Roanoke Logperch (*Percina rex*) Population Structure and Habitat Use

Final Report

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INTRODUCTION

The Roanoke logperch (*Percina rex*) is a large darter that occurs only within the Roanoke and Chowan drainages of Virginia (Jenkins and Burkhead 1993). Within the Roanoke drainage, logperch can be found in the upper Roanoke, Pigg, and Smith rivers and some of their larger tributaries. Within the Chowan drainage, logperch are distributed along the fall zone between the piedmont and coastal plain physiographic provinces in the Nottoway River and its largest tributary, Stoney Creek. The greatest population densities of Roanoke logperch are in the upper Roanoke River (Burkhead 1983, Jenkins and Burkhead 1993) and in the Nottoway River drainage (see below; Objective 3). Based on its limited distribution and the vulnerability of its largest population centers to urban and industrial stresses, Roanoke logperch have been placed on the federal endangered species list (Federal Register Vol. No. 159).

Some general aspects of life history, habitat use, and behavior of Roanoke logperch are summarized in previous research (Jenkins 1977, Burkhead 1983, Jenkins and Burkhead 1993, Ensign 1995); however, most of this information is based in the upper Roanoke River during warm months. Adult logperch in the Roanoke River are typically found in deep, high velocity riffle and run habitats, while young and juveniles have been observed in slow runs and pools, where they are frequently observed over clean sand bottoms. Spawning of logperch typically occurs in scoured, deep riffles and runs (Burkhead 1983). The eggs are adhesive and demersal, and larvae are thought to drift to calm water areas after hatching (Burkhead 1983). Because standard electrofishing techniques collect very small logperch inefficiently, Burkhead (1983) only observed two young-of-year (YOY) over the duration of his two-year study. Both were observed in shallow, sandy pool margins. Roanoke logperch of all age classes seem intolerant of moderately to heavily silted substrates in the Roanoke River, possibly due to their feeding behavior unique to the subgenus *Percina*. Logperch use their conical snout to flip gravel and feed on exposed invertebrates. This exploits prey sheltered beneath rocks that may be unavailable to other benthic fishes; however, this feeding behavior relies on the availability of loosely embedded substrate.

Major gaps in our knowledge of Roanoke logperch habitat use and life history include seasonal and ontogenetic habitat use, movement by individual fishes, and differences in age structure and demographics among populations. Further, outside of the Roanoke River, habitat use by other populations of logperch is largely unknown. Differences in habitat availability between these rivers may influence patterns of habitat use. This basic information will be critical to making recovery efforts effective and will enhance managers' understanding of factors that limit logperch distribution and abundance relevant to the long-term viability of logperch populations.

Purpose and objectives of study

The purpose of this project is to supplement and collect information on the biology of the endangered *Percina rex* (Roanoke logperch). The following are the primary objectives: 1) compare habitat use by logperch between summer and winter, 2) compare habitat use by logperch among the upper Roanoke, Pigg, and Nottoway river systems, 3) compare demographics of logperch populations among the upper Roanoke, Pigg, and Nottoway river systems, and 4) document the extent of logperch movement between seasons and years. The basic information contained in this report significantly advances our limited understanding of environmental needs and limitations of Roanoke logperch and will contribute to guiding strategies for recovery. The reach of the Roanoke River targeted for this study extends 10 river km downstream of the confluence of the North and South Forks; for the Pigg River we targeted the reach downstream the Town of Rocky Mount and upstream of the river's confluence with Leesville Lake (Appendix I). We sampled sites along the fall zone between the Piedmont and Coastal Plain physiographic provinces in the Nottoway River (Appendix I). The period of time covered by this report is from August 1999 to March 2002.

OBJECTIVE 1: SEASONAL HABITAT USE BY ROANOKE LOGPERCH

In the summer of 1999, a reachwide inventory of 10km of the Roanoke River was conducted using the Basinwide Visual Estimation Technique described in Dolloff et al. (1993). Eight riffle:run:pool series were systematically selected from these reachwide inventories for summer quantitative underwater observation using line transect snorkeling methods (Appendix I). Winter protocols for sampling in the Roanoke River included strip transect methods outlined in Ensign et al. (1999). This method met with limited success in 1998-1999. New methods were used in the Roanoke River for the winters of 1999 and 2000.

Summer sampling methods

Summer survey observations for each riffle:run:pool series were made via line-transect snorkeling methods described in Ensign et al. (1995). One to three parallel lines oriented with river flow were marked with yellow line on the day of sampling. Spacing between lines was a minimum of 1.5 times maximum underwater visibility on the day of sampling. The length of the lines was based on the length of the habitat units but did not exceed 50m per unit (150m per site). Visibility was determined by suspending a Secchi disk in the water column in front of a snorkeler. The snorkeler moved away from the disk until the black patterns on the disk were no longer distinguishable from the water. The distance between the snorkeler and the disk was measured and served as the maximum visibility for that day. Surveys were not conducted if maximum visibility was less than 1.5 meters (from Leftwich et al. 1997).

To minimize effects of disturbance and allow fish to settle, snorkelers did not begin sampling until at least one hour after placement of the transect lines. Snorkelers entered the water downstream of the area to be sampled and moved slowly upstream along the lines, keeping the center of the body over the line. Each observer scanned the stream bottom, mid-water, and upper-water column directly in front and to both sides of the line of travel. When a logperch was sighted, a numbered weighted marker was placed on the stream bottom precisely where the fish was first spotted. The number-code of markers and age class (adult or subadult) were recorded on dive slates. Double counting of logperch was avoided by simultaneously sampling all three transect lines with snorkelers staying even with each other while moving upstream. Continuous communication between snorkelers also minimized double counting. After the pool:riffle:run sequence was sampled, snorkelers returned to the base of transects to count markers and collect habitat data.

Microhabitat data included water depth, bottom and mean water velocities, and point substrate size (9-category Wentworth scale). We also recorded substrate characteristics within a 1-m^2 area around the marker, including dominant and subdominant substrate size, embeddedness (5 categories: 1 ≥ 95% embedded, 2 = 50-94%, 3 = 25-49%, 4 = 5-24%, 5 = 0-5%, i.e. exposed), and silt cover (5 categories: 1 = 76-100% cover, 2 = 51-75%, 3 =26-50%, 4 = 1-25%, 5 = 0%). To record microhabitat availability, we placed horizontal transects along the wetted width of the river at 10-meter intervals along the length of the site within 24 hours of the snorkeling run. Every three meters on the horizontal transects, depth, mean and bottom water velocities, silt cover, dominant and subdominant substrates within a 1-m^2 area were recorded.

Winter sampling methods

Sampling methods for the winters of 1998-1999 in the Roanoke River followed methods outlined by Ensign et al. (1999). Previous work indicated that logperch are quiescent in winter, residing in interstitial spaces between boulders and cobbles (Burkhead 1983, Ensign et al. 1999). To sample for logperch, a team of three divers swam along a 50-m longitudinal transect along the deepest part of the channel and along 10-m perpendicular transects centered at the 5-, 15-, 25-, 35-, and 45-m locations on the longitudinal transect. One of the divers turned over cobbles and boulders within a 15-cm wide strip along these transects to search for logperch, while the other divers flanked the first diver, recorded data on dive slates, and set underwater markers where logperch were observed. For each site, attempts were made to sample a riffle and pool. Habitat availability was measured at 5-m intervals along the 45-m transect and the five perpendicular transects. Habitat data included depth, mean and bottom velocities, substrate size (5-category Wentworth scale), and silt cover. This sampling protocol was time-intensive; each set of transects took about 7 hours to census completely and covered only 13.5 m^2 of the stream bottom.

Limited success in the winters of 1998 and 1999 led to the development of alternative winter sampling methods for Roanoke logperch. These methods allowed the sampling of a greater variety of habitat types, and, unlike the strip transect method, did not restrict divers to the thalweg of the river. It also allowed all three divers to search for logperch, rather than a single diver. A team of three snorkelers moved up a previously delineated riffle, run, pool sequence in a zigzag fashion, turning all lightly embedded cobbles, boulders, and deadfall substrate in a shoulder-wide (~50cm) strip to count logperch. Divers concentrated on sampling a variety of habitats. When a logperch was observed, a weighted marker was placed at the site of

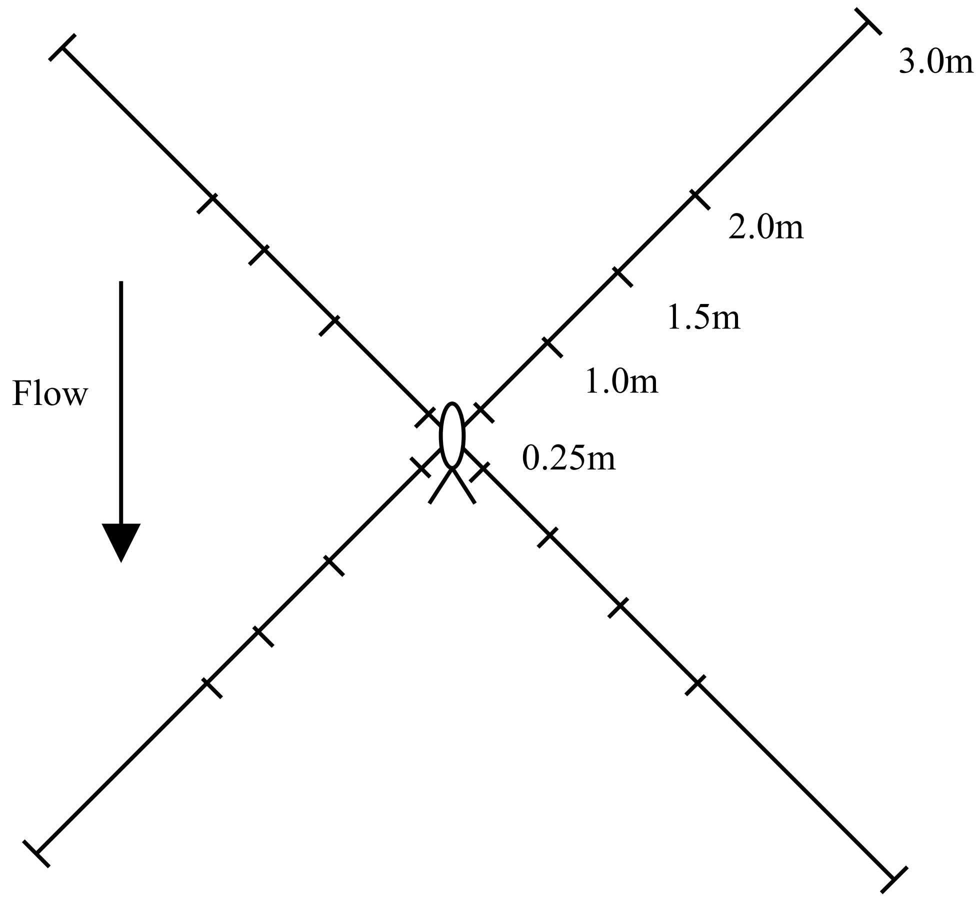


Figure 1. Schematic of “transect cross” used to sample habitat during winters of 1999-2000. This transect was also used to quantify habitat use of YOY logperch.

observation. After the selected river length was sampled, divers returned to these sites to take sighting location and habitat data. In one day, three snorkelers would typically sample an entire riffle, run, pool sequence (~100 m long), adding to a total of 150 m^2 of the stream bottom.

At each location where a logperch was observed, the following information was recorded: distance of sighting from stream bank (left or right), description of rock formation, and mesohabitat type. Habitat use and availability data were recorded at the site where each fish was observed using a cross-shaped transect, which was centered on the logperch sighting location (Figure 1). Habitat use data were taken along transect arms set at 45°, 135°, 225°, and 315° from this center sighting location (Figure 1). These angles minimized collection of habitat data in areas where divers had disturbed substrate. Habitat use was measured at five points, including the site of observation and 0.25 m from the center point along each transect line (four 0.25-m measurements). Habitat availability was measured at 16 points, including 1, 1.5, 2.0, and 3.0 m from the center point along each transect. The following habitat variables were recorded at each point: depth, mean water velocity, bottom water velocity (if possible, measured behind rock where logperch was sighted), rank embeddedness, and rank substrate size.

Data analysis

We made 6 attempts to observe Roanoke logperch in the Roanoke River during winter, and sampled 8 sites in the Roanoke River during summer (Table 1). Due to the limited window of opportunity and area sampled, only 5 adult Roanoke logperch were observed during winter months from 1999-2000. Microhabitat data that were comparable using summer and winter methods included depth (cm), mean velocity (m/s), bottom velocity (m/s), point substrate (rank category), embeddedness (rank category), and silt cover (rank category). Differences among winter and summer habitat use for each characteristic was tested with Mann-Whitney U tests.

Table 1. Summary of sites visited in the Roanoke River during summer and winter months, including water quality information (per site), number of Roanoke logperch observed, and mesohabitat types sampled.

Season	**# sites**	**mesohabitats**	**observations (mean, SD)**	**DO (mg/L, mean, SD)**	**Temp (°C, mean, SD)**	**Cond (µs, mean, SD)**
Summer	8	pool, riffle, run	6.14 ± 9.8	9.6 ± 1.3	20.5 ± 2.4	346.4 ± 29.1
Winter	5	pool, riffle, run, secondary channel	1 ± 0.7	14.2 ± 0.6	5.8 ± 2.8	382.9 ± 3.1

Results

Logperch observed in the summer were found in deep, high velocity microhabitats with exposed, silt-free gravel substrate. Logperch observed in winter months selected deep microhabitats around exposed gravel and cobble substrate. We could not detect differences between seasons in logperch use of substrate or water depths ($\chi^2 < 0.99$, $P > 0.32$, Table 2). However, logperch observed in the winter appeared to use habitat with slower mean and bottom water velocities than logperch observed in summer months ($\chi^2 > 7.3$, $P < 0.008$, Table 2). In addition, logperch in the winter were observed in less embedded substrate than logperch observed in the summer ($\chi^2 = 6.9$, $P = 0.008$, Table 2). Logperch in the winter also appeared to select less silted habitat than logperch in the summer, though the Mann-Whitney U test was only marginally significant ($\chi^2 = 3.6$, $P = 0.06$, Table 2).

Table 2. A comparison of summer and winter habitat use by Roanoke logperch in the Roanoke River based on surveys conducted from 1999-2001. ** Indicates a significant difference at the 0.05 level (Mann-Whitney U-test); * Indicates marginal significance.

Habitat variable	**Summer**	**Winter**	χ^2	**P**	
Depth (cm), SD	51.5 ± 12.8	66.0 ± 29.1	0.99	0.32	
Mean velocity (m/s), SD	0.59 ± 0.68	0.46 ± 0.21	12.2	< 0.001	**
Bottom velocity (m/s), SD	0.15 ± 0.30	0.03 ± 0.04	7.34	0.007	**
Substrate (mean rank), SD	5.8 ± 1.6	6.2 ± 1.1	0.58	0.47	
Embeddedness (mean rank), SD	3.8 ± 1.1	5.0 ± 0.0	6.9	0.008	**
Silt Cover (mean rank), SD	4.0 ± 1.2	5.0 ± 0.0	3.6	0.06	*
N	54	5			

Discussion

Prior to this study, it has been proposed that logperch use deep pools for winter habitat (Burkhead 1983). Our limited observations suggest that this is not so; winter habitat use of Roanoke logperch is not as dramatically different from summer habitat use as has been suggested. Adults observed in both seasons were found in high-velocity, deep microhabitat in riffles and runs over exposed, silt-free gravel in areas dominated by cobble and boulder substrate. However, even with our low sample size, we were able to detect some key seasonal differences in logperch habitat use. Logperch in the winter appeared to use lower water velocities than logperch in the summer. Swimming ability of logperch in the winter may be limited due to cold temperatures that depress metabolism. Use of lower bottom velocities would reduce necessary activity for quiescent individuals. In addition, logperch observed in the winter were found over substrate that was less embedded with smaller substrates and less covered with silt. Because logperch require interstitial pockets within cobbles and boulders for resting in the winter, it is not surprising that logperch use particularly silt-free, unembedded substrate. For active logperch during summer months, some embeddedness and silt cover may not be a significant deterrent.

Objective 2: A comparison of habitat use by logperch among the upper Roanoke, Pigg, and Nottoway river systems

Understanding of logperch habitat use to this point is described in Burkhead (1983) and Jenkins and Burkhead (1993) and is based exclusively on data collected in the Roanoke River. Adult logperch in the Roanoke River are typically found in deep, high velocity riffle and run habitats. Habitat use by logperch outside of the Roanoke River is largely unknown, including populations in the Pigg and Nottoway rivers. Differences in habitat availability between these rivers may influence patterns of habitat use. The Roanoke River is a clear, coolwater, high gradient system, and the Pigg River in the Roanoke River drainage is a coolwater, medium gradient system. The Nottoway River in the Chowan drainage is tannin-stained, warmwater, and lowland (Jenkins and Burkhead 1993). The Nottoway River is similar in gradient to the Roanoke and Pigg rivers only in the Fall Zone between the Piedmont and Coastal Plain physiographic provinces, where riffle and run habitat similar to the montane rivers occur.

Studies have demonstrated differences in habitat use for different populations of a fish species (Bozek and Rahel 1992, Freeman et al. 1997), particularly populations from different regions (Groshens and Orth 1994). Therefore, a comparison of habitat availability and habitat use between the rivers will be meaningful. Understanding different habitat use patterns between populations in different systems or regions can offer insight into limiting factors for a species. Consistency in the use of a particular habitat feature over different regional conditions implies that feature is critical for the persistence of that species. We can relate differences in habitat use between populations to differences in habitat availability. This can contribute to more informed management plans for imperiled species and the appropriate allocation of conservation resources.

We have separated this objective into five sections. The first section evaluates differences in mesohabitat availability (e.g. pool, run, riffle) between the Roanoke and Nottoway rivers using data obtained through a reachwide survey of the Roanoke and Nottoway rivers. Unfortunately, limited time prevented a reachwide survey of the Pigg River. The second section examines differences in microhabitat availability among all three rivers. These data were obtained during summer snorkeling surveys. The third section examines differences between the Nottoway and Roanoke rivers in aquatic insect abundance in riffle and run habitats. The fourth section evaluates differences in microhabitat use by Roanoke logperch in the Roanoke, Pigg, and Nottoway river systems. In the fifth section, we discuss differences in logperch habitat use in light of differences between the three systems in meso- and micro- habitat availability and insect abundance. This comparative approach gives insight to mechanisms behind habitat use patterns of Roanoke logperch in the three river systems.

