Assessment of Lake Sturgeon Reintroduction in the Coosa River System, Georgia–Alabama

JUSTIN BEZOLD AND DOUGLAS L. PETERSON*

Warnell School of Forestry and Natural Resources, University of Georgia
Athens, Georgia, 30602, USA

Abstract.—At the extreme southern boundary of its range, the lake sturgeon Acipenser fulvescens was once an important biological component of the Coosa River system of Georgia–Alabama. During the 1970s, the population was extirpated by the combined effects of overfishing and degraded water quality. Over the past 20 years, water quality has improved, and in 2002, the Georgia Department of Natural Resources initiated a lake sturgeon reintroduction program with the goal of establishing a self-sustaining population within 20 years. From 2004 to 2007, we evaluated the initial phase of this reintroduction program by quantifying poststocking survival and seasonal habitat use of juvenile lake sturgeon in the Coosa River. We used gill nets and trammel nets to capture juveniles at several locations in both riverine and reservoir habitats. Fourteen individual juveniles were randomly selected for surgical implantation of radio tags to monitor their seasonal movements and habitat use. Over the 3 years of the study, we captured a total of 597 juvenile lake sturgeon measuring 231–790 mm total length. Using capture probabilities calculated from Program MARK (White and Burnham 1999), we estimated a total abundance of 789 (690–889, 95% confidence interval) juvenile lake sturgeon in 2006. Survival of each cohort from date stocked to summer 2006 varied from 1% to 14%, depending on year and size of fish stocked. Seasonal movements of juveniles varied; however, most fish occupied a relatively short reach in the lower river during summer months when water temperatures were more than 25°C. At least 1% of fish stocked in each cohort have survived, and 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 first cohorts reach maturity.

Introduction

The lake sturgeon Acipenser fulvescens is 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 up to 150 years 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 and 15 years of age, with subsequent spawning every 2–3 years thereafter. Females mature later, typically between 18 and 27 years with a 4– to 6-year resting period between reproductive cycles (Roussow 1957; Priegel and Wirth 1971; Scott and Crossman 1973; Fortin et al. 1996; Bruch 1999).

Historically, lake sturgeon were found in the Mississippi River, Hudson Bay, and
Great Lakes drainages (Harkness and Dymond 1961). An isolated but naturally re-
producing population of lake sturgeon also
was documented in the Coosa River system of Georgia and Alabama in the mid-1900s
(Smith-Vaniz 1968; Dahlberg and Scott 1971). Although once considered abundant
throughout much of their range, lake stur-
geon stocks were decimated by overfishing,
pollution, and dam construction on spawn-
ing tributaries during the late 19th and early
20th centuries (Rochard et al. 1990; Birstein
1993; Peterson et al. 2007). Following pas-
sage of the U.S. Clean Water Act in 1972,
improved water quality and new protections
for remaining stocks and habitats helped
spark public support for lake sturgeon resto-
ration in both the United States and Canada.
Therefore, several states and provinces have
initiated restoration programs (Peterson et
al. 2007). In the northern United States and
southern Canada, these efforts have focused
primarily on protection of remnant stocks,
habitat improvement, and limited stocking
of hatchery-reared juveniles (Schram et al.
1999; Jackson et al. 2002; Drauch and Rhoe-
des 2007; Peterson et al. 2007). However, in
the southern United States, intensive stock-
ing programs have become more prevalent
because many native populations were extir-
pated during the 1900s. In Georgia, the lake
sturgeon population of the Coosa River was
reportedly extirpated by overfishing and
habitat degradation, but direct causes re-
main uncertain. Although the Coosa River is
still impacted by a variety of anthropogenic
factors, recent surveys have documented a
marked improvement in water quality over
the past three decades (Georgia Environ-
mental Protection Division 1998).

