maturity compared to other freshwater fishes (Beamish et al. 1996). A large female may produce nearly three million eggs at spawning but 0.8 to 1.0 million eggs is more typical (Etnier and Starnes 1993).

Lake sturgeon are potomodromous, completing their entire life-cycle in large freshwater systems and typically spawning in natal tributary streams (Harkness and Dymond 1961; Priegel and Wirth 1971; Scott and Crossman 1973; Becker 1983). As lake sturgeon migrate to spawning grounds, the distances seldom exceed 400 km (Scott and Crossman 1973). Spawning typically occurs in fluvial environments, but they've been documented spawning in well oxygenated, 12 – 18 C water over clean, rocky substrates in lacustrine systems (Harkness and Dymond 1961; Scott and Crossman 1973; Becker1983). As spawning takes place, females disperse eggs over several days and locations, and males fertilize eggs after extrusion (Harkness and Dymond 1961; Priegel and Wirth 1971). The period of incubation is determined by water temperature, but maximum incubation estimates are 8 d at 12 C (Harkness and Dymond 1961). After hatching, the larvae deplete their yolk-sacs in 12-14 d, at which time they begin exogenous feeding as fully developed juveniles (Priegel and Wirth 1971).

Etnier and Starnes (1993), Fortin et al. (1996), and Mettee et al. (1996) suggest that lake sturgeon may reach maturity much sooner in southern populations due to the potential for increased growth rates possible in a longer growing season. However, often when researchers refer to a "southern" population of lake sturgeon, the geographic location of the population is southern Canada or the southern Great Lakes region (Fortin et al. 1996; Power and McKinley 1997). Although, there is no existing evidence supporting or refuting this theory for lake sturgeon in the southern U.S, but southern populations of shortnose sturgeon (*Acipenser brevirostrum*) typically mature at 3-6 years, while those from northern populations mature between 12-18 years of age (Dadswell et al. 1984; Bain 1997; Kynard 1997).

Habitat Use

Habitat use of lake sturgeon varies depending on habitat availability and specific ontogenetic requirements of each life stage, but may include rivers, lakes, and freshwater estuaries areas (Scott and Crossman 1973; Auer 1996a). Juveniles seem to utilize sand substrates where soft bodied invertebrate prey are abundant (Becker 1983; Kempinger 1996; Chiasson et al. 1997; Peake 1999), and they typically inhabit lotic and lentic environments, with no clear preference for either environment (Smith and King 2005). Adults use a wide range of depths, but are not commonly found in extremely deep waters with low current velocities (Rusak and Mosindy 1997; Borkholder et al. 2002). For both juveniles and adults, water temperature appears to become a factor in habitat preference as temperatures approach upper and lower thermal tolerances (Peake 1999).

The use of particular habitats as feeding grounds by lake sturgeon has not been well documented; however, Werner and Hayes (2005) suggest that adults prefer coarser substrates where they may find larger prey. If correct, this assertation may suggest that juveniles may prefer finer substrates that contain smaller prey (Chiasson et al. 1997; Threader 1998; Nilo et al. 2006; Werner and Hayes 2005). Boase et al. (2005) and Werner and Hayes (2005) found that adults and juveniles are often found together in certain habitat types; however, there is no evidence to suggest that the two compete for the same prey (Werner and Hayes 2005).

Habitat selection by adult and juvenile lake sturgeon is thought to be dependent on season (Rusak and Mosindy 1997; Knights et al. 2002; Werner and Hayes 2005); additionally, habitat selection may be a result of seasonal shifts in prey availability (Werner and Hayes 2005). Small shifts in adult habitat selection often occur in areas of relatively deep, cool water over coarse substrates (Becker 1983; Knights et al. 2002), which are thought to comprise the best available habitat seasonally (Rusak and Mosindy 1997; Knights et al. 2002). Shifts in juvenile habitat use may be linked to increased body size and changing prey preferences (Werner and Hayes 2005); although, juveniles in the Tennessee River System appear to select habitat on a seasonal basis (Martin 2001). Overall, very few studies have described the seasonal habitat use of juvenile lake sturgeon (Peterson et al. 2007). One notable exception is the work of Martin (2001) that describes general patterns of habitat use in the Tennessee River; however, the author was unable to monitor seasonal habitat use of individual fish for an entire year, so inferences are limited.

Movements

Numerous studies have shown that adult lake sturgeon typically establish well defined home ranges, but little is known about seasonal movements of juveniles (Harkness and Dymond 1961; Priegel and Wirth 1971; Becker 1983; Knights et al. 2002; Martin 2001). While spawning adults often migrate long distances from their home range (Fortin et al. 1993; Rusak and Mosindy 1997; Knights et al 2002), several authors have suggested that juveniles also may establish home ranges; however, supporting evidence is lacking because previous studies have not monitored a single group of individual fish throughout an entire year (Martin 2001; Werner and Hayes 2005; Smith and King 2005; Lord 2007).

Many studies have characterized spawning migrations of adult lake sturgeon and found that adults may move extensive distances to reach their natal waters (Harkness and Dymond

1961; Priegel and Wirth 1971; Borkholder et al. 2002; Peterson et al. 2007). Borkholder et al. (2002) found that non-spawning adults moved freely throughout the Kettle River, MN according to discharge fluctuations throughout the year. Similar conclusions were reached by several authors (Auer 1996b; Rusak and Mosindy 1997; Knights et al. 2002) who suggest that adult movements in large northern rivers vary depending on seasonal changes in discharge. Similar behavior has been observed in the shovelnose sturgeon, which is also an inhabitant of large river systems (Hurley et al. 1987; Curtis et al. 1997).

Studies of juvenile movement patterns are limited in availability, but are considered crucial to the successful protection and management of the species throughout its range (Auer 2003; Peterson et al. 2007). Martin (2001) suggests that stocked juveniles are highly mobile and may move up to 10 km/d during fall and spring months. Smith and King (2005) and Lord (2007) also suggest that juveniles are highly mobile but provide no information about seasonal movements beyond late spring and summer. By describing juvenile movements, lake sturgeon management may become more efficient and effective.

Growth

A key aspect of lake sturgeon life history is illustrated by the drastic changes in growth that accommodate the various ontogenetic stages of their life cycle. Early studies by Harkness and Dymond (1961) and Priegel and Wirth (1971) suggest that juvenile growth is characterized by a rapid increase in length during the first 5 years of life, followed by slower, more allometric growth thereafter. More recent studies have focused on closely documenting this shift, particularly by demonstrating growth pattern shifts associated with sexual maturity (Beamish et al. 1996; Fortin et al. 1996).

Throughout their historic range, lake sturgeon growth rates are highly variable and dependent on environmental parameters, such as water temperature and food quality (Priegel and Wirth 1971; Scott and Crossman 1973; Fortin et al. 1996; Chiasson et al. 1997; Power and McKinley 1997; Volkman et al. 2004). Several authors, Beamish et al. (1996), Fortin et al. (1996), and Power and McKinley (1997) suggest that lake sturgeon growth rates may increase as latitude decreases and mean annual water temperatures increase. However, none of these studies provide data from lake sturgeon populations south of the Great Lakes region, where the species was largely extirpated by the mid-1900's (Power and McKinley 1997). Nonetheless, latitudinal comparisons of growth for other sturgeon species, such as shortnose sturgeon support the theory that growth is negatively correlated with latitude (Dadswell et al. 1984; Gilbert 1989). Although this relationship may be used to predict sizes of southern lake sturgeon based on measures from northern stocks, Power and McKinley (1997) suggest that other thermal effects should be considered when estimated growth and condition of southern lake sturgeon. Conover (1990) demonstrated that excessively high water temperatures may limit fish growth for some species found in southern waters, and that growing conditions in the south are sub-optimal compared to conditions in more northerly portions of a species range. Hence, potential thermal limitations to growth may be critical in accurately predicting lake sturgeon growth in southern systems (Fortin et al. 1996; Power and McKinley 1997).

Historical Abundance and Exploitation

The historic range of lake sturgeon included the Mississippi, Great Lakes, and Hudson Bay drainages, and extended south to the Coosa River system in northwest Georgia (Priegel and Wirth 1971; Scott and Crossman 1973; Becker 1983; Mettee et al. 1996); however, pre-European settlement abundances are unknown. As such, relative abundance estimates (using catch-per-unit-effort) are often derived from commercial landings as a guide for restoration efforts (Harkness and Dymond 1961; Hay-Chmielewski and Whelan 1997). Estimates of historic relative abundances are often derived using catch-per-unit-effort, which likely overestimate populations because the fish were targets of intense fishing pressure; alternatively, estimates of historic distribution and relative abundances prior to commercial fishing may be underestimated due to extirpation or general apathy towards the fish (Hay-Chmielewski and Whelan 1997).

Lake sturgeon were once widely exploited throughout their range. Prior to westward expansion of European immigrants, lake sturgeon supported numerous subsistence fisheries of Native Americans (Harkness and Dymond 1961; Priegel and Wirth 1971). Ironically, European fisherman initially regarded lake sturgeon as a nuisance that often damaged gear deployed for other species (Tody 1974). Because large lake sturgeon could easily damage commercial fishing gear, settlers began intentionally removing lake sturgeon from systems during the early 1800's to protect fishing gear (Harkness and Dymond 1961; Priegel and Wirth 1971). During this period, settlers disposed of lake sturgeon carcasses by burning them, turning them into fertilizer, and feeding them to livestock (Harkness and Dymond 1961; Priegel and Wirth 1971; Scott and Crossman 1973; Becker 1983).

As a commercial market for the lake sturgeon developed in the late 1800's, public perception shifted and many populations were targeted by commercial fishing operations (Harkness and Dymond 1961; Priegel and Wirth 1971; Peterson et al. 2007). In New York, over 1,500 tons were harvested from Lake Erie in 1885 and 254 tons from Lake Ontario in 1879 (Carlson 1995). In Missouri, over 25 tons of lake sturgeon were harvested from the Missouri and Mississippi rivers in 1894 alone (Pflieger 1997). In Lake of the Woods, commercial fishing began in 1888 and by 1915 the fishery had collapsed (Holzkamm and McCarthy 1988). In

Canada, abundant catches also were reported as commercial popularity for lake sturgeon increased (Harkness and Dymond 1961). In the southern U.S., small populations supported subsistence fisheries but only anecdotal evidence exists supporting southern commercial fisheries (Beisser GADNR, personal communication). As a result of commercial fishing, lake sturgeon experienced severe population declines and localized extirpation (Tody 1974; Hay-Chmielewski and Whelan 1997).

Reintroductions

Recently, the release of hatchery-reared fish has become a popular method of re-establishing extirpated species (Schram et al. 1999; Mueller and Wydoski 2004; Drauch and Rhodes Jr. 2007). Reintroduction efforts often use remnant stocks as brood sources or when these are unavailable closely related fish serve as broodstock (Shute et al. 2005; Drauch and Rhodes Jr. 2007). However, habitat remediation and removal of mechanisms that lead to the decline of the species are critical for a successful reintroduction (Peterson et al. 2007). For lake sturgeon, bans on commercial fishing, improved water quality, and habitat protection have facilitated reintroduction programs in several states (Peterson et al. 2007). As such, reintroduction or restoration programs are currently underway in Missouri, Tennessee, Georgia, and the Great Lakes region (Peterson et al. 2007). Near Lake Superior, the St. Louis River received annual releases of lake sturgeon throughout the 1990's as part of the collaborative reintroduction efforts by WI-MN (Schram et al. 1999). The resulting increase in juvenile abundance documented since the program began, suggests that the effort has been a success; however, Schram et al. (1999) suggests that long-term monitoring is required to assess the ultimate success of the program. On Oneida Lake, New York, increases in juvenile lake sturgeon abundance have been documented after only 5 years of stocking (Jackson et al. 2002).

In Missouri and Tennessee, quantification of reintroduction efforts has been difficult because of the large size of the target rivers in these states; however, increased catches of lake sturgeon in commercial fisheries suggests that these programs may also be successful (B. Todd, Missouri Department of Conservation, personal communication). In Georgia, lake sturgeon reintroduction efforts began in 2002 with a 20 year GADNR commitment to the continued annual stocking of the Coosa River (Beisser GADNR, personal communication). Because no lake sturgeon were present in Georgia when the GADNR began their reintroduction effort, the mere presence at any level of lake sturgeon abundance could be seen as a positive result. However, the determining success of re-establishing a self-sustaining population may require many years, if not decades, of research. Because their unique life history, lake sturgeon reintroductions require long-term monitoring (>20 years) to fully evaluate program success (Hay-Chmielewski and Whelan 1997; Schram et al. 1999). Beamesderfer and Farr (1997) suggest that monitoring efforts should focus on identification of individual cohorts, determination of post-stocking survival rates, and assessment of relative population and individual health. Additionally, reintroduction in the southern portions of the species ranges may provide a unique opportunity to address critical information gaps regarding habitat use, movements, growth, and ecology.

References

Auer, N.A. 1996a. Importance of habitat and migration to sturgeons with emphasis on lake sturgeon. Canadian Journal of Fisheries and Aquatic Sciences 53:152-160.

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. 1999. Population characteristics and movements of lake sturgeon in the Sturgeon River and Lake Superior. Journal of Great Lakes Research 25:282-293.

Auer, N.A. (ed.). 2003. A lake sturgeon rehabilitation plan for Lake Superior. Great Lakes Fisheries Commission Miscellaneous Publication. 2003-02, Ann Arbor, Michigan.

Bain, M.B. 1997. Atlantic and shortnose sturgeons of the Hudson River: common and divergent life history attributes. Evolutionary Biology of Fishes 48:347-358.

Beamesderfer, R.C.P., and R.A. Farr. 1997. Alternatives for the protection and restoration of sturgeons and their habitat. Environmental Biology of Fishes 48:407-417.

Beamish, F.W.H., J. Jebbink, A. Rossiter, and D.L.G. Noakes. 1996. Growth strategy of juvenile lake sturgeon (*Acipenser fulvescens*) in a northern river. Canadian Journal of Fisheries and Aquatic Sciences 53:481-489.

Becker, G.C. Lake Sturgeon. 1983. Pages 219-226 *in* Fishes of Wisconsin. The University of Wisconsin Press.

Boase, J., B. Manny, G. Kennedy, and M. Thomas. 2005. Evaluation of juvenile lake sturgeon. U.S. Fish and Wildlife Service Biological Report. Alpena, Michigan. 29 pp.

Borkholder, B.D., S.D. Morse, H.T. Weaver, R.A. Hugill, A.T. Linder, L.M. Schwarzkopf, T.E. Perrault, M.J. Zacher, and J.A. Frank. 2002. Evidence of a year-round resident population of lake sturgeon in the Kettle River, Minnesota, based on radiotelemetry and tagging. North American Journal of Fisheries Management 22:888-894.

Bruch, R.M. 1999. Management of lake sturgeon on the Winnebago System – long term impacts of harvest and regulations on population structure. Journal of Applied Ichthyology 15:142-152.

Carlson, D.M. 1995. Lake sturgeon waters and fisheries in New York state. Journal of Great Lakes Research 21:35-41.

Chiasson, W.B., D.L.G. Noakes, and F.W.H. Beamish. 1997. Habitat, benthic prey, and distribution of juvenile lake sturgeon (*Acipenser fulvescens)* in northern Ontario Rivers. Canadian Journal of Fisheries and Aquatic Sciences 54:2866-2871.

Conover, D.O. 1990. The relation between capacity for growth and length of growing season: evidence for and implications of countergradient variation. Transactions of the American Fisheries Society 119:416-430.