Reachwide survey of the Roanoke and Nottoway rivers: comparison of mesohabitat availability

Methods

Habitat inventories were completed for 10 river kilometers of the Roanoke River and 20 kilometers of the Nottoway River. These lengths allowed the sampling of a wide range of habitat types. Along each length of river, habitat inventory was conducted via the Basinwide Visual Estimation Technique (BVET, Hankin and Reeves 1988; Dolloff et al. 1993). A two- to three person crew classified and inventoried habitat configurations along each reach of river.

One crewmember identified each habitat unit by type (pool, run, or riffle), took channel width measurements along the stream with an optical range finder, and recorded data. The second crewmember visually classified the dominant and subdominant substrate by particle size (using an 8 – category Wentworth scale), average silt cover (5 categories: 1 = 76-100% cover, 2 = 51-75%, 3 =26-50%, 4 = 1-25%, 5 = 0%) and embeddedness of larger substrates (i.e. boulders, cobble, and gravel; 5 categories: 1 ≥ 95% embedded, 2 = 50-94%, 3 = 25-49%, 4 = 1-24%, 5 = 0%, i.e. exposed). This crewmember also estimated the minimum, maximum, and average depth of each habitat unit by measuring these parameters at 10-20 points along the habitat unit while traveling downstream and across the channel in a zigzag pattern. The final crewmember measured the length and width of each habitat unit and the presence of woody debris. Woody debris greater than 50cm diameter or greater than 5m long was counted and assigned to classes measured along a 4-category scale following Flebbe (1999; **1**: >50 cm diameter, 1-5 m length; **2**: 10-50 cm diameter, >5 m length; **3**: >50 cm diameter, > 5 m length; and **4**: root wads).

Data analysis

Mesohabitat data collected using BVET were separated by habitat type (pools, runs, or riffles). We report estimated total area of each habitat type in the sample reaches. For each habitat type we compared average depth, maximum depth, number and type of woody debris per unit, embeddedness, silt cover, dominant substrate, and subdominant substrate between the two rivers using t-tests.

Results

Summarized BVET data indicate that pool habitat is dominant, runs uncommon, and riffles rare in the Nottoway River relative to the Roanoke River (Table 3). This is expected due

Table 3. Summary of mesohabitat characteristics of the Nottoway and Roanoke rivers from data collected using the Basinwide Visual Estimation Technique (BVET, Dolloff et al. 1993). *Indicates a significant difference at the 0.05 level (t-test).

		Roanoke River	Nottoway River	t	P
Area (m^2)/ km	**pool**	14306 (58.1%)	25916 (78%)		
	run	5361 (21.8%)	5750 (17.3%)		
	riffle	4698 (19.1%)	1548 (4.7%)		
Ave depth (cm), SD	**pool**	79.3 ± 47.6	76.1 ± 33.3	0.40	0.53
	run	32.1 ± 11.0	41.3 ± 17.6	11.5	<0.001*
	riffle	22.3 ± 11.7	27.2 ± 19.0	3.9	0.05*
Ave Maximum depth (cm), SD	**pool**	113.3 ± 69.9	109.6 ± 50.1	0.23	0.63
	run	48.0 ± 18.2	62.5 ± 24.5	13.9	<0.001*
	riffle	36.1 ± 22.0	41.9 ± 21.5	2.8	0.10
Ave # 1 woody debris/unit, SD	**pool**	0.1 ± 0.2	0.0 ± 0.3	0.47	0.49
	run	0.0 ± 0.2	0.0 ± 0.1	0.70	0.40
	riffle	0.0 ± 0.2	0.0 ± 0.0	2.3	0.13
Ave # 2 woody debris/unit, SD	**pool**	2.0 ± 3.9	7.7 ± 8.5	39.8	<0.001*
	run	0.9 ± 1.6	3.0 ± 3.7	16.9	<0.001*
	riffle	0.7 ± 1.3	1.9 ± 2.3	15.2	<0.001*
Ave # 3 woody debris/unit, SD	**pool**	0.5 ± 1.2	1.0 ± 1.7	6.1	0.01*
	run	0.2 ± 0.5	0.3 ± 0.9	2.1	0.15
	riffle	0.1 ± 0.3	0.4 ± 1.4	3.4	0.07
Ave # 4 woody debris/unit, SD	**pool**	3.5 ± 5.3	3.4 ± 5.0	0.01	0.91
	run	1.6 ± 2.0	1.5 ± 2.5	0.16	0.67
	riffle	1.2 ± 1.3	0.6 ± 1.6	6.6	0.01*
Ave rank embeddedness, SD	**pool**	1.7 ± 0.7	4.2 ± 0.7	680.4	<0.001*
	run	2.1 ± 0.7	3.1 ± 1.2	23.4	<0.001*
	riffle	2.8 ± 0.8	4.3 ± 1.0	95.7	<0.001*
Ave rank silt cover, SD	**pool**	2.6 ± 1.5	3.5 ± 1.2	27.8	<0.001*
	run	3.8 ± 1.3	4.3 ± 0.19	6.3	0.01*
	riffle	4.7 ± 0.8	4.8 ± 0.7	0.65	0.42
Ave rank dominant substrate, SD	**pool**	6.8 ± 1.9	5.7 ± 2.2	17.2	<0.001*
	run	6.8 ± 1.4	6.2 ± 2.4	3.2	0.08
	riffle	7.1 ± 1.0	8.1 ± 1.4	23.7	<0.001*
Ave rank subdominant substrate, SD	**pool**	5.8 ± 2.0	6.0 ± 2.7	0.28	0.60
	run	6.3 ± 1.5	6.3 ± 2.4	0.0	0.97
	riffle	6.5 ± 1.2	6.4 ± 1.8	0.15	0.70

to difference in gradient between the two rivers. Pools in the Nottoway River contain more medium woody debris (rank 2: 10-50 cm diameter, >5 m length; $t = 39.8$, $P < 0.001$) and large woody debris (rank 3: >50 cm diameter, > 5 m length; $t = 6.1$, $P = 0.01$) than pools in the Roanoke River (Table 3). Although Nottoway River pools have smaller dominant substrates (i.e., sand) than pools in the Roanoke River ($t = 17.2$, $P < 0.001$), larger substrates such as gravel, cobble, and debris in Nottoway River pools were dramatically less embedded and silt free in comparison to substrate in Roanoke River pools ($t \geq 27.8$, $P < 0.001$, Table 3). Medium-sized woody debris is more frequently encountered in Nottoway River runs ($t = 16.9$, $P < 0.001$), which are deeper and less silted and embedded than runs in the Roanoke River ($t \geq 6.3$, $P \leq 0.01$, Table 3). Although silt cover in riffles does not differ significantly between rivers ($t = 0.65$, $P = 0.42$), Nottoway River riffles are less embedded ($t = 95.7$, $P < 0.001$, Table 3). Roanoke River riffles are shallower than Nottoway River riffles ($t = 3.9$, $P = 0.05$). The predominance of bedrock in Nottoway River riffles results in a larger dominant substrate sizes than riffles in the Roanoke River ($t = 23.7$, $P < 0.001$, Table 3). Root wads are more exposed in Roanoke River riffles (#4 woody debris, $t = 6.6$, $P = 0.01$), perhaps due to increased frequency of undercut banks in the Roanoke River. Medium-sized woody debris is more common in Nottoway River riffles than Roanoke River riffles ($t = 15.2$, $P < 0.001$, Table 3).

Discussion

It is not surprising that there is significant separation among many habitat characteristics between the Roanoke and Nottoway rivers, considering differences between the rivers in physiography, gradient, and anthropogenic disturbance. The most consistent and dramatic differences are in embeddedness, silt cover, and frequency of woody debris. The Nottoway River is relatively pristine and undeveloped compared to the Roanoke River. Intact riparian zones in the Nottoway River contribute woody debris and stabilize banks, which, in turn, reduce sediment loads that cover and embed substrate. Exposed root wads, more common in Roanoke River riffles than Nottoway River riffles, are sometimes the result of undercutting that characterizes an unstable streambank. The Nottoway River is a larger and wider system than the upper Roanoke, thus the presence of deeper runs and riffles in the Nottoway River.

These results indicate significant differences in reachwide habitat characteristics between the two systems, which could have a strong impact on Roanoke logperch habitat use. Past studies indicate that logperch are severely limited by heavy silt loads and substrate embeddedness, which are common in the Roanoke River. Still, the logperch population in the Roanoke River persists, indicating that choice of microhabitats by logperch in this system may compensate for the presence of habitats degraded by sedimentation.

Differences among the Roanoke, Pigg, and Nottoway Rivers in microhabitat availability

Methods

Habitat availability was recorded for 8 sites in the Roanoke and Nottoway rivers and 6 sites in the Pigg River. Microhabitat availability was recorded within 24 hours of the snorkeling run described in Objective 1 (*Summer sampling methods*). To record microhabitat availability for each site, horizontal transects along the wetted width of the river were placed at 10-meter intervals along the length of the pool:riffle:run series. Every three meters on the horizontal transect, depth, mean and bottom water velocities, embeddedness, silt cover, and dominant and subdominant substrate within a 1-m^2 area were recorded.

Data analysis

We used analysis of variance (ANOVA) to compare microhabitat availability between the Roanoke, Pigg, and Nottoway rivers. Availability variables included channel width, depth, bottom velocity, mean velocity, dominant and subdominant substrate in a 1-m^2 area, rank embeddedness, and rank silt cover. Variables were separated by habitat unit type (pool, run, or riffle) before analysis. Pairwise differences between river habitat unit types were examined separately using Scheffe's multiple comparisons. We also used multivariate discriminant analysis to compare overall microhabitat availability among the three rivers.

Results

Widths of pools in the Nottoway River were larger than the widths of pools in the Roanoke and Pigg rivers ($F \geq 39.2$, $P < 0.001$, Table 4). Pigg river widths and depths were consistently smaller for all mesohabitat types than corresponding mesohabitats in the Roanoke and Nottoway rivers ($F \geq 39.2$, $P < 0.001$, Table 4). Bottom velocities were greatest for Roanoke River riffles and pools ($F \geq 3.7$, $P \leq 0.02$); however, bottom velocities did not vary among rivers for runs ($F = 0.30$, $P = 0.71$, Table 4). Mean velocities in runs and riffles did not differ between rivers ($F \leq 3.1$, $P \geq 0.06$). For pools, mean velocities were fastest in the Roanoke River, intermediate in the Nottoway River, and slowest in the Pigg River ($F = 8.3$, $P < 0.001$, Table 4).

Substrate characteristics of pools, riffles, and runs differed among rivers, particularly silt and embeddedness (Table 4). Dominant substrate was largest for the Roanoke River for all mesohabitat unit types ($F \geq 23.7$, $P < 0.001$). Dominant substrate size in the Pigg and Nottoway river pools and runs did not differ. For riffles, the Nottoway River had larger dominant substrate sizes than the Pigg River ($F = 30.1$, $P < 0.001$). Subdominant substrate in all rivers ranged

Table 4. Summary of microhabitat characteristics of pools, riffles, and runs in the Roanoke, Pigg, and Nottoway rivers. *Indicates a significant difference at the 0.05 level (ANOVA). Underlines indicate no significant difference between river pairs (Sheffe's multiple comparisons, $\alpha = 0.05$).

POOL CHARACTERISTICS	Roanoke River (R)	Pigg River (P)	Nottoway River (N)	F	P	
Channel width (m, SD)	24.8 ± 4.3	20.0 ± 4.3	33.1 ± 5.7	438	<0.001 *	R P N
Depth (m, SD)	75.7 ± 45.1	38.8 ± 23.3	84.9 ± 35.9	82.4	<0.001 *	R P N
Bottom velocity (m/s, SD)	0.06 ± 0.24	0.03 ± 0.05	0.04 ± 0.09	3.7	0.02 *	R $\underline{\text{P N}}$
Mean velocity (m/s, SD)	0.21 ± 0.45	0.10 ± 0.08	0.15 ± 0.15	8.3	<0.001 *	R P N
Dominant substrate (mean rank, SD)	5.9 ± 2.5	4.6 ± 2.2	4.7 ± 2.2	23.7	<0.001 *	R $\underline{\text{P N}}$
Subdominant substrate (mean rank, SD)	4.8 ± 1.9	4.4 ± 2.2	4.6 ± 2.4	1.3	0.27	$\underline{\text{R P N}}$
Embeddedness (mean rank, SD)	2.5 ± 1.4	1.8 ± 0.90	3.5 ± 1.3	110	<0.001 *	R P N
Silt (mean rank, SD)	2.4 ± 1.5	1.4 ± 0.80	3.4 ± 1.5	116	<0.001 *	R P N
RUN CHARACTERISTICS						
Channel width (m, SD)	28.9 ± 7.8	16.9 ± 4.0	27.8 ± 5.2	130	<0.001 *	$\underline{\text{R}}$ P $\underline{\text{N}}$
Depth (m, SD)	35.8 ± 21.16	24.8 ± 10.5	50.7 ± 24.0	61.5	<0.001 *	R P N
Bottom velocity (m/s, SD)	0.08 ± 0.16	0.08 ± 0.09	0.07 ± 0.13	0.30	0.71	$\underline{\text{R P N}}$
Mean velocity (m/s, SD)	0.25 ± 0.31	0.19 ± 0.14	0.28 ± 0.33	3.1	0.06	$\underline{\text{R P N}}$
Dominant substrate (mean rank, SD)	7.0 ± 1.7	5.5 ± 1.6	5.4 ± 2.2	43.3	<0.001 *	R $\underline{\text{P N}}$
Subdominant substrate (mean rank, SD)	5.9 ± 1.6	5.2 ± 1.7	5.1 ± 2.1	12.0	<0.001 *	R $\underline{\text{P N}}$
Embeddedness (mean rank, SD)	3.3 ± 1.3	3.1 ± 1.0	3.9 ± 1.3	20.3	<0.001 *	$\underline{\text{R P}}$ N
Silt (mean rank, SD)	3.4 ± 1.4	3.1 ± 1.3	4.3 ± 1.2	42.7	<0.001 *	R P N
RIFFLE CHARACTERISTICS						
Channel width (m, SD)	26.5 ± 6.1	21.2 ± 6.2	28.9 ± 8.8	39.2	<0.001 *	$\underline{\text{R}}$ P $\underline{\text{N}}$
Depth (m, SD)	26.2 ± 16.3	16.0 ± 8.9	34.3 ± 21.3	39.9	<0.001 *	R P N
Bottom velocity (m/s, SD)	0.16 ± 0.30	0.11 ± 0.15	0.08 ± 0.19	5.8	0.003 *	R $\underline{\text{P N}}$
Mean velocity (m/s, SD)	0.40 ± 0.44	0.25 ± 0.23	0.37 ± 0.48	2.5	0.10	$\underline{\text{R P N}}$
Dominant substrate (mean rank, SD)	7.7 ± 1.0	6.1 ± 1.5	6.9 ± 2.3	30.1	<0.001 *	R P N
Subdominant substrate (mean rank, SD)	5.7 ± 1.6	5.5 ± 1.6	5.6 ± 2.0	0.24	0.79	$\underline{\text{R P N}}$
Embeddedness (mean rank, SD)	3.7 ± 1.1	3.3 ± 1.2	4.3 ± 1.1	27.7	<0.001 *	R P N
Silt (mean rank, SD)	4.0 ± 1.4	3.4 ± 1.4	4.5 ± 1.0	30.5	<0.001 *	R P N

between sizes 4 (sand) and 6 (large gravel) for pools and riffles and did not differ among rivers ($F \leq 1.3$, $P \geq 0.27$, Table 4). Subdominant substrate in Roanoke River runs was largest compared to Pigg and Nottoway river runs ($F = 12.0$, $P < 0.001$, Table 4). Differences in embeddedness and silt cover among the three rivers were consistent and dramatic. The Nottoway River had the most exposed and least silted habitat for all mesohabitat types (Table 4), while the Pigg River had the most embedded and silted habitats ($F \geq 20.3$, $P < 0.001$), with the exception of runs.

Discriminant analysis was used to summarize differences among rivers for all mesohabitat types and all microhabitat variables combined (Figure 2). This analysis corroborates univariate analyses, suggesting that the rivers differ most in channel width and substrate characteristics. Canonical discriminant functions of the two axes (Table 5) indicate that the first axis is loaded most heavily by channel width and silt cover (Figure 2). Plots of the confidence intervals around mean canonical scores for each river indicate that the Nottoway River was the widest and least silted, the Roanoke River intermediate, and the Pigg River the narrowest and most silted (Figure 2). The second axis is loaded most heavily by dominant substrate size and embeddedness characteristics (Table 5, Figure 2). There is little separation among rivers along the second axis; however, as the univariate analysis indicates, the Roanoke River has the largest substrate sizes that are more embedded than Nottoway River substrates (Figure 2). The Pigg River is intermediate between the Roanoke and Nottoway Rivers along this axis, probably due to the confounding substrate characteristics (Figure 2). Substrate in the Pigg River is small compared to the Roanoke River; however, substrate in the Pigg River is more embedded than in the other rivers. Regardless, confidence intervals around mean canonical scores indicate that, despite differences, there is overlap in microhabitat characteristics among rivers.

