# Dispersal and Dam Passage of Sonic-tagged Juvenile Lake Sturgeon in the Upper Tennessee River

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*Abstract:* More than 90,000 state-endangered lake sturgeon (*Acipenser fulvescens)* have been stocked into the French Broad River, Holston River, and Fort Loudoun Lake in the upper Tennessee River system. Although incidental reports of anglers catching these fish have increased, little is known about their fate after stocking. Therefore, this study was conducted to evaluate lake sturgeon dispersal throughout the system. Seven submersible ultrasonic receivers were deployed in the upper Tennessee River system and 37 juvenile fish (mean fork length = 660 mm) were surgically implanted with ultrasonic transmitters in the fall of 2007. These fish were stocked at two sites in the headwaters of Fort Loudoun Lake. The receivers logged 1,345 detections of tagged fish and manual tracking located 32 of the 37 tagged lake sturgeon over 21 months. Ten (31%) tagged fish passed through Fort Loudoun Dam and were located downstream in the headwaters of Watts Bar Reservoir; the other tagged fish were still at large above Fort Loudoun Dam when tracking ceased in 2009. Of all fish stocked, three (9%) were last located in the French Broad River and none were located in the Holston River.

*Keywords*: lake sturgeon, dam passage, dispersal, movement

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Lake sturgeon (*Acipenser fulvescens*) once thrived throughout the Mississippi River basin, but populations at the southern extent of the species' range have declined or been extirpated since the early and middle twentieth century. Like all sturgeon, lake sturgeon are long-lived, slow-growing fish that attain maturity relatively late (>10 years) and may only reproduce every few years (Etnier and Starnes 1993). These characteristics make them especially prone to population declines (Beamesderfer and Farr 1997). Declines in lake sturgeon populations have been attributed to over-exploitation, dam construction, habitat alteration, and degraded water quality (Slade 1996). By the 1950s, the Tennessee Valley Authority (TVA) had completed a 1,050-km navigation channel spanning the entire length of the Tennessee River using a series of locks and dams. Dams alter natural flow regimes, modify physical habitat (e.g., substrate) and restrict upstream and downstream movements of fish, even in the presence of navigation locks (Bain et al. 1998, Cooke and Leach 2004). Knights et al. (2002) found that lake sturgeon moved both downstream and upstream through upper Mississippi River navigation locks and dams; however, those dams appeared to be intermittent barriers to upstream passage. Auer (1996a) observed a change in lake sturgeon spawning behavior on the Sturgeon River, Michigan, related to hydroelectric facility operations. Habitat degradation via point and non-point source pollution was a major problem throughout the United States prior to passage of the Clean Water Act of 1973 and probably contributed to the extirpation of lake sturgeon from the Tennessee River (Auer 2005).

Commercial harvest of lake sturgeon commenced in reservoirs on the Tennessee River in Alabama after World War II and peaked in 1956 when an estimated 7,700 kg were harvested; however, by 1961 there were no reports of lake sturgeon harvested (TVA 1962). Until recently, there were few sightings or incidental captures of lake sturgeon in Tennessee after the 1950s; between 1974 and 1993 there were no reports of lake sturgeon in the upper Tennessee River system (Etnier and Starnes 1993). Although the lake sturgeon is not listed under the Endangered Species Act, the decline of this species prompted 18 states within its historical range, including Tennessee, to list it as Endangered, Threatened, or Protected (Chiasson et al. 1997).

To improve water quality and minimum flows on the French Broad River, Holston River, and upper Tennessee River, the Reservoir Releases Improvements/Lake Improvement Plan was implemented by the TVA at Douglas and Cherokee Dams (Scott et al. 1996). Dissolved oxygen levels in the French Broad River and Holston River increased due to installation of surface water pumps

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and oxygen injection systems at Douglas Dam in 1993 and Cherokee Dam in 1995; turbine venting was added in 1995 to further increase dissolved oxygen levels in both tailwaters. Minimum flows of 16.5 cubic meters per second (cms) below Douglas Dam and 9.2 cms below Cherokee Dam were instituted and maintained by turbine pulsing in 1987 to improve benthic macroinvertebrate and fish communities (Scott et al. 1996).