Curtis, G.L., J.S. Ramsey, and D.L. Scarnecchia. 1997. Habitat use and movements of shovelnose sturgeon in pool 13 of the upper Mississippi River during extreme low flow conditions. Environmental Biology of Fishes 50:175-182.

Dadswell, M.J., B.D. Taubert, T.S. Squiers, D. Marchette, and J. Buckley. 1984. Synopsis of biological data on shortnose sturgeon *Acipenser brevirostrum* LeSueur 1818. FAO Fisheries Synopsis #40. 45 pp.

Dahlberg, M. D. and D. C. Scott. 1971. The freshwater fishes of Georgia. Bulletin of the Georgia Acadamey of Science 29(1): 1-64.

Drauch, A.M. and O.E. Rhodes, Jr. 2007. Genetic evaluation of the lake sturgeon reintroduction program in the Mississippi and Missouri Rivers. North American Journal of Fisheries Management 27: 434-442.

Etnier, D.A., and W.C. Starnes. Lake Sturgeon. 1993. Pages 99-101 *in* The Fishes of Tennessee. The University of Tennessee Press.

Fortin, R., J.R. Mongeau, G. Desjardins, and P. Dumont. 1993. Movements and biological statistics of lake sturgeon (*Acipenser fulvescens)* populations from the St. Lawrence and Ottawa River system, Quebec. Canadian Journal of Zoology 71:638-650.

Fortin, R., P. Dumont, and S.Guenette. 1996. Determinants of growth and body condition of lake sturgeon (*Acipenser fulvescens)*. Canadian Journal of Fisheries and Aquatic Sciences 53:1150-1156.

Gilbert, C.R. 1989. Species Profiles: Life histories and environmental requirements of coastal fishes and invertebrates (Mid-Atlantic Bight) shortnose sturgeons. U.S. Fish and Wildlife Service Biological Report #82. 28pp.

Harkness, W.J., and J.R. Dymond. 1961. The lake sturgeon: the history of its fishery and problems of conservation. Ontario Department of Lands and Forest. Fish and Wildlife Branch. 121p.

Hay-Chmielewski, E.M., and G.E. Whelan. 1997. Lake sturgeon rehabilitation strategy. Michigan Department of Natural Resources Fisheries Division Special Report Number 18. 51p.

Holzkamm, T., and M. McCarthy. 1988. Potential fishery for lake sturgeon (*Acipenser fulvescens*) as indicated by the returns of the Hudson’s Bay Company Lac la Pluie District. Canadian Journal of Fisheries and Aquatic Sciences 45:921-923.

Hurley, S.T., W.A. Hubert, and J.G. Nickum. 1987. Habitats and movements of shovelnose sturgeons in the upper Mississippi River. Transactions of the American Fisheries Society 116:655-662.

Jackson, J.R., A.J. VanDeValk, T.E. Brooking, O.A. vanKeeken, and L.G. Rudstam. 2002. Growth and feeding dynamics of lake sturgeon, *Acipenser fulvescens,* in Oneida Lake, New York: results from the first five years of a restoration program. Journal of Applied Ichthyology 18:439-443.

Johnson, G.C., R.E. Kidd, C.A. Journey, H. Zappia, and J.B. Atkins. 2002. Environmental setting and water-quality issues of the Mobile River basin, Alabama, Georgia, Mississippi, and Tennessee. U.S. Geological Survey Water-Resources Investigations Reports 02-4162. 70p.

Kynard, B. 1997. Life history, latitudinal patterns, and status of the shortnose sturgeon, *Acipenser brevirostrum*. Environmental Biology of Fishes 48:319-334.

Lord, K. 2007. Movements and habitat use of juvenile lake sturgeon in the north channel of the St. Clair River. Masters Thesis. University of Michigan.

Kempinger, J.J. 1996. Habitat, growth, and food of young lake sturgeons in the Lake Winnebago system, Wisconsin. North American Journal of Fisheries Management 16:102-114.

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.

MacKay, H.H. 1963. Fishes of Ontario. Ontario Department of Lands and Forests. Bryant Press Limited, Toronto, Ontario.

Martin, R. 2001. Movements, habitat use, and survival of captive-reared lake sturgeon (*Acipenser fulvescens*) released into the upper Tennessee River system. Masters Thesis. Tennessee Tech. University.

Mettee, M.F., P.E. O'Neil, and J.M. Pierson. Lake Sturgeon. 1996. Pages 77-78 *in* Fishes of Alabama and the Mobile Basin.

Mueller, G. A., and R. Wydoski. 2004. Reintroduction of the flannelmouth sucker in the lower Colorado River. North American Journal of Fisheries Management 24:41-46.

Nilo, P., S. Tremblay, A. Bolon, J. Dodson, P. Dumont, and R. Fortin. 2006. Feeding ecology of juvenile lake sturgeon in the St. Lawrence River system. Transactions of the American Fisheries Society 135:1044-1055.

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

Peterson, D.L., P. Vecsei and C.A. Jennings. 2007. Ecology and biology of the lake sturgeon: a synthesis of current knowledge of a threatened North American *Acipenseridae*. Reviews in Fish Biology 17(1):59-76.

Pflieger, W.L. Lake Sturgeon. 1997. Pages 49-50 *in* The Fishes of Missouri. Missouri Department of Conservation.

Power, M., and R.S. McKinley. 1997. Latitudinal variation in lake sturgeon size as related to the thermal opportunity for growth. Transactions of the American Fisheries Society 28:175-182.

Priegel, G.R., and T.L. Wirth. 1971. The lake sturgeon: its life history, ecology, and management. Wisconsin Department of Natural Resources #240-70.

Rusak, J.A., and T. Mosindy. 1997. Seasonal movements of lake sturgeon in Lake of the Woods and the Rainy River, Ontario. Canadian Journal of Zoology 74:383-395.

Schram, S.T., J. Lindgren, and L.M. Evrard. 1999. Reintroduction of lake sturgeon in the St. Louis River, Western Lake Superior. North American Journal of Fisheries Management 19:815-823.

Scott, W.B., and E.J. Crossman. 1973. Lake sturgeon *in* Freshwater Fishes of Canada. Bulletin 184 Fisheries Research Board of Canada.

Shute, J.R., P.L. Rakes, and P.W. Shute. 2005. Reintroduction of four imperiled fishes in Abrams Creek, Tennessee. Southeastern Naturalist 4:93-110.

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.

Smith-Vaniz, W.F. 1968. Freshwater fishes of Alabama. Paragon Press, Montgomery, Alabama.

Threader, R., R. Pope, and P. Schaap. 1998. Development of a habitat suitability index model for lake sturgeon. Report no.: H-07015.01—0012 for Ontario Hydropower.

Tody, W. H. 1974. Whitefish, sturgeon, and the early Michigan commercial fishery. Michigan Department of Natural Resources, Lansing, MI.

Volkman, E.T., K.L. Pangle, D.A. Rajchel, and T.M. Sutton. 2004. Hatchery performance attributes of juvenile lake sturgeon fed two natural food types. North American Journal of Aquaculture. 66:105-112.

Werner, R.G., and J. Hayes. 2005. Contributing factors in habitat selection by lake sturgeon (*Acipenser fulvescens)*. USEPA-GLNPO. 19p.

CHAPTER 2

ASSESSMENT OF LAKE STURGEON REINTRODUCTION EFFORTS IN THE COOSA RIVER SYSTEM, GEORGIA – ALABAMA: A SHORT TERM STUDY[1]

---

[1] Bezold, J. and D. Peterson. Submitted to

4th International Reservoir Symposium 30-June-2007.

Abstract

At the extreme southern boundary of its range, the lake sturgeon was once present in the Coosa River system of Georgia –Alabama, but during the 1970's the population was extirpated by overfishing and habitat degradation. Over the past 2 decades however, habitat conditions have improved and in 2002, the Georgia Department of Natural Resources initiated a new lake sturgeon reintroduction program with the goal of re-establishing a self sustaining lake sturgeon population. From 2004 to 2007, I evaluated this reintroduction program by quantifying post-stocking survival and seasonal habitat use of juvenile lake sturgeon in the Coosa River System. I used gill and trammel nets to capture lake sturgeon at several random locations including both riverine and reservoir habitats. Fourteen juvenile lake sturgeon were randomly selected for surgical implantation of radio-tags to monitor seasonal movement and habitat use. Over the 3 years of the study, I captured a total of 597 juvenile lake sturgeons measuring 231 – 790 mm (TL). I used capture probabilities determined with program MARK to adjust my capture data to estimate 2006 abundance at 789 (690 – 889, 95% CI) juvenile lake sturgeon. Post-stocking survival rates of each cohort varied from 1-14%, depending on year and size of fish stocked. Seasonal movement of juveniles was variable; however, most fish occupied a relatively small reach in the lower river during summer months when temperatures were >25 ^{o}C. My results show that at least some fish from each stocked cohort have survived and that the population appears to be gradually increasing with each additional year of stocking. Further studies are needed to monitor annual recruitment and to evaluate reproductive success as the oldest cohorts reach maturity.

Introduction

Lake sturgeon (*Acipenser fulvescens*) are a large, long-lived, late maturing species endemic to North America (Harkness and Dymond 1961; Priegel and Wirth 1971; Scott and Crossman 1973). They can live 150 years or more and attain weights in excess of 140 kg (Harkness and Dymond 1961; MacKay 1963). Although time to sexual maturity may vary with latitude, males typically mature between 12 – 15 yrs of age, with subsequent spawning every 2-3 years thereafter. First spawning for females normally occurs at 18 – 27 yrs with a 4-6 years resting period between reproductive cycles (Roussow 1957; Priegel and Wirth 1971; Scott and Crossman 1973; Fortin et al. 1996; Bruch 1999).

The historic distribution of lake sturgeon included three major drainages in North America: the Mississippi River, Hudson Bay, and Great Lakes (Harkness and Dymond 1961). An isolated but naturally reproducing population of lake sturgeon was also found in the Coosa River system in northwest Georgia and Alabama (Smith-Vaniz 1968; Dahlberg and Scott 1971). Although once considered abundant throughout much of their range, lake sturgeon populations were decimated by overfishing and habitat fragmentation and pollution during the first half of the 20^{th} Century (Rochard et al.1990; Birstein 1993; Peterson et al. 2007). Following passage of the U.S. Clean Water Act in 1972, however, improved water quality and new protections for remaining stocks and their habitats helped spark public support for lake sturgeon restoration in both the US and Canada. As a result, several states and provinces have since initiated new restoration or reintroduction programs (Peterson et al. 2007). In the northern U.S. and Canada, these programs have focused primarily on protection of remnant stocks, habitat improvement, and to a lesser extent, stocking of hatchery-reared juveniles (Schram et al. 1999; Jackson et al. 2002; Drauch and Rhodes 2007; Peterson et al. 2007). In the southern US, however, intensive stocking programs have become more prevalent because native populations were largely extirpated during the 1900's. In Georgia, the lake sturgeon population of the Coosa River was reportedly extirpated by overfishing and habitat degradation but direct causes remain uncertain. Although the Coosa River is still impacted by a variety of anthropogenic factors, recent surveys (GA EPD 1998) suggest that water quality has improved markedly over the past few decades.

In response to growing public interest in native fish restoration, the Georgia Department of Natural Resource (GADNR) initiated a new lake sturgeon reintroduction program in the Coosa River in 2002 by releasing hatchery-reared fingerlings produced at the GADNR Summerville Fish Hatchery (Beisser 2007). While annual stocking of lake sturgeon is a key component of this 20-yr reintroduction program, much of the plan is devoted to understanding how the life history and population dynamics of the reintroduced population are affected by specific habitat characteristics of the Coosa River. Because information regarding life history of lake sturgeon are completely lacking for populations at the southern edge of the range, the GADNR reintroduction program provides a unique opportunity to examine the critical links between lake sturgeon ecology and habitat.

As an integral part of the Coosa River lake sturgeon reintroduction program, the primary goal of this study was to assess post-stocking survival and monitor seasonal habitat use of juvenile lake sturgeon in the Coosa River System. The specific objectives were to 1) quantify post-stocking growth and survival, 2) identify and describe seasonal movements and habitat use and 3) identify environmental factors that may limit post-stocking survival of juvenile lake sturgeon.

Site Description

All field data were collected from the mainstem of the Coosa River beginning at Rome, Georgia, to Weiss Dam located near Leesburg, Alabama (Figure 2.1). Four habitat channel types were headwater (rkm 74 – 95), upper river (rkm 50 – 38), lower river (rkm 38 – 50) and reservoir (rkm 0 – 38) (Appendix 1). The headwater channel type averaged 1.9 m deep and 82.9 m wide and consisted of coarse, hard substrates. The upper channel averaged 5.7 m deep and 95.3 m wide and consisted of sandy substrates, while the lower channel averaged 6.2 m deep and 125.0 m wide with fine substrates. The reservoir channel type averaged 7.0 m deep and 106.7 m wide with fine substrates (Appendix 1). The 12,000-ha reservoir drains a watershed area of 13,649 km^2, approximately 75% of which is forested, 15% is agricultural. Less than 3% of the watershed is urban/developed; however, two additional major impoundments are situated upstream of the study area on tributary rivers (Johnson et al. 2002). Weiss reservoir is managed for hydropower production, although it also supports popular recreational fisheries for crappie (*Pomoxis sp.*) catfish (*Ictalurid sp.*) and striped bass (*Morone saxitalis*).

Methods

Fish Stocking

In 2002, the GADNR began an annual stocking program reintroduce lake sturgeon into the Coosa River System. Fingerling lake sturgeon were grown at the GADNR Summerville Fish Hatchery and stocked as either Phase I fingerlings (~ 120 mm TL and 4 months of age) or Phase II (130 – 300 mm TL at 6-10 months of age). Numbers of stocked fingerlings were variable depending on culture success; however, at least 10,000 fingerlings were stocked in each year except 2002 (Table 2.1). Individual cohorts were batch marked prior to release to aid in survival estimates.

Fish Sampling

From March 2004 to March 2007 juvenile lake sturgeon were sampled using bottom-set gill and trammel nets measuring 91-m in length by 2 m in depth. Gill nets were constructed of either 7.6 cm or 10.2 cm stretch measure monofilament webbing, while trammel nets were constructed of 7.6 cm (inner panel) and 30.5 cm (outer panel) monofilament mesh. All nets were fished perpendicular to the flow from dusk to dawn. Netting locations were randomized for both population abundance and survival estimates, and targeted sampling was used to collect additional specimens for estimates of growth and seasonal condition. Netting methods of randomized sampling for population abundance estimates was conducted similarly, except that effort was apportioned randomly within upper and lower river strata that were delineated by gross differences in channel morphometry.

As nets were retrieved captured lake sturgeon were placed into an aerated live-well onboard the research vessel. After all nets were retrieved, each fish was scanned for a PIT tag. If none was found, one was injected under the forth or fifth dorsal scute. Each fish was then measured (TL), weighed, and inspected for unique batch marks. Prior to release a 5 – 10 mm section of the leading pectoral fin spine was removed for subsequent age estimation. Fish were then allowed to recover in the live-well prior to their release. Once all fish had been released, water temperature and dissolved oxygen (DO) were measured using a YSI® 85 multimeter.

Age, Growth, and Condition

Fin spine samples from captured lake sturgeon were air dried for ≥6 months, and then were sectioned to a thickness of 0.3 – 0.5 mm using an Isomet® low-speed saw. The sections were then mounted on glass slides using clear, thermo-plastic epoxy and viewed under a variable magnification dissecting scope. Each slide was viewed independently by two technicians.