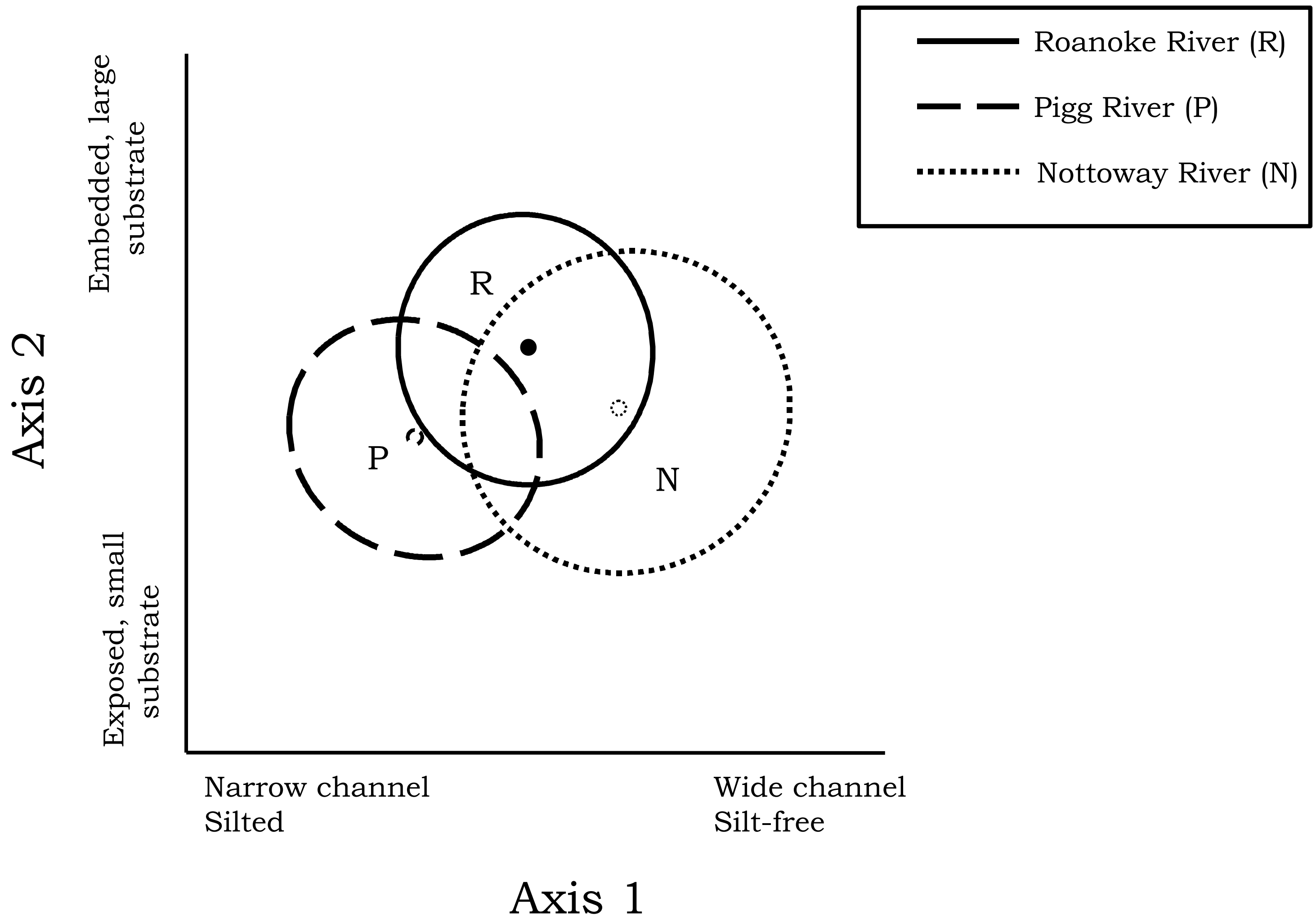


Figure 2. Discriminant analysis of microhabitat availability measurements for the Roanoke, Pigg, and Nottoway rivers. Axis labels are based on canonical discriminant functions of Factor 1 and 2. Circles represent 95% confidence intervals around the mean canonical value for each river.

Table 5. Canonical discriminant functions of a discriminant analysis comparing microhabitat availability between the Roanoke, Pigg, and Nottoway rivers (Figure 4).

Microhabitat characteristics	Axis 1	Axis 2
Channel width	0.642	0.362
Depth	0.495	0.199
Bottom velocity	-0.164	0.35
Mean veocity	-0.022	0.02
Dominant substrate size	-0.117	0.967
Subdominant substrate size	-0.165	0.189
Embeddeness	0.282	-0.549
Silt Cover	0.621	-0.068

Discussion

Availability of different microhabitat configurations can have a significant impact on fish habitat use. For the Roanoke, Pigg, and Nottoway rivers, microhabitat characteristics vary among rivers and mesohabitat types. Differences among the three rivers reflect their relative size and gradient. The Nottoway River is the largest and deepest of the rivers and the Pigg River the smallest and shallowest. The Roanoke River, with the highest gradient, has the largest substrates for all mesohabitat types and highest bottom velocities in its riffles. The most dramatic differences among rivers are in embeddedness and silt characteristics. For all mesohabitat types, the Nottoway River is the least silted and embedded and the Pigg River the most heavily embedded with silt. The Nottoway River is a relatively pristine system with complete riparian zones, while the Roanoke and Pigg rivers are experiencing heavy sedimentation from nearby agriculture and construction activities. Because Roanoke logperch require silt-free, exposed substrate for their unique feeding strategy, this difference in microhabitat availability may cause differences in habitat use among the three rivers. However, overlap in microhabitat characteristics among the three rivers indicate that some habitat configurations are available in all three rivers, and logperch could potentially overlap in habitat use.

Insect availability in Roanoke and Nottoway river pools and riffles

Methods

Six riffle:run:pool sites were selected in the Roanoke and Nottoway rivers for invertebrate sampling. All sampling took place between June 24 and July 13, 2001 to avoid seasonal effects on invertebrate composition and densities. D-net sampling for invertebrates took place in each pool unit and riffle unit per site (12 samples per river). Within a pool or riffle, we randomly selected three locations at least two meters from the river edge for invertebrate sampling. These locations were combined to represent a "pool" or "riffle" sample. For riffles, D-nets were placed on the stream bottom, and substrate 0-1 m upstream from the net was kicked. Insects dislodged from the substrate that floated downstream into the nets were picked and preserved in 95% ethanol. Pool habitats typically did not have strong enough currents to sweep insects downstream into the D-net; therefore, we swept with the net a 1-m-long swath of the stream above the sampling location three times to capture insects. Preserved samples were taken to Virginia Tech for analysis. Insects in these samples were separated from substrate and identified to order, and, if possible, family.

Data analysis

Two-way analysis of variance (ANOVA) was used to examine differences between mesohabitat types and between rivers in aquatic insect abundance. Additional analyses were performed on the three insect families in the highest numbers in stomach contents of adult and subadult logperch from the Roanoke River (Burkhead 1983). For adult logperch (> 86mm SL), these families were: Order Trichoptera, Family Hydropsychidae (26.0% of diet); Order Diptera, Family Chironomidae (25.5% of diet); and Order Ephemeroptera, Family Baetidae (4.9% of diet). For subadult logperch (31 – 85mm TL), these families were: Order Diptera, Family

Chironomidae (26.1% of diet); Order Coleoptera, Family Elmidae (13.5% of diet); and Order Trichoptera, Family Hydropsychidae (12.3% of diet). Differences in abundance of these families between habitat types in the Roanoke and Nottoway rivers were examined with two-way ANOVA.

Results

We identified 7 orders and 26 families of aquatic insects from riffle and pool sites in the Roanoke and Nottoway rivers, including the top three insect families found by Burkhead (1983) in adult and subadult logperch stomachs (Table 6). Insects tend to be more abundant in Roanoke River riffles than Nottoway River riffles, while insect abundance tends to be higher in Nottoway River pools than Roanoke River pools (Riffles mean insect abundance ± SD: Roanoke = 268.5 ± 139.7, Nottoway = 198.2 ± 164.1; Pools mean insect abundance ± SD: Roanoke = 25.3 ± 9.7, Nottoway = 48.5 ± 36.4; Table 6). However, we were unable to detect statistically significant differences between rivers in total invertebrate abundance using two-way ANOVA ($F = 0.28$, $P = 0.60$, Table 7A). Not surprisingly, we found more insects in riffles than pools ($F = 19.3$, $P < 0.001$*, Table 7A), but this difference was more striking in the Roanoke River than the Nottoway River (10x vs. 4x). We did not, however, detect a significant river-mesohabitat interaction with two-way analysis of variance ($F = 1.1$, $P = 0.31$).

Abundances of insects preferred by adult logperch were similar between the Roanoke and Nottoway rivers ($F = 2.3$, $P = 0.14$, Table 7B), while abundances of insects that dominate subadult logperch diets were greater in Roanoke River riffles ($F = 4.3$, $P = 0.05$, Table 7C). Although the marginal significance of statistical tests and the high variability of the data set limit the conclusiveness of these analyses, several patterns may be important factors in logperch habitat use in the two rivers. The Roanoke River tended to have fewer preferred insects for adult

Table 6. Summary of insect abundance (mean ± SD) in 6 pool and 6 riffle locations in the Roanoke and Nottoway rivers, including the most abundant families in each order captured. The table denotes the three primary insect families found in stomach contents for adult ([a]) and subadult ([s]) logperch based on Burkhead (1983) data collected from the Roanoke River.

		Roanoke River		Nottoway River	
Order	**Family**	**Pools**	**Riffles**	**Pools**	**Riffles**
Coleoptera	[s] Elmidae	6.3 ± 5.3	126.5 ± 107.3	8.0 ± 6.1	13.3 ± 8.9
	Psephenidae	0.8 ± 1.2	10.7 ± 6.0	0.0 ± 0.0	0.0 ± 0.0
Diptera	[a,s] Chironomidae	4.5 ± 3.3	19.8 ± 16.6	9.2 ± 5.5	3.0 ± 1.8
	Simuliidae	0.2 ± 0.4	0.7 ± 1.2	0.2 ± 0.4	28.0 ± 27.1
Ephemeroptera	[a] Baetidae	0.3 ± 0.8	6.8 ± 16.7	6.8 ± 13.0	38.2 ± 15.5
	Inocelliidae	0.7 ± 0.8	27.8 ± 27.0	1.7 ± 4.1	19.5 ± 31.3
	Ephemerellidae	4.2 ± 2.7	22.5 ± 15.7	3.2 ± 4.9	13.3 ± 10.2
Megaloptera	Corydalidae	0.0 ± 0.0	2.8 ± 3.8	0.0 ± 0.0	0.0 ± 0.0
Odonata	Gomphidae	0.2 ± 0.4	0.0 ± 0.0	1.2 ± 1.8	0.5 ± 0.8
Plecoptera	Perlodidae	0.2 ± 0.4	1.7 ± 1.6	0.0 ± 0.0	2.2 ± 2.9
Trichoptera	[a,s] Hydropsychidae	0.5 ± 0.8	10.5 ± 10.0	0.3 ± 0.8	22.7 ± 31.1
Total Insect Abundance					
All insects		25.3 ± 9.7	268.5 ± 139.7	48.5 ± 36.4	198.2 ± 164.1
Insects important in adult diets		5.3 ± 3.1	37.2 ± 35.1	16.3 ± 17.7	63.8 ± 45.9
Insects important in subadult diets		11.3 ± 6.8	156.8 ± 125.6	17.5 ± 18.2	39.0 ± 39.1

Table 7. (A) Two-way ANOVA testing differences between rivers in total insect abundance with unit type (pool or riffle) and site as the covariate. (B & C) Two-way ANOVA testing differences between rivers in abundance of insects in families that are the top three components of adult (B) and subadult (C) logperch diet based on Burkhead (1983) from the Roanoke River.

(A)

Source	**Sum of Squares**	**Mean-square**	**F-ratio**	**P**
River	3337	3337	0.28	0.60
Mesohabitat	231477	231477	19.3	< 0.001*
River*Mesohabitat	13113	13113	1.1	0.31
Error	239371	11969		

(B)

Source	**Sum of Squares**	**Mean-square**	**F-ratio**	**P**
River	2128	2128	2.3	0.14
Mesohabitat	9441	9441	10.3	0.004*
River*Mesohabitat	368	368	0.4	0.55
Error	18302	915		

(C)

Source	**Sum of Squares**	**Mean-square**	**F-ratio**	**P**
River	18704	18704	4.3	0.05*
Mesohabitat	41834	41834	9.6	0.006*
River*Mesohabitat	23064	23064	5.3	0.03*
Error	87376	4369		

logperch than the Nottoway River (Table 6). Although more preferred insects for subadults are in Roanoke River riffles compared to Nottoway River riffles, more preferred insects for subadults were found in Nottoway River pools than Roanoke River pools (Table 6).

Discussion

Small sample sizes and high variability in insect abundance in both rivers limit the conclusiveness of these analyses. Further, selection of insects important in logperch diet is based on data collected in the Roanoke River (Burkhead 1983); it is probable that logperch diets are not identical in the two river systems. However, we can still detect some important trends. First, there are more insects in riffle habitats, particularly in the Roanoke River, where we found more insects preferred by subadult logperch. The Nottoway River appears to have more insects preferred by adults and more insects within pool habitats. However, invertebrate abundances and taxonomic composition between the two systems are comparable. The most striking and consistent trends in these data are differences between Roanoke and Nottoway river pools. Previous analyses demonstrated that Nottoway River pools, are, in general, free of heavy silt when compared to Roanoke River pools (Table 3 and 4). Heavy silt in Roanoke River pools may clog interstitial spaces in the substrate that provide habitat for aquatic insects. In addition, woody debris is much less common in the Roanoke River (Table 3) and rarely available in pools. Woody debris can serve as substrate for invertebrates and provide food for foraging fishes (Angermeier 1985). These two factors may play a role in higher abundance of aquatic insects in Nottoway River pools.

Differences among the Roanoke, Pigg, and Nottoway Rivers

in habitat use patterns of Roanoke logperch

Methods

In the summers of 2000 and 2001, we surveyed 8 sites in the Roanoke and Nottoway rivers and 6 sites in the Pigg River for Roanoke logperch (see Objective I *Summer Sampling Methods* and Appendix I). Each site consisted of a riffle:run:pool sequence. Microhabitat availability was recorded within 24 hours of snorkeling runs using the grid technique described in this objective, in the section describing differences among the Roanoke, Pigg, and Nottoway rivers in microhabitat availability.

Data analysis

Microhabitat data included depth (cm); mean velocity (m/s); bottom velocity (m/s); embeddedness (rank category); silt cover (rank category); and point, dominant, and subdominant substrates (rank category). G-tests with Williams' correction (Williams 1976) were used to detect habitat selection of logperch for each river by comparisons of actual habitat use with that expected if logperch used habitat randomly. Alpha values were adjusted for multiple tests using the Dunn-Sidak correction (α'=0.01). Differences in logperch habitat use among the three rivers for each habitat characteristic were tested with analysis of variance (ANOVA) and Sheffe's multiple comparisons.

Multivariate analysis of logperch habitat use with available habitat in all three rivers was examined with principal components analysis (PCA) using a correlation matrix with varimax rotation. In addition, PCA was used to indicate patterns of differences among rivers in habitat use by Roanoke logperch. Differences among rivers in logperch habitat use were quantitatively examined with multivariate analysis of variance (MANOVA) and discriminant analysis.

Results

Logperch in the Roanoke and Pigg rivers were primarily observed in runs, occasionally in riffles, and rarely in pools (Table 8). Differences in Roanoke logperch mesohabitat use in the Nottoway River are striking; logperch were observed primarily in pools, occasionally in runs, and rarely in riffles (Table 8). Logperch observed in the Roanoke River selected deep, high velocity microhabitats with exposed, silt free gravel substrate ($G \geq 23.7$, $P < 0.001$) and did not appear to select for bottom velocities ($G = 1.3$, $P = 0.83$, Figure 3A). Although we were unable to detect logperch selection of depth or bottom velocity categories in the Pigg River ($G \leq 10.7$, $P \geq 0.02$, Figure 3B), we observed a similar habitat selection pattern to the Roanoke River. Logperch in the Pigg River selected fast water habitats with exposed, silt-free gravel substrate ($G \geq 17.3$, $P < 0.005$, Figure 3B). A different pattern of selection was observed in the Nottoway River. Roanoke logperch in the Nottoway River selected deep microhabitats with medium mean velocities and low bottom velocities ($G \geq 11.3$, $P \leq 0.01$, Figure 3C). Logperch in the Nottoway River did not appear to select for substrate or embeddedness categories ($G \leq 10.6$, $P \geq 0.02$), but selected substrates free of silt ($G = 16.9$, $P = 0.005$).

Table 8. A summary of habitat characteristics of locations where adult Roanoke logperch were observed during snorkeling surveys in the Roanoke, Pigg and Nottoway rivers.

	Roanoke River	*Pigg River*	*Nottoway River*
% Total logperch observed in			
Pools	11 %	0 %	69 %
Riffles	22 %	36 %	21 %
Runs	67 %	64 %	10 %
Depth (cm), SD	51.5 ± 12.8	32.0 ± 10.4	84.2 ± 27.8
Mean Flow (m/s), SD	0.59 ± 0.68	0.30 ± 0.15	0.20 ± 0.17
Bottom Flow (m/s), SD	0.15 ± 0.30	0.11 ± 0.09	0.02 ± 0.09
Point Substrate (mean rank), SD	5.8 ± 1.6	5.4 ± 0.5	5.1 ± 2.0
Dominant Substrate (mean rank), SD	7.2 ± 1.6	6.4 ± 0.8	6.1 ± 2.1
Subdominant Substrate (mean rank), SD	5.4 ± 1.6	5.9 ± 1.1	5.2 ± 2.2
Embeddedness (mean rank), SD	3.8 ± 1.1	4.0 ± 0.9	4.2 ± 1.0
Silt (mean rank), SD	4.0 ± 1.2	4.0 ± 1.2	4.5 ± 0.7
N	54	14	39