In 2001, the Georgia Department of
Natural Resources (GDNR) responded to
growing public interest in native fish resto-
ration by initiating a 20-year lake sturgeon
reintroduction program to re-establish a
self-sustaining population in the Coosa Riv-
er. To accomplish this, the GDNR acquired
approximately 20,000 fertilized lake stur-
geon eggs from the Wisconsin Department of
Natural Resources in spring 2002. Finger-
lings produced from these eggs, which
originated from spawning adults on the Fox
River, Wisconsin, were reared at the GDNR
Summerville Fish Hatchery for about 6
months prior to release into the Coosa River
(Beisser 2007). Since the initial release of
fingerlings in autumn 2002, annual stock-
ing of lake sturgeon has been a key compo-
nent of the GDNR reintroduction program.
However, understanding basic life history,
recruitment mechanisms, and population
dynamics of the reintroduced population
has been critically important in evaluating
program success. Because life history data
do lake sturgeon are completely lacking for
southern populations, the GDNR reintro-
duction program provides a unique oppor-
tunity to examine critical links between lake
sturgeon ecology and habitat at the southern
limit of the species range. The objectives of
this study were to (1) quantify poststocking
growth and survival, (2) identify and de-
scribe seasonal movements and habitat use,
and (3) identify environmental factors that
may limit poststocking survival of juvenile
lake sturgeon.

Study Site

All field data were collected from the main
channel of the Coosa River beginning at
Rome, Georgia, downstream to Weiss Dam
located near Leesburg, Alabama (Figure 1).
The 12,000-ha reservoir created by Weiss
Dam drains a watershed area of 13,649 km²,
approximately 75% of which is forested,
15% is agricultural, and 10% is urban/de-
veloped/mixed use. Within this reach, four
distinct channel types were identified by Be-
zold (2007). These channel types included
headwater, upper river, lower river, and reservoir. The headwater reach (river kilometer [rkm] 74–95) had a narrow and shallow channel with predominantly sand substrates (Table 1), while the upper river reach (rkm 50–38) had a deeper and wider channel with sand and silt substrates. The lower river reach (rkm 38–50) had a relatively deep and wide channel with mostly silt and sand substrates. The reservoir reach (rkm 0–38) had the deepest channel, but a narrower channel than the lower river, and soft, silt substrates. Two other hydropower reservoirs are situated upstream of the study area on Coosa River tributaries (Johnson et al. 2002). The effects of daily peaking discharges from both upstream reservoirs are limited by re-regulation dams and the distance from the reservoirs to Weiss Reservoir and the Coosa River. Weiss Reservoir is managed for hydropower production and recreational fisheries for crappies Pomoxis spp., catfish Ictaluridae spp., and striped bass Morone saxatilis.

Methods

Fish Stocking

In 2002, the GDNR began an annual stocking program by release of either phase I (~120 mm total length [TL] and 4 months of age) or phase II (130–300 mm TL at 6–10 months of age) fingerling lake sturgeon. Numbers of fingerlings stocked depended on culture success; however, at least 10,000 fingerlings were stocked in each year after 2002 (Table 2). A portion of each individual
Table 1. Mean values of key measured physical characteristics of Coosa River channel types according to discriminant function analysis (Bezold 2007). Substrate classes are as defined by Cummins (1962).

<table>
<thead>
<tr>
<th>Physical characteristic</th>
<th>Headwater</th>
<th>Upper</th>
<th>Lower</th>
<th>Reservoir</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary substrate class</td>
<td>Sands</td>
<td>Sands</td>
<td>Fines</td>
<td>Fines</td>
</tr>
<tr>
<td>(% presence)</td>
<td>(94)</td>
<td>(59)</td>
<td>(53)</td>
<td>(99)</td>
</tr>
<tr>
<td>Mean channel depth (m)</td>
<td>1.9</td>
<td>5.7</td>
<td>6.2</td>
<td>7.0</td>
</tr>
<tr>
<td>(range)</td>
<td>(1.1–2.4)</td>
<td>(3.0–9.1)</td>
<td>(1.5–12.4)</td>
<td>(2.7–9.4)</td>
</tr>
<tr>
<td>Mean channel width (m)</td>
<td>82.9</td>
<td>95.3</td>
<td>125.0</td>
<td>106.7</td>
</tr>
<tr>
<td>(range)</td>
<td>(78.7–88.7)</td>
<td>(84.1–111.6)</td>
<td>(93.3–151.8)</td>
<td>(100.0–110.0)</td>
</tr>
</tbody>
</table>

