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Authors: Zachary W. Anglin, and Gary D. Grossman

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Movement of Southern Brook Charr in a North Carolina Headwater Stream

Zachary W. Anglin[1] and Gary D. Grossman[1,*]

Abstract - Little is known about the genetically distinct southern strain of *Salvelinus fontinalis* Mitchell (Brook Charr), a species that is likely to be negatively affected by global climate change at the southern extent of its range. We tagged 35 Southern Brook Charr between March and October of 2011 and sampled for movements in May and October 2011 and May 2012. The study site in Ball Creek, NC, was 330 m long, and we sampled 2 ancillary 50-m sites located 300 m above and below the site boundaries. We recaptured a total of 12 fish: 10 fish once, 1 fish twice, and another fish 3 times for a total of 15 recaptures. Individuals recaptured in spring 2011 moved an average of 9 m downstream, whereas fish recaptured in autumn 2011 moved an average of 7 m upstream. Fish recaptured in spring 2012 moved an average of 6 m upstream from their locations in autumn 2011. There was no relationship between fish length or growth and either distance or direction moved. In addition, there were no significant differences in length or mass of fish that were recaptured and those that were not. The maximum distance moved by a single fish was 49 m downstream. Our results suggest that Southern Brook Charr in headwater streams may have relatively small home ranges (<20 m), although our conclusions were limited by small sample sizes and a 34% recapture percentage based on individual fish. Given that most populations of Southern Brook Charr occur in small streams above barriers, limited movements suggest that population persistence will depend on satisfactory foraging, shelter, and reproductive habitat types within a relatively small area. These requirements should be a concern for managers given that global climate change will affect ambient temperatures and these populations have limited opportunity for movement and emigration.

Introduction

The native distribution of *Salvelinus fontinalis* Mitchell (Brook Charr) encompasses nearly the entire length of the Appalachian Mountain system. In streams within their native range, especially within the Southern Appalachian region, native Brook Charr populations generally are restricted to habitats above barriers that prevent invasion by *Salmo trutta* L. (Brown Trout) and *Oncorhynchus mykiss* Walbaum (Rainbow Trout), species introduced in eastern North America in the late 19th century (Behnke 2002, Galbreath et al. 2001). Brook Charr occur in 2 genetically distinct strains, i.e., Northern and Southern Brook Charr (Habera and Moore 2005, Stoneking et al. 1981), and these forms likely justify the reclassification of Brook Charr into separate subspecies or species. Despite strong genetic differentiation, there is little published ecological information that can be used for management or conservation of Southern Brook Charr (but see Anglin and Grossman 2013,

[1]Warnell School of Forestry and Natural Resources, University Of Georgia, Athens GA 30602. [*]Corresponding author - grossman@uga.edu.

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Grossman et al. 2010, Habera and Moore 2005). The need for ecological information is particularly critical because the abundance and distribution of Brook Charr in general and Southern Brook Charr specifically, has decreased substantially in the past 3 decades primarily due to habitat degradation, invasive trout, and widespread stocking of Northern Brook Charr (Hudy et al. 2008). In addition, given that Southern Brook Charr exist at the southernmost extent of the species' natural range, they are likely to be affected by temperature increases and increasingly variable precipitation produced by global climate change in the Southern Appalachian Mountains (Flebbe et al. 2006, Ford et al. 2011, Laseter et al. 2012).

Although movement studies on Northern Brook Charr are not uncommon (Davis et al. 2015, Petty et al. 2012), there appears to be little or no published information on movements of Southern Brook Charr. Data for the northern strain demonstrate a range of movement patterns, with headwater mountain populations demonstrating relatively low movements (2 m/d) and main-stem or riverine populations displaying substantial movements (Davis et al. 2015, Hartman and Logan 2010, Petty et al. 2012). Given the lack of information on movement patterns of Southern Brook Charr, coupled with the small population sizes and restricted distribution of this species (Anglin and Grossman 2013, Grossman et al. 2010), we quantified movement of Southern Brook Charr in a North Carolina headwater stream via passive integrated transponder (PIT) tagging over 14 months. Grossman et al. (2010) demonstrated that this population displays: (1) small maximum sizes (<15 cm SL), (2) low maximum ages (3+), (3) low densities, and (4) population regulation via density-dependent processes, although high winter flows affect growth of young-of-the-year. We hypothesized that movements of Southern Brook Charr would be affected by season, and that older (larger) fish would move greater distances than younger (smaller) fish.