Improved water quality and physical habitat below many TVA dams led some fisheries biologists to believe that lake sturgeon could be reintroduced into their historic range in the Tennessee River. In 1995, the Tennessee River Lake Sturgeon Working Group was created, which is a multi-agency partnership between the Tennessee Wildlife Resources Agency, TVA, U.S. Fish and Wildlife Service, Tennessee Aquarium Conservation Institute, Tennessee Cooperative Fishery Research Unit, University of Tennessee, Wisconsin Department of Natural Resources, U.S. Geological Survey, Tennessee Technological University, World Wildlife Fund, and the Tennessee Clean Water Network. In 1998, this group adopted the Lake Sturgeon Reintroduction Plan, which had the primary objective of restoring lake sturgeon populations to historic levels so that the species could be de-listed by the State of Tennessee and possibly support a limited sport fishery.

Since 2000, over 90,000 hatchery-reared lake sturgeon have been reintroduced into the upper Tennessee River and reports of incidental catches of lake sturgeon by anglers have increased throughout the river system (Jason Henegar; TWRA, personal communication). Although such news is encouraging, more information is needed to properly assess the stocking program. The purpose of this study was to assess dispersal and dam passage of lake sturgeon stocked into the upper Tennessee River system.

## Study Area

This study was conducted in eastern Tennessee on 52 km of the lower French Broad River below Douglas Dam, 84 km of the Holston River below Cherokee Dam, all of Fort Loudoun Lake and Tellico Lake, and the headwaters of Watts Bar Lake and Chickamauga Lake (Figure 1). Reservoir surface areas and maximum turbine discharge at each dam are listed in Table 1. Most lake sturgeon are stocked at the Seven Islands Wildlife Refuge on the French Broad River, 23 km downstream of Douglas Dam. Lake sturgeon have occasionally been stocked at Louisville Point on the southern bank of Fort Loudoun Lake at Tennessee River (TR) km 1,006.5. Water in Tellico Lake is diverted through a small navigable canal (at TRkm 970.4) into Fort Loudoun Lake, linking the two reservoirs in their joint flood-control functions.

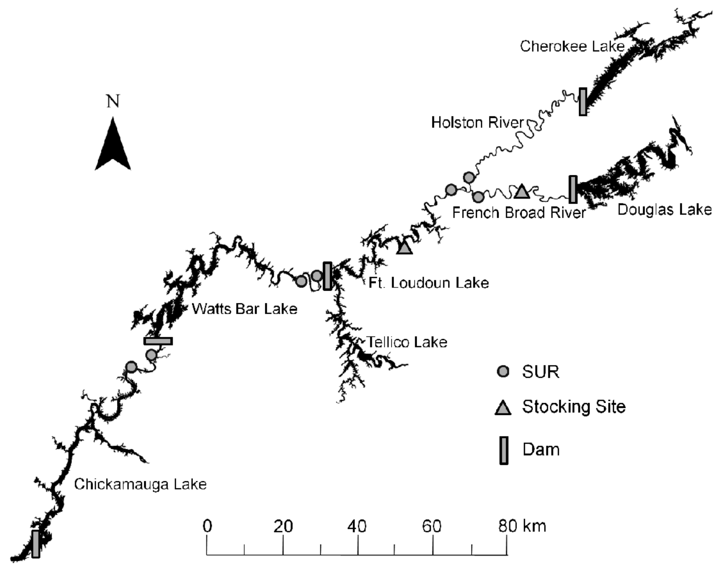


**Figure 1.** Map of the upper Tennessee River system showing the two stocking sites for tagged lake sturgeon and the location of seven submersible ultrasonic receivers (SUR).