Disagreements in age estimates were resolved by a third reader, with agreement of two of three estimates determining the final age. Because a portion of each stocked cohort was batch-marked with a unique combination of fin clips and/or scute removals, age estimates from know-aged individuals were used to validate those of unmarked fish. Relative abundance of each cohort detected was determined by dividing number of fish sampled in the cohort by the total number of fish sampled during primary sampling, summer 2006.

To estimate growth of stocked juveniles, I used least-squares regression of known-aged fish as described by Jackson et al. (2002). I also determined growth from direct measures of TL obtained from captured and recaptured individuals. Means and 95% confidence limits of relative condition factor (K_n) were calculated for each season (by Julian calendar) across all years (Le Cren 1951; Anderson and Neumann 1996). Significant differences in condition among seasons were identified using by non-overlap of confidence limits. I used $\log_e$ linear regression to determine significant differences in the length-weight relationships among seasons (Craig et al. 2005). Goodness of fit of $\log_e$ linear regression was determined by examining the r^2 value. Assumptions were tested by examining $\log_e$ linear regression residuals.

Population Estimates

Post-stocking abundance and survival of juvenile lake sturgeon was estimated in 2006 using double sampling as described by Williams et al. (2002). Primary sampling was conducted from 31 – May to 14 – June and double sampling from 18 – June to 2 – August. Primary sampling was conducted in the upper (rkm 50 – 64) and lower (rkm 36 – 50) strata. Secondary sampling sites were chosen at random from a subset of primary sampling sites in each stratum where catch-per-net-night of lake sturgeon was >0.9. Huggins closed-captures procedure was used in Program MARK (Huggins 1989, 1991; White and Burnham 1999) to estimate capture probabilities based on capture histories of individual fish caught during secondary sampling. Models were tested with capture (P) and recapture (C) probabilities constant, varied by time and group, and with total length as a covariate to determine the model that best fits the data. Capture probability estimates were then obtained from the model yielding the lowest AICc value (i.e. best fit model) to estimate population abundance in the corresponding sample reach. Individual cohort abundances then were calculated by multiplying the relative abundance of each cohort by the total population estimate. Mean survival for all stocked fish (all stocked cohorts to data of sampling) was calculated by dividing the total population estimate by the total number of all stocked fish, excluding cohorts that had not fully recruited to sampling gear as determined from post-hoc analysis of age-frequency histograms. Individual cohort survival estimates were calculated by dividing each cohort abundance estimate by the number of fish stocked in the corresponding cohort.

Surgical Implantation of Radio Transmitters

A total of 14 juvenile lake sturgeon measuring 530 – 635 mm TL and weighing 600 – 1100 g were selected from captured fish and transported in an aerated hauling tank from the Coosa River to University of Georgia's Whitehall Fisheries Research Laboratory. Following anesthesia via immersion in a 32 mg/L solution of buffered MS-222 (tricaine methanesulfonate), each fish was surgically implanted with an ATS Model F1840 radio transmitter equipped with a 300-mm trailing antenna. These cylindrical transmitters measured 53 x 17 mm and weighed ~15 g. Surgical procedures were identical to those described by Collins et al. (2002) except that the trailing antenna was guided through the body wall using a 13-gauge pipetting needle inserted through a 3-mm hole drilled into a ventral scute located immediately posterior to the main incision. Incisions were closed with a resorbable suture and sealed with a sterile surgical adhesive. Following surgery, all fish were allowed to recover for 14 – 21 days in a 1600-l tank supplied with fresh water to ensure that surgical incisions had fully healed. Incomplete healing of incisions resulted in transmitter removal and implantation into a new fish. Incisions in the original fish were then cleaned and re-closed. All fish were returned to their capture sites in the Coosa River.

Radio Telemetry

Tracking of each radio-tagged fish began immediately upon release and continued through December 2006. Movements of these fish were monitored weekly, by traversing the entire study area in a small boat, while listening for individual fish radio-tag signals with a portable radio receiver (ATS R2000) and closed-loop antenna. As signals of individual fish were detected, their specific locations were determined to the nearest 100 m by adjusting antenna orientation and frequency gain. Coordinates were then recorded using a Trimble GeoExplorer-3 portable GPS receiver, after which water temperature and dissolved oxygen (DO) were measured using a YSI® 85 multimeter, while depth was measured with a Furuno LS4100 depthsounder.

I used ArcGIS (ESRI 2006, Redlands, California) to plot GPS coordinates of radio-tagged fish relocations and then determine rkm's of each relocation event. Movements were then determined based on differences in successive relocation river kilometers. I used ANOVA's to determine the effects of season, year, and season*year on range, displacement, movement rate (km/day), and total kilometers with Proc GLM in SAS 9.1.3 (SAS v9.1.3, Cary, North Carolina) (Knights et al. 2002). Tukey's Studentized Range (HSD) separation of means was then used to identify specific significant differences among the movement values (Knights et al. 2002). All statistical tests were conducted with $\alpha = 0.05$.

Habitat Sampling and Classification

Habitat use of juvenile lake sturgeon was evaluated calculating the number of relocation events for each fish by habitat type and season. These values were then compared to the defining channel reach characteristics to determine if habitat use was correlated to specific characteristics. Finally, point measures of DO levels were used to calculate mean monthly DO every 3-5 rkm from rkm 0 to 83, from fall 2006 to fall 2007. Using Arc GIS, these values were then plotted with rkm's of each fish relocation event by month to evaluate habitat use in relation to changes in DO (Secor and Niklitschek 2001; Campbell and Goodman 2004).

Results

I sampled 640 net-nights and captured 597 juvenile lake sturgeon from March 2004 – 2007 in the Coosa River System (Table 2.2). Both CPUE and mean fish size increased in each year of the study as successive cohorts recruited to the sampling gear. Recruitment to gear occurred when fish were >300 mm TL (Figure 2.2). Mean size of captured lake sturgeon increased from 392 mm TL to 557 mm TL, while annual CPUE increased from 0.07 to 1.44 fish/net-night. In 2006, 84 net-nights of primary and 36 net-nights of double sampling yielded 105 and 76 juvenile lake sturgeon respectively (Table 2.3). According to AICc values, P(.) resulted in the best fitting model (Table 2.4). The final capture probability estimate was 0.152. The sample area total population estimate was 789 (690 – 889, 95% CI) juvenile lake sturgeon.

Fin spine samples were obtained from 97 of the 105 juveniles captured during random sampling. Of these, 50 possessed hatchery marks indicating their cohort of origin, and hence, age. Accuracy of age estimates for these fish varied from 50-100% among readers; the consensus estimates were 100% accurate for all age classes (Table 2.5). Length frequency analysis of 50 marked and 47 unmarked juveniles revealed that stocked cohorts were not equally represented in the catch (Figure 2.2). Subsequent estimates of cohort size showed that the largest year-class originated from the release of 11,866 fingerlings in 2003 (Table 2.6). Estimates of cohort survival show that phase II fingerlings stocked in 2002 exhibited the highest annual survival, and phase II fish appeared to survive better than phase I fish overall (Table 2.6).

Using the general equation of [Wt = 3.2093 *(TL) – 5.9371] with $r^2 = 0.92$ calculated from lengths and weights of 385 juvenile lake sturgeon collected across all seasons and years, I found that relative condition was highest in spring ($K_n = 1.08$; 95% CL 1.06 – 1.11), followed by winter ($K_n = 1.01$; 95% CL 0.97 – 1.05), summer ($K_n = 1.00$, 95% CL 0.98 – 1.02), and fall ($K_n = 0.92$; 95% CL 0.89 – 0.96). Regression analysis of the length-weight relationship (Figure 2.3) showed that the slope and intercept of fall-captured fish differed significantly from those captured in spring and winter, but not from those captured in summer ($P<0.01$) (Table 2.7). Parameter estimates indicated that lake sturgeon captured in spring and winter were significantly heavier than those of similar length captured in fall; however, this disparity became less evident in as total length of juveniles increased. Lake sturgeon captured in summer were not significantly heavier than those captured in fall. No significant slope or interaction differences were detected in any comparison of fish captured in spring, summer, or winter. All assumptions of regression analysis were met.

Using least-squares regression of length-at-age data I determined a length-at-age relationship of Y = 316.4 + 71.2*(X) with $r^2 = 0.48$, where (Y) is TL in mm and (X) is age in years. The estimated daily growth rate of juvenile lake sturgeon in the Coosa River was 0.20 mm/d. Mean (standard error) daily growth calculated from 150 recaptured individuals is 0.29 (0.04) mm/d with a range of 1 – 640 d and mean of 151 d between recapture events.

Weekly tracking of the 14 radio-transmittered juvenile lake sturgeon yielded 673 relocations from spring 2005 to fall 2006 (Table 2.8). Analysis of fish movements indicated that season had a significant effect on displacement, range, and rate of movement ($P < 0.0001$). Separation of means revealed that the fish were exhibited more movement in spring and fall than in summer or winter (Table 2.8). The total percentage of lake sturgeon relocations observed in each of the four channel types varied widely by season (Table 2.9). The highest percentage of relocations in any given season, were observed in the upper river during spring, followed closely by lower river and reservoir in winter. The lowest percentage of relocations in all seasons occurred in the headwater reach. Although juvenile lake sturgeon were frequently found in reservoir channels during fall and winter months, they were seldom found there during summer months when dissolved oxygen ≤3 mg/L (Figure 2.4).

Discussion

Over the three years of my study, annual increases in CPUE and mean TL of fish caught, along with my population estimate of 789 (690 – 889, 95% CI), provided evidence that a new population of lake sturgeon has started to take hold in the Coosa River. Although comparable studies of lake sturgeon reintroduction programs are rare, increases in annual CPUE have been used previously as an indicator of a successful lake sturgeon reintroduction (Schram et al. 1999; Jackson et al. 2002). Nonetheless, CPUE data are often highly variable because of environmental or sampling conditions. Consequently, future monitoring of the Coosa River population should employ a more quantitative approach, such as double sampling with effort allocated in proportion to the amount of seasonally available habitat. This may be the most effective method for monitoring the population in future years.

Although my population estimates suggest that only 2.5% of all fish stocked since 2002 have survived, at least some juveniles from each stocked cohort were documented. However, I also found that phase II fingerlings survived better than phase I fingerlings, suggesting that the reintroduction program may benefit from stocking a higher percentage of these older, larger juveniles in future years. While I did not directly examine the effects of stocking density on fish survival, the highest survival rates I observed occurred in years when stocking densities were low, but variations in the age and size of fish stocked in each year preclude any quantitative evaluation of this relationship. Future studies are needed to better understand recruitment mechanisms and the influence of size, age, and stocking density on year-class formation of juvenile lake sturgeon.

Studies examining seasonal changes in lake sturgeon condition are rare and limited to larger populations in the northern part of the species' range. The results of my study show that relative condition of juveniles varies seasonally; however, the relationship appears to be size dependent. In general, juveniles captured in spring were in the best condition, while those captured during the fall were in the poorest condition. Although these results are consistent with those of Beamish et al. (1996), this author reported no significant seasonal differences in condition. Using regression analysis, I found that seasonal changes in length-weight relationship were significant when comparing fish captured in fall with those captured in spring. Causal mechanisms for these findings are unclear; however, I hypothesize that seasonal changes in water temperature and/or prey availability are probably responsible. Given that previous studies report the maximum upper temperature tolerance of lake sturgeon to be 25 ^{o}C (Wehrly 1995); I suspect that juvenile lake sturgeon in the Coosa River become increasingly more stressed during summer months as temperatures routinely exceed 25 ^{o}C (Figure 2.5). As a result, when fall begins, the fish are in poor condition despite decreasing water temperatures. As fall progresses and more optimal water temperatures are reached, fish condition increases and a rebound of condition is observed in winter. Additional studies of southern lake sturgeon populations are needed to understand how seasonal changes in juvenile growth and survival (and ultimately maturation are influenced by availability and quality of prey and habitat.

Fortin et al. (1996) suggest that lake sturgeon growth may be inversely correlated with latitude. In the Coosa River, the highest annual growth rate I observed was 105 mm/y. In contrast, annual growth rates of 113 mm/y and 145 mm/y were reported for juveniles in Lake Winnebago, WI and Oneida Lake, NY, respectively (Jackson et al. 2002). However, in both of these northern populations data from older juveniles (≥5 y) were included. Because these previous studies report growth as annual increases in TL for all juveniles combined, the slower growth rates observed in my study may simply reflect the absence of older juvenile cohorts in the Coosa River System compared to the northern populations. Nonetheless, Power and McKinley (1997) suggest that lake sturgeon populations located on the extreme southern edge of their range may grow more slowly because of prolonged periods of excessively high water temperatures. Based on seasonal differences in their relative condition, juvenile lake sturgeon appeared to grow best in the Coosa River in spring and fall, but not in summer as has been previously reported in northern populations. Future studies are needed to evaluate seasonal patterns of lake sturgeon growth in the Coosa River and to determine how these patterns differ from those observed in more northern populations, where water temperatures are optimal during summer months. Regardless, as the Coosa River population ages, the relationship between juvenile growth and water temperatures should become more evident as additional data from older juveniles become available.

Very little is known about habitat use or seasonal movements of juvenile lake sturgeon, but Holey et al. (2000) identified these topics as key information gaps vital to successful recovery of lake sturgeon stocks. I found that during spring and fall, lake sturgeon were generally more active than during summer and winter, as evidenced by the daily movement rates and their range. Several previous studies (Rusak and Mosindy 1997; Borkholder et al. 2002; Knights et al. 2002) report similar results for spring months; however, they also reported the greatest activity in summer. I hypothesize that the difference in summer movement patterns I observed in the Coosa River were likely caused by summer temperatures (>25 ^{o}C) that were well above the optimum of 20-22 ^{o}C reported by Hochleithner and Gessner (2001). Unlike northern waters, optimal temperatures for Coosa River lake sturgeon occur during two discrete seasons; in spring as water temperatures increase, and during fall as temperatures decline. During summer months, both condition and activity levels declined, suggesting that the fish were probably experiencing thermal stress. Although all data I collected support this conclusion, movement patterns of juvenile lake sturgeon may also be affected by a variety of other environmental factors, such as prey availability or discharge fluctuations, that I did not examine.

Seasonal movement data also revealed that juvenile lake sturgeon made extensive use of all habitat reaches during some part of the year, except for shallow headwaters with relative swift current and hard substrate. While these reaches appeared to be relatively unimportant to juveniles, the presence of these habitats in the Coosa River is noteworthy because they may eventually provide critical spawning habitat for adults. Although juveniles apparently preferred the deeper channel habitats within the reservoir during most of the year, they moved into the river reaches during summer months when DO in the reservoir was <3.0 mg/L. Regardless of this seasonal change in habitat use, juveniles were almost always found over a heterogeneous mix of substrates. This was somewhat surprising because previous studies suggest that juveniles prefer sand substrates (Peake 1999; Knights et al. 2002; Smith and King 2005). In the Coosa River my data suggest that juvenile lake sturgeon are "channel generalists", capable of using a variety of channel types depending on seasonally changing conditions.

The results of this study indicate that the current GADNR reintroduction program has been successful in re-establishing a juvenile population of lake sturgeon in the Coosa River. Although my results show that post-stocking survival has been lower than that typical of other sport fish stocking programs, minor adjustments in the GADNR stocking program may yield dramatically better results. To the greatest extent feasible, I recommend that GADNR increase the proportion of phase II fingerlings stocked in each year; however, further studies are needed to evaluate the effects of stocking density on post-stocking survival. Although the ultimate success of the reintroduction program will depend on the ability of these juveniles to grow, survive, and successfully reproduce, future monitoring of the population will be essential for many years to ensure that the long-term goal of re-establishing a self-sustaining population is achieved.