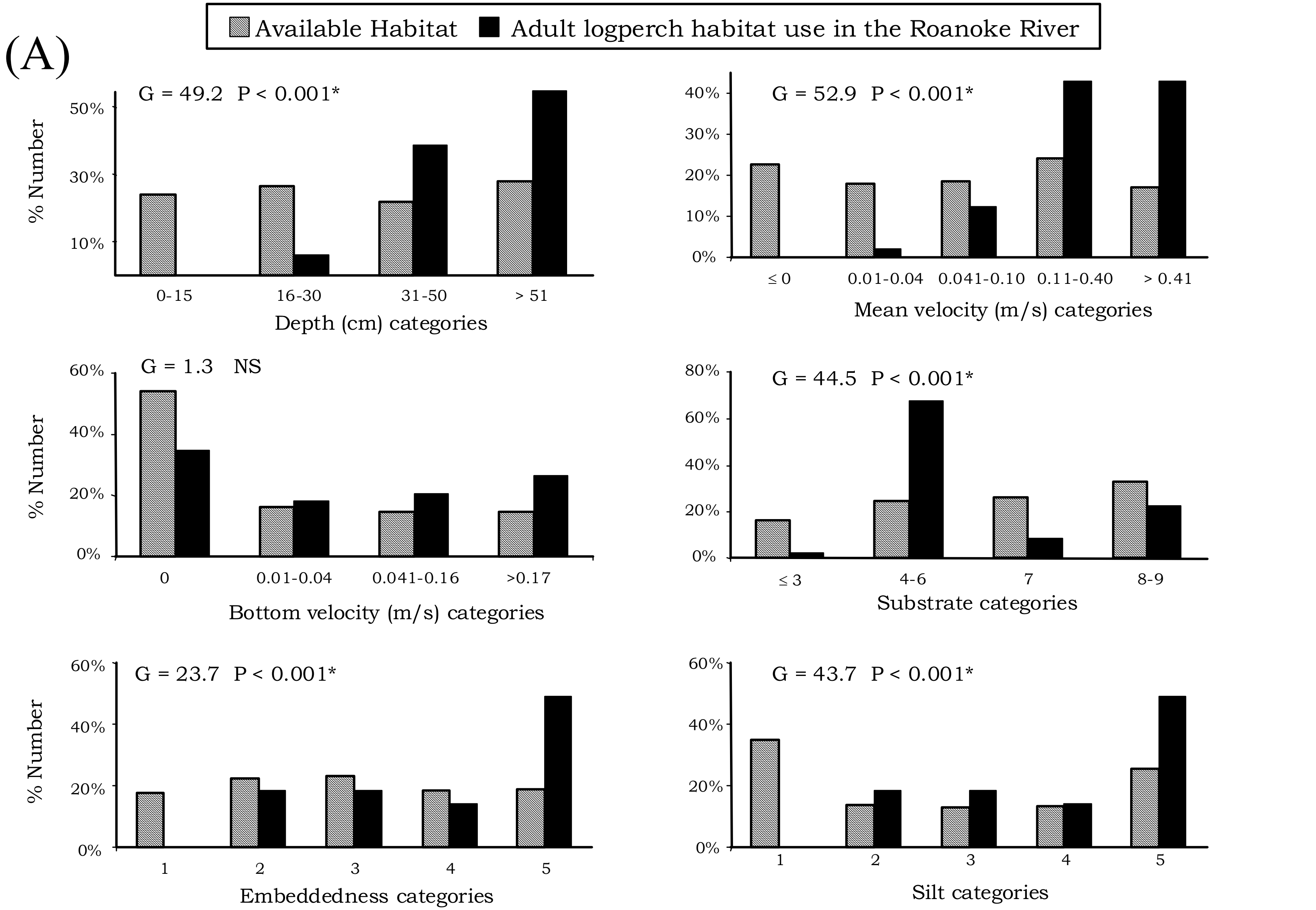
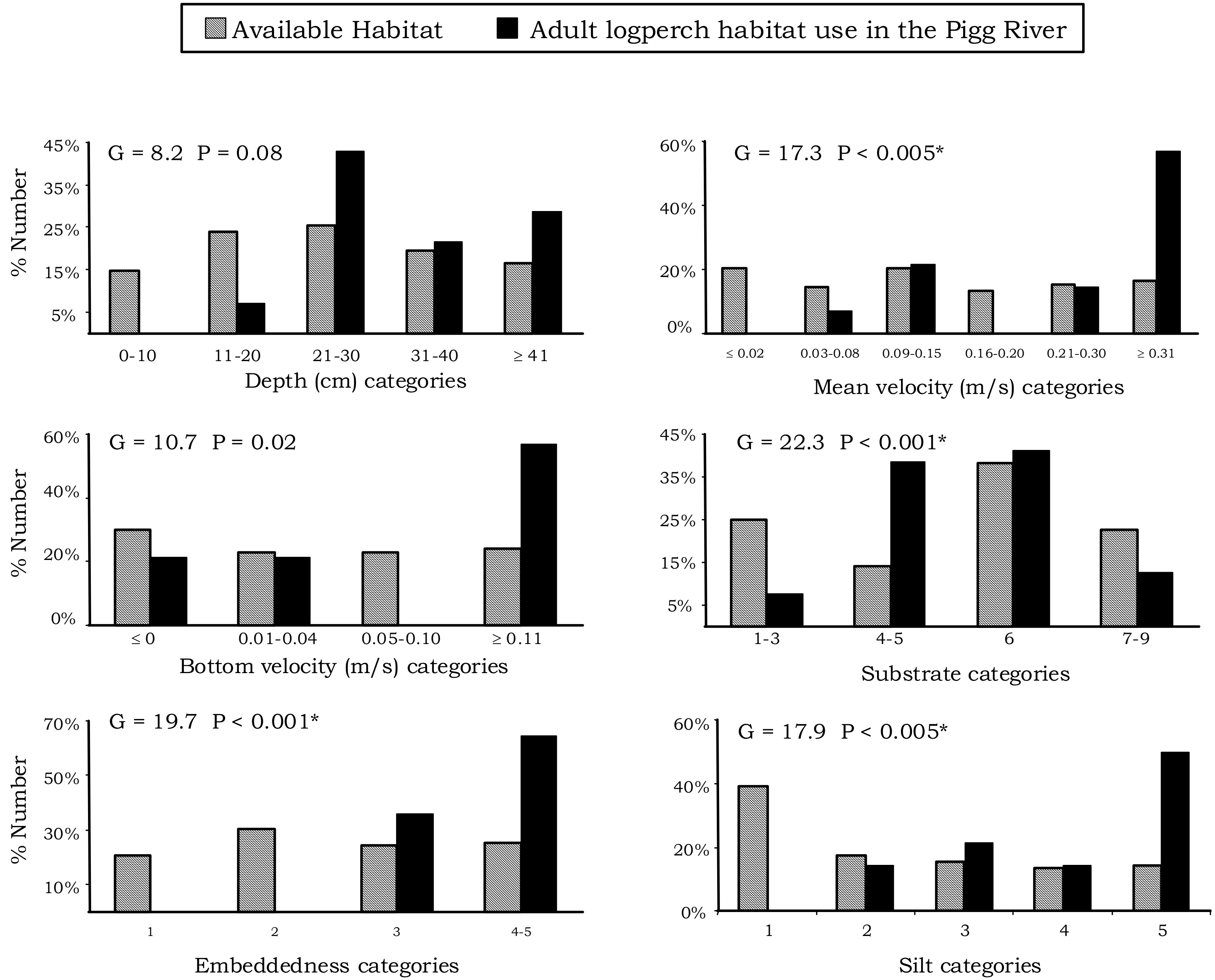
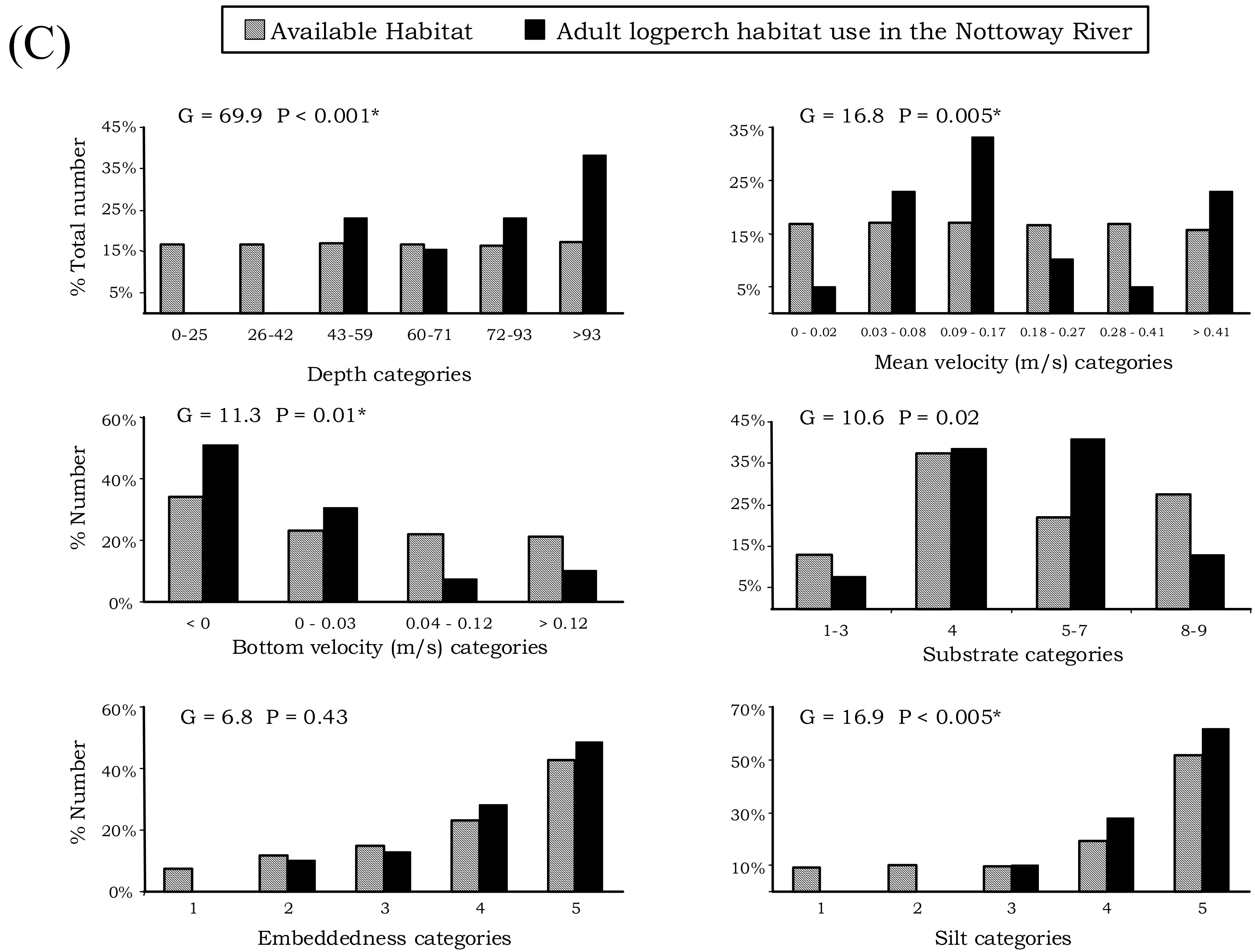


Figure 3. Proportional abundance of available habitat and proportional occurrence of adult logperch in habitat cateogories in the Roanoke (A), Pigg (B), and Nottoway (C) rivers. Data were collected during summer sampling. * indicates a significant G-test at the 0.01 level (Dunn-Sidak correction for multiple tests). Significance indicates non-random selection.

(B)



Available Habitat
Adult logperch habitat use in the Pigg River
G = 8.2 P = 0.08
% Number
45%
35%
25%
15%
5%
0-10
11-20
21-30
31-40
≥ 41
Depth (cm) categories
G = 17.3 P < 0.005*
60%
40%
20%
0%
≤ 0.02
0.03-0.08
0.09-0.15
0.16-0.20
0.21-0.30
≥ 0.31
Mean velocity (m/s) categories
G = 10.7 P = 0.02
% Number
60%
40%
20%
0%
≤ 0
0.01-0.04
0.05-0.10
≥ 0.11
Bottom velocity (m/s) categories
G = 22.3 P < 0.001*
45%
35%
25%
15%
5%
1-3
4-5
6
7-9
Substrate categories
G = 19.7 P < 0.001*
% Number
70%
50%
30%
10%
1
2
3
4-5
Embeddedness categories
G = 17.9 P < 0.005*
60%
40%
20%
0%
1
2
3
4
5
Silt categories


(C)
Available Habitat
Adult logperch habitat use in the Nottoway River
G = 69.9 P < 0.001*
% Total number
45%
35%
25%
15%
5%
0-25
26-42
43-59
60-71
72-93
>93
Depth categories
G = 16.8 P = 0.005*
35%
25%
15%
5%
0 - 0.02
0.03 - 0.08
0.09 - 0.17
0.18 - 0.27
0.28 - 0.41
> 0.41
Mean velocity (m/s) categories
G = 11.3 P = 0.01*
% Number
60%
40%
20%
0%
< 0
0 - 0.03
0.04 - 0.12
> 0.12
Bottom velocity (m/s) categories
G = 10.6 P = 0.02
45%
35%
25%
15%
5%
1-3
4
5-7
8-9
Substrate categories
G = 6.8 P = 0.43
% Number
60%
40%
20%
0%
1
2
3
4
5
Embeddedness categories
G = 16.9 P < 0.005*
70%
50%
30%
10%
1
2
3
4
5
Silt categories

Although logperch always selected relatively deep habitats, there were significant differences among rivers: Nottoway River logperch selected the deepest habitat, Roanoke River logperch selected intermediate depths, and Pigg River logperch selected the shallowest depths ($F = 47.5$, $P < 0.001$, Scheffe's multiple comparisons, Table 8, Figure 4). We also observed variation in the use of water velocities. Roanoke River logperch were found in faster water than logperch in the Pigg and Nottoway rivers ($F = 5.8$, $P = 0.004$, Table 8, Figure 4). We were unable to detect differences in use of bottom velocities among the three rivers ($F = 2.4$, $P = 0.10$, Table 8, Figure 4).

Roanoke logperch in the Roanoke, Pigg, and Nottoway rivers were remarkably consistent in their use of substrate characteristics (Table 8, Figure 5). Logperch from all three rivers were observed consistently over small to large gravel (ranks 5 and 6, $F = 0.44$, $P = 0.65$) in areas dominated by large gravel to boulders (ranks 6 through 8, $F = 2.7$, $P = 0.07$, Figure 5). Subdominant substrates around the point where the logperch were observed in all three rivers consisted of small to large gravel (ranks 5 and 6, $F = 0.76$, $P = 0.47$, Figure 5). Although there were dramatic differences between rivers in embeddedness and silt characteristics (see above availability analysis) and logperch mesohabitat use, we did not detect a significant difference among rivers in the embeddedness and silt cover of substrates over which logperch were observed ($F \leq 2.1$, $P \geq 0.13$, Figure 5). Roanoke logperch were consistently observed over loosely embedded substrate with little to no silt cover (Figure 5).

Habitat use and availability data for the Roanoke, Pigg, and Nottoway rivers ordinated through PCA into two primary principal components (Table 9). The first component was loaded heavily by mean and bottom velocities, while the second component was loaded heavily by silt cover, embeddedness, and dominant substrate (Table 9). These rotated axes explain 27.5 and

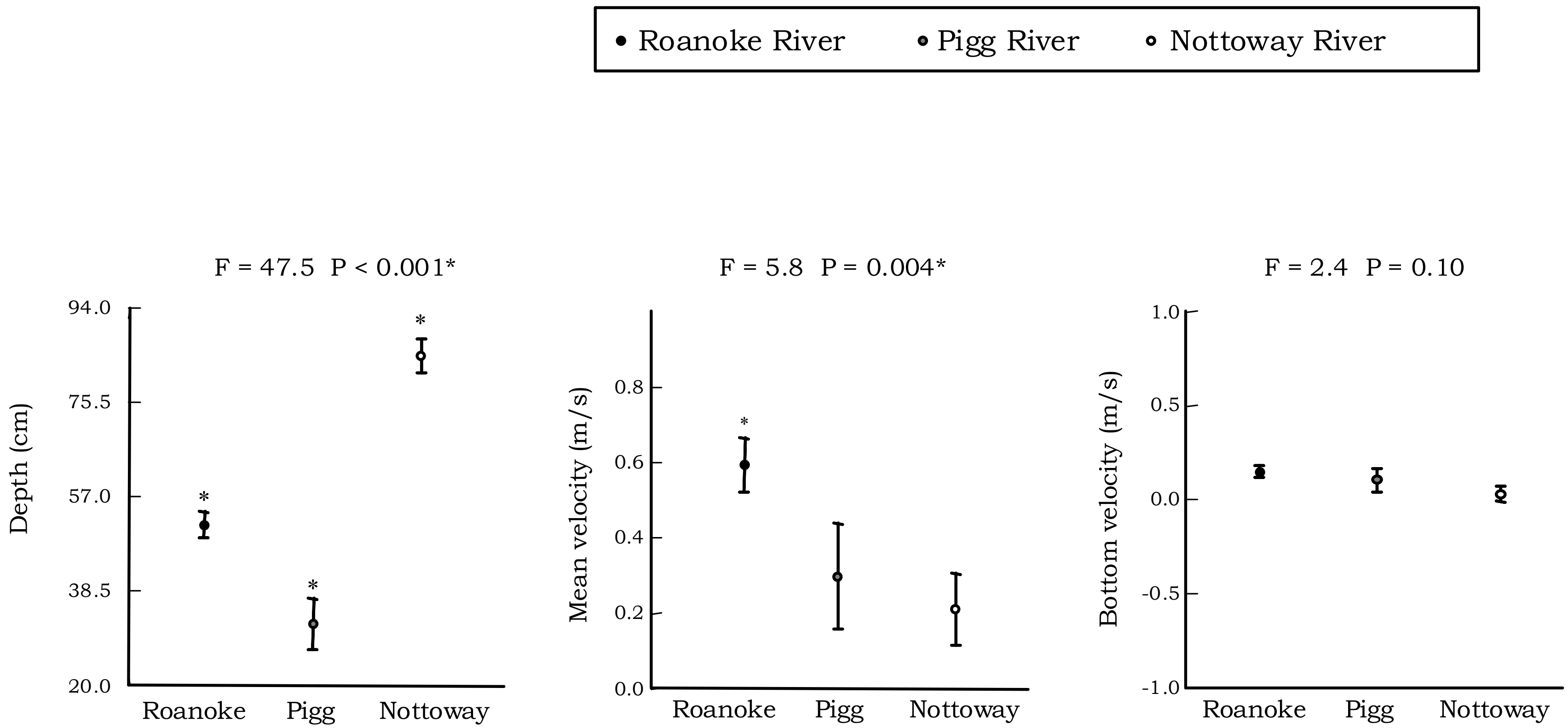


Figure 4. Mean habitat use (depth, mean velocity, and bottom velocity) of adult Roanoke logperch observed in the Roanoke, Pigg, and Nottoway Rivers. *Indicates a significant difference at the 0.05 level (ANOVA, Scheffe's multiple comparisons).