**Table 1.** Dams in the upper Tennessee River system where tagged lake sturgeon were stocked and tracked in 2007–2008.

| Dam | River impounded | Reservoir surface area (ha) | Maximum turbine discharge (cms) | Navigation locks present? |
|---|---|---|---|---|
| Cherokee | Holston | 11,650 | 467 | No |
| Douglas | French Broad | 11,500 | 521 | No |
| Tellico | Little Tennessee | 6,300 | No turbines | No |
| Fort Loudon | Tennessee | 5,900 | 849 | Yes |
| Watts Bar | Tennessee | 15,800 | 1,302 | Yes |

## Methods

### Surgical Implantation of Transmitters

Ultrasonic tags were implanted into 32 juvenile lake sturgeon on 26 June 2007 at the University of Georgia's Cohutta Fisheries Center in Cohutta, Georgia. These fish were subsequently held for 100 days to assess mortality and tag shed rates. All fish were measured (fork length [FL], mm) and weighed (g) before they were tagged. Sonotronics CHP-87-L transmitters (80 x 16 mm; 11.5 g) with a guaranteed battery life of 18 months were implanted into fish following standard surgical practices (Wagner and Cooke 2005). Fish were at least 565 mm FL and weighed more than 1.2 kg, which conferred a tag burden of less than 1% of body weight to minimize mortality due to tag insertion (Winter 1996).

Narcosis was induced by incrementally adding tricaine methanesulfonate (MS-222) to a 28-L tub of water until loss of equilibrium and lack of response to external stimuli occurred, usually at 150–225 ppm MS-222. Sturgeon were then placed ventral side up into a shallow, inclined PVC trough lined with foam and clean plastic sheeting located in a larger tub. Sturgeon were positioned whereby water partially covered the head and a maintenance dose of 50 ppm MS-222 was retained during surgery. During the surgery a plastic turkey baster was used to manually irrigate the gills, a sterile drape covered the posterior half of the fish, and the surgeon wore surgical gloves.

Surgeries were performed according to the methods of Wildgoose (2000). Fish received four or five interrupted sutures with absorbable 0-, 1-0, or 2-0 Monocryl or Vicryl suture material using reverse-cutting needles and were placed into a raceway to recover. Total surgical times ranged between four and eight minutes (mean = 5.43 minutes).

All 32 fish tagged in June 2007 survived the holding period, but 4 fish (11%) shed their tags. Thus, 28 tagged lake sturgeon were stocked on 4 October 2007 at Seven Island Wildlife Refuge on the French Broad River. Enough tags were available to implant a second cohort of lake sturgeon ($n = 9$) on 6 November 2007; those fish were stocked at the Louisville Point boat ramp on Fort Loudoun Lake later that same day.

### Movements

Submersible ultrasonic receivers (SUR; Sonotronics SUR-1) were deployed on 26–27 September 2007 in the upper Tennessee River system at seven sites (Figure 1). The SUR locations were chosen to detect upstream and downstream movements from stocking sites as well as dam passage(s). The SURs were placed into 40-kg anchors that were lowered to the bottom at each site using a winch and divers. Complete details of SUR deployment and retrieval were provided by Bettoli et al. (2010). The SURs were retrieved to replace batteries and download data and then redeployed in the same sites on 28–29 May 2008 and 15–16 October 2008. The SURS were retrieved at the end of the study on 29–30 June 2009. Data were downloaded from each SUR using SURsoft, a software program provided by Sonotronics, and examined to determine the time and day a tagged sturgeon was detected by the SUR. A SUR "detection" was a single logged event where both frequency and interval (interval tolerance: ± 5 milliseconds) of a sonic tag was recorded by a SUR. A "hit" was defined as two or more consecutive detections logged by a SUR in a 24-hour day. Although the range of the tags we implanted into lake sturgeon had a range of up to 3 km when using a directional hydrophone, an SUR (equipped with an omnidirectional hydrophone) would probably not detect a tagged fish that was not within ~100–150 m (Casto-Yerty and Bettoli 2009).