Methods and Materials

Study site

The study site consisted of a 330-m section of stream located within a third-order stretch of Ball Creek, located on the USDA Forest Service Coweeta Hydrologic Laboratory (35°11'N; 83°23'W) in Otto, NC. This site is typical of many relatively undisturbed small streams in the Southern Appalachian region, especially those occupied by Southern Brook Charr (Grossman et al. 2010). The study site was bisected by a small natural waterfall, a possible barrier to fish movement. We used this natural separation to split the site into upper and lower segments, each measuring ~150 m in length. The upper and lower sections were further sub-divided and marked off at 10-m benchmark increments for movement estimates. The entire 330-m site was called the main site.

The main site was composed of riffle–pool geomorphology with little variation in width (mean wetted width = 5.2 m ± 0.3 m 95% CI; measurements made every 5 m of linear bank). The surrounding mixed hardwood–conifer forest provided dense canopy cover, shading the stream during the growing season. Riparian vegetation was dominated by *Rhododendron maximum* (Rhododendron), typical of headwater streams in the Blue Ridge Province of the southern Appalachian Mountains. The fish assemblage within the site is composed of only 3 species: pure Southern Brook Charr (T. King, United States Geological Survey, Leetown, WV, now deceased, pers. comm.) and occasional *Cottus bairdi* Girard (Mottled Sculpin) and Rainbow Trout (G.D. Grossman, pers. observ.).

Movement

We quantified movement patterns of Southern Brook Charr using electrofishing and mark–recapture techniques with 12.0-mm PIT (Biomark) tags. These tags have minimal effects after insertion (Acolas et al. 2007, Ombredane et al. 1998); however, it was logistically infeasible to measure tag loss given the low density of the population (see Grossman et al. 2010) and small number of fish tagged. We used a seasonal sampling regime, and on 25 March 2011, we made a 1-pass electrofishing sweep, starting 50 m above the downstream border of the main site and ending 50 m below the upstream border of the main site (the middle 230 m). Southern Brook Charr in this population can be aged (0+, 1+, 2+) by their lengths, which show little overlap (Grossman et al. 2010), and we tagged all fish longer than 7 cm (standard length [SL]). We did not tag smaller fish were for fear of internal injuries or negative behavioral effects from handling stress and the size of tags, and so just returned them to their point of capture. In addition, we did not tag fish in the upper- and lowermost 50-m sections of the site because of the possibility that these fish would move out of the sampled area; although these 50-m sections always were sampled subsequently for tagged fish.

Tagging consisted of injecting a uniquely coded PIT tag into the body cavity using a syringe tipped with a 12-gauge hypodermic needle. We weighed (digital scale, ± 0.01 g), and measured (SL, straight edge, ± 1.0 mm) each tagged fish and held them for a 30-minute recovery period prior to release at the site of capture. We observed neither mortality nor aberrant behavior in fish during the recovery period. All fish-capture locations were recorded to the nearest meter using maps drawn of the main site. We calculated movement as the linear distance between capture and recaptures, or between sequential recaptures for fish recaptured multiple times. All subsequent seasonal samples (19 May 2011, 25 October 2011, and 25 May 2012) employed this sampling methodology. We did not sample during summer because the combination of high water temperatures, the disturbance from handling, and the procedure of tagging unmarked fish likely would have stressed fish substantially. We used a hand-held PIT tag reader to identify recaptured fish. To detect fish that may have moved long distances (e.g., out of the site), we also sampled two 50-m sites both 300 m below and above the borders of the site just after the 25 October 2011 sample. We used Wilcoxon rank sum tests to examine whether SL and mass differed significantly between recaptured fish and unrecaptured fish. We also tested for significant differences in movement based on length and sampling date using analysis of variance (ANOVA). Given that fish can be aged based on their lengths, we report results as length/age.