cohort was batch marked prior to stocking to aid in subsequent estimates of annual survival. The 2002 cohort was not marked; however, subsequent cohorts were marked with varying combinations of pelvic fin clips and lateral scute removals.

**Fish Sampling**

From March 2004 to March 2007, juvenile lake sturgeon were sampled using bottom-set gill and trammel nets (91 × 2 m). Gill nets were constructed of either 7.6-cm or 10.2-cm stretch measure monofilament mesh 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 current from dusk to dawn. Netting locations were randomized for population abundance and survival estimates, with sampling effort apportioned randomly at in the sample reach. Targeted sampling was used to collect additional specimens for estimates of growth and seasonal condition.

As nets were retrieved, captured lake sturgeon were removed from the nets and placed into an aerated live well onboard the research vessel. After all nets had been pulled, each fish was scanned for a passive

Table 2. Cohort abundance and survival to date of stocked juvenile lake sturgeon in the Coosa River system as estimated from double sampling procedure, summer 2006. Phase I fish were ~120 mm total length (TL) and 4 months of age and phase II fish were 130–300 mm TL and 4–10 months of age. Survival was calculated from time of stocking to the time of capture in 2006.

<table>
<thead>
<tr>
<th>Cohort</th>
<th>Phase stocked</th>
<th>Number stocked</th>
<th>2006 abundance (95% CI)</th>
<th>Survival (%) (range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005a</td>
<td>I</td>
<td>12,910</td>
<td>8 (7–9)</td>
<td>–</td>
</tr>
<tr>
<td>2004a</td>
<td>I</td>
<td>16,460</td>
<td>41 (36–46)</td>
<td>0.2 (0.2–0.3)</td>
</tr>
<tr>
<td></td>
<td>II</td>
<td>2,728</td>
<td>211 (185–238)</td>
<td>7.8 (6.8–8.7)</td>
</tr>
<tr>
<td>2003</td>
<td>I</td>
<td>6,373</td>
<td>32 (28–36)</td>
<td>0.3 (0.2–0.3)</td>
</tr>
<tr>
<td></td>
<td>II</td>
<td>5,493</td>
<td>331 (290–373)</td>
<td>2.8 (2.4–3.1)</td>
</tr>
<tr>
<td>2002</td>
<td>II</td>
<td>1,127</td>
<td>166 (145–187)</td>
<td>14.7 (12.9–16.6)</td>
</tr>
<tr>
<td>Total</td>
<td>–</td>
<td>45,091</td>
<td>789 (690–889)</td>
<td>2.5 (2.1–2.8)</td>
</tr>
</tbody>
</table>

*a* 2004 and 2005 cohort not fully recruited.
integrated transponder tag, and 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 (Peterson et al. 2002). Fish were then allowed to recover in the live well for 5–10 min prior to their release. Once all fish had been released, surface and bottom water temperatures and dissolved oxygen (DO) were measured using a YSI 85 multimeter in the middle of the sample reach.

**Age, Growth, and Condition**

Fin spine samples from lake sturgeon were air dried for $\geq$ 6 months and then sectioned to a thickness of 0.3–0.5 mm using an Isomet low-speed saw. The sections were then mounted on glass slides with clear, thermoplastic epoxy and viewed under a variable magnification dissecting scope. Separate age estimates of each fish were obtained by two independent readers. Disagreements in the two independent age estimates were resolved by a third independent reader (Rossiter et al. 1995; Rusak and Mosindy 1997). Because a portion of each stocked cohort was batch-marked with a unique combination of fin clips and/or scute removals, age estimates from known-aged individuals were used to validate those of unmarked fish. Relative abundance of each cohort was then determined by dividing number of fish sampled in a cohort by the total number of fish sampled during primary sampling, which is defined below.