Manual tracking was also conducted throughout the upper Tennessee River system during fall 2008, winter 2008/2009, and spring 2009. A Sonotronics directional hydrophone (DH-4) and Sonotronics receivers (USR-5W and USR-96) were used to locate tagged fish. Manual tracking was conducted by proceeding by boat downstream and searching for tagged fish at 1-km intervals. Geographic locations of tagged fish were recorded as waypoints using a Garmin GPSmap 535 Sounder Global Positioning System (GPS). The entire French Broad River below Douglas Dam, the lower 4.8 km of the Holston River, and all of Fort Loudoun and Tellico Reservoirs were manually searched at least once during the course of the study.

A Kolmogorov-Smirnov two-sample test was performed in SAS 9.2 to determine if there was a significant difference between total days spent in a particular habitat (lacustrine or riverine) by lake sturgeon stocked at either location. Statistical significance was declared at $P = 0.05$.

## Results

The SURs logged 75,851 "detections" and 1,345 "hits" of tagged sturgeon. Three SURs (in the French Broad River, in Fort Loudoun Lake, and one of the two below Fort Loudoun Dam) had a total of six confirmed misses (i.e., the SUR did not detect a fish traveling up or downstream between two other SURs). The SURs logged between 1 and 188 hits for each tagged fish (mean = 45, SE = 7.8).

Three tagged lake sturgeon stocked at Seven Island Wildlife Refuge on the French Broad River were never detected by a SUR or manual tracking. The other 25 were at large for 1 to 126 days (mean = 13 days; SE = 5.3 days) before being detected by a SUR for the first time. These lake sturgeon traveled a minimum of 25 to 33 km (mean = 25.9 km, SE = 0.5 km) during that time. Twenty-two of these 25 fish (88%) left the riverine habitat in the French Broad River and were last located in Fort Loudoun Reservoir or below Fort Loudoun Dam in Watts Bar Reservoir. Five (23%) dispersed out of the river during fall 2007, 3 (14%) during winter 2007–2008, 5 (23%) during spring 2008, and 9 (41%) during summer 2008. The remaining three fish never dispersed out of the French Broad River and were last observed in the river.

Seven of the nine lake sturgeon (78%) stocked at Louisville Point on Fort Loudoun Reservoir swam 37.9 to 44.2 km (mean = 42.9, SE = 1.26) between 45 to 313 days post-stocking (mean = 110, SE = 51.0) before they were detected by a SUR. SURs or manual tracking never located the two other tagged lake sturgeon stocked at Louisville Point. These seven fish demonstrated the general pattern of downstream dispersal that was observed for fish stocked into the French Broad River. Three fish (43%) were last located upstream of Fort Loudoun Dam in either Fort Loudoun Lake or Tellico Lake. The remaining four fish (57%) swam downstream through Fort Loudoun Dam during winter 2007–2008; they were

**Table 2.** Mean days (+ SE) spent in riverine and lacustrine habitats by tagged lake sturgeon stocked at Seven Islands Wildlife Refuge, Louisville Point, and both stocking locations combined in Fort Loudoun Lake, Tennessee.

| Stocking location | Mean riverine days | Mean lacustrine days |
|---|---|---|
| Seven Islands | 130 (22.6) | 254 (27.4) |
| Louisville Point | 0.0 | 220 (75.9) |
| Combined | 101 (19.9) | 246 (26.7) |

last located in the headwaters of Watts Bar Lake. None of the fish stocked at Louisville Point were ever located upstream in a riverine environment (i.e., the Holston or French Broad rivers).