Results

During sampling, we captured a total of 56 Southern Brook Charr (March 2011: 12 fish, May 2011: 23 fish, October 2011: 16 fish, and May 2012: 4 recaptures) of which 12 fish were recaptured out of a total of 35 fish tagged (10 single recaptures, 1 double recapture, and 1 triple recapture). Twenty-one untagged fish were captured and released: 3 were either too small (less than 70 mm, SL) to tag, and 18 were captured in either the upper- or lowermost 50-m sections of the site. Recapture rates based on individual fish and total recaptures were 34% and 43%, respectively. Recaptured fish varied in size from 112 to 169 mm SL and represented mostly 2+ fish (Fig. 1). Of the 10 Southern Brook Charr recaptured once, 1 remained at the initial position of capture, 6 moved an average of 18.2 (SD = 11.6) m upstream, 2 moved an average of 6.5 (SD = 2.1) m downstream, and 1 individual moved 49 m downstream. Although sample sizes were too small for statistical testing, the 6 individuals recaptured on 19 May 2011 moved an average of 9 (SD = 20.3) m downstream and grew an average of 25 (SD = 5.0) mm SL over a 55-day period. The 5 individuals recaptured on 25 October 2011, moved an average of 11.4 (SD = 13.2) m upstream and grew an average of 13 (SD = 14.7) mm SL over a 159-day period. The 3 individuals recaptured on 25 May 2012 grew an average of 10 (SD =15.0) mm SL and moved an average of 6 (SD = 22.8) m upstream from their locations on 25 October 2011, nearly a 7-month period. The double recapture displayed only downstream movement (7 m and 2 m), whereas the triple recapture moved upstream (7 m), maintained position (0 m), and moved downstream (8 m) over the course of sampling. We did not observe either upstream or downstream movement

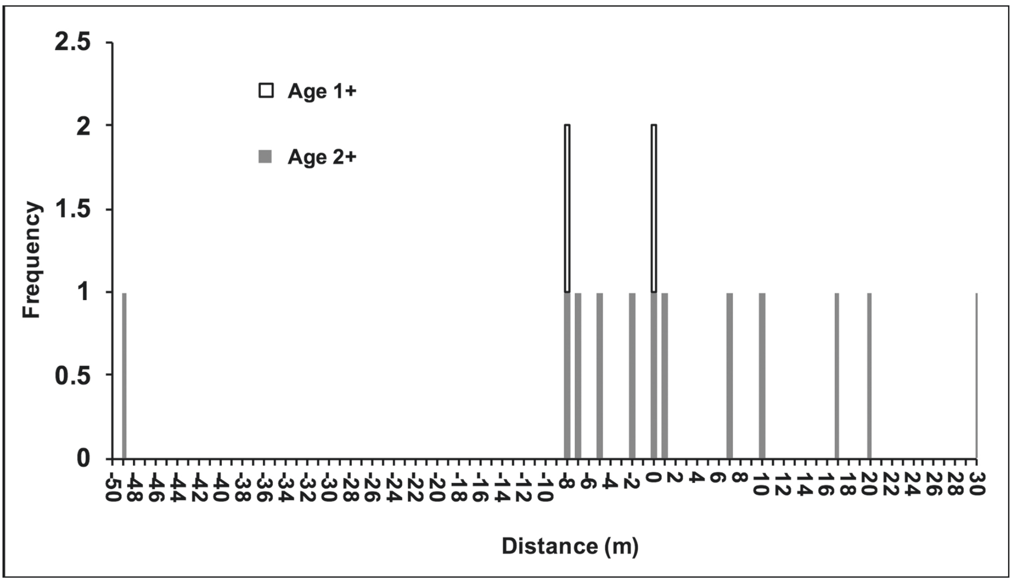

Figure 1. Movement data for age 1+ (<120 mm) and age 2+ (≥125 mm) Southern Brook Trout in Ball Creek for all sampling seasons. Negative x-values indicate downstream movement whereas positive x-values indicate upstream movement. Demographic data on this population can be found in Grossman et al. (2010).

of fish over the waterfall. Movement data suggest that home ranges of Southern Brook Charr in upper Ball Creek may be less than 20 m. There were no significant differences in either length (W = 94.5, $P = 0.11$) or mass (W = 109.0, $P = 0.27$) between recaptured and unrecaptured fish. In addition, fish length/age ($F_{1, 11} = 0.46$, $P = 0.51$) or growth in length ($F_{1, 11} = 0.21$, $P = 0.66$) did not significantly affect upstream or downstream movement or total distance moved. No tagged individuals were recaptured in the sites 300 m below or above the main site.