Acknowledgements

I acknowledge the Georgia Department of Natural Resources for funding this research and contributing field equipment and expertise. I acknowledge David Higginbotham and James Peterson for their technical and analytical assistance. I acknowledge Julie Wilson and Paul Schueller for GIS contributions. I also acknowledge Daniel McLaughlin, Kyle Dresser, Richard Childers, Audrey Owens, Drew Taylor, and Kelvin Young for their technical contributions while collecting data.

References

Anderson, R.O. and R.M. Neumann. 1996. Length, weight, and associated structural indices. Pages 447-482 *in* B.R. Murphy and D.W. Willis, editors. Fisheries Techniques, 2nd Edition. American Fisheries Society, Bethesda, Maryland.

Beamish, F.W.H., J.A. Jebbink, A. Rossiter, and D.L.G. Noakes. 1996. Growth strategy of juvenile lake sturgeon (*Acipenser fulvescens*) in a northern river. Canadian Journal of Fisheries and Aquatic Sciences 53:481-489.

Beisser, G. 2007. Lake sturgeon reintroduction to the Coosa River Basin. Georgia Department of Natural Resources. Available: www.gofishgeorgia.com/content/displaycontent.asp?txtDocument=305. (May 2007).

Birstein, V.J. 1993. Sturgeons and paddlefishes: threatened fishes in need of conservation. Conservation Biology 7:773-787.

Borkholder, B.D., S.D. Morse, H.T. Weaver, R.A. Hugill, A.T. Linder, L.M. Schwarzkopf, T.E. Perrault, M.J. Zacher, and J.A. Frank. 2002. Evidence of a year-round resident population of lake sturgeon in the Kettle River, Minnesota, based on radiotelemetry and tagging. North American Journal of Fisheries Management 22:888-894.

Bruch, R.M. 1999. Management of lake sturgeon on the Winnebago System – long term impacts of harvest and regulations on population structure. Journal of Applied Ichthyology 15:142-152.

Campbell, J.G. and L.R. Goodman. 2004. Acute sensitivity of juvenile shortnose sturgeon to low dissolved oxygen concentrations. Transactions of the American Fisheries Society 133:772-776.

Craig, J.M., M.V. Thomas, and S.J. Nichols. 2005. Length-weight relationship and relative condition factor equation for lake sturgeon (*Acipenser fulvescens*) from the St. Clair River System (Michigan, USA). Journal of Applied Ichthyology 21:81-85.

Dahlberg, M.D. and D.C. Scott. 1971. The freshwater fishes of Georgia. Bulletin of the Georgia Acadamey of Science 29(1):1-64.

Drauch, A.M. and O.E. Rhodes, Jr. 2007. Genetic evaluation of the lake sturgeon reintroduction program in the Mississippi and Missouri Rivers. North American Journal of Fisheries Management 27:434-442.

Fortin, R., P. Dumont, and S.Guenette. 1996. Determinants of growth and body condition of lake sturgeon (Acipenser fulvescens). Canadian Journal of Fisheries and Aquatic Sciences 53:1150-1156.

Georgia Environmental Protection Division (EPD). 1998. Coosa River basin management plan. Georgia Department of Natural Resources. Atlanta, Georgia.

Harkness, W.J., and J.R. Dymond. 1961. The lake sturgeon: the history of its fishery and problems of conservation. Ontario Department of Lands and Forest, Fish and Wildlife Branch Toronto, Ontario.

Hochleithner M. and J. Gessner. 2001. The sturgeons and paddlefishes of the world. Aquatech Publications. Kitzbuehel, Austria.

Holey, M., E. Baker, T. Thuemler, and R. Elliott. 2000. Research and assessment needs to restore lake sturgeon in the Great Lakes. Great Lakes Fishery Trust, Lansing Michigan.

Huggins, R.M. 1989. On the statistical analysis of capture experiments. Biometrika 76:133-140.

Huggins, R.M. 1991. Some partical aspects of conditional likelihood approach to capture experiments. Biometrics 47:725-732.

Jackson, J.R., A.J. VanDeValk, T.E. Brooking, O.A. vanKeeken, and L.G. Rudstam. 2002. Growth and feeding dynamics of lake sturgeon, *Acipenser fulvescens,* in Oneida Lake, New York: results from the first five years of a restoration program. Journal of Applied Ichthyology 18:439-443.

Johnson, G.C., R.E. Kidd, C.A. Journey, H. Zappia, and J.B. Atkins. 2002. Environmental setting and water-quality issues of the Mobile River basin, Alabama, Georgia, Mississippi, and Tennessee. United States Geological Survey National Water-Quality Assessment Program. Water-resources Investigations Report 02-4162, Montgomery, Alabama.

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.

Le Cren,, E.D. 1951. The length-weight relationship and seasonal cycle in gonad weight and condition in the perch *Perca fluviatilis*. Journal of Animal Ecology 20:201-219.

MacKay, H.H. 1963. Fishes of Ontario. Ontario Department of Lands and Forests. Bryant Press Ltd., Toronto, Ontario.

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

Peterson, D.L., P. Vecsei and C.A. Jennings. 2007. Ecology and biology of the lake sturgeon: a synthesis of current knowledge of a threatened North American *Acipenseridae*. Reviews in Fish Biology 17(1):59-76.

Power, M. and R.S. McKinley. 1997. Latitudinal variation in lake sturgeon size as related to thermal opportunity for growth. Transactions of the American Fisheries Society 126:549-558.

Priegel, G.R. & T.L. Wirth. 1971. The lake sturgeon: its life history, ecology and management. Wisconsin Department of Natural Resources Publication. Number 4-3600(77), Madison, Wisconsin.

Rochard, E., G. Castelnaud and M. Lepage. 1990. Sturgeons (Pisces: Acipenseridae): threats and prospects. Journal of Fish Biology 37:123–132.

Roussow, G. 1957. Some considerations concerning sturgeon spawning periodicity. Journal .of the Fisheries Research Board of Canada 14 553–572.

Rusak, J.A., and T. Mosindy. 1997. Seasonal movements of lake sturgeon in Lake of the Woods and the Rainy River, Ontario. Canadian Journal of Zoology 74:383-395.

Secor, D.H. and E.J. Niklitschek. 2001. Hypoxia and sturgeons: report to the Chesapeake Bay Program dissolved oxygen criteria team. Technical Report Series Number TS-314-01-CBL.

Schram, S.T., J. Lindgren, and L.M. Evrard. 1999. Reintroduction of lake sturgeon in the St. Louis River, Western Lake Superior. North American Journal of Fisheries Management 19:815-823.

Scott, W.B., and E.J. Crossman. 1973. Fishes of Canada. Bulletin 184 Fisheries Research Board of Canada.

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.

Smith-Vaniz, W.F. 1968. Freshwater fishes of Alabama. Paragon Press, Montgomery, Alabama.

Wehrly, K.E. 1995. The effect of temperature on the growth of juvenile lake sturgeon, *Acipenser fulvescens*. Michigan Department of Natural Resources, Fisheries Division. Research Report 2004, Lansing, Michigan.

White, G.C. and K.P. Burnham. 1999. Program MARK: Survival estimation from populations of marked animals. Bird Study 46(Supplement):120-138.

Williams B.K., J.D. Nichols, and M.J. Conroy. 2002. Analysis and management of animal populations. Academic Press, San Diego, California.

Tables

Table 2.1. Annual numbers of juvenile lake sturgeon stocked by the GADNR into the Coosa River System from 2002 to 2005. Hatchery marks are: L/R pelvic = left or right pelvic fin clip, R4 scute = right side 4th lateral scute removed, and none = no mark.

Year	Number stocked	Phase	Hatchery marks
2002	1,127	II	none
2003	6,373	I	L/R pelvic
	5,493	II	none
2004	16,460	I	L/R pelvic
	2,728	II	R4 scute
2005	12,910	I	none

Table 2.2. Annual catch statistics of juvenile lake sturgeon captured from the Coosa River System from March 2004 to March 2007 (sampling year is 1 January to 31 December). The 2007 sampling year is excluded from CPUE because sampling was incomplete.

Year	Fishing effort	N	CPUE	TL (mm) Mean	TL (mm) Range
2004	133	9	0.07	392	231 - 433
2005	184	193	1.05	492	335 - 695
2006	231	334	1.45	512	306 - 754
2007[1]	92	61	-	557	404 - 790
Totals	640	597	0.98	-	-

Table 2.3. Total summer primary and double sampling effort and catch of juvenile lake sturgeon from the Coosa River System from June to August 2006.

	Primary sample				Double sample			
	rkm	Total effort	N	CPUE	rkm	Total effort	N	CPUE
Upstream	14	42	70	1.66	2	18	52	2.88
Downstream	14	42	35	0.83	2	18	24	1.33

Table 2.4. Capture (P) and recapture (C) models fit to capture histories of fish caught during the double sample period, July to August 2006. TL indicates use of total length as a covariate.

Model	Delta AICc	Model likelihood	K	Deviance
p(.) = c(.)	0.00	1.00	1	203.2
p(TL) = c(TL)	0.65	0.72	2	201.9
p(g) = g)	1.90	0.39	2	203.1
p(.) c(.)	2.04	0.36	2	203.2
p(.) c(g)	3.78	0.15	3	202.9
p(g) c(.)	3.78	0.15	3	202.9
p(t) c(.)	4.09	0.13	3	203.2
p(.) c(t)	4.09	0.13	3	203.2
p(g) c(g)	5.54	0.06	4	202.6
p(t) c(g)	5.84	0.05	4	202.9
p(g) c(t)	5.85	0.05	4	202.9
p(g*t) c(.)	6.67	0.04	5	201.6
p(.) c(g*t)	7.96	0.02	5	202.9
p(t) c(t)	8.26	0.02	5	203.2
p(g*t) c(g)	8.47	0.01	6	201.3
p(g) c(g*t)	9.76	0.01	6	202.6
p(t) c(g*t)	10.07	0.01	6	202.9
p(g*t) c(t)	10.93	0.00	7	201.6
p(g*t) c(g*t)	12.78	0.00	8	201.3

Table 2.5. Total number of age-validated fin spine samples, and individual and combined reader accuracy of assigning ages as part of Coosa River random sample population age structure for June to August 2006.

Age (years)	N	Reader accuracy (%) 1	2	3	Combined Accuracy (%)
1	1	0	100	100	100
2	30	97	93	100	100
3	11	82	64	100	100
4	8	75	50	100	100
Total	50	86	80	100	100

Table 2.6. Cohort abundance and mean survival of juvenile lake sturgeon in the Coosa River System as estimated from double sampling procedure, summer 2006. Phase I fish were ~120 mm TL and 4 months of age and phase II fish were 130 – 300 mm TL and 4 – 10 months of age.

Cohort	Phase Stocked	# stocked	2006 Abundance Est. (95% CI)	Mean Survival (%)
2005[a]	I	12,910	8 (7 – 9)	-
2004[a]	I	16,460	41 (36 – 46)	0.2 (0.2 – 0.3)
	II	2,728	211 (185 – 238)	7.8 (6.8 – 8.7)
2003	I	6,373	32 (28 – 36)	0.3 (0.2 – 0.3)
	II	5,493	331 (290 – 373)	2.8 (2.4 – 3.1)
2002	II	1,127	166 (145 – 187)	14.7 (12.9 – 16.6)
Total	-	45,091	789 (690 – 889)	2.5 (2.1 – 2.8)

[a] 2004 and 2005 cohort not fully recruited.

Table 2.7. Parameter estimates of the length-weight relationship of juvenile lake sturgeon with fall as the baseline relationship (main effect) of fish captured from the Coosa River System from March 2004 to March 2007. Significant differences are indicated with superscript (w).

Effect	Parameter Estimate (intercept)	Parameter Estimate (slope)	Standard error	P-values
Intercept	-14.8608	-	0.5981	<.0001^{w}
Intercept*Spring	2.24543	-	0.81963	0.0064^{w}
Intercept*Summer	1.02006	-	0.76289	0.182
Intercept*Winter	2.29158	-	0.87705	0.0093^{w}
Slope	-	3.38774	0.09655	<.0001^{w}
Slope*Spring	-	-0.33636	0.13204	0.0112^{w}
Slope*Summer	-	-0.15157	0.12318	0.2193
Slope*Winter	-	-0.35555	0.14101	0.0121^{w}

Table 2.8. Seasonal movements of radio-transmittered juvenile lake sturgeon in the Coosa River System, spring 2005 to fall 2006. Significant differences as determined by ANOVA and Tukey's means separation test among season are denoted by letters (alpha=.05).

Movement Variable	Fall (N=10)	Winter (N=10)	Spring (N=11)	Summer (N=12)
Relocation events (Mean # / Fish)	18.3	9.9	13.1	20.6
Net Displacement[b] (km)	-19.6^{x} SD = 20.1	-2.8^{yx} SD = 10.9	17.9^{z} SD = 22.0	-5.4^{y} SD = 8.8
Mean total seasonal movement (km / fish / season)	71.9^{z} SD = 45.1	21.2^{y} SD = 13.3	68.9^{z} SD = 33.8	18.3^{y} SD = 9.1
Seasonal range (km)	34.5^{z} SD = 16.6	12.3^{zy} SD = 6.4	30.7^{z} SD = 16.6	10.3^{y} SD = 6.7
Mean daily movement (km / fish /day)	1.0^{z} SD = 0.6	0.3^{y} SD = 0.2	1.0^{z} SD = 0.5	0.2^{y} SD = 0.1

[b] Negative (downstream) and positive (upstream) values indicate direction of movement.

Table 2.9. Apparent habitat use of juvenile lake sturgeon in the Coosa River, from spring 2005 to fall 2006. Total relocation events by season and percent of relocations per habitat type, including net captures and radio-telemetry relocations.