To estimate growth of stocked juveniles, we used least-squares regression of known-aged fish, as described by Jackson et al. (2002). We also determined growth from direct measures of total length obtained from captured and recaptured individuals. Means and 95% confidence limits of relative condition ($K$) were calculated for fish captured in each season across all years (Le Cren 1951; Anderson and Neumann 1996). Seasons were defined as spring (March 21 to June 20), summer (June 21 to September 20), fall (September 21 to December 20), and winter (December 21 to March 20). Significant differences among length–independent seasonal $K$ values were identified when 95% confidence limits failed to overlap. Seasonally unequal sample sizes necessitated use of log linear regression to determine significant differences in length–weight relationships among seasons (Craig et al. 2005). Pair-wise means comparisons of seasonal length–weight relationships were used to identify significant differences between seasons. Goodness of fit of loge linear regression was determined by examining the $r^2$ value. Assumptions were tested by examining loge linear regression residuals.

**Population Estimates**

Poststocking abundance and survival of juvenile lake sturgeon were estimated in 2006 using double sampling, as described by Thompson et al. (1998) and Williams et al. (2002). Double sampling involves the random selection of a subset of previously established sample units that are resampled (i.e., double sampled) using an unbiased population estimator, such as a capture–recapture. The modeled relationship between the raw catch data and the unbiased estimate of fish abundance (i.e., estimated using the statistical estimator) from double sampled sites is then used to correct the raw catch data collected from the other sample sites. In this study, primary sampling was conducted from May 31 to June 14 and double sampling from June 18 to August 2. Primary sampling was conducted in 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 of lake sturgeon was more than 0.9 fish/net night. Huggins closed-captures procedure was used in Program MARK (White and Burnham 1999) to estimate capture probabilities based on capture histories of individual fish caught during secondary sampling (Huggins 1989, 1991; White and Burnham 1999). Data were tested with capture ($P$) and recapture ($C$) probabilities constant, variable by time and group, and with total length as a covariate to determine the best fit model (lowest AICc value). Capture probability estimates were then obtained from the best fit model to estimate population abundance in the corresponding sample reach. Absolute cohort abundances were calculated by multiplying the relative abundance of each cohort by the total population estimate. Overall survival of all stocked fish (all stocked cohorts to date of sampling) was calculated by dividing the total population estimate by the total number of stocked fish, excluding those cohorts that were not fully recruited to sampling gear at the time of the estimate, as determined from posthoc 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**

Fourteen juvenile lake sturgeon were captured between rkm 20–60 from February to September 2005 and implanted with radio transmitters (ATS model F1840 radio transmitter, 40 mHz). Radio tags measured $53 \times 17$ mm, weighed 15 g (including the trailing antenna), and had a guaranteed battery life of 450 d. Fish implanted with radio tags varied in length from 530 to 635 mm TL and weighed 600–1,100 g. Immediately after capture, the fish were transported in an aerated hauling tank from the Coosa River to the University of Georgia Whitehall Fisheries Research Laboratory (Athens, Georgia) for surgical procedures. Each fish was anesthetized by immersion in a 32-mg/L solution of buffered MS-222 (tricaine methanesulfonate) and placed into recumbency. A 3- to 5-cm incision was then made in the ventral surface of the abdominal wall to implant the tag. Surgical procedures were identical to those of 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 immediately posterior to the main incision. Incisions were closed with resorbable sutures and sealed with sterile surgical adhesive. Following surgery, all fish were allowed to recover for 14–21 d in a 1,600-L tank supplied with freshwater to ensure that surgical incisions had healed completely. All fish were returned to original capture sites in the Coosa River.