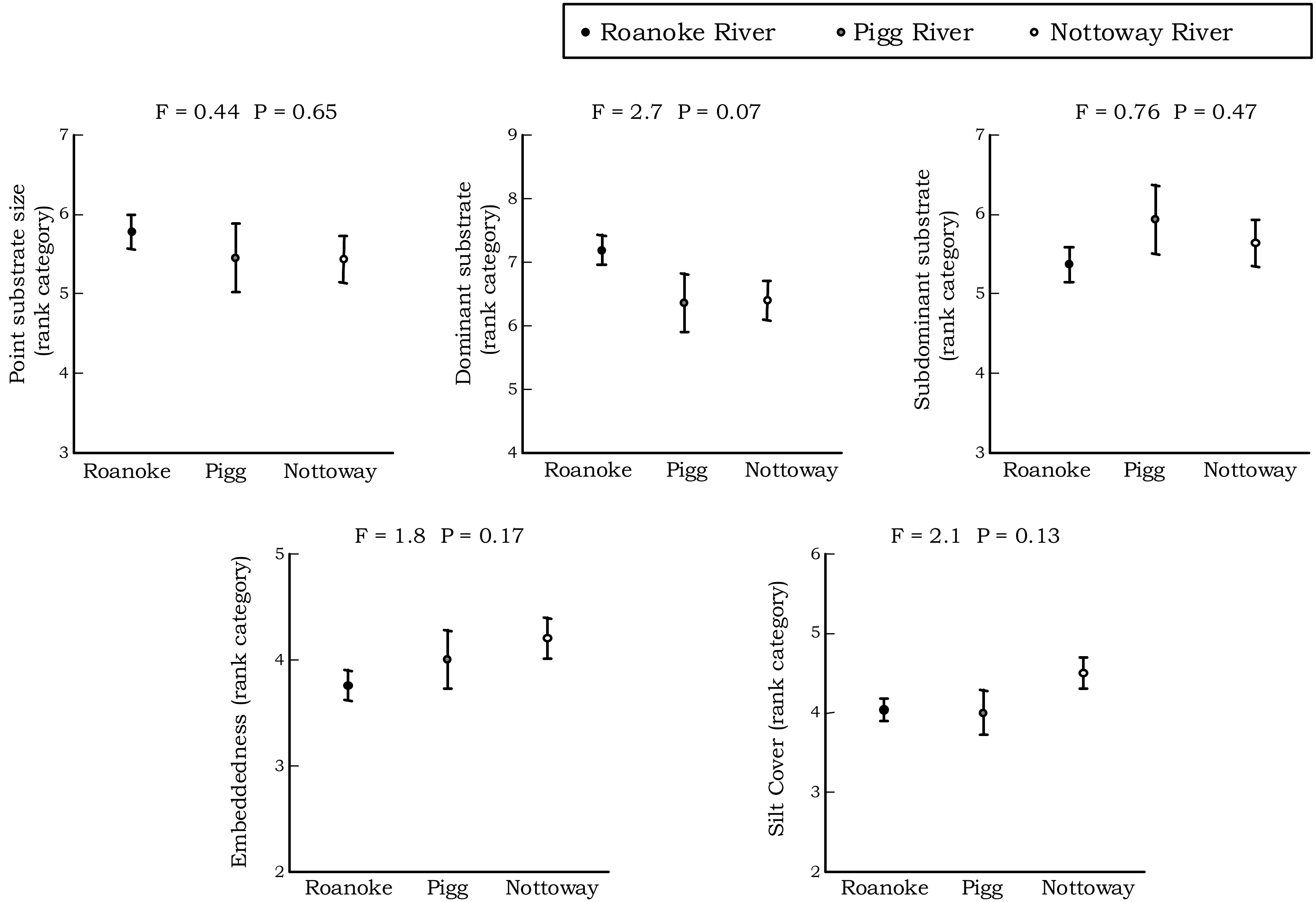


Figure 5. Mean use of substrate characteristics of adult Roanoke logperch observed in the Roanoke, Pigg, and Nottoway Rivers.

Table 9. Summary of PCA analysis of logperch habitat use and habitat availability for the Roanoke, Pigg, and Nottoway rivers (see Figure 8) and loadings of seven habitat variables on the first two principal components and percent of total variance explained by each component.

	Axis 1	**Axis 2**
Eigenvalue	2.69	1.11
% variance explained	27.5	26.7
Component Loadings:		
Bottom velocity	0.88	0.03
Mean velocity	0.85	0.19
Silt Cover	0.50	0.63
Embeddedness	0.40	0.68
Dominant Substrate	0.05	0.68
Subdominant Substrate	-0.08	0.06
Depth	-0.13	-0.32

26.7% of the variance in the data, respectively (Table 9). When factor scores for availability and habitat use locations are plotted in two-dimensional multivariate space (Figure 6), the first axis represents stagnant versus high-velocity habitat, while the second represents habitat that is silted and embedded with small substrates versus habitat that is scoured, free of silt, and dominated by larger substrates (Figure 6). Polygons represent the habitat availability for the three rivers (Figure 6).

PCA indicates strong overlap in habitat availability for all three rivers, with the Roanoke River providing the highest velocities (Figure 6). Further, PCA indicates that the Pigg River provides smaller, more embedded and silted substrate when compared to the Roanoke and Nottoway rivers. Logperch use a range of habitat configurations in each river, but avoid extremes along axes and areas with the slowest velocities and the most silted, embedded, and smallest substrates (Figure 6). Logperch locations from the three rivers along both axes overlap significantly. Logperch locations along Axis 1 indicate that logperch in the Roanoke River

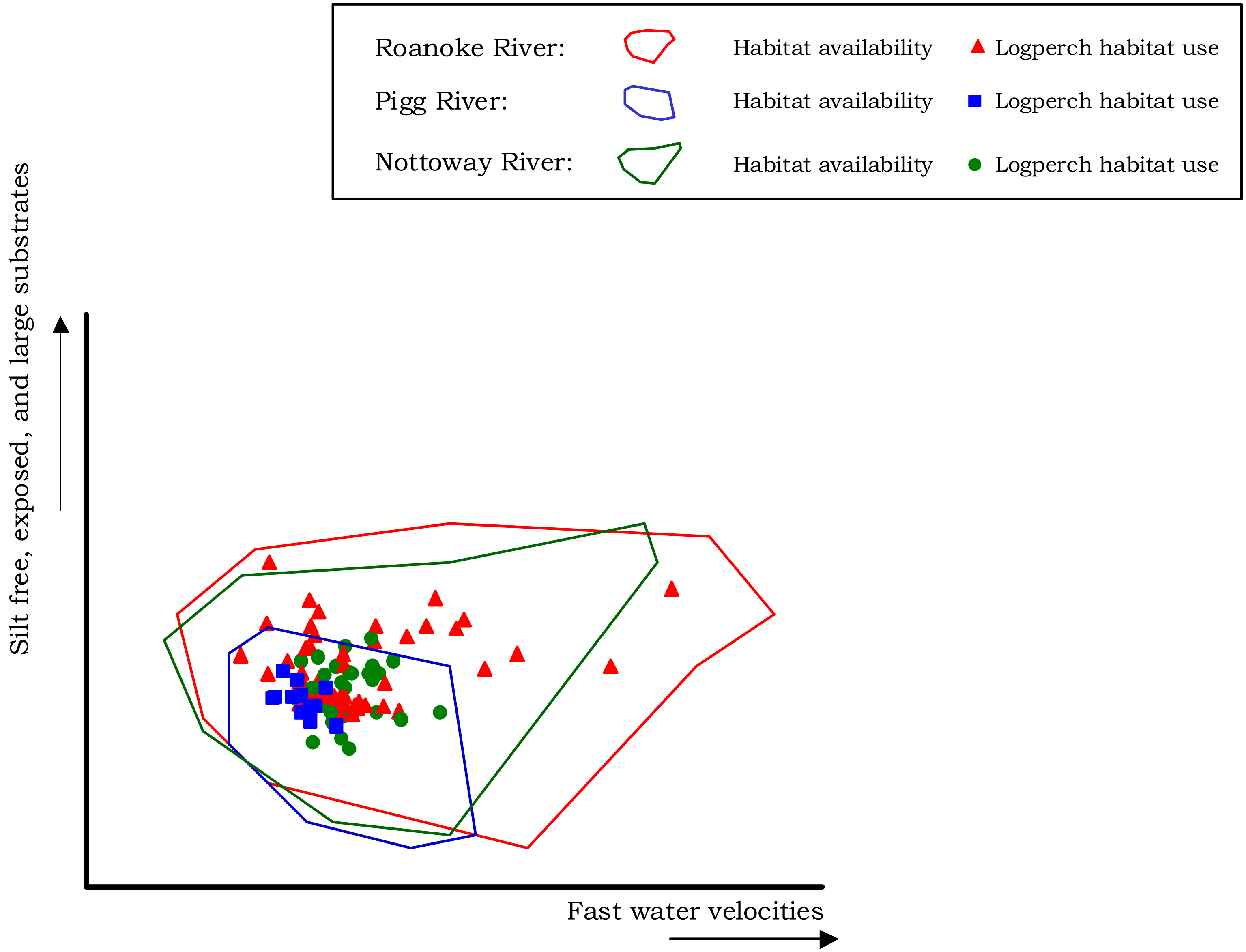


Figure 6. A graphic presentation of principal component scores for Roanoke logperch and availability habitat locations for the Roanoke, Pigg, and Nottoway rivers. The polygon in each figure circumscribes the area representing available habitat locations.

range from the slowest to the fastest water, whereas Pigg and Nottoway river logperch occupy slow to intermediate velocities. This corroborates univariate analysis, which indicates that logperch in the Roanoke River can be found in the fastest waters (Figure 4). As the univariate analysis indicates, there is a lack of distinct segregation of logperch from the three rivers on the second axis, which represents substrate characteristics. However, Roanoke logperch from the Roanoke River appear to use the widest range of substrates, taking advantage of the greater availability of exposed, large substrates in this system (Figure 6).

Multivariate habitat use by adult Roanoke logperch differed significantly among the Roanoke, Pigg, and Nottoway rivers ($F = 9.59$, Wilk's lambda = 0.29, $P < 0.001$). Further, plots of discriminant analysis scores indicate segregation among rivers in habitat use (Figure 7). The first discriminant axis is loaded primarily by depth and silt characteristics, while the second axis is most heavily loaded by velocity and embeddedness (Table 10). The canonical scores plot corroborates univariate analyses, indicating that rivers differ most markedly in logperch use of depth and velocities. However, this multivariate analysis also indicates that embeddedness and silt play a role in discriminating habitat use among systems. The Nottoway River and the Pigg River segregate most markedly along the first discriminant axis, indicating that Nottoway River logperch are in deeper and less silted habitats than logperch observed in the Pigg River (Figure 7). The Roanoke River is intermediate along this axis. As was seen with the PCA analysis, logperch in the Roanoke River appear to range into faster waters but were in habitat more embedded than in the Pigg and Nottoway rivers, which strongly overlap along the second axis.

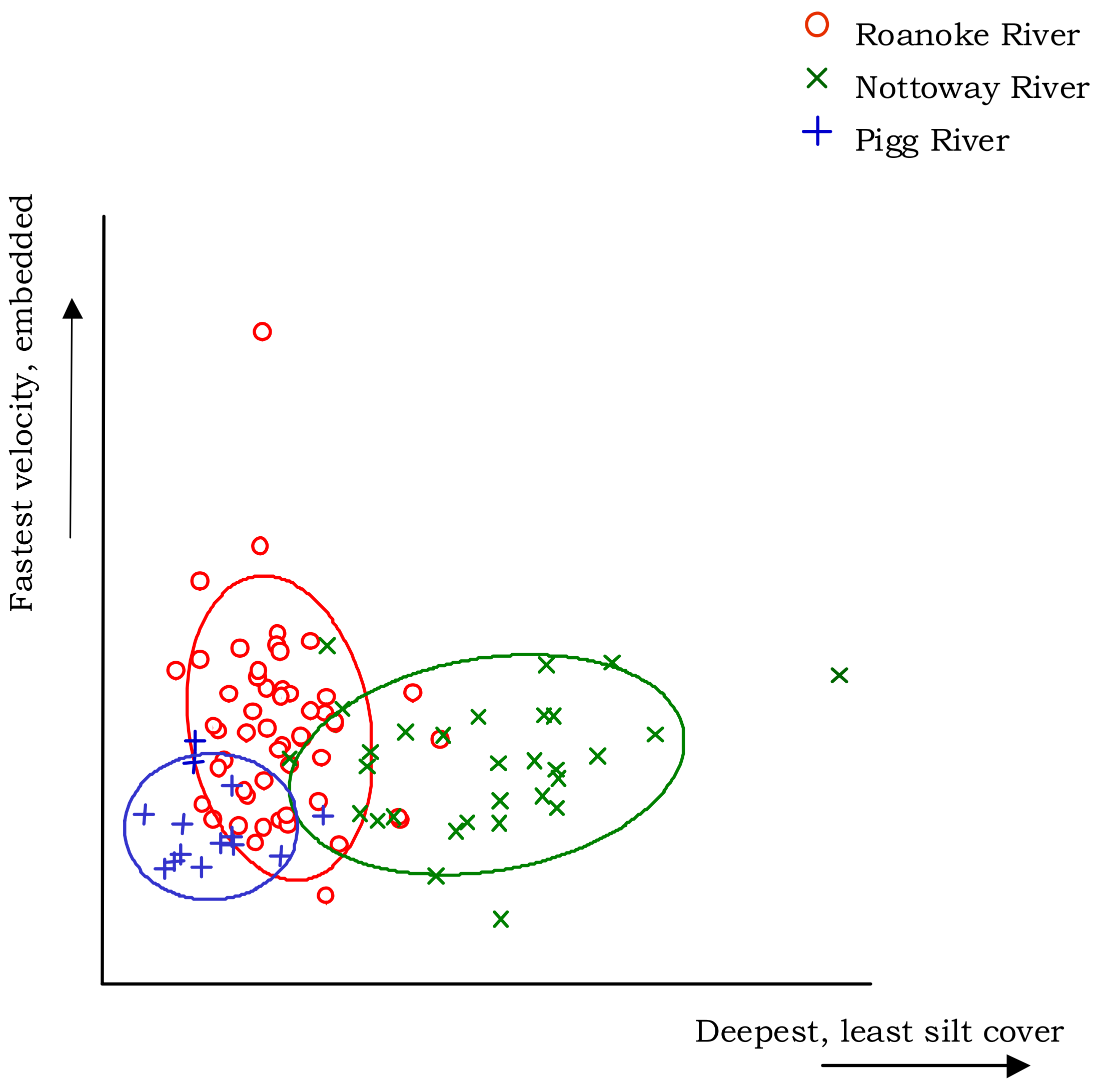


Figure 7. Discriminant analysis of habitat use by Roanoke logperch in the Roanoke, Pigg, and Nottoway rivers. Ellipses around data points are 95% confidence intervals around mean canonical scores.

Table 10. Canonical discriminant functions for discriminant analysis of logperch habitat use for the Roanoke, Pigg, and Nottoway rivers (see Figure 9).

Canonical Discriminant Functions	**1**	**2**
Depth	1.09	0.31
Bottom velocity	-0.11	0.12
Mean velocity	-0.34	0.73
Point substrate	0.05	0.16
Dominant Substrate	-0.32	0.33
Subdominant Substrate	-0.15	0.39
Embeddedness	-0.11	-0.78
Silt Cover	0.86	0.33

Discussion

Although strong overlap in habitat availability between the river systems indicate that logperch can occupy similar habitat types in the Roanoke, Pigg, and Nottoway rivers, our analyses indicate key differences as well as similarities in habitat use among logperch populations. First, logperch in the Nottoway River are found primarily in pools, while logperch in the Pigg and Roanoke rivers are found primarily in runs. Logperch in the Roanoke River occupied faster velocity habitats compared to logperch observed in the Pigg and Nottoway rivers. Logperch in both the Roanoke and Pigg rivers selected for fast water habitats. PCA indicates that the fastest-water habitats available in the Roanoke River were not available in the sites we sampled in the Pigg River. Logperch in the Nottoway River, however, did not select the fastest waters available; instead, they were observed in intermediate velocities. In addition, logperch varied in the depths of water in which they were found between systems, although logperch in all systems selected relatively deep habitats. Despite these differences, Roanoke logperch were quite consistent in their use of substrate characteristics. In each river, logperch were observed over silt-free, loosely embedded gravel substrate.

Roanoke logperch habitat use patterns and microhabitat and mesohabitat availability in the Roanoke, Pigg, and Nottoway rivers

Differences in habitat availability between the Roanoke, Pigg, and Nottoway river systems can help explain differences in habitat use patterns of Roanoke logperch among systems. The Roanoke River is the highest gradient system with the fastest water velocities and the largest substrate sizes, while the Pigg River is the smallest system with the most embedded and silted habitats. The Nottoway River is unique; it is the largest and most lowland of the three rivers, which corresponds with wide channels, a dominance of pool habitats, and smaller substrate sizes. Although agriculture and logging occur throughout the Nottoway River watershed, riparian zones are complete and soils less prone to erosion, resulting in substrate that is less embedded with silt. Further, large woody debris that is uncommon in the Roanoke and Pigg rivers is abundant in all mesohabitat types in the Nottoway River. Finally, less silted pool habitats in the Nottoway River appear to contain more insects than Roanoke River pools, including families preferred by adult and subadult logperch.

Analyses of Roanoke logperch habitat use in the Roanoke, Pigg, and Nottoway river systems indicate that habitat use is not entirely transferable between rivers; however, commonalities between systems give insight into limiting factors for Roanoke logperch. Although most descriptions of logperch habitat use thus far have been based on depth, velocity, and mesohabitat preferences, logperch are not consistent in their use of velocity and depth characteristics and their use of different mesohabitat types in the three rivers. This indicates descriptions based on these characteristics are not appropriate if we wish to transfer these habitat use patterns between systems. Despite these differences, Roanoke logperch were surprisingly consistent in their use of substrate characteristics. This consistency indicates that availability of suitable substrate is the most limiting factor for logperch, and adult logperch can occupy a variety of depths, velocities, and mesohabitats to accommodate substrate requirements. This requirement may be due to the unique feeding strategy of logperch. By flipping small rocks and debris to feed on exposed insects, logperch may rely on the availability of small, loosely embedded substrate.

The mechanism behind differential use of pools, riffles, and runs may lie with logperch substrate requirements. Habitat availability data indicate that fast velocity habitat similar to what logperch use in the Roanoke and Pigg rivers is available in the Nottoway River. Further, invertebrate abundances in Nottoway River riffles, though lower, are comparable to invertebrate abundances in Roanoke River riffles. This indicates that complete habitat use overlap is possible between the three river systems. Logperch in the Nottoway River may be avoiding energetic costs of navigating fast waters in riffles and runs, while food availability, low silt loads, and woody debris in Nottoway River pools enable logperch to thrive in these habitats. Mean values of silt and embeddedness characteristics of Nottoway River pools correspond closely with mean habitat use values of silt and embeddedness for logperch in all river systems. Silt cover and embeddedness characteristics of Pigg and Roanoke river pools fall far below conditions preferred by Roanoke logperch. Further, woody debris common in the Nottoway River can provide shelter from predators in Nottoway River pools, including smallmouth bass, largemouth bass, Roanoke bass, longnose gar, chain pickerel, and bowfin. We observed logperch flipping small gravel, bark, and sticks to search for small insects near woody debris. Woody debris can serve as substrate for invertebrates and provide food for foraging fishes (Angermeier 1985). Foraging attempts in Nottoway River pools may be more likely to be successful than in the Roanoke

River; invertebrate analyses indicate that pools in this system may have more insects important in logperch diet.

Use of low velocity habitats such as pools in the Roanoke and Pigg rivers may not be an option for Roanoke logperch because of excessive silt loads, embedded substrate, and low food availability in these depositional areas. It is unclear whether logperch in the Pigg and Roanoke Rivers would select pool habitats if they were free of silt and contained more woody debris; however, we can examine habitat use patterns of other logperch species to speculate on this possibility. *Percina burtoni*, the blotchside logperch and the closest relative to the Roanoke logperch, is frequently observed in slow run and pool habitats as well as riffles (Jenkins and Burkhead 1993). *Percina caprodes*, a widespread species of logperch also uses a variety of depths and mesohabitats, including deep river runs and reservoirs. In addition to mainstem rivers with strong current, *Percina macrolepida*, the bigscale logperch, has been observed in small impoundments and streams. This suggests that logperch are, in general, substrate specialists but mesohabitat generalists that can occupy a range of velocities and depths to find appropriate substrate for feeding. Logperch in the Pigg and Roanoke rivers may be experiencing higher energetic costs of foraging than logperch in the Nottoway Rivers because they must navigate fast water habitat to find suitable feeding substrate. Spawning habitat of most logperch species, including the blotchside logperch, is in fast-water habitat. This may explain the distribution of logperch in the Nottoway River along the fall zone where riffle and run habitat are common despite its apparent preference for pools. Logperch in the Nottoway River may require these habitats only during the spawning season.