	Relocation events				
Season	Total (mean / fish)	Reservoir (%)	Lower (%)	Upper (%)	Headwaters (%)
Spring	144 (13)	35	16	47	2
Summer	247 (21)	17	40	40	3
Fall	183 (18)	43	21	35	1
Winter	99 (10)	44	45	1	0
All Seasons	673	32	30	36	2

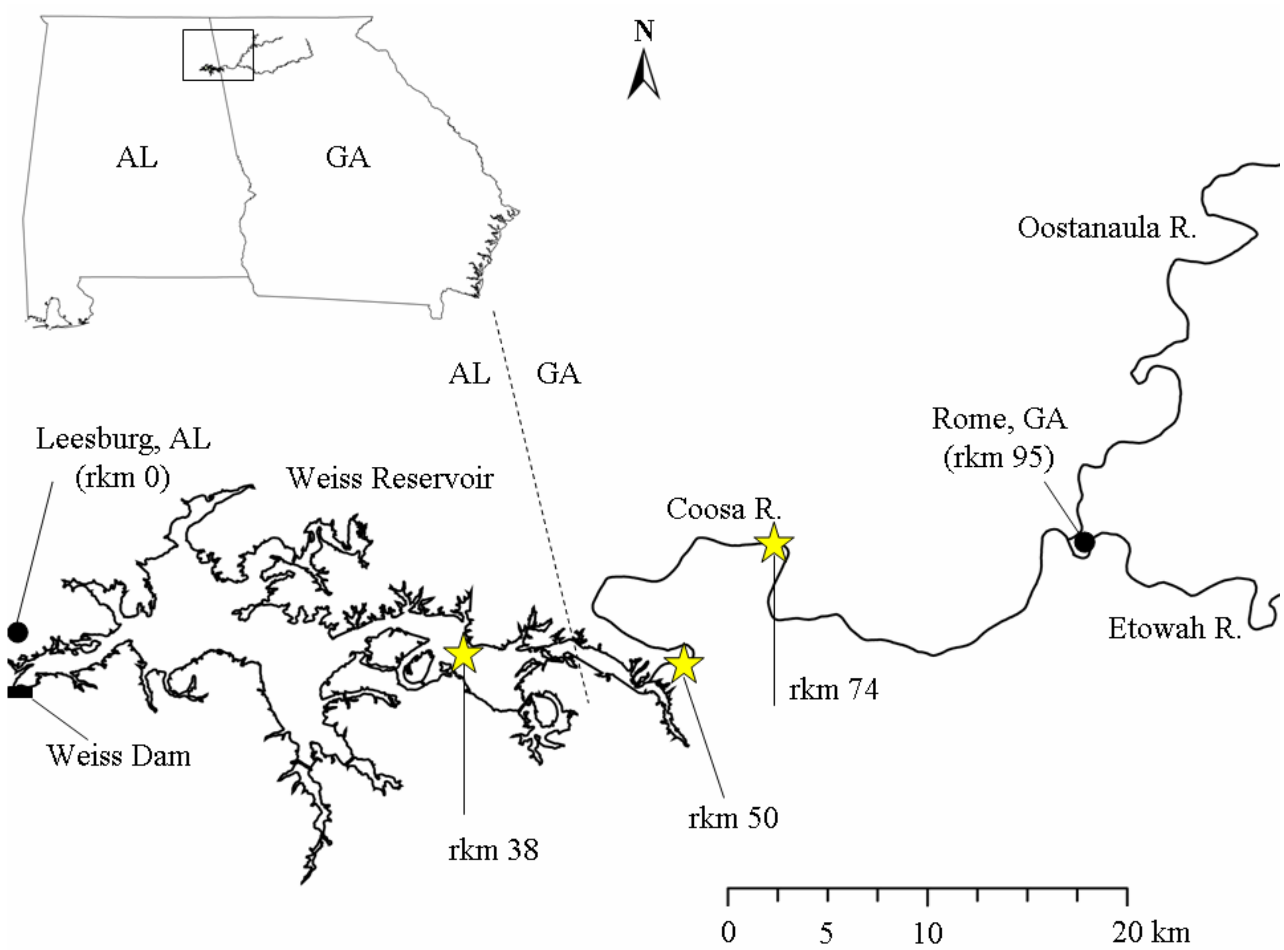

Figure 2.1. Map of the Coosa River and Weiss Reservoir in Georgia and Alabama study with rkm's marking upper and lower extent of channel reaches delineated and the Etowah and Oostanaula tributary rivers shown.

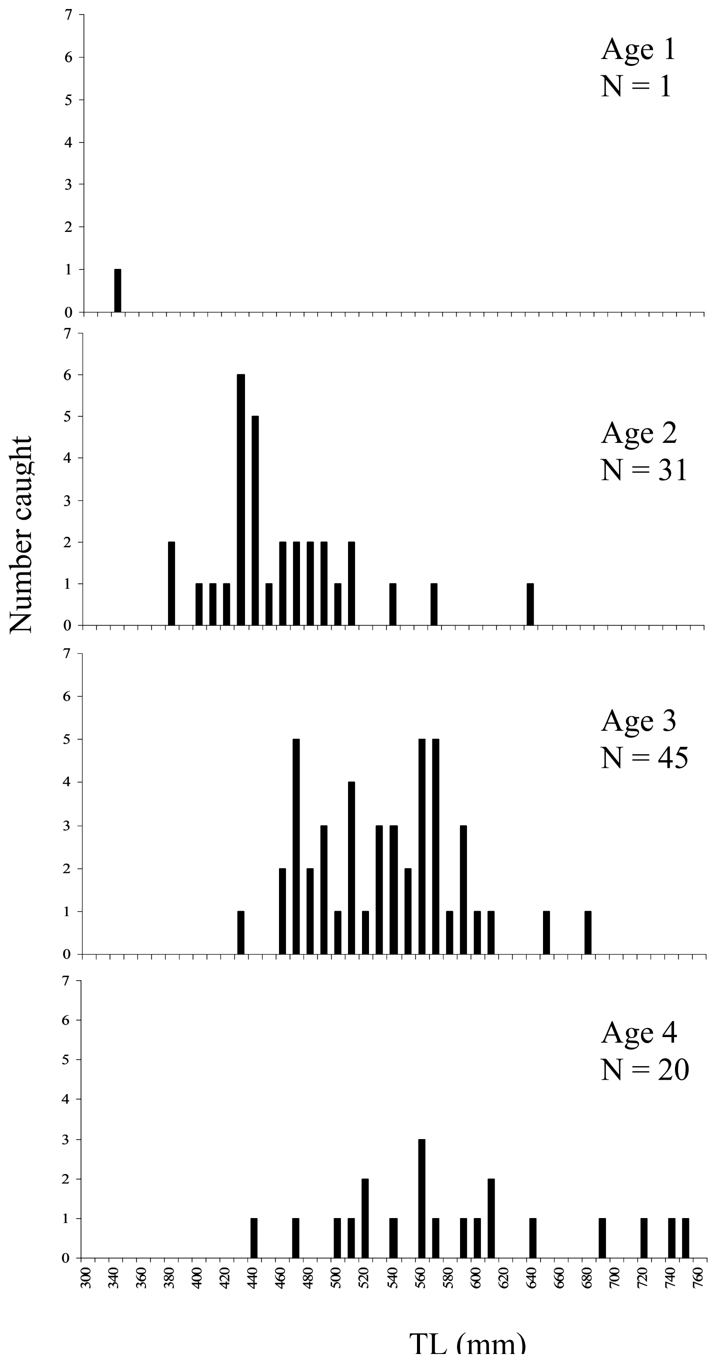

Figure 2.2. Length-frequency distribution of juvenile lake sturgeon captured in 87 net nights during random sampling in the Coosa River from May to August 2006.

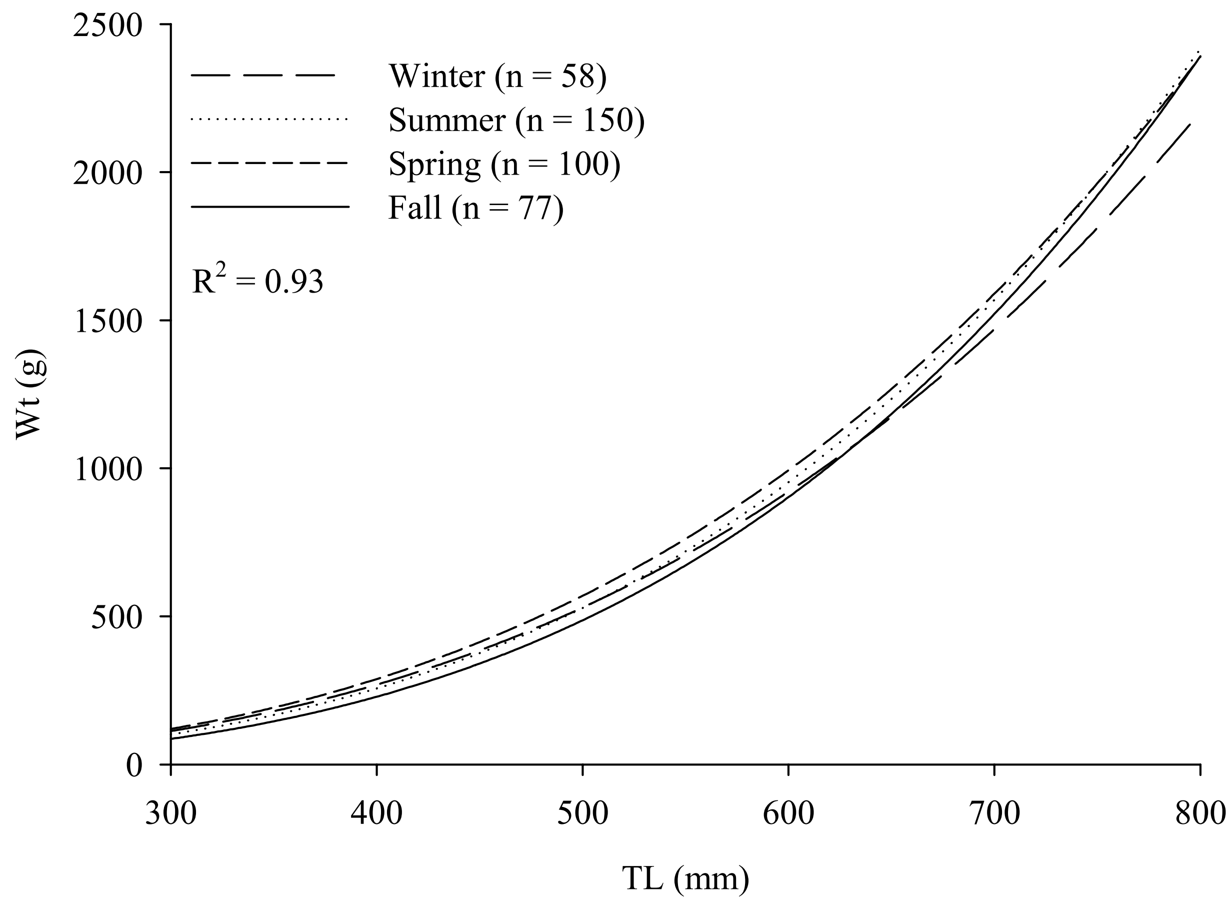

Figure 2.3. Seasonal length-weight relationships of juvenile lake sturgeon captured from the Coosa River from October 2004 to March 2007. Seasons were defined by the Julian calendar.

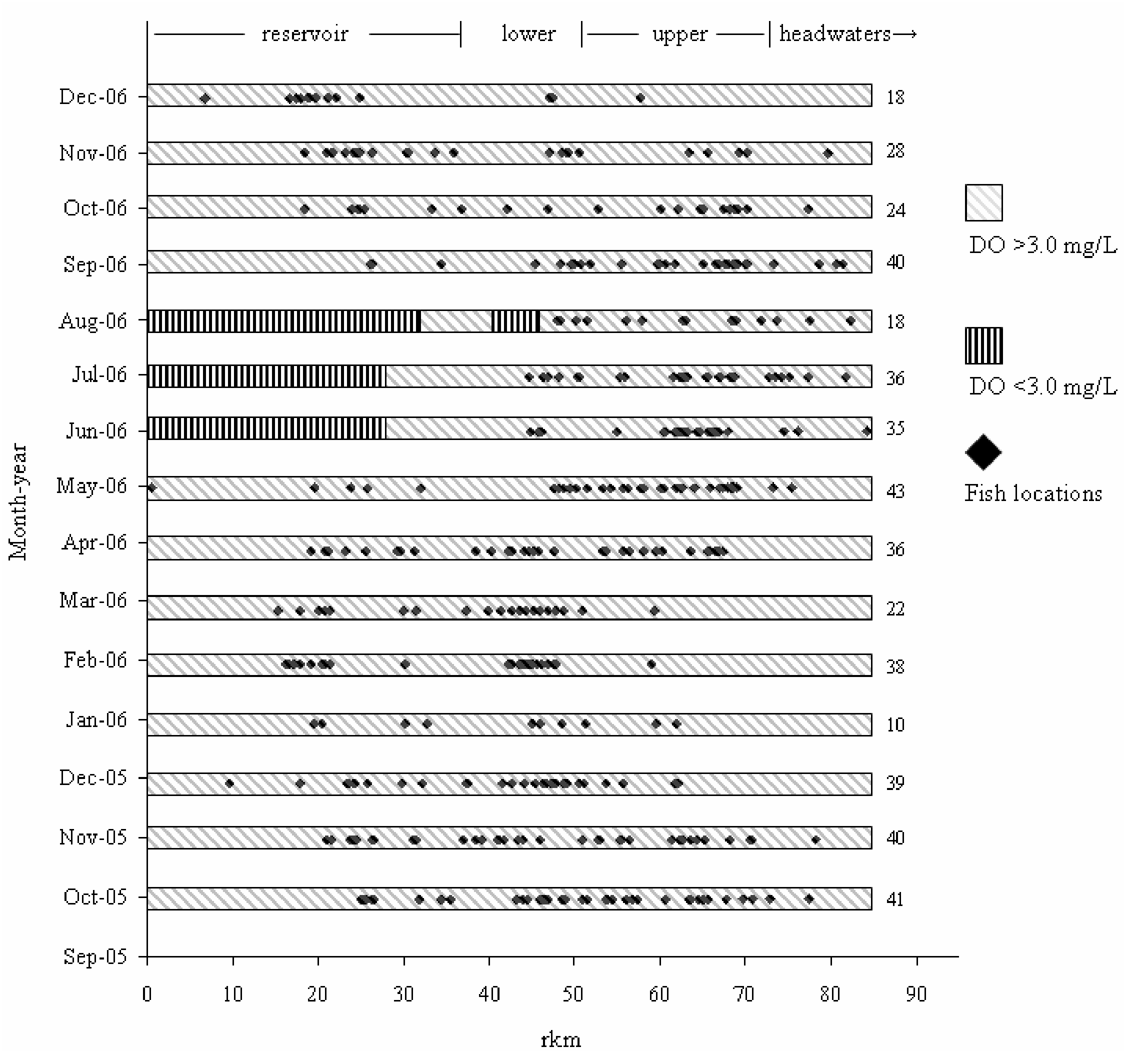

Figure 2.4. Monthly relocations of 14 radio-tagged fish and mean dissolved oxygen readings in the Coosa River System from October 2005 to December 2006. Total number of monthly relocations is indicated by values at the end of each bar, while habitat types are labeled at the chart top.