Discussion

To our knowledge, these are the first published estimates of movements of Southern Brook Charr, a species that is likely to be strongly affected by increases in water temperature and precipitation variability predicted to occur with global climate change (Flebbe et al. 2006, Ford et al. 2011, Laseter et al. 2012). Although most Southern Brook Charr displayed some movement in all seasons, total distances moved frequently were fairly limited (generally less than 20 m). However, our design was biased against fish that moved long distances (e.g., out of the study site), although sampling of 2 sites 300 m above and below the study site boundary yielded no recaptures. Given that most populations of Southern Brook Charr are confined to headwater streams above barriers, it is fortuitous that at least some individuals in Ball Creek possess home ranges sufficiently small to complete their life-cycles and maintain a persistent population in this restricted habitat (see Grossman et al. 2010). Nonetheless, most Southern Brook Charr populations are isolated and subject to genetic drift and inbreeding because of limited genetic exchange among populations.

A variety of factors could have affected our analysis including the small number of fish marked and recaptured. Nonetheless, recapture success (recapture rate = 34%) was similar to several other salmonid tagging studies (Creswell 1981, Deiterman and Hoxmeier 2009, Turek et al. 2010). Regardless, the fate of individuals that were not recaptured (i.e., a majority of fish sampled) remains unknown. Some may have moved long distances that took them out of the study site and adjacently sampled areas, others may have shed tags, and still others may have perished (Meyer et al. 2011). Nonetheless, Meyer et al. (2011) suggested that salmonids of similar size tagged with PIT tags should not experience high mortality. Finally, logistical constraints prevented extensive upstream and downstream sampling aside from the two 50-m sites, located 300 m from the upstream and downstream border of the study site, and we may not have been able to detect many large-scale movements. Finally, our data indicate that some 1+ and 2+ older Southern Brook Charr display relatively restricted movements (sensu Gerking 1959), but it is unclear whether this conclusion can be extrapolated to the population as a whole. Petty et al. (2012) also found restricted movement of Northern Brook Charr in headwater streams.

All but 2 recaptured Southern Brook Charr were at least 2 years old. This may be an artifact of electrofishing (i.e., older larger individuals are easier to capture with electrofishing; Hense et al. 2010). Consequently, our movement data may only be valid for larger and older Southern Brook Charr, although in a previous study older Northern Brook Charr were shown to be the most mobile segment of the population (Petty et al. 2005). However, our data are from a 14-month period, without summer sampling, and should be used with caution in years with differing environmental conditions (i.e., low flows). Our results also were affected by the low numbers of Southern Brook Charr present in the main site when compared to previous years (Grossman et al. 2010).

Previous studies of Brook Charr movement have shown that a variety of factors may affect movement, including gradient, water quality, reproduction, and resource competition (Fausch and Young 1995, Petty et al. 2005, Riley et al. 1992). Roghair and Dolloff (2005) observed Brook Charr recolonization of a Virginia stream after natural defaunation, noting that 1.9 km of defaunated stream was recolonized from upstream to downstream in 2.5 to 3.0 years (average = 0.69 $km^{-1}year^{-1}$). Brook Charr in some populations display limited movement (e.g., <100 m; Adams et al. 2000, Hartman and Logan 2010, Hudy et al. 2010), whereas others from invasive populations outside the native range show large-scale movements (e.g. >3000 m; Gowan and Fausch 1996, Gowan et al. 1994).

Habitat degradation is a major problem for salmonids in North America (Elser 1968, Elwood and Waters 1969, Mortensen 1977), and global climate change will likely exacerbate this problem via changes in physico-chemical factors such as temperature, flow, and sedimentation. Our movement data should assist in the conservation and management of Southern Brook Charr, the only salmonid native to the Southern Appalachians. Our data suggest that management plans may need to maintain all essential habitat types (spawning and foraging habitat) within a relatively small area if populations of Southern Brook Charr are to persist.

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