OBJECTIVE 3: A COMPARISON OF DENSITY AND AGE STRUCTURE OF LOGPERCH POPULATIONS AMONG THE UPPER ROANOKE, PIGG, AND NOTTOWAY RIVERS

Basic information on population structure of logperch is critical to making recovery efforts effective, including information on logperch demographics such as population density, age structure, and growth. In addition, we must understand habitat requirements of this species over ontogeny to ensure conservation of critical habitats. We have separated this objective into three sections. The first section addresses adult and subadult logperch densities and the Roanoke, Pigg, and Nottoway rivers. The second section addresses growth characteristics of these logperch populations. The final and largest section addresses habitat use of Roanoke logperch over ontogeny in the Roanoke and Nottoway rivers.

Density of Roanoke logperch populations in the Roanoke, Pigg, and Nottoway rivers

Methods and Data analysis

In the summers of 2000 and 2001, we surveyed 8 sites in the Roanoke and Nottoway rivers and 6 sites in the Pigg River for Roanoke logperch using line transects (see Objective I *Summer Sampling Methods*). Ensign et al. (1995) suggest that strip transect models that assume that the probably of sighting the target species remains constant out to the limits of observer visibility are not appropriate for Roanoke logperch. Ensign et al. (1995) therefore suggest using a distance-weighted model that assumes decreased sighting probably with increasing distance of the target from the observer.

Emlen (1971) developed a model that assumes probability of detection is equal to 1 out to a certain distance, and this distance can be calculated by plotting distance of observed target species from the transect line and marking the distance at which observations sharply dropped (critical distance or D_c). The Emlen model (1971) also includes a coefficient of detectability that can be calculated based on the width of the outer boundary of visibility, the width of area in which sighting probably is equal to 1, and the number of observations sighted within those two widths. These coefficients of detectability are segregated based on visibilities. Unfortunately, reliable use of this method requires more data than were collected for this study. We use a simplified and conservative approach that plots the distance of logperch observed from the transect line and marks the distance at which observations sharply dropped. This distance (D_c) is considered the width of the strip, and only logperch observed at or less than this distance are included for density analysis. Because of our limited data set, we do not segregate D_c based on visibility, but combine adult and subadult data sets. The data do not indicate that sighting distances are different for adult and subadult logperch. Once D_c was determined for each river, densities were obtained using the following formula: Densities (#/ha) = $\{[(D_c*2)*\text{transect length}]/\#\text{ logperch observations at distance} < D_c\}*10{,}000$. Differences between rivers in adult, subadult, and combined densities were assessed with Kruskal-Wallis tests and multiple comparisons. In addition, density estimates were separated by year 2000 and 2001 for the Roanoke and Nottoway rivers to examine inter-annual variation in density estimates. Because we sampled the Pigg River in 2001 only, we could not examine inter-annual variation there.

Results

Plots of percent observations in distance categories for each river indicate a D_c of 1m for the Roanoke River, 0.60m for the Nottoway River, and 0.60m for the Pigg River (Figure 8). Adult logperch density estimates were similar between the three rivers, while subadults were most common in the Nottoway River and no subadult logperch were observed in the Pigg

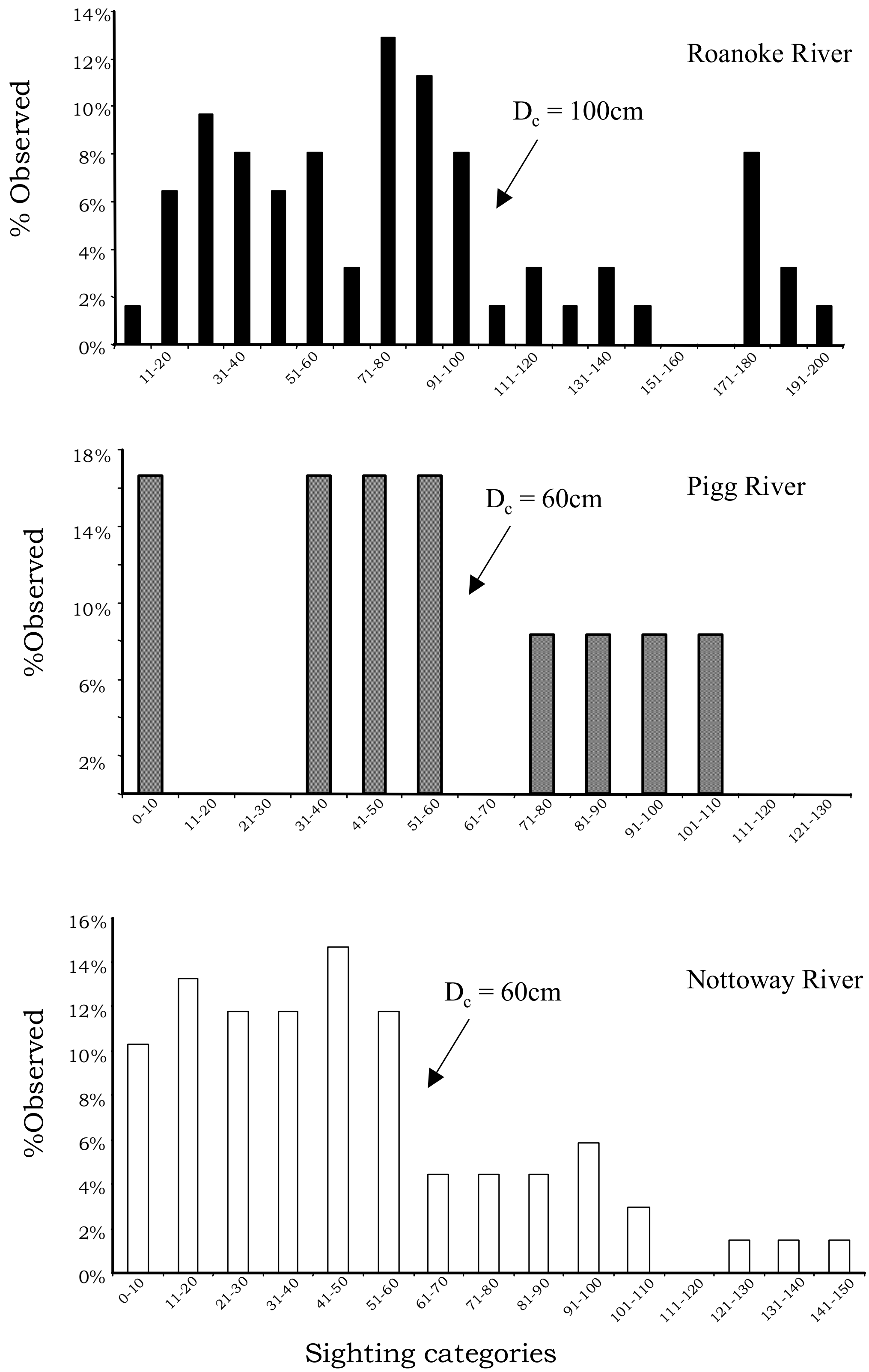


Figure 8. Sighting-distance frequency histogram for adult and subadult logperch in the Roanoke, Pigg, and Nottoway rivers, indicating critical sighting distance (D_c) used for density estimates.

River (Table 11). We were unable to detect differences between rivers in adult logperch densities ($\chi^2 = 2.4$, P = 0.39). Subadult densities, however, varied widely between river systems ($\chi^2 = 11.9$, P = 0.003); the highest subadult densities were observed in the Nottoway River (Figure 9). Only in the Nottoway River were subadult densities comparable to adult densities (Table 11). If adult and subadult logperch are combined for analysis, there is a trend of highest densities of Roanoke logperch in the Nottoway River ($\chi^2 = 5.4$, P = 0.07).

Table 11. Summer density estimates of adult and subadult Roanoke logperch in sites surveyed in the Roanoke, Pigg, and Nottoway rivers using a modified strip transect approach.

	Roanoke River		**Pigg River**		**Nottoway River**	
Sites	**adult**	**subadult**	**adult**	**subadult**	**adult**	**subadult**
1	83.3	0	325.5	0	169.3	225.7
2	66.7	0	38.6	0	92.5	123.4
3	19.8	0	31.8	0	55.6	55.6
4	337.7	168.9	31.8	0	0	0
5	32.8	32.8	0	0	47.7	310
6	59.0	0	0	0	49.2	245.8
7	0	0			42.2	168.7
8	70.7	0			44.7	89.3
Mean	83.8	25.2	71.3	0.0	62.7	152.3
Standard deviation	106.4	59.2	125.7	0.0	49.8	104.6

High variability and low sample sizes precluded statistical analysis of inter-annual variation in adult densities in the two rivers; however, we present these data to examine trends that may warrant further investigation. We also note that we did not sample the same sites in either river both years; therefore, between-site variation may be confounding our ability to assess annual variation in logperch densities. Inter-annual variation in adult density estimates follows similar trends in the Roanoke and Nottoway rivers. In both cases, density estimates were lower for 2001 than 2000 (Figure 10). We did not observe similar trends in inter-annual variation in

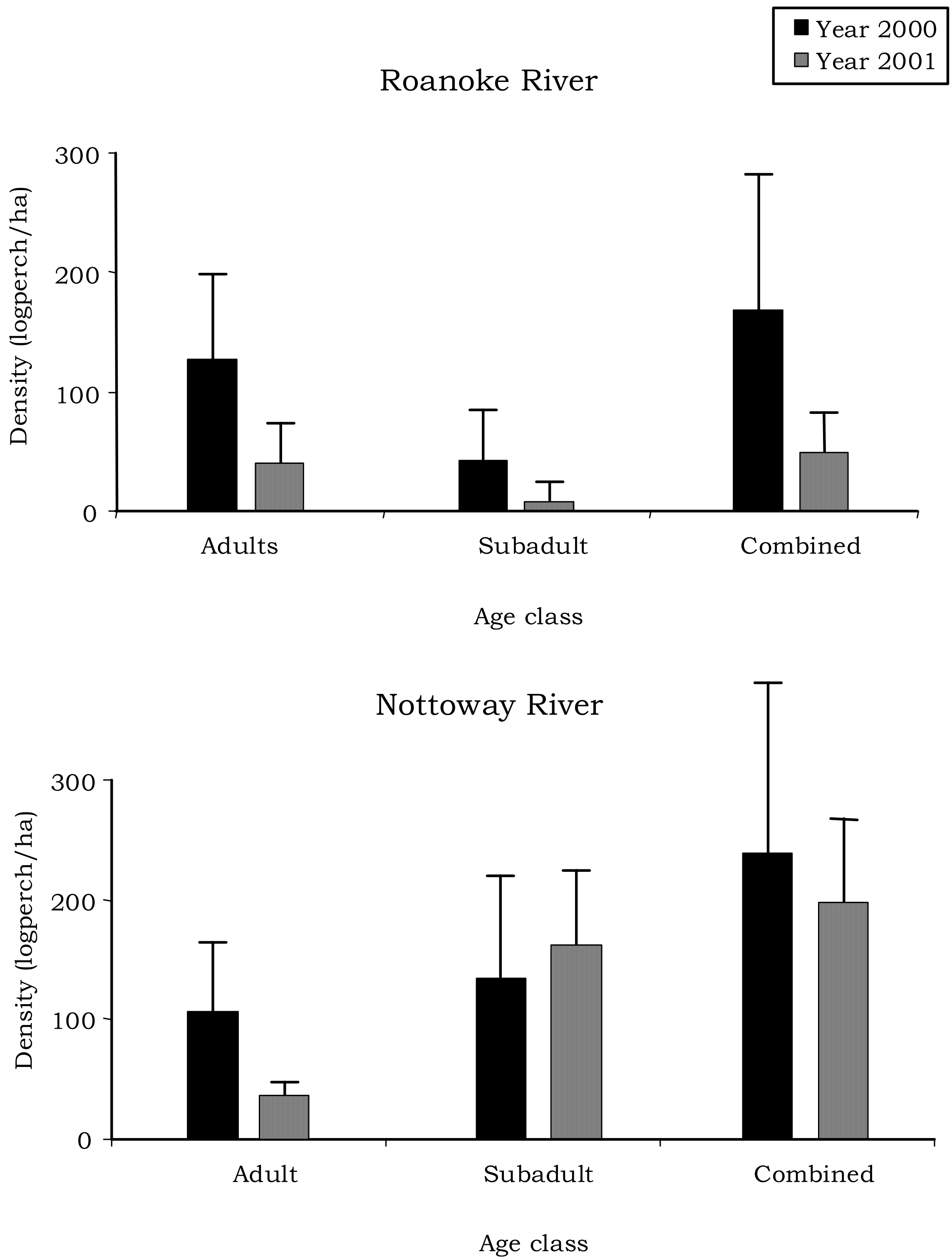


Figure 10. Inter-annual variation in estimated logperch densities for sites sampled in the Roanoke and Nottoway rivers for the years 2000 and 2001 (mean densities ± 95% C.I.).

subadult densities between the two rivers (Figure 10). Subadult densities were lower in 2001 than in 2000 in the Roanoke River, while subadult densities in the Nottoway River remained constant between years.

Discussion

Previous discussions of logperch densities in the three river systems in Virginia assert that the strongest population of Roanoke logperch can be found in the Roanoke River (Jenkins and Burkhead 1993); however, analysis and trends suggest that the population in the Nottoway River may be just as strong as the population in the Roanoke River. Greater densities of subadult logperch in this system indicate that younger life stages of Roanoke logperch compose a greater portion of the population in the Nottoway River than the Roanoke and Pigg rivers, and the Nottoway River has greater recruitment to the subadult stage. It is possible that the relatively pristine condition of and increased availability of insects in low velocity habitats in the Nottoway River, whichYOY and subadults prefer (Burkhead 1983 and this report) contribute to a stronger subadult population in this system. In addition, we consistently found subadult logperch in Nottoway River sites and between years, indicating relative stability in subadult densities. Our analysis indicates trends only. Additional studies that monitor identical sites from year to year could more definitively examine inter-annual variation in logperch densities.

Although Roanoke logperch were rare in the Pigg River system, it is encouraging that adult logperch densities at our sites are comparable to densities observed in the Roanoke and Nottoway rivers. Historical surveys for logperch in the Pigg River indicated that this river was sparsely inhabited (James 1979, Jenkins and Burkhead 1993). A chemical spill during 1975 in the middle portion of the Pigg River at Rocky Mount, Virginia caused a catastrophic fish kill that extended 36 kilometers downstream. This event likely caused a severe bottleneck in this already stressed population. Our analysis indicates that the logperch population in the Pigg River may be recovering. However, adult densities were very low in most Pigg River sites (Table 11) and we failed to observe subadult logperch. This indicates that this population, while recovering, is still sparse and at risk.

Growth of Roanoke logperch in the Roanoke, Pigg, and Nottoway Rivers

Differences in habitat use, habitat availability, and demographics among the three rivers have the potential to impact individual growth of logperch. In addition, previous study of logperch growth has been based entirely on specimens from the Roanoke River (Burkhead 1983), and little is known about growth in other populations. Demographic differences among the rivers may give insight into population health. Our objective in this section is to characterize age profiles and growth rates in Roanoke, Pigg, and Nottoway river populations and discuss results in light of habitat use and food availability in the Roanoke and Nottoway rivers. For this study, data collection, analysis, and interpretation were completed in collaboration with an undergraduate student in the Virginia Tech Department of Fisheries and Wildlife Sciences, Virginia Lintecum, as part of her undergraduate independent research project.

Methods

Logperch were captured during the summers of 2000 and 2001 using electrofishing techniques. All fish were measured at capture. Lengths ranged from 9.0 cm to 15.1 cm. Scales were collected from 48 logperch in the Roanoke River, 15 logperch in the Pigg River, and 35 logperch in the Nottoway River. Scales were taken from the same body location for each fish, directly under the anterior dorsal fin. All scales were placed on plastic slides and examined with a microprojector. At least three scales were examined for each fish. Deformed or regenerated scales were discarded. Annuli were identified and counted for each fish to determine age. Two individuals aged each fish at different times and results were compared for accuracy. Discrepancies were simultaneously re-examined until agreement was reached or the scale discarded. During age determination, measurements were made from the origin to each annulus and to the scale edge for back-calculation of growth. Scale ages were compared with ages from otoliths from three fish inadvertently killed during field sampling. Two researchers aged otoliths independently. Afterwards, the same individuals, without indication of which otolith the scales matched, independently read corresponding scales.

Growth was back-calculated from scale measurements using two methods, the direct proportion method and the Fraser-Lee method. Different trajectories for body-scale relationships have been found among populations of a single species (Pierce et al. 1996), so intercepts were estimated for each population individually before back-calculation of growth rates. The direct proportion method was chosen as the best method for back-calculating growth. While this method has more assumptions (Murphy and Willis 1996), it produced more biologically sound data (estimated length of final age classes was closer to length at capture).

Data Analysis

Length-at-age was plotted for each population. Average length for each age class was validated by comparison with previous literature. An analysis of variance with Scheffe's multiple comparisons was used to compare growth among the three rivers. Analysis of variance was also used to compare growth among year classes within each population.

Results

For all rivers, logperch length increases sharply until age 2 and then growth slows from age 3 to age 5 (Table 12, Figure 11). Lengths at age from the Roanoke River correspond closely with lengths at age reported in Burkhead (1983). Inter-annual variation in growth within each population was examined (Table 13). In the Roanoke population, there was little inter-annual variation in growth rates. Only growth from age 2 to 3 was significantly different among year classes ($F = 3.5$, $p = 0.05$, Figure 12). We were unable to detect differences in inter-annual variation of growth rates in the Pigg River. The Nottoway population showed significant differences among year classes in growth to year one and growth from age one to age two ($F = 6.6$, $p = 0.001$ and $F = 4.5$, $p=0.01$, respectively, Figure 13). Trends indicate that growth in the youngest year class is greatest compared to other year classes for the first year of growth (Figure 13). Younger year classes also seem to exhibit greater growth during year two than older year classes (Figure 13).

Table 12. Mean length at age of individuals from the Roanoke, Pigg, and Nottoway rivers based on back-calculation growth rates from scale data (Roanoke River, N = 53; Pigg River, N = 19; Nottoway River, N = 38).