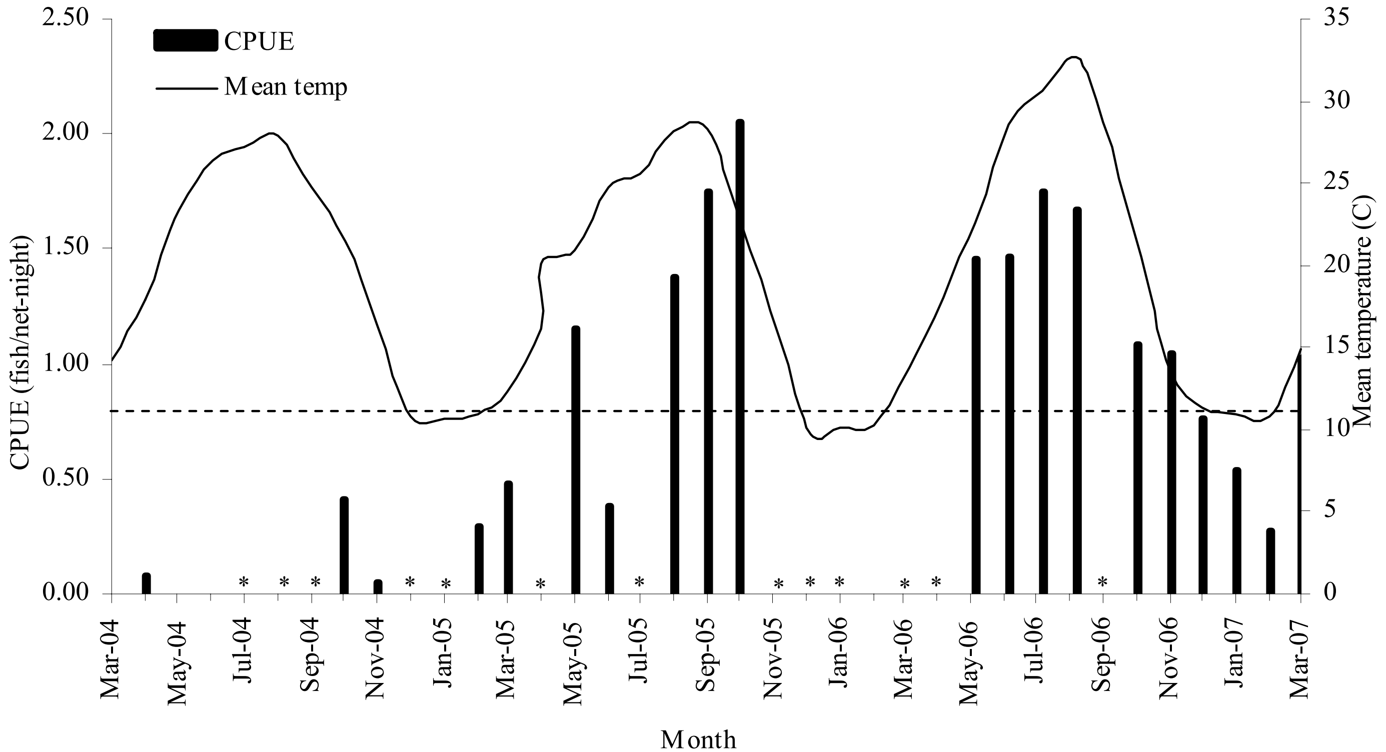

Figure 2.5. Monthly CPUE (unit effort = one net-night) of juvenile lake sturgeon from March 2004 to March 2007 in the Coosa river; (*) indicates months that effort <9 net-nights. The dashed line denotes mean sampling period CPUE of 0.93.

CHAPTER 3

COMPARING HATCHERY-REARED (NAÏVE) AND WILD-CAUGHT (NATURALIZED) JUVENILE LAKE STURGEON USED IN A RADIO-TELEMETRY STUDY IN THE COOSA RIVER SYSTEM, GEORGIA – ALABAMA[2]

[2] Bezold, J., D. Peterson, and J. Peterson *to be submitted to*

Canadian Journal of Fisheries and Aquatic Sciences fall 2007

Abstract

Radio-telemetry studies are used often as a tool to describe movements or habitat use by fishes. However, studies that compare the performance of hatchery–reared (naïve) to wild fish in telemetry studies have not been conducted. The objective of my study is to provide a comparison of naïve and wild fish that addresses the research void regarding this topic. I compared the performance of 10 naïve and 11 naturalized juvenile lake sturgeon in a radio-telemetry study in the Coosa River System, Georgia-Alabama. I surgically implanted 21 lake sturgeon with radio transmitters and conducted weekly boat tracking during 2004 – 2006 to relocate each fish. I used t-tests ($\alpha = 0.05$) to compare maximum number of days each that group of fish both persisted and survived in the study period, as well as the post-surgical movements of the two groups of fish. A chi-square test ($\alpha = 0.05$) was used to test determine if fish source (hatchery or river) significantly affected final fate (dead, alive, censored). My results showed that wild fish persisted and survived significantly ($p<0.005$) longer than naïve fish and moved significantly ($p<0.001$) fewer post-surgical kilometers than did naïve fish. Additionally, post-stock wild fish exhibited a pattern of upstream movements, whereas naïve fish tended to move downstream. Chi-square analysis indicated that the source (hatchery or wild) of the fish had a significant ($p<0.001$) effect on ultimate fate. The results of my study suggest that telemetry data obtained from naïve, hatchery-reared lake sturgeon, may not accurately represent short-term seasonal habitat use or movement patterns of their wild or naturalized counterparts.

Keywords: Coosa, sturgeon, biotelemetry, survival, juvenile, naïve

Introduction

Biotelemetry studies often are used in fisheries research to gain an increased understanding of habitat use and migration patterns of fish species. Frequently, researchers designing bio-telemetry studies must choose between hatchery-reared (naïve) and wild (or naturalized) individuals (Bradford and Gurtin 2000; Popoff and Neumann 2005). Although naïve fish (no prior exposure to natural systems) often are used in telemetry studies to evaluate post-stocking movements and habitat use (Popoff and Neumann 2005), wild/naturalized fish (stocked or naturally reproducing fish from natural environments, hereafter referred to as wild) are typically preferred for longer term studies of seasonal migrations or to locate critical habitat (Borkholder et al. 2002).

The choice between naïve and wild fish for use in telemetry studies often is dependent on the availability of the potential subjects (Bradford and Gurtin 2000). Both naïve and wild fish have specific advantages and disadvantages that must be considered in relation to study objectives. Hatchery fish, for example, may be readily accessible at low cost; however, with no prior exposure to natural systems or conditions, researchers must *assume* natural behavior of hatchery-reared fish (Bradford and Gurtin 2000; Jordan et al. 2006). Jordan et al. (2006) report that hatchery-reared juvenile pallid sturgeon were useful for identifying long-term behavior of juvenile pallid sturgeon in nature, but the short-term (<1 year) behavior of hatchery fish may place undue importance on non-critical habitats and inaccurately describe movement patterns. Although the use of wild fish may minimize this problem, these animals must first be live-captured from the wild, a process that may be difficult and expensive depending on population abundance, behavior, or location (Schram et al. 1999; Bradford and Gurtin 2000).

In recent years, the lake sturgeon (*Acipenser fulvescens*) has become the subject of extensive research and restoration efforts (Priegel and Wirth 1971; Birstein 1993; Peterson et al. 2007). Following decades of range-wide declines resulting from overfishing and habitat degradation, several state and federal management agencies have recently funded biotelemetry studies of lake sturgeon to better understand how seasonal movements and habitat use of both adults and juveniles may affect restoration efforts (Auer 1999, Caswell et al. 2002, Peterson et al. 2002; Smith and King 2005). Although biotelemetry offers a valuable tool for lake sturgeon researchers, studies comparing the use of wild and hatchery reared lake sturgeon are lacking. The primary objective of this study was to compare post-surgical movements, persistence, and survival of juvenile lake sturgeon captured from the wild at least 1-year post stocking, with those of naïve, hatchery-reared individuals of similar age and size.

Methods

Study Site

All field research was conducted in the Coosa River System, with the majority conducted in the main channel of the Coosa River between rkm 95 and 0 (Figure 3.1). Channel depth of this reach varied from 1.5 to 17.0 m with substrates typically consisting of clay and sand interspersed with woody debris, gravel, cobble, and boulders. The 12,000-ha reservoir drains a watershed area of 13,649 km^2, approximately 75% of which is forested, 15% is agricultural. Less than 3% of the watershed is urban/developed; however, another two major impoundments are situated upstream of the study area on tributary rivers (Georgia EPD 1998). The reservoir is primarily managed for hydropower production, although it also supports popular recreational fisheries for crappie (*Pomoxis sp*.) catfish (*Ictalurid sp*) and striped bass (*Morone saxitalis*).

Sources of Juvenile Lake Sturgeon

In December 2002, 1,100 lake sturgeon fingerlings from the Georgia Department of Natural Resources (GADNR) Summerville Fish Hatchery were stocked into the Oostanaula and Etowah Rivers as part of an ongoing lake sturgeon reintroduction program. Fifty of these individuals were retained at the hatchery until they had reaching approximately 510-560 mm TL after an additional 15 – 17 months of culture. Ten of these juveniles were then randomly selected for surgical implantation of radio transmitters to serve as the "naïve" study group following their release into to the Coosa River System. From 6-February-2005 to 12-September-2005 the "naturalized" study group was obtained directly from the Coosa River using monofilament gill and trammel nets deployed at several sites between rkm 20-50 (Figure 3.1). Gill nets were constructed from 7.62 cm or 10.16 cm stretch mesh while trammel nets were made from a combination of 30.48 cm mesh (outside panels) and 7.62 cm mesh (inside panel). All nets were anchored on the bottom of the main channel, perpendicular to the current, and fished overnight. Upon retrieval of the nets, captured lake sturgeon were placed in an aerated live-well until they could be weighed and measured. The first 11 fish > 510 mm (TL) (with no physical limitations apparent) were immediately transferred to a 30-gal hauling tank filled and transported to the University of Georgia's Whitehall Fisheries Research Facility for surgical implantation of radio transmitters.

Surgical Implantation of Radio Transmitters

Prior to surgery, all fish were anesthetized by immersion in a solution of a 32 mg/L of buffered MS-222 (Finquel®, Argent Chemical Labs, Redmond, WA). Radio transmitters were equipped with a 300-mm trailing antenna and measured 53 x 17 mm with a total weight of ~15 g. Surgical implantation of the transmitters was performed as described by Collins et al. (2002)

except that the antenna was guided through the body wall using a blunt-tip13-gauge pipette needle inserted through a 3-mm hole drilled into the lateral surface of a ventral scute, approximately 1-2 cm posterior to the main incision (Figure 3.2). Incisions were closed with 2-0 synthetic absorbable suture material (Ethicon PDSII®) and sealed with sterile surgical adhesive (Ethicon Dermabond®). Elapsed surgical time was approximately 6 min, after which, fish were revived in a 400-gal recovery tank supplied with fresh water maintained at 20-22 ^{o}C. Following surgery, the fish were held in these tanks for 14-21 d to ensure that surgical incisions had completely healed prior to their release. Naturalized fish were returned to their original capture sites, while naïve fish were released at one of two public access site located on the Coosawattee and Etowah Rivers (5 fish released at each site) (Figure 3.1).

Radio Telemetry

Radio tracking of naïve fish began immediately following their releases on 18-February and 24-March-2004, and continued through August 2005. Naturalized fish were tracked weekly from May 2005 through October 2006 using a small boat equipped with a portable radio receiver (ATS R2000) attached to a closed-loop antenna. As signals of individual fish were detected, their approximate positions were determined to within 100 m and recorded using a Trimble GeoExplorer 3 handheld GPS unit. At each relocation site, I measured dissolved oxygen and temperature using a YSI® 85 multimeter and recorded depth using a Furuno LS4100 depthsounder.

Although transmitters were not programmed to emit a mortality signal, radio-tagged fish were considered dead if they remained stationary for at least three consecutive weeks and showed no movement at any time thereafter. Individuals were censored (considered censored) when their radio signals could not be detected for at least four consecutive weeks of relocation efforts. Fish were considered alive only when subsequent relocations showed that a discernable movement had occurred during the interval between relocation events. A failed transmitter battery was determined by documenting a gradually declining detection distance of the signal over three weeks, followed by an undetectable signal for remainder of study.

Data Analysis

Radio telemetry relocation data were plotted using ArcGIS (ESRI, Redlands, California) to calculate relocation rkm's and movement rates. Persistence of naïve and naturalized fish during the study was evaluated by comparing the mean number of days in the study for all individuals in each group from date of release to study completion. Significant differences in persistence were detected using a one-tailed *t*-test. Mean number of days survived of known fate fish were used to compare post-release survival rates (# days alive / total # days in study). Only those fish that could be verified as either "dead" or "alive" were used for this comparison, no "dead battery" fish were included. A chi-square test was used to compare source of fish (naïve or naturalized) with fate (dead, censored, or alive). Mean movement rates were compared by calculating average daily distance traveled by fish in each group from the time of release until first relocation after 7 days at large (Hurley et al. 1997). Significant differences in movement rates were identified using a one-tailed *t*-test, while a chi-squared test was used to identify significant differences in direction of movement. Mean seasonal values of water temperature, dissolved oxygen and discharge were obtained from USGS river gaging stations (station #02397530 and #02397000) and compared using ANOVA to identify any significant differences among study years. Tukey's means separations tests were used to identify specific significant differences between years. All statistical tests were conducted using either SAS (SAS v9.1.3, Cary, North Carolina) or Microsoft Excel with $\alpha = 0.025$ for T-tests and $\alpha = 0.05$ for chi-square comparisons.

Results

During the 22 months after their release, survival of naïve lake sturgeon was significantly poorer than the naturalized group based on both persistence and their ultimate fate as determined at the end of the study period. Naïve fish persisted significantly ($p<0.0001$) fewer days (121 ± 44, mean ± SE) than did naturalized fish (410 ± 22) (Table 3.1). By the end of the study, 90% of naïve individuals had either been lost from the study area or confirmed dead. In contrast, only 9% of the naturalized fish died and none were lost. Chi-square analysis showed that the treatment effect (source of fish) was significant ($\chi^2 = 11.22$, $p<0.002$) with regard to the ultimate fate (dead, alive, lost) of each group by the end of the study.

Analysis of radio-telemetry data showed that following their release, naturalized fish tended to remain near their release sites while naïve fish moved rapidly downstream (Table 3.2). The mean daily movement rate of naturalized fish (2.2 rkm/d) was significantly ($p<0.01$) less than for naïve fish (5.2 rkm/d). Chi-square analysis revealed that fish source also had a significant effect ($\chi^2 = 10.29$, $p<0.001$) on the post-stocking direction of fish movement, with naïve fish moving downstream and wild fish moving upstream. Analysis of annual water temperature, dissolved oxygen, and discharge from USGS gaging station revealed several significant differences among study years; however, none of the recorded values exceeded known environmental tolerances of juvenile lake sturgeon.

Discussion

Radio-telemetry is a valuable tool for fisheries managers interested in evaluating post-stocking behavior and survival of hatchery-reared fishes; however, our results suggest that the use of naïve hatchery fish as surrogates for wild fish may yield aberrant data. While naïve lake sturgeon in this study did provide some valuable insights regarding seasonal habitat use, post-stocking survival of these fish was significantly less than that of their wild counterparts. Furthermore, rate and direction of movement, and total displacement were significantly different for naïve versus naturalized individuals. Although causal mechanisms for these differences were uncertain, previous studies suggest that mass downstream movements may result when naïve hatchery-reared fish are released into riverine environments (Cresswell 1981). Regardless, the results of this study revealed that degree of acclimation (naturalization) to the wild may have a dramatic effect on the behavior and survival of hatchery-reared juvenile lake sturgeon.

Although my results demonstrated significant differences in both survival and movement among naive and naturalized lake sturgeon juveniles, my findings should be regarded with some caution because the two treatment groups in my study were not released or monitored concurrently. Analysis of environmental variables showed that treatment groups were, in fact, exposed to slightly different environmental conditions; however, all of the values obtained were well within the known tolerances of juvenile lake sturgeon. Although other variables not measured could have potentially biased my results, the environmental data collected suggest that conditions in the Coosa River were similar to those of lake sturgeon habitats in other systems. Nonetheless, future comparisons of hatchery and wild fish should monitor survival and seasonal movements of each group concurrently to eliminate the potentially confounding effects of temporal variation in environmental conditions.

From both research and management perspectives, naturalized lake sturgeon “performed” much better than naïve individuals in every comparison we examined. These findings illustrate the importance of the environmental history of surrogate fish used in telemetry studies, particularly when seasonal movements or habitat use of wild fish is of primary interest. Although our findings support the long-standing practice of using wild fish in these types of studies, hatchery-reared fish are often the only feasible alternative when wild populations are endangered. In these instances, hatchery-reared fishes should be acclimated to the wild to the greatest extent possible, prior to stocking. Future studies are needed, however, to determine how the length of the acclimation period affects post-stocking performance of hatchery-reared fishes.