**Radio Telemetry**

Radio-tagged fish were tracked immediately upon release to maintain contact with the fish. Tracking of radio-tagged fish was conducted from February 2004 to December 2006. Movements of individual fish were monitored weekly by traversing the entire study area in a small boat equipped with a portable radio receiver (ATS R2000) and closed-loop antenna. As signals of individual fish were detected, their specific locations were determined to within 100 m by adjusting frequency gain and antenna orientation. Coordinates of transmitted fish were then recorded using a Trimble GeoExplorer-3 portable Global Positioning System (GPS) receiver, after which surface and bottom water temperatures and dissolved oxygen (DO) were measured using a YSI 85 multimeter. Depth was recorded using a Furuno LS1100 depthsounder.

We used ArcGIS (ESRI 2006, Redlands, California) to plot GPS coordinates of ra-
dio-tagged fish relocations and to determine the specific river kilometer of each relocation event. Transmittered fish relocations recorded during the first 10 d at large were discarded from analysis to minimize potential biases caused by handling stress (Hurley et al. 1987). Distance and direction of movements were calculated based on each successive relocation event. Data were then analyzed using analysis of variances to evaluate the effects of season, year, and their interactions on range (distance between upstream and downstream most relocations); displacement (calculated as net distance moved); movement rate (km/d); and total movement (gross of all movements) (Knights et al. 2002; SAS Institute 2002). Tukey’s studentized range (honestly significant difference test) separation of means was 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 by calculating the number of relocation events for each fish according to channel type and season. These values were compared to the defining channel reach characteristics as previously described by Bezold (2007) to determine if specific characteristics were related to habitat use. Finally, point measures of DO were used to calculate mean monthly DO every 3–5 rkm from rkm 0 to 83, from fall 2006 to fall 2007. Using ArcGIS (ESRI, ArcGIS 9.2, Redlands, California), these values were plotted with corresponding river kilometers of fish relocation events to evaluate seasonal movements and habitat use in relation to seasonal changes in DO.

**Results**

From 2002 to 2005, 45,091 phase I and phase II juvenile lake sturgeon were released into the Coosa River system. From March 2004 to March 2007 we captured 597 juvenile lake sturgeon in 640 total net-nights (Table 3). Both CPUE and mean fish size increased in each year of the study as successive cohorts recruited to the sampling gear. Juvenile lake sturgeon did not fully recruit to the sampling gear until they were \( \geq 300 \) mm TL (Figure 2). Mean size of captured lake sturgeon increased from 392 mm TL in 2004 to 557 mm TL in 2006, while annual catch per unit effort (CPUE) increased from 0.07 to 1.45 fish/net-night. In 2006, 105 and 76 juvenile lake sturgeon were collected in primary (84 net-nights) and secondary (36 net-nights) samplings, respectively. The best-fit model (lowest AICc value) had capture and recapture probabilities equal and constant over time and space \( [p(t) = c] \). The final capture probability estimate was 0.152. Population abundance was estimated at 789 (690–889, 95% CI) juvenile lake sturgeon.

Fin spine samples were obtained from 97 of the 105 juveniles captured during primary (random) sampling. Of these, 50 possessed hatchery marks indicating their cohort of origin and age. Accuracy of age estimates for these fish varied from 50% to 100% among readers; however, consensus estimates using all three readers were 100% accurate for all age-classes examined. Stocked cohorts were not equally represented in the catch according to length-frequency analysis of the 97 age-assigned juveniles (Figure 2). The largest year-class originated from the release of 11,866 phase I and II fingerlings in 2003 (Table 2). However, 1,127 phase II fingerlings released in 2002 exhibited the highest annual survival, and phase II fish exhibited higher survival than phase I fish in all years (Table 2).

Using lengths and weights of 385 juvenile lake sturgeon captured from all seasons and years, the length–weight relationship was \( W_f = 3.2093 * (TL) - 5.9371 \) with \( r^2 = \)
Table 3. Annual catch statistics of juvenile lake sturgeon captured from the Coosa River system from March 2004 to March 2007 (sampling year is January 1 to December 31). The 2007 sampling year is excluded from catch per unit effort (CPUE) because sampling was incomplete.