Age	Roanoke River mean length (cm), SD	Pigg River mean length (cm), SD	Nottoway River mean length (cm), SD
1	7.0 ± 1.4	8.6 ± 0.8	7.5 ± 1.3
2	9.7 ± 1.5	10.6 ± 0.8	9.7 ± 1.1
3	10.8 ± 1.4	11.9 ± 0.5	11.2 ± 0.9
4	12.0 ± 1.2	13.1 ± 0.8	12.3 ± 0.8
5	12.4 ± 1.2	13.7, NA	13.1 ± 0.4

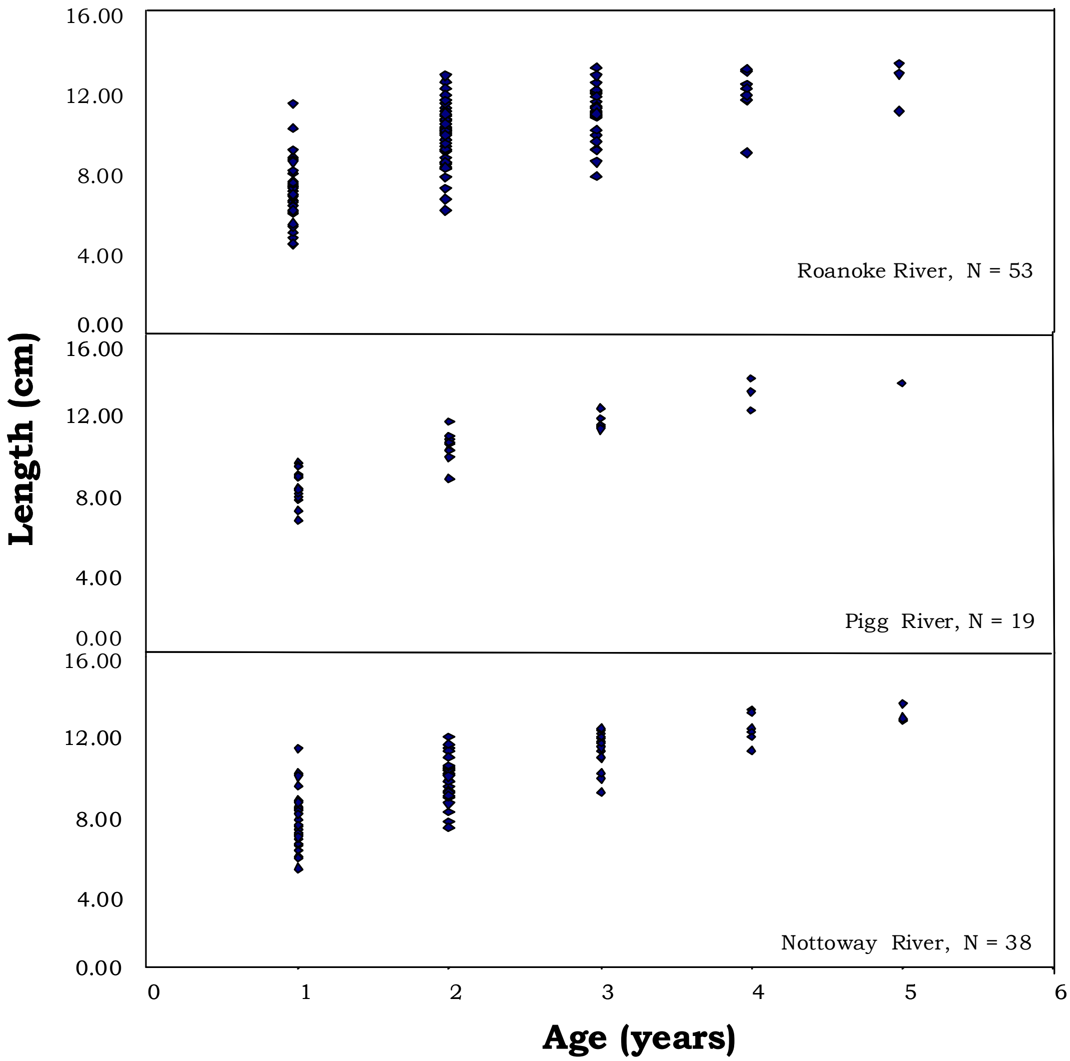


Figure 11. Length-at -age for individuals from the Roanoke, Pigg, and Nottoway rivers based on back-calculation growth rates from scales.

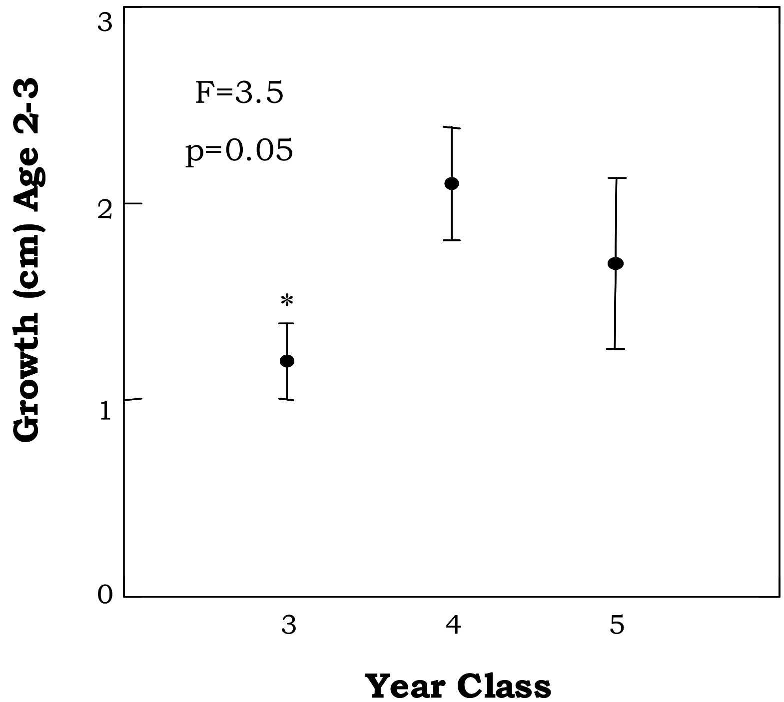
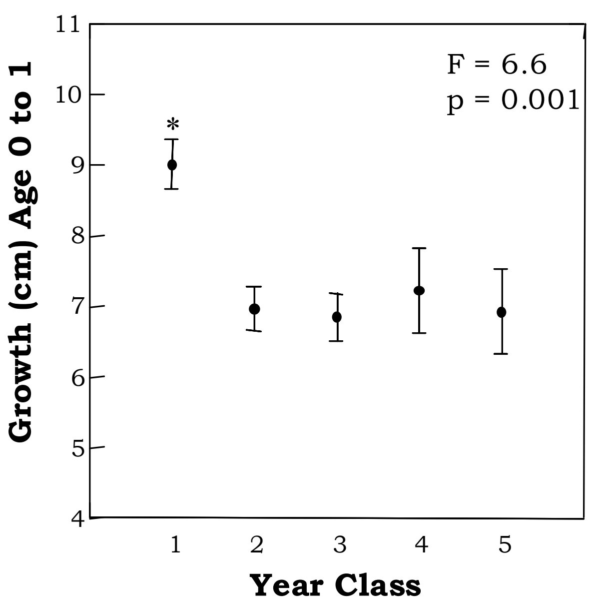


Figure 12. Inter-annual variation in growth from age 2 to age 3 in the Roanoke River population. Bars are 95% confidence intervals around mean values



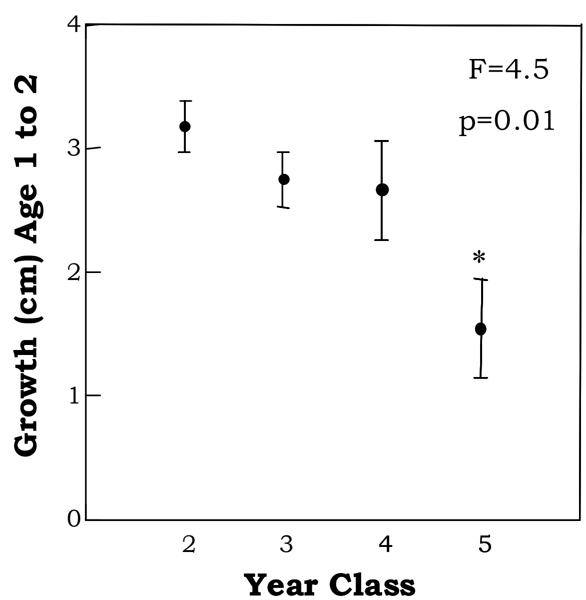


Figure 13. Inter-annula variation in growth from age 0 to age 1 and age 1 to age 2 in the Nottoway River population. Bars are 95% confidence intervals around mean values.

Table 13. Summary of ANOVA tests examining differences in annual growth among year classes for each population.

	Source	Sum of Squares	df	Mean-Square	F-ratio	P	
Roanoke River Population							
Growth to Age 1	Year Class	6.1	4	1.5	0.74	0.57	
	Error	87.8	43	2.0			
Growth to Age 2	Year Class	6.1	3	2.0	1.9	0.15	
	Error	41.1	38	1.1			
Growth to Age 3	Year Class	4.0	2	2.0	3.5	0.05	*
	Error	12.6	22	0.60			
Growth to Age 4	Year Class	0.02	1	0.02	0.03	0.88	
	Error	5.4	8	0.68			
Pigg River Population							
Growth to Age 1	Year Class	2.1	4	0.54	0.70	0.61	
	Error	8.5	11	0.77			
Growth to Age 2	Year Class	2.3	3	0.76	0.66	0.61	
	Error	6.9	6	1.2			
Growth to Age 3	Year Class	0.31	2	0.16	1.0	0.44	
	Error	0.61	4	0.15			
Nottoway River Population							
Growth to Age 1	Year Class	29.2	4	7.3	6.6	0.001	*
	Error	34.1	31	1.10			
Growth to Age 2	Year Class	6.4	3	2.1	4.5	0.01	*
	Error	11.0	23	0.48			
Growth to Age 3	Year Class	2.3	2	1.2	2.4	0.13	
	Error	6.3	13	0.48			
Growth to Age 4	Year Class	0.05	1	0.05	0.72	0.45	
	Error	0.26	4	0.07			

Growth during each year was compared among the populations (Figure 14). Growth to age one was greatest for the Pigg River population ($F=8.8$, $p<0.01$, Scheffe's multiple comparisons, Figure 14). Second year growth, however, was slowest in the Pigg River ($F=4.2$, $p=0.02$, Scheffe's multiple comparisons, Figure 14). We did not detect significant differences among the three populations during the third year of growth ($F=2.5$, $p=0.10$, Figure 14), however the trend of slower growth in the Pigg River continued. We were unable to detect differences among the populations in fourth or fifth year growth rates (F=1.5, p=0.26, and F=0.43, p=0.68, respectively, Figure 14).

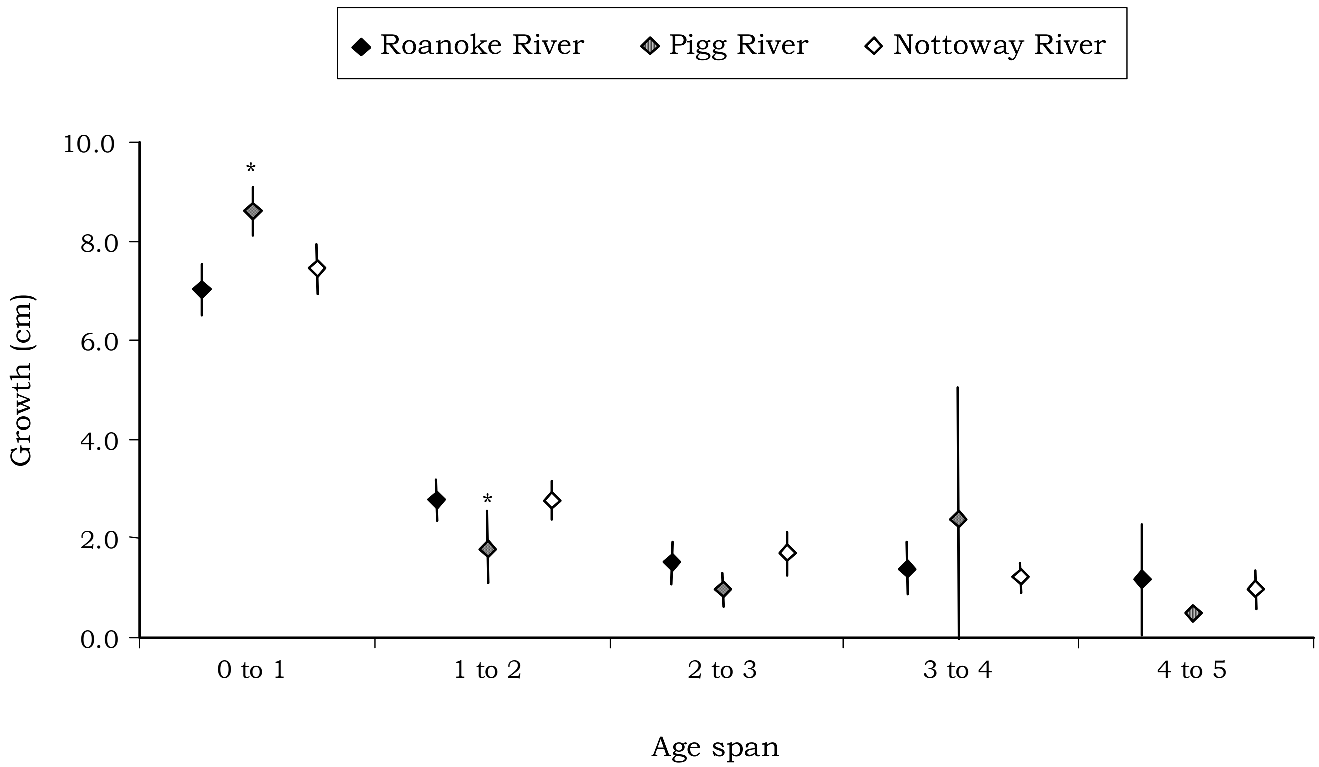


Figure 14. Annual growth from age 1 to age 5 of Roanoke logperch populations in the Roanoke, Pigg, and Nottoway rivers based on back-calculated growth rates from scales. * indicates significance at the 0.05 level (ANOVA, Scheffe multiple comparisons). Bars are 95% confidence intervals around mean values. The Pigg River growth from age 4 to 5 is based on a single specimen, therefore a confidence interval could not be calculated for this data point.

Discussion

Despite differences in habitat use and availability between the Roanoke and Nottoway rivers, logperch show almost identical growth patterns. This is surprising, considering that the Nottoway River is a lowland river with a longer growing season and comparable food availability to the Roanoke River. Logperch in the Nottoway River, however, are found primarily in pools rather than riffle habitats; it is possible that lower food availability in pools offsets the effects of the lower energetic costs of locomotion in pools and a longer growing season in the Nottoway River. Inter-annual variation in growth was not evident in the Pigg River; however, we did observe variation in the 2nd to 3rd year of growth for the Roanoke River. This is the age at first reproduction for logperch, a time where this population may be particularly vulnerable to seasonal variation in weather conditions. Younger age classes of Roanoke logperch in the Nottoway River may also be vulnerable to seasonal variation in weather conditions.

The Pigg River population is unique in its growth patterns. Growth is highest from ages 0 to 1, then drops below levels in the Roanoke and Nottoway rivers for ages 1 to 2 and 2 to 3. Young-of-the-year in the Roanoke River use backwaters and shallow habitats (see next section). The Pigg River is a medium-gradient, small river; it is possible that young individuals have more of these shallow habitats available that young stages can exploit. For Pigg River subadults and adults, habitat quality may be relatively poor, leading to depressed growth rates for these stages in comparison to the Roanoke and Nottoway rivers. Alternatively, heavy silt loads in the Pigg River may depress the quality of habitat for smaller individuals, resulting in especially strong selection for individuals that grow quickly to the next stage. Further study of the Pigg River population may reveal mechanisms behind these differences.

<u>Habitat use of Roanoke logperch over ontogeny in the Roanoke and Nottoway rivers</u>

Current understanding of logperch life history is described in Burkhead (1983) and Jenkins and Burkhead (1993) and is based exclusively on data collected in the Roanoke River. Adult logperch in the Roanoke River are typically found in deep, high velocity riffle and run habitats, while young and juveniles have been observed in slow runs and pools, where they are frequently observed over clean sand bottoms. The eggs are adhesive and demersal, and larvae are thought to drift to calm water areas after hatching (Burkhead 1983). Because standard electrofishing techniques collect very small logperch inefficiently, Burkhead (1983) observed only two young-of-year (YOY) during his two-year study. Both were observed in shallow, sandy pool margins. Outside of the Roanoke River, habitat use by logperch is largely unknown, including the population in the Nottoway River. Differences in habitat availability between these rivers may influence ontogenetic patterns of habitat use.

The purpose of this section is to further document and quantify shifts in habitat use by Roanoke logperch over ontogeny in the Roanoke and Nottoway rivers. We examine the habitat use of individuals in three size categories in the Roanoke River and two size categories in the Nottoway River to determine: 1) if age classes of logperch in the Nottoway and Roanoke rivers exhibit habitat selectivity, 2) if age classes differ in habitat use, and 3) if ontogenetic patterns of habitat use differ between the Roanoke and Nottoway river populations. We use our results to create hypotheses on what factors may regulate habitat use over Roanoke logperch ontogeny. Our comparison of habitat availability between rivers (summarized in previous section) will give insight into mechanisms that contribute to differences in habitat use. We discuss the relative importance of factors in the two river systems and use commonalities between the two rivers to form generalized hypotheses about the habitat requirements of this species. Finally, we discuss management strategies that will preserve habitat mosaics required over Roanoke logperch life history for the Roanoke and Nottoway populations.

Methods

In the summer of 1999, a reachwide inventory of 10km of the Roanoke River and 22km of the Nottoway River was conducted using the basinwide visual estimation technique described in Dolloff et al. (1993). Eight riffle-run-pool series for both the Roanoke and Nottoway rivers were systematically selected from these reachwide inventories for quantitative underwater observation of adult and subadult logperch using line transect snorkeling methods (see Objective I *Summer sampling methods* and Appendix I). Once methods were established for YOY observations, a 2-km stretch of the Roanoke River was selected for visual survey. This stretch was selected based on river access and was centrally located along the inventoried stretch of river. Due to logistic and time constraints, we did not search for YOY in the Nottoway River.