Acknowledgements

I acknowledge David Higginbotham and Daniel McLaughlin for statistical and technical assistance. Additionally, I acknowledge the Georgia Department of Natural Resources for their financial support of this project. I also acknowledge the Warnell School of Forestry and Natural Resources for the use of their fisheries research facility. I acknowledge Cecil Jennings for his suggestions for improving the manuscript. Finally, I acknowledge Brad Konwick for his review of the manuscript, Audrey Owens for her editorial comments and contribution of figure 3.2, and Julie Wilson for her aide in developing figure 3.1.

References

Auer, N.A. 1999. Population characteristics and movements of lake sturgeon in the Sturgeon River and Lake Superior. Journal of Great Lakes Research 25(2):282-293.

Birstein, V.J. 1993. Sturgeons and paddlefishes: threatened fishes in need of conservation. Conservation Biology 7:773-787.

Borkholder, B.D., S.D. Morse, H.T. Weaver, R.A. Hugill, A.T. Linder, L.M. Schwarzkopf, T.E. Perrault, M.J. Zacher, and J.A. Frank. 2002. Evidence of a year-round resident population of lake sturgeon in the Kettle River, Minnesota, based on radio-telemetry and tagging. North American Journal of Fisheries Management 22:888-894.

Bradford, R.H. and S.D. Gurtin. 2000. Habitat use by hatchery-reared adult razorback suckers released into the lower Colorado River, California-Arizona. North American Journal of Fisheries Management 20:154-167.

Buckley, J. and B. Kynard. 1985. Yearly movements of shortnose sturgeons in the Connecticut River. Transactions of the American Fisheries Society 114:813-820.

Buckmeier, D.L., R.K. Betsill, and J.W. Schlechte. 2005. Initial predation of stocked fingerling largemouth bass in a Texas reservoir and implications for improving stocking efficiency. North American Journal of Fisheries Management 25:652-659.

Collins, M.R., D.W. Cooke, T.I.J. Smith, W.C. Post, D.C. Russ, and D.C. Walling. 2002. Evaluation of four methods of transmitter attachment on shortnose sturgeon, *Acipenser brevirostrum*. Journal of Applied Ichthyology 18:491-494.

Casswell, N., D. Peterson, B. Manny, and G. Kennedy. Spawning by lake sturgeon (Acipenser fulvescens) in the Detroit River. Journal of Applied Ichthyology 20:1-6.

Cresswell, R.C. 1981. Post-stocking movements and recapture of hatchery-reared trout released into flowing waters-a review. Journal of Fish Biology 18:429-442.

Georgia Environmental Protection Division (EPD). 1998. Coosa River basin management plan. Georgia Department of Natural Resources. Atlanta, Georgia.

Heidinger, R.C. 1999. Stocking for sport fisheries enhancement. Pages 375 – 430 *in* C. C. Kohler and W. A. Hubert, editors. Inland fisheries management in North America, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Hurley, S.T., W.A. Hubert, and J.G. Nickum. 1987. Habitats and movements of shovelnose sturgeons in the upper Mississippi River. Transactions of the American Fisheries Society 116:655-662.

Jordan, G.R., R.A. Klumb, G.A. Wanner, and W.J. Stancill. 2006. Postocking movements and habitat use of hatchery-reared juvenile pallid sturgeon in the Missouri River below Fort Randall Dam, South Dakota and Nebraska. Transactions of the American Fisheries Society 135:1499-1511.

Peake, S., F.W.H. Beamish, R.S. McKinley, D.A. Scruton, and C. Katopodis. 1997. Relating swimming performance of lake sturgeon, Acipenser fulvescens, to fishway design. Canadian Journal of Fisheries and Aquatic Sciences 54:1361-1366.

Peterson, D.L., B. Gunderman, and P. Vecsei. 2002. Lake Sturgeon of the Manistee River: a current assessment of Spawning stock size, age, and growth. i*n* W. Van Winkle, P. J. Anders, D. H. Secor, and D. A. Dixon, editors. Biology, Management, and Protection of North American Sturgeon. American Fisheries Society Symposium 28:175-183.

Peterson, D.L., P. Vecsei and C.A. Jennings. 2007. Ecology and biology of the lake sturgeon: a synthesis of current knowledge of a threatened North American *Acipenseridae*. Reviews in Fish Biology. 17:59-76.

Popoff, N.D., and R.M. Neumann. 2005. Range and movement of resident holdover and hatchery brown trout tagged with radio transmitters in the Farmington River, Connecticut. North American Journal of Fisheries Management 25:413-422.

Porak, W.F., W.E. Johnson, S. Crawford, D.J. Renfro, T.R. Schoed, R.B. Stout, R.A. Krause, and R.A. DeMauro. 2002. Factors affecting survival of largemouth bass raised on artificial diets and stocked into Florida lakes. Pages 649 – 665 *in* D. P. Phillip and M. S. Ridgway, editors. Black Bass: ecology, conservation, and management. American Fisheries Society, Symposium 31, Bethesda, Maryland.

Priegel, G.R. & T.L. Wirth. 1971. The lake sturgeon: its life history, ecology and management. Wisconsin Department of Natural Resources Publication. No. 4–3600(77).

Schram S.T., J.Lindgren, and L.M. Evrard. 1999. Reintroduction of lake sturgeon in the St. Louis River, western Lake Superior. North American Journal of Fisheries Management 19:815-823.

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.

Table 3.1. Persistence and survival of 10 naïve and 11 wild radio-transmittered juvenile lake sturgeon in the Coosa River System, Georgia-Alabama from February 2004 to December 2006. Fate code is: A = alive, C = censored, D = dead, and BF = battery failure.

Naïve					Wild				
Fish #	Relocations	Persistence (d)	Survival (%)	Fate	Fish #	Relocations	Persistence (d)	Survival (%)	Fate
1	59	450	100	A	1	69	450	100	A
2	1	28	-	C	2	40	240	-	BF
3	2	28	6	D	3	67	450	100	A
4	2	35	-	C	4	57	438	-	BF
5	1	85	-	C	5	47	450	100	A
6	2	35	-	C	6	79	450	100	A
7	4	93	21	D	7	51	385	86	D
8	6	261	58	D	8	69	450	100	A
9	1	6	-	C	9	76	450	100	A
10	2	195	43	D	10	61	450	100	A
-	-	-	-	-	11	47	295	-	BF
Mean	8	121	46	-	-	60	410	98	-

Table 3.2. Post-stocking movements (upstream = (+), downstream = (-)) of 10 naïve and 11 naturalized juvenile lake sturgeon used for a radio telemetry study in the Coosa River System, Georgia-Alabama from February 2004 to December 2006.

Naïve				Naturalized			
Fish #	Days to first relocation	Post-surgical movement (rkm)	Rate (km/d)	Fish #	Days to first relocation	Post-surgical movement (rkm)	Rate (km/d)
1	21	-196	9.3	1	13	+38	2.9
2	28	-213	7.6	2	10	+15	1.5
3	22	-213	9.7	3	12	-30	2.5
4	35	-213	6.1	4	10	+36	3.6
5	85	-140	1.6	5	15	+27	1.8
6	29	-162	5.6	6	10	+23	2.3
7	93	-143	1.5	7	10	+4	0.4
8	28	-137	4.9	8	13	+33	2.5
9[a]	6	-	-	9	13	+14	1.1
10	188	-162	0.9	10	15	+80	5.3
-	-	-	-	11	15	-3	0.2
Mean	54	-175	5.2	-	11	22	2.2

[a] Only relocation of individual occurred 6 days after its release, approximately 120 km downstream of its release site.

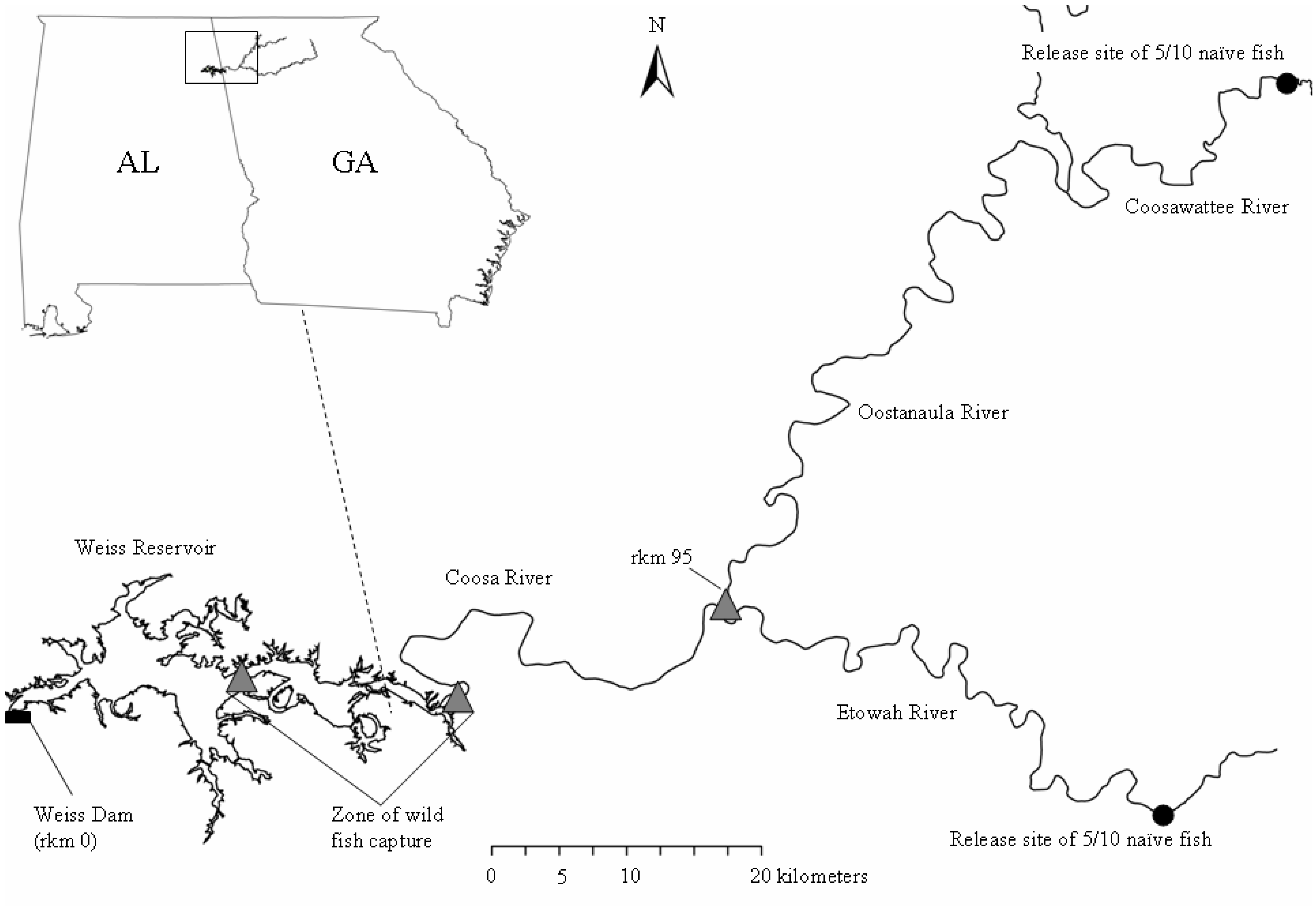

Figure 3.1. Map of the Coosa River System and Weiss Reservoir showing release locations of naïve radio-tagged juvenile lake sturgeon and zone of wild juvenile lake sturgeon captures.

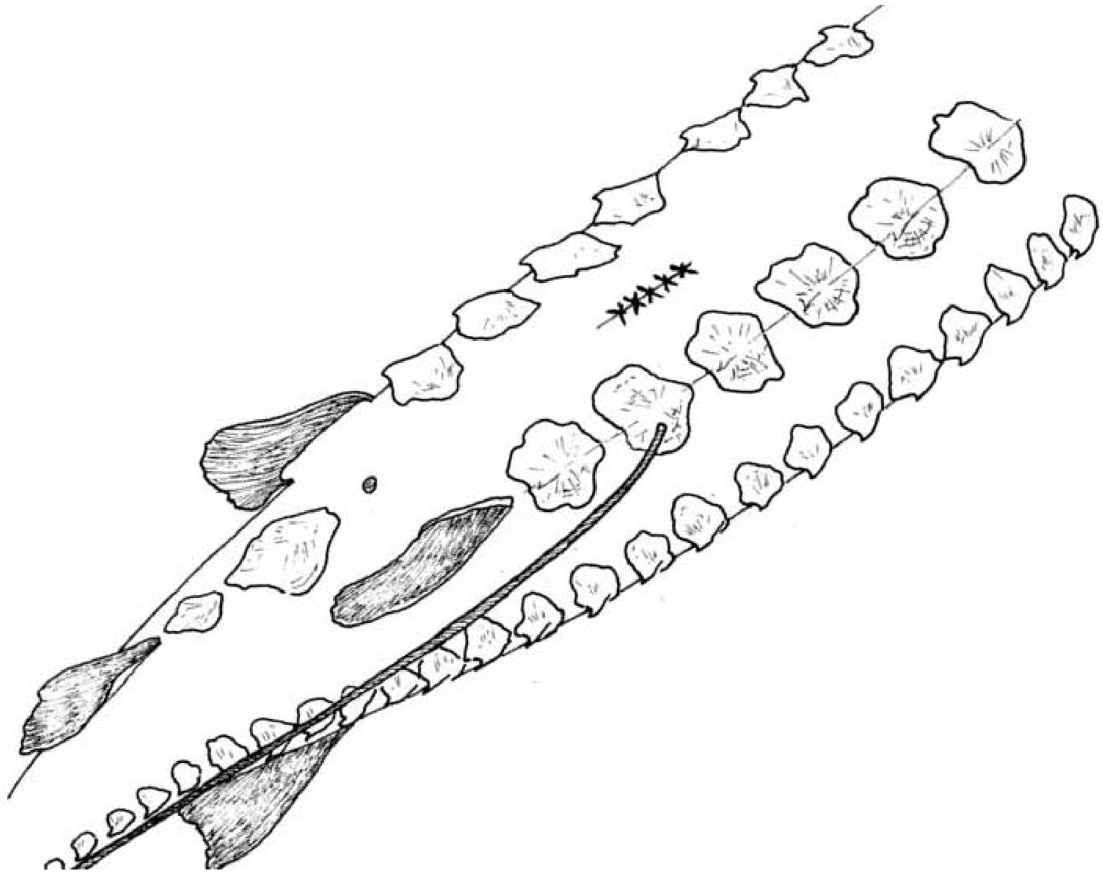

Figure 3.2. Lateral-ventral view of juvenile lake sturgeon with internal radio-transmitter, showing sutured incision and transmitter antenna protruding through a 3-mm hole drilled into a ventral scute immediately posterior to the incision.

CHAPTER 4

CONCLUSION

The goal of the GADNR's Coosa River reintroduction program is to achieve a self-sustaining population of lake sturgeon after 20 years of stocking efforts. Currently, the reintroduction program should be viewed as a preliminary success, though more time is needed to determine if the program is a complete success. The results of my study yielded a population estimate of 793 (694 – 893, 95% CI). This is the first population estimate of lake sturgeon ever presented for the Coosa River System and the first documented occurrence of lake sturgeon from the system since 1968 (Smith-Vaniz 1968). I found that the population is currently comprised of four different cohorts, each exhibiting different levels of survival. By comparing survival of these cohorts, I found that juvenile lake sturgeon stocked as phase II fingerlings apparently survive better than those stocked as phase I fingerlings. The presence of multiple cohorts in the Coosa is similar to results seen in Missouri, Tennessee, and New York (Jackson et al. 2002; Hughes et al. 2005; Drauch and Rhodes 2007). However, none of these states have quantified data on survival of stocked juvenile lake sturgeon (Drauch and Rhodes 2007).