<table>
<thead>
<tr>
<th>Year</th>
<th>Fishing effort</th>
<th>N</th>
<th>CPUE</th>
<th>Mean</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td>133</td>
<td>9</td>
<td>0.07</td>
<td>392</td>
<td>231–433</td>
</tr>
<tr>
<td>2005</td>
<td>184</td>
<td>193</td>
<td>1.05</td>
<td>492</td>
<td>335–695</td>
</tr>
<tr>
<td>2006</td>
<td>231</td>
<td>334</td>
<td>1.45</td>
<td>512</td>
<td>306–754</td>
</tr>
<tr>
<td>2007</td>
<td>92</td>
<td>61</td>
<td>–</td>
<td>557</td>
<td>404–790</td>
</tr>
<tr>
<td>Totals</td>
<td>640</td>
<td>597</td>
<td>0.98</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

Figure 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.
Relative condition was highest in spring ($K_s = 1.08; 95\% \text{ CL } 1.06–1.11$), followed by winter ($K_s = 1.01; 95\% \text{ CL } 0.97–1.05$), summer ($K_s = 1.00, 95\% \text{ CL } 0.98–1.02$), and fall ($K_s = 0.92; 95\% \text{ CL } 0.89–0.96$). Regression analysis of the length–weight relationship showed that the slope and intercept for fall-captured fish differed significantly from juveniles captured in spring and winter but not summer ($r^2 = 0.93, P < 0.01$; Table 4). Parameter estimates indicated that juveniles captured in spring and winter were significantly heavier than those of similar length captured in fall, but the disparity decreased in larger juveniles. No significant slope or intercept differences were detected in pairwise means comparisons between seasons. All assumptions of regression analysis were met.

The length-at-age relationship calculated with least-squares regression was $\text{TL} (\text{mm}) = 316.4 + 71.2 \times \text{age (years)}$, with $r^2 = 0.48$. Estimated growth rate of juvenile lake sturgeon was 0.20 mm/d. Mean (standard error) daily growth calculated directly from 150 recaptured individuals was 0.29 (±0.04) mm/d. The mean number of days between recapture events for these individuals was 151, with a range of 1–640 d.

Weekly tracking of the 14 radio-transmittered juvenile lake sturgeon yielded 673 relocations from spring 2005 to fall 2006 (Table 5). Analysis of fish movements indicated that season had a significant effect on displacement, range, and movement rate ($P < 0.0001$). Transmittered fish were more active in spring and fall than in summer or winter (Table 5). The total percentage of lake sturgeon relocations observed in each of the four channel types varied widely by season (Table 6). The highest percentage of relocations was observed in the upper river during spring, followed closely by lower river and reservoir during the winter. The lowest percentage of relocations occurred in the headwater reach, regardless of season. Although juvenile lake sturgeon were found in the main channel of the reservoir during fall and winter months, they were seldom relocated there during summer months when dissolved oxygen was $\lesssim 3.0$ mg/L (Figure 3).

**Discussion**

To date, reintroduction efforts by the GDNR have been successful in establishing a small but steadily increasing population of juvenile lake sturgeon in the Coosa River system. Over the 3 years of our study, CPUE and mean total length of fish caught have steadily increased, and by 2006, estimated