No YOY logperch (< 4cm total length; TL) were observed during snorkeling surveys. Instead, young individuals were first discovered when walking through a backwater area in the Roanoke River. To search for small logperch, 2-3 persons equipped with polarized glasses and binoculars surveyed shallow waters associated with backwaters, secondary channels, and river edges. When an individual or a school of YOY fish was observed, the surveyor identified any logperch found in that area. Markers were placed on spots that small logperch were seen foraging. Habitat use and availability data were recorded at the site where each fish was observed using a cross-shaped transect also used for winter sampling, which was centered on the logperch sighting location (Figure 1). Habitat data were taken along transect arms set at 45°, 135°, 225°, and 315° from this center sighting location. Habitat availability was measured in each transect line 1, 1.5, 2.0, and 3.0 meters from the center point. The following habitat variables were recorded: depth, mean and bottom water velocities, embeddedness and silt cover in a 10-cm^2 area, and substrate size over which the YOY was observed. Data collection for adults and subadults differed from data collection for YOY individuals primarily in its scale of measurement (habitat extent and grain). We presumed that small individuals perceive and use habitat at a smaller scale than do larger individuals. This presumption justifies comparison among data sets for a subset of the microhabitat measurements.

Data analysis

Microhabitat data included mean velocity (m/s), bottom velocity (m/s), substrate (rank category), embeddedness (rank category), silt cover (rank category), and depth (cm). Logperch were segregated into three age categories based on Burkhead (1983). Individuals < 4cm were classified as YOY. Roanoke logperch mature at two to three years (8-11.4 mm TL, Burkhead 1983); therefore individuals between 4cm and 8cm were considered subadults between the ages of 1 and 2, and adults over 8cm were considered adults between the ages of 3 and 6. G-tests with Williams' correction (Williams 1976) were used to detect habitat selection by each age class by comparison of actual habitat use with habitat use expected if logperch selected habitat in proportion to that available. Alpha values were adjusted for multiple tests using the Dunn-Sidak correction (α'=0.02). Differences among age classes for each habitat parameter were tested with Kruskal-Wallis tests for the Roanoke River and Mann-Whitney-U tests for the Nottoway River. Multivariate comparison of logperch habitat use with available habitat was examined with PCA. In addition, PCA was used to indicate marked differences among age classes in habitat use. Differences among age classes in habitat use were quantitatively examined with multivariate analysis of variance (MANOVA) and discriminant analysis.

Results

Habitat use descriptions

Adult logperch in the Roanoke River were most frequently observed in runs, occasionally in riffles, and rarely in pools (Table 14). Within habitat units, adult logperch primarily use deep, medium to high water velocities, often directly over gravel substrate in areas dominated by cobble. Subadults in the Roanoke were observed primarily in runs over moderately embedded gravel in shallower and lower velocity habitats than the adults (Table 14). Subadults were occasionally observed in riffles and pools (Table 14). Logperch less than 4cm TL, in contrast, were found in nearly stagnant areas such as backwaters and secondary channels (Table 14). These small individuals were consistently found in water around 20 cm deep with small, slightly embedded substrate. A heavy silt blanket covered these areas; however, small logperch foraged in small patches of silt-free, loosely embedded gravel (Table 14). Adult and subadult logperch in the Roanoke River did not exhibit schooling behavior, but YOY logperch were observed in mixed-species schools. These mixed schools included unidentified YOY cyprinids and *Hypentelium* spp. Small logperch occasionally separated from schools to feed, flipping small gravel. We were unable to observe if these foraging attempts were successful.

Adult and subadult logperch in the Nottoway River were observed primarily in pools and occasionally in runs. Few adults and no subadults were observed in riffle habitat (Table 14). Both adult and subadult logperch in the Nottoway River were found over sand and gravel in deep, low velocity habitats (Table 14). Although both age classes were found over relatively exposed and lightly silted habitats, the subadults were found in slightly more silted habitat with lower velocities. Unlike the Roanoke River, subadults were observed frequently in the Nottoway River (Table 11, Table 14).

Table 14. Habitat use by age classes of Roanoke logperch and available habitat in the Roanoke and Nottoway rivers, Virginia.

Roanoke River

	YOY	Subadult	Adult	Available Habitat
Fish length (cm)	< 4	4 - 8	> 8	
Mesohabitat unit types (% occurrence)				
Backwaters and secondary channels	100 %	0 %	0 %	
Pools	0 %	23 %	16%	
Runs	0%	54%	51%	
Riffles	0%	23%	32%	
Mean depth (cm), SD	19.7 ± 3.4	34.2 ± 10.6	52.5 ± 12.7	40.9 ± 36.1
Mean velocity (m/s), SD	0.02 ± 0.04	0.19 ± 0.23	0.63 ± 0.70	0.21 ± 0.38
Mean bottom velocity (m/s), SD	-0.01 ± 0.02	0.04 ± 0.11	0.16 ± 0.32	0.07 ± 0.21
Substrate (mean rank), SD	5.0 ± 0	6.0 ± 1.3	5.8 ± 1.7	6.3 ± 2.2
Embeddedness (mean rank), SD	3.8 ± 1.1	2.7 ± 0.95	3.7 ± 1.1	3.0 ± 1.4
Silt (mean rank), SD	4.0 ± 1	3.1 ± 1.3	3.9 ± 1.2	2.8 ± 1.6
N	17	13	49	

Nottoway River

	YOY	Subadult	Adult	Available Habitat
Fish length (cm)	< 4	4 - 8	> 8	
Mesohabitat unit types (% occurrence)				
Pools		60 %	69 %	
Runs		40 %	21 %	
Riffles		0 %	10 %	
Mean depth (cm), SD		81.8 ± 35.7	84.4 ± 27.8	61.5 ± 36.0
Mean velocity (m/s), SD		0.07 ± 0.09	0.20 ± 0.17	0.25 ± 0.33
Mean bottom velocity (m/s), SD		0.0 ± 0.04	0.02 ± 0.09	0.06 ± 0.13
Substrate (mean rank), SD		4.9 ± 2.3	5.1 ± 2.0	5.5 ± 2.4
Embeddedness (mean rank), SD		4.0 ± 1.2	4.2 ± 1.0	3.8 ± 1.3
Silt (mean rank), SD		3.8 ± 0.9	4.5 ± 0.07	3.9 ± 1.4
N	0	40	39	

Univariate analysis

All age classes of logperch used habitat non-randomly in both rivers. All age classes selected for depth in the Roanoke River ($G \geq 10.0$, $df = 3$, $P < 0.01$, Figure 15A). Adults selected deeper habitats, while subadults selected intermediate depths. YOY consistently selected water depths between 16 and 30 cm deep (Figure 15A). All age classes selected for mean water velocity in the Roanoke River, with individuals proportionally skewed towards higher velocities for adults ($G = 52.9$, $df = 4$, $P < 0.001$), medium velocities for subadults ($G = 20.1$, $df = 4$, $P < 0.001$), and nearly stagnant velocities for YOY ($G = 29.7$, $df = 4$, $P < 0.001$, Figure 15A). There was no apparent selection, however, for bottom water velocity by any age classes ($G \leq 7.1$, $df = 3$, $p < 0.10$, Figure 15A). Adults and subadults selected substrates ranging from sand to cobble ($G \geq 11.2$, $df = 3$, $P < 0.02$), while YOY selected smaller substrates (sand and small gravel, $G = 46.1$, $df = 3$, $P < 0.001$, Figure 15A). Adults and YOY selected for moderately embedded to exposed substrate with little silt ($G \geq 16.6$, $df = 4$, $P < 0.005$, Figure 15A). No apparent selection for embeddedness or silt categories was observed in subadults in the Roanoke River ($G \leq 10.3$, $df = 4$, $P > 0.05$), though no age classes were observed in severely embedded or heavily silted substrate (Figure 15A).

In the Nottoway River, both adult and subadult logperch selected for deep-water habitats ($G \geq 13.0$, $df = 5$, $P < 0.02$, Figure 15B). However, age classes selected different mean water velocities, with adults selecting moderate fast water ($G = 16.1$, $df = 5$, $P < 0.01$) and subadults selecting slow water ($G = 32.2$, $df = 5$, $P < 0.001$, Figure 15B). Despite these differences, both age classes selected slow bottom velocities ($G \geq 11.3$, $df = 3$, $P < 0.01$, Figure 15B). Adults selected substrate suitable for feeding (small to large gravel or cobble) and sand, the most common substrate category in the Nottoway River ($G = 10.1$, $df = 3$, $P = 0.02$, Figure 15B).

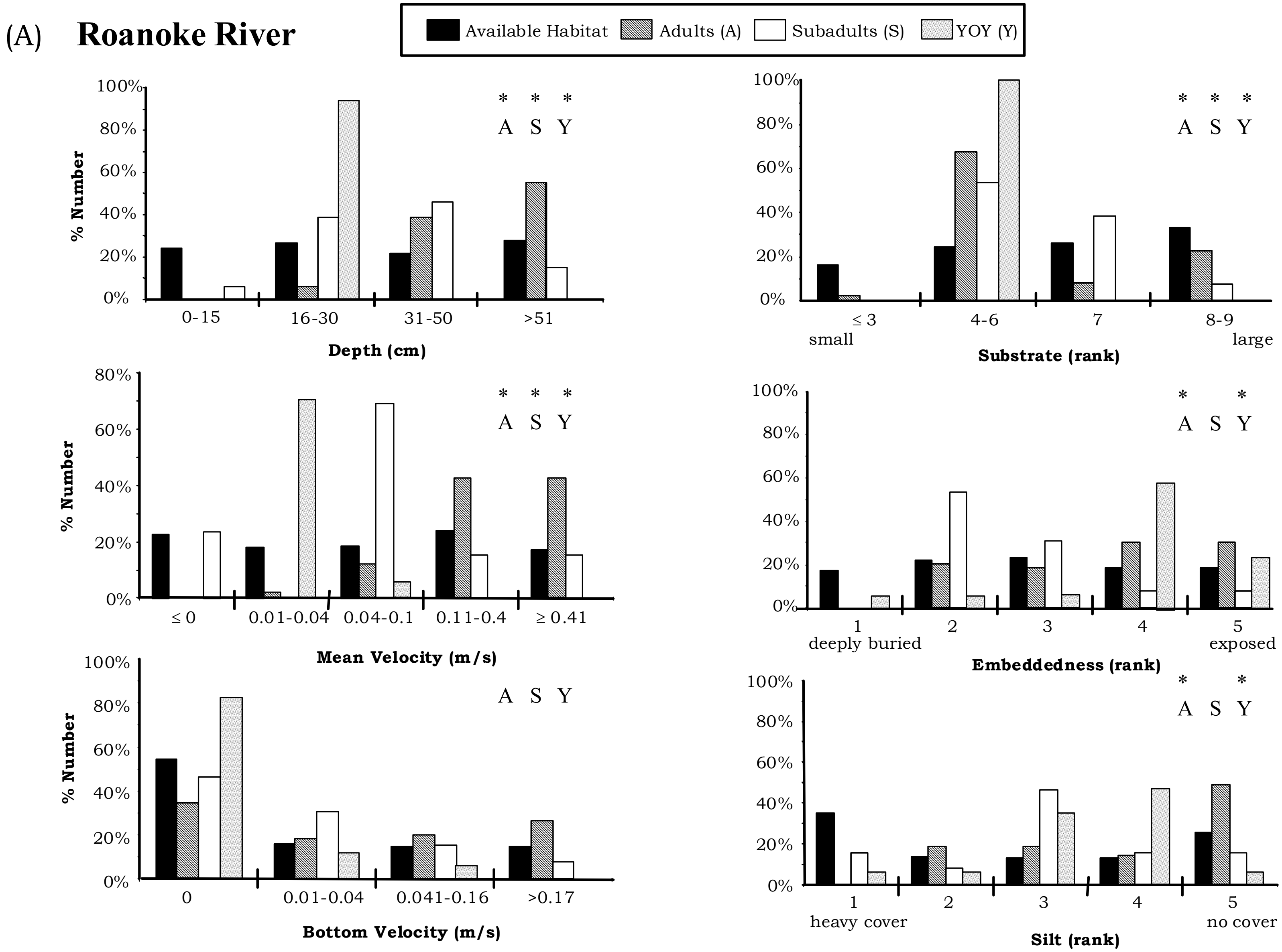
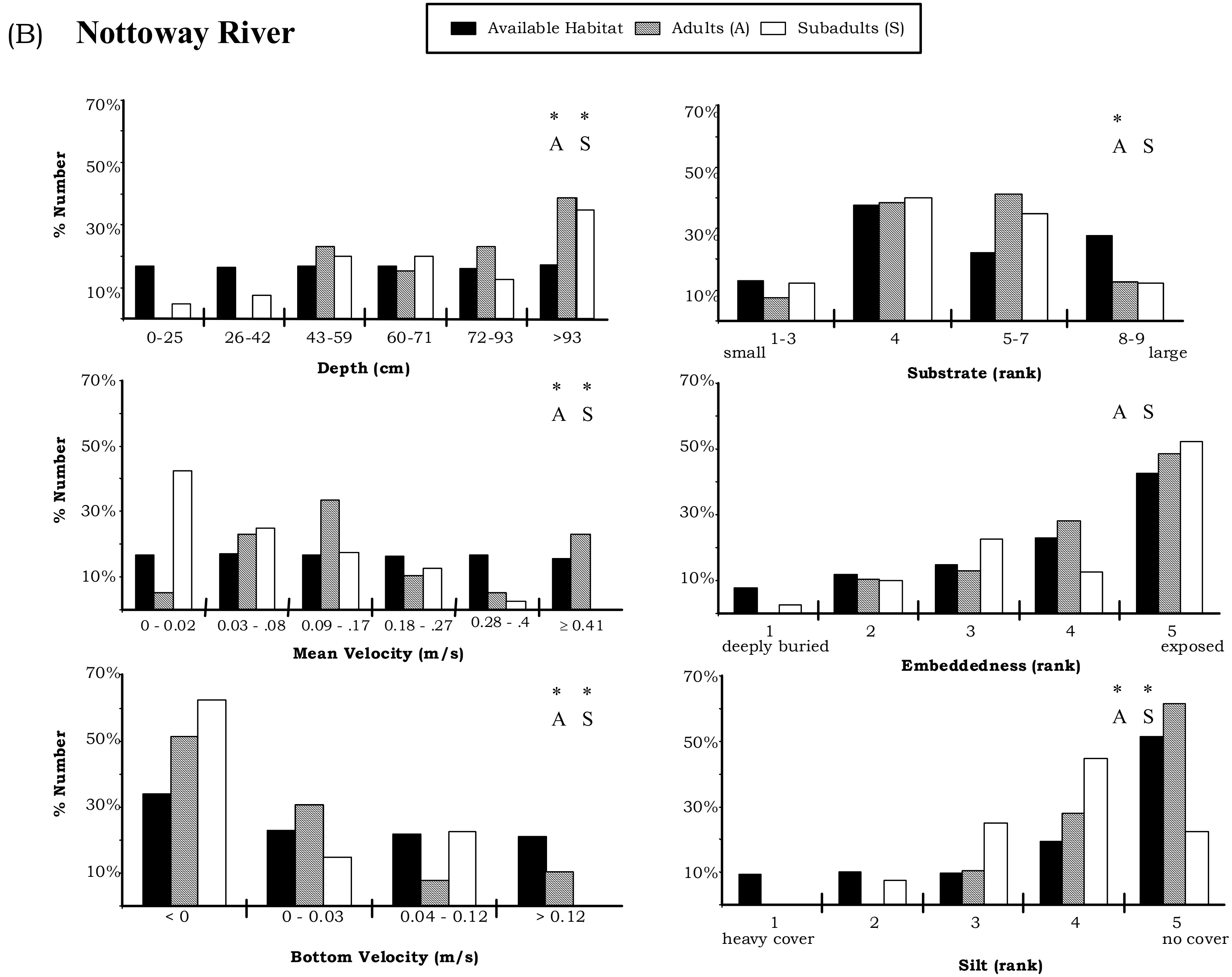


Figure 15. Proportional abundance of available habitat and proportional occurrence of observed adult, subadult and young of year logperch in habitat categories for the Roanoke River (A) and Nottoway River (B). * indicates a significant G-test at the 0.02 level (Dunn-Sidak correction for multiple tests). Significance indicates non-random selection of a habitat variable by the age class (A = adult, S = subadult, Y = young-of-year).


(B) Nottoway River
Available Habitat
Adults (A)
Subadults (S)
% Number
70%
50%
30%
10%
* *
A S
0-25
26-42
43-59
60-71
72-93
>93
Depth (cm)
*
A S
1-3
small
4
5-7
8-9
large
Substrate (rank)
* *
A S
0 - 0.02
0.03 - .08
0.09 - .17
0.18 - .27
0.28 - .4
≥ 0.41
Mean Velocity (m/s)
A S
1
deeply buried
2
3
4
5
exposed
Embeddedness (rank)
* *
A S
< 0
0 - 0.03
0.04 - 0.12
> 0.12
Bottom Velocity (m/s)
* *
A S
1
heavy cover
2
3
4
5
no cover
Silt (rank)

Subadults did not appear to select for substrate category, though individuals were frequently observed over sand and gravel ($G = 6.46$, $df = 3$, $P > 0.1$, Figure 15B). Adults and subadults were frequently observed flipping small pieces of organic debris for foraging when over sand. Adults and subadults did not appear to select for embeddedness ($G \leq 6.8$, $df = 4$, $P > 0.1$); however, both adults and subadults selected habitat with little to no silt cover ($G \geq 16.9$, $df = 4$, $P < 0.005$).

Kruskal-Wallis tests indicate that adult logperch use deeper, faster water than subadults and YOY in the Roanoke River ($\chi^2 \geq 44.7$, $df = 2$, $P < 0.001$). Roanoke River subadults were found in intermediate depths when compared to adults and YOY ($\chi^2 \geq 44.7$, $df = 2$, $P < 0.001$) and use more deeply embedded habitats ($\chi^2 = 9.8$, $df = 2$, $P = 0.008$, non-parametric multiple comparisons, $\alpha \leq 0.05$, Figure 16A). No significant differences among age classes in median habitat characteristics were observed for substrate size, silt cover, and bottom water velocity in the Roanoke River ($\chi^2 \leq 8.05$, $df = 2$, $P \geq 0.02$, Figure 16A).

Like in the Roanoke River, Nottoway River logperch adults were found in faster mean velocities than subadults ($\chi^2 = 18.3$, $P < 0.001$). In addition, adults were found in less silted habitats than subadults ($\chi^2 = 13.2$, $P < 0.001$, Figure 16B). No significant differences among age classes in median habitat characteristics were observed for depth, bottom velocity, substrate, and embeddedness in the Nottoway River ($\chi^2 \leq 0.65$, $P > 0.42$, Figure 16B).

(A) Roanoke River