Prior to this study, little information was known regarding growth and condition of either stocked or juvenile lake sturgeon. I found that growth of lake sturgeon in the Coosa River System may be lower than estimates reported for northern populations, but more data is needed to fully determine if this is true as the population ages. Additionally, I found that condition changes according to fish size and season. While growth rates were lower than expected, the data suggest that lake sturgeon growth may be subject to an upper thermal limit as suggested by

Power and McKinley (1997). For the Coosa River population, such a consequence could mean that maximum size of lake sturgeon may not be as large as individuals in northern waters.

The movements and habitat use of Coosa River lake sturgeon were similar to those reported for other populations. In general, Coosa lake sturgeon appeared to be most active during spring and fall and least active during summer and winter. The seasonal shifts in movements suggested that the fish were potentially responding to changes in habitat conditions, such as water temperature and dissolved oxygen. Additionally, habitat use of Coosa juveniles was similar to that reported for northern fish, with most individuals selecting a heterogeneous mix of habitat types throughout the year. However, as hypoxic conditions developed in reservoir habitat during summer, the importance of river habitats increased regardless of substrate type. . Although speculative, decreased summer habitat availability could limit future recruitment because of density dependent issues, but more data is needed to address this issue.

Finally, the comparison of naïve and naturalized juvenile lake sturgeon in a radio-telemetry study yielded some potentially important findings. Overall, naturalized fish outperformed naïve fish in every category, suggesting that whenever possible, naturalized fish should be used for radio-telemetry studies. However, when naïve fish are the only viable research option, researchers should design their studies to account for potential acclimation periods and high degrees of mortality and should acknowledge that their findings are the result of using naïve fish.

To help ensure the long-term success of the reintroduction efforts, I believe that the GADNR may need to amend their current stocking practices in one of two ways. First, I suggest that the GADNR shift more of their efforts to stocking phase II fish. However, if this is undertaken, then the GADNR needs to determine the effect of stocking density on cohort survival and adjust the number of fish stocked accordingly. Second, as the new population ages, the GADNR should monitor growth and maturation. As juvenile lake sturgeon mature, efforts should be made to develop local sources of broodstock for future stockings. Hopefully, this will ensure that genes of naturalized fish are passed to future generations and help artificially speed the process of genetic selection. However, the GADNR should continue to stock fish from other populations. This should help increase the genetic variability of the population, thereby allowing for a more genetically diverse population to deal with unknown future environmental conditions. Additionally, development of a local broodstock should be done in conjunction with allowing individuals to reproduce naturally, thereby potentially increasing reproductive success of the population.

To date, the lake sturgeon reintroduction efforts of the GADNR appear to be a qualified success, although several additional years of research and management will be needed to ensure that a self-sustaining population has been re-established in the Coosa River System. The recruitment of four successive cohorts to the juvenile population is a positive result for this program. I believe that if the GADNR continues to stock phase I fish, while increasing the number of phase II fish stocked, the future could be very bright for the fish. Additionally, I hope that the data I have presented on growth, condition, movements, and habitat use aide the GADNR in future management decisions. Future studies of lake sturgeon in the Coosa River should be conducted to monitor annual mortality, age and size at sexual maturity, and diet. More knowledge in these research areas could help the reintroduction program succeed, as well as providing new information regarding the ecology of lake sturgeon in southern rivers.

References

Drauch, A.M. and O.E. Rhodes, Jr. 2007. Genetic evaluation of the lake sturgeon reintroduction program in the Mississippi and Missouri Rivers. North American Journal of Fisheries Management 27: 434-442.

Hughes, T.C., C. E. Lowie, and J.M. Haynes. 2005. Age, growth, relative abundance, and scuba capture of a new or recovering spawning population of lake sturgeon in the lower Niagara River, New York. North American Journal of Fisheries Management 25:1263-1272.

Jackson, J.R., A.J. VanDeValk, T.E. Brooking, O.A. vanKeeken, and L.G. Rudstam. 2002. Growth and feeding dynamics of lake sturgeon, *Acipenser fulvescens,* in Oneida Lake, New York: results from the first five years of a restoration program. Journal of Applied Ichthyology 8:439-443.

Power, M., and R.S. McKinley. 1997. Latitudinal variation in lake sturgeon size as related to the thermal opportunity for growth. Transactions of the American Fisheries Society 28:175-82.

Smith-Vaniz, W.F. 1968. Freshwater fishes of Alabama. Paragon Press, Montgomery, Alabama.

APPENDIX 1

METHODS AND RESULTS OF HABITAT SAMPLING AND CLASSIFICATION

Methods

Habitat sampling was conducted from 1-June to 15-August 2006 using the line-transect method described by Bain and Stevenson (1999) to quantify channel width, depth, substrate composition, and bottom (< 0.5 m) water temperature and dissolved oxygen. At least 3 transects were made in each of 5 different habitat types that were first delineated based on gross differences in channel morphometry. These habitat types were headwater (rkm 95 - 74), upper river (rkm 74 - 55), middle river (rkm 55 - 50), lower river (rkm 50 - 38), and reservoir (rkm 38 - 0). Within each of these habitat types, habitat measures were recorded at five evenly spaced points along transects (excluding banks). Channel width was determined to the nearest 0.1 m with a Leupold RXII® laser rangefinder. Water temperature (C) and dissolved oxygen (mg/L) were measured within 0.5 m of the bottom with a YSI® 85 multimeter. Depth was determined to the nearest 0.1 m with a Furuno LS4100®. Substrate size and composition were classified using a modified Wentworth scale (Cummins 1962) after visual examination of substrate samples collected using a Wildco® Petite Ponar grab sampler.

Habitat data were analyzed using discriminant function analysis (DFA) in SAS 9.1.3 (SAS v9.1.3, Cary, North Carolina) to determine which habitat characteristics accounted for the greatest variation among habitat reaches with habitat type as the class variable and the specific habitat characteristics as individual variables. Results of the analysis were interpreted using standardized function coefficients and discriminant function correlations as described by Peterson and Rabeni (2001). Absolute correlation values (>0.20) were used to interpret discriminant functions, while redundant variables were identified using absolute coefficient values (Stevens 1992; Peterson and Rabeni 2001). Mean canonical scores of discriminant functions were plotted to determine degree of difference among habitat reaches (Stevens 1992).

Results

Differences between neighboring habitat types were minimal, but differences between non-neighboring types was obvious. In general, the headwaters had the narrowest and shallowest channel with the coarsest substrate. Upper, middle, and lower reaches had gradually finer substrates according to distance downstream, and the reservoir had the finest substrates and a wider, deeper channel than other habitats (Table A1.1). Due to similarities of the middle river type to both upper and lower river types, middle river was split and each half added to the upper and lower types respectively. Discriminant function analysis indicates that mean depth, width, and temperature, and primary substrate explain most variation between discriminant function one and two (Table A1.2). Mean depth, primary and secondary substrate presence and size explain remaining variation between the reaches as indicated by discriminant functions three and four (Table A1.2). The standardized canonical discriminant function coefficient values indicate very low levels of redundancy between discriminant function one and two. Higher levels of redundancy exist between functions three and four (Table A1.3). Biplots of mean canonical scores indicate that the reservoir and headwater types are most different on most characteristics, but the other three habitat types differ mainly because of mean channel depth, width, and temperature (Figure A1.1).

References

Cummins, K.W. 1962. An evaluation of some techniques for the collection and analysis of benthic samples with special emphasis on lotic waters. American Midland Naturalist 67:477-504.

Peterson, J.T. and C.F. Rabeni. 2001. Evaluating the physical characteristics of channel units in an Ozark stream. Transactions of the American Fisheries Society 130:898-910.

Stevens, J. 1992. Applied multivariate statistics for the social sciences, 2^{nd} edition. Lawrence Erlbaum Associates, Hillsdale, New Jersey.

Table A1.1. Summary statistics of habitat variables measured for each habitat reach in the Coosa River System from July to August 2006. Substrate types (mean size) are A = organic material, B = fines, C = sands, D = gravel, E = pebble, F = cobble, G = boulder, and H = bedrock as defined by Cummins (1962). Primary and secondary substrates are presented in percent dominance in each reach, depth and width are in m, temperature in C, and dissolved oxygen in mg/L.

	Reach				
Measured Variables	Headwater	Upper	Middle	Lower	Reservoir
Mean primary substrate	94	59	47	53	99
(percent dominance)	SD = (23)	SD = (12)	SD = (09)	SD = (11)	SD = (11)
Primary substrate class	C	C	C	B	B
Mean secondary substrate	11	38	35	30	<5
(percent dominance)	SD = (6)	SD = (10)	SD = (10)	SD = (08)	SD = (0)
Secondary substrate class	F	B	B	C	n/a
Mean channel depth	1.9	5.7	6.7	6.2	7.0
(m)	SD = (0.5)	SD = (0.3)	SD = (0.4)	SD = (0.9)	SD = (0.2)
Mean channel width	82.9	95.3	101.4	125.0	106.7
(m)	SD = (5.2)	SD = (5.5)	SD = (8.2)	SD = (10.5)	SD = (5.7)
Mean water temperature	25.7	28.7	29.4	30.1	28.6
(^{o}C)	SD = (0.1)	SD = (0.7)	SD = (0.0)	SD = (0.3)	SD = (0.2)
Mean dissolved oxygen	7.97	8.21	7.46	6.08	2.84
(mg/L)	SD = (0.05)	SD = (0.87)	SD = (0.21)	SD = (1.04)	SD = (0.26)

Table A1.2. Standardized canonical discriminant function coefficient values for all habitat variables measured during July and August 2006 in the Coosa River System. Negative values indicate a weak relationship with other variables, while positive values indicate a strong relationship.

Habitat Variable	DF1	DF2	DF3	DF4
Primary substrate dominance	-0.77	1.07	0.72	1.04
Primary substrate class	0.15	-0.23	-0.15	0.68
Secondary substrate dominance	-0.30	-0.40	0.27	0.76
Secondary substrate class	0.03	0.18	-0.32	0.12
Mean depth	1.31	-0.28	1.18	0.07
Mean width	2.11	0.25	-0.71	0.96
Mean temperature	0.68	-0.22	0.21	0.17
Mean dissolved oxygen	0.25	-1.26	0.03	0.57

Table A1.3. Variable canonical discriminant function correlation values for all habitat variables measured during July and August 2006 in the Coosa River System. Values with (*) indicate those >0.20 used for interpretation of redundancy.

Habitat Variable	DF1	DF2	DF3	DF4
Primary substrate dominance	-0.51	0.74*	0.24*	0.27*
Primary substrate class	-0.19	-0.22	0.01	0.37*
Secondary substrate dominance	-0.03	-0.68	0.13	0.36*
Secondary substrate class	-0.10	0.08	-0.24	-0.07
Mean depth	0.63*	-0.07	0.70*	-0.15
Mean width	0.84*	0.33*	-0.33	0.16
Mean temperature	0.86*	-0.05	0.05	0.14
Mean dissolved oxygen	-0.52	-0.72	-0.10	0.07

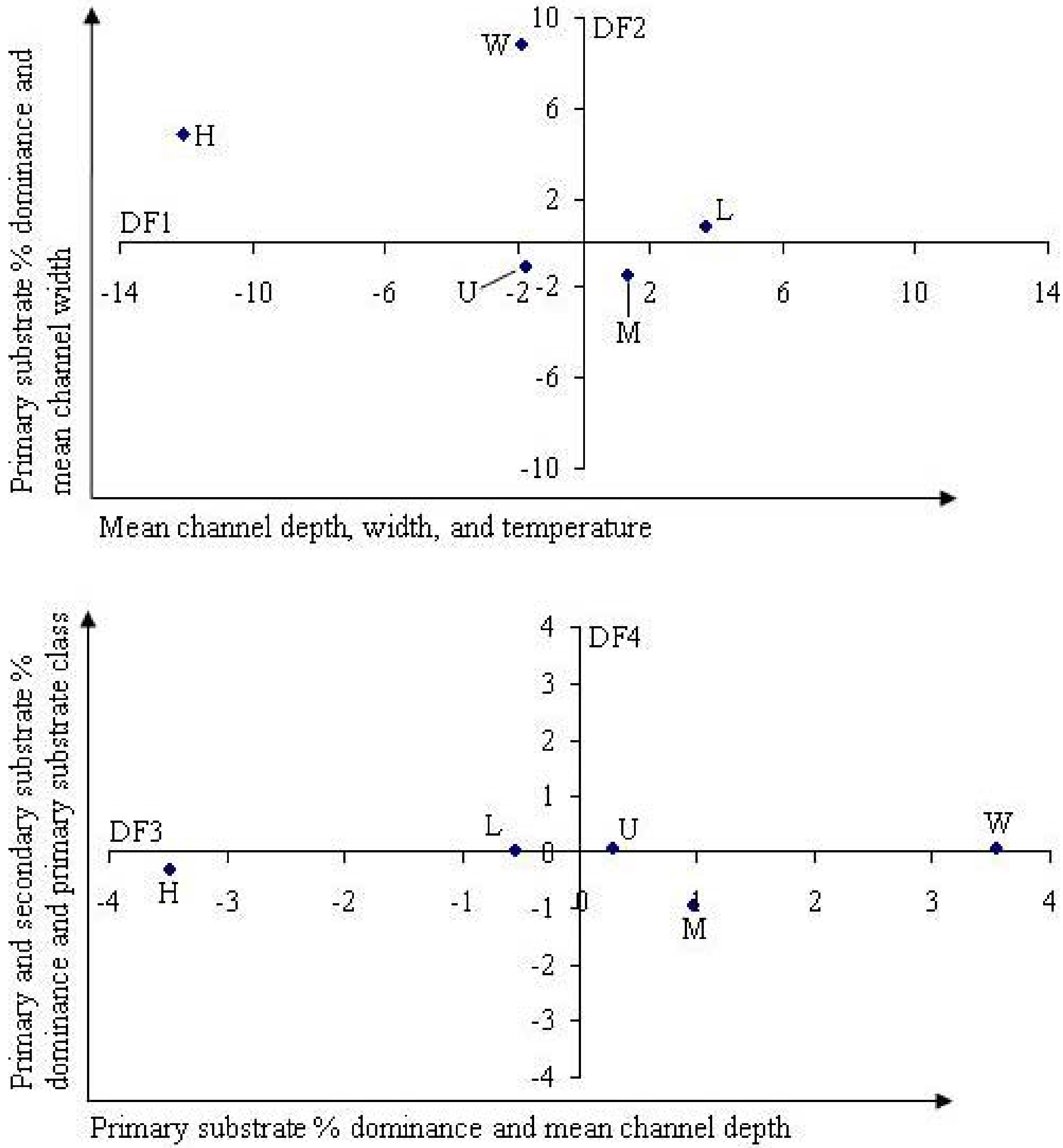

Figure A1.1. Discriminant function biplots of mean canonical scores for all four discriminant functions of habitat variables from the Coosa River System, July to August 2006. Sites are denoted as H = headwaters, U = upper river, M = middle river, L = lower river, and W = Weiss reservoir. Labeled arrows (at left and below each biplot) denote increasing values of descriptors for each axis.