<table>
<thead>
<tr>
<th>Effect</th>
<th>Parameter estimate</th>
<th>Standard error</th>
<th>$P$-values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>-14.86080</td>
<td>0.59810</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Spring</td>
<td>2.24543</td>
<td>0.81963</td>
<td>0.0064</td>
</tr>
<tr>
<td>Summer</td>
<td>1.02006</td>
<td>0.76289</td>
<td>0.182</td>
</tr>
<tr>
<td>Winter</td>
<td>2.29158</td>
<td>0.87705</td>
<td>0.0093</td>
</tr>
<tr>
<td>Log(TL)</td>
<td>3.38774</td>
<td>0.09655</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Log(TL)*spring</td>
<td>-0.33636</td>
<td>0.13204</td>
<td>0.0112</td>
</tr>
<tr>
<td>Log(TL)*summer</td>
<td>-0.15157</td>
<td>0.12318</td>
<td>0.2193</td>
</tr>
<tr>
<td>Log(TL)*winter</td>
<td>-0.35555</td>
<td>0.14101</td>
<td>0.0121</td>
</tr>
</tbody>
</table>
Table 5. Seasonal movements of radio-transmittered juvenile lake sturgeon in the Coosa River system, spring 2005 to fall 2006. Number of fish tracked in each season is in parentheses. Means with the same letter (x, y, z) did not differ among seasons (Tukey’s honestly significant difference test \( \alpha = 0.05 \)). Standard deviation is abbreviated SD.

<table>
<thead>
<tr>
<th></th>
<th>Fall ( N = 10 )</th>
<th>Winter ( N = 10 )</th>
<th>Spring ( N = 11 )</th>
<th>Summer ( N = 12 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relocation events (mean #/fish)</td>
<td>18.3</td>
<td>9.9</td>
<td>13.1</td>
<td>20.6</td>
</tr>
<tr>
<td>Net displacement(^a) (km)</td>
<td>(-19.6^x)</td>
<td>(-2.8^y)</td>
<td>17.9(^z)</td>
<td>(-5.4^y)</td>
</tr>
<tr>
<td>(SD)</td>
<td>(20.1)</td>
<td>(10.9)</td>
<td>(22.0)</td>
<td>(8.8)</td>
</tr>
<tr>
<td>Mean total movement (km)</td>
<td>71.9(^z)</td>
<td>21.2(^y)</td>
<td>68.9(^z)</td>
<td>18.3(^y)</td>
</tr>
<tr>
<td>(SD)</td>
<td>(45.1)</td>
<td>(13.3)</td>
<td>(33.8)</td>
<td>(9.1)</td>
</tr>
<tr>
<td>Range (km)</td>
<td>34.5(^z)</td>
<td>12.3(^y)</td>
<td>30.7(^z)</td>
<td>10.3(^y)</td>
</tr>
<tr>
<td>(SD)</td>
<td>(16.6)</td>
<td>(6.4)</td>
<td>(16.6)</td>
<td>(6.7)</td>
</tr>
<tr>
<td>Mean daily movement (km/d)</td>
<td>1.0(^z)</td>
<td>0.3(^y)</td>
<td>1.0(^z)</td>
<td>0.2(^y)</td>
</tr>
<tr>
<td>(SD)</td>
<td>(0.6)</td>
<td>(0.2)</td>
<td>(0.5)</td>
<td>(0.1)</td>
</tr>
</tbody>
</table>

\(^a\) Negative (downstream) and positive (upstream) values indicate direction of movement.

Table 6. Relocations of juvenile lake sturgeon in the four channel types in the Coosa River, from spring 2005 to fall 2006.