Of the 32 lake sturgeon that were located at least once, 19 (59%) were last located above Fort Loudoun Dam (in either Fort Loudoun or Tellico lakes), ten (31%) passed through Fort Loudoun Dam into Watts Bar Reservoir, and three (9%) were last located in the headwaters of Fort Loudoun reservoirs (i.e., the French Broad or Holston rivers). Only one fish was ever located in Tellico Lake and it was found near the canal connecting the two Loudoun reservoirs. Lake sturgeon stocked in the upper Tennessee River system spent significantly more days in a lacustrine environment (i.e., Fort Loudoun or Tellico reservoirs) than in riverine habitats (i.e., French Broad and Holston rivers) ($t = 1.78$; $P < 0.0036$) (Table 2).

## Discussion

Most (81%) of the juvenile lake sturgeon stocked either in the French Broad River or Fort Loudoun Lake dispersed rapidly downstream. This dispersal pattern has been documented in other studies of juvenile lake sturgeon movements in regulated systems. Thuemler (1988) reported that most juvenile lake sturgeon in the Menominee River, Wisconsin, moved downstream out of the river and lake sturgeon in the Mattagami River, Ontario, rapidly dispersed downstream in the fall when temperatures began to decrease (McKinley et al. 1998). Martin (2001) and Huddleston (2006) also documented juvenile lake sturgeon dispersing in the fall out of the French Broad River and into Fort Loudoun Lake. Martin (2001) also suspected that nearly half (46%) of the lake sturgeon stocked into the French Broad River that he tracked eventually passed through Fort Loudoun Dam.

In the present study more lake sturgeon moved downstream through Fort Loudoun Dam than remained in the headwaters of Fort Loudoun Lake (i.e., the French Broad or Holston rivers) and no lake sturgeon were detected passing upstream through Fort Loudoun Dam. The extent of dam passage by lake sturgeon has not been well documented and few studies have examined this topic in great detail. Knights et al. (2002) found that lake sturgeon in the Mississippi River were more likely to pass downstream through a dam than upstream. Few (4%) tagged white sturgeon (*Acipenser transmontanus*) in the Columbia River passed downstream through dams, but even fewer (1%) made an upstream dam passage (North et al. 1993). Kynard et al. (1999) estimated that as many as 30% of tagged adult shortnose sturgeon (*A. brevirostrum)* in the Connecticut River, Massachusetts, made a downstream run through Holyoke Dam within a year of being released. Of 50 tagged shortnose sturgeon spawning downstream of Pinopolis Dam in the Cooper River, South Carolina, none subsequently moved upstream through the dam's lock into Lake Moultrie (Collins et al. 2003). Shortnose sturgeon, unlike lake sturgeon, are anadromous and therefore a greater percentage should make downstream runs back to the ocean.

The relatively high number (31%) of lake sturgeon that passed through Fort Loudoun Dam and their use of lacustrine habitats over riverine habitats are evidence that tagged lake sturgeon in the Fort Loudoun Lake ecosystem were dispersing downstream. Smith and King (2005) described the movements by juvenile lake sturgeon as complex, noting that larger juveniles displayed longer daily movements than smaller juveniles. Their tagged lake sturgeon selected depths between 6 and 14 m; water that deep is rare or absent in the French Broad and Holston Rivers, but is common in reservoirs on the Tennessee River. Similar to other studies describing dam passage of sturgeon (North et al. 1993, Collins et al. 2003), no tagged lake sturgeon in the present study were observed passing upstream through Fort Loudoun Dam. The lack of upstream dam passage could be a management concern because spawning adult lake sturgeon require fast-flowing water or main channel environments often found in the upper reaches of a river system (Auer 1996b). Whereas it is not known whether (or where) lake sturgeon in the upper Tennessee River system will spawn, hydroelectric dams often serve as partial or complete barriers to upstream movements (Knights et al. 2002). Fisheries managers concerned with lake sturgeon spawning success in the Tennessee River may have to consider how dams affect sturgeon movements. Mapping potential lake sturgeon spawning habitats throughout the upper Tennessee River system and better understanding the influence of stocking locations and size-at-stocking (if any) on sturgeon movements and survival are other areas of research that might be worth investigating.

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