<table>
<thead>
<tr>
<th>Season</th>
<th>Total (mean/fish)</th>
<th>Reservoir (%)</th>
<th>Lower (%)</th>
<th>Upper (%)</th>
<th>Headwaters (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring</td>
<td>144 (13)</td>
<td>35</td>
<td>16</td>
<td>47</td>
<td>2</td>
</tr>
<tr>
<td>Summer</td>
<td>247 (21)</td>
<td>17</td>
<td>40</td>
<td>40</td>
<td>3</td>
</tr>
<tr>
<td>Fall</td>
<td>183 (18)</td>
<td>43</td>
<td>21</td>
<td>35</td>
<td>1</td>
</tr>
<tr>
<td>Winter</td>
<td>99 (10)</td>
<td>44</td>
<td>45</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>All seasons</td>
<td>673 (32)</td>
<td>32</td>
<td>30</td>
<td>36</td>
<td>2</td>
</tr>
</tbody>
</table>
fish appeared to survive better when stocked at low densities, but phase I fish appeared to survive poorly regardless of stocking density. However, annual variation in age and size of fish stocked precluded 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 survival of stocked 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 our 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. Beamish et al. (1996) found that lipids, protein, and energy content of lake sturgeon were higher in March than in June and October; however, body condition did not differ among seasons. Using regression analysis, we 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, we 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
Bezold and Peterson suspect that juvenile lake sturgeon in the Coosa River became increasingly stressed during summer months as temperatures routinely exceeded 25°C (Figure 4). As a result, fish entered the fall in poor condition despite declining autumn water temperatures. As fall progressed, water temperatures continued to decline toward a more optimal level, at which time fish condition began to increase, with a rebound of condition observed in winter. Although seasonal changes in condition have not been previously reported in juvenile lake sturgeon, this pattern has been observed in other fish species, including striped bass (Haeseker et al. 1996), rainbow trout *Oncorhynchus mykiss*, and brown trout *Salmo trutta* (Cada et al. 1987). Additional studies of southern lake sturgeon populations are needed to understand how seasonal changes in juvenile growth, 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 we observed was 105 mm/year. In contrast, annual growth rates of 113 and 145 mm/year were reported for juveniles in Lake Winnebago, Wisconsin and Oneida Lake, New York, respectively (Jackson et al. 2002). However, in both studies of these northern populations, data from older juveniles (≥5 years) were included in the analyses. Because these previous studies report growth as annual increases in total length for all juveniles combined, the relatively slower growth rates observed in our study may simply reflect the absence of older juvenile cohorts in the Coosa River system. 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

Figure 4. Monthly catch per unit effort (unit effort = one net-night) of juvenile lake sturgeon from March 2004 to March 2007 in the Coosa River; * indicates months that effort was less than 9 net-nights. The dashed line denotes mean sampling period catch per unit effort of 0.93.
differences in their relative condition, juvenile lake sturgeon appeared to grow best in the Coosa River during spring and fall, but unlike northern populations, growth was poorest during summer. 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 close to 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. Lake sturgeon in the Coosa River were more active in spring and fall than in summer and winter; however, in more northern areas of their range, this species has been found to be most active in summer (Rusak and Mosindy 1997; Borkholder et al. 2002; Knights et al. 2002). We hypothesize that the difference in summer movement patterns observed in the Coosa River were caused by summer temperatures (>25°C) above the optimum 20–22°C suggested 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 (Figure 4). During summer months, both condition and activity levels declined, suggesting that the fish were probably experiencing thermal stress. Although all data we 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, which we 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, with the exception of headwaters reaches. While these reaches appeared to be relatively unimportant to juveniles, the presence of shallow headwaters in the Coosa River is noteworthy because they may eventually provide critical spawning habitat for adults (Peterson et al. 2007). Although juveniles apparently preferred the deeper channel habitats within the reservoir during most of the year, they moved into the deep river reaches during summer months when DO in the reservoir was less than 3.0 mg/L. Regardless of this seasonal change in habitat use, juveniles were almost always found over a heterogeneous mix of substrates. However, previous studies suggest that juvenile lake sturgeon often congregate in areas with sand and silt substrates (Peake 1999; Smith and King 2005). The Coosa River data suggested that juvenile lake sturgeon were “channel generalists,” capable of using a variety of channel types depending on seasonally changing conditions.

The current GDNR reintroduction program has been successful in re-establishing a juvenile population of lake sturgeon in the Coosa River. Although poststocking survival has been lower than that typical of other sport fish stocking programs, minor adjustments in the GDNR stocking program may yield better results. To the greatest extent feasible, we recommend that the GDNR increase the proportion of phase II fingerlings stocked in each year; however, further studies are needed to evaluate the effects of stocking density on poststocking survival. While the ultimate success of the reintroduction program will depend on the ability of these juveniles to grow, survive, and successfully reproduce, the results of our study provide a baseline for evaluations of future reintroductions of lake sturgeon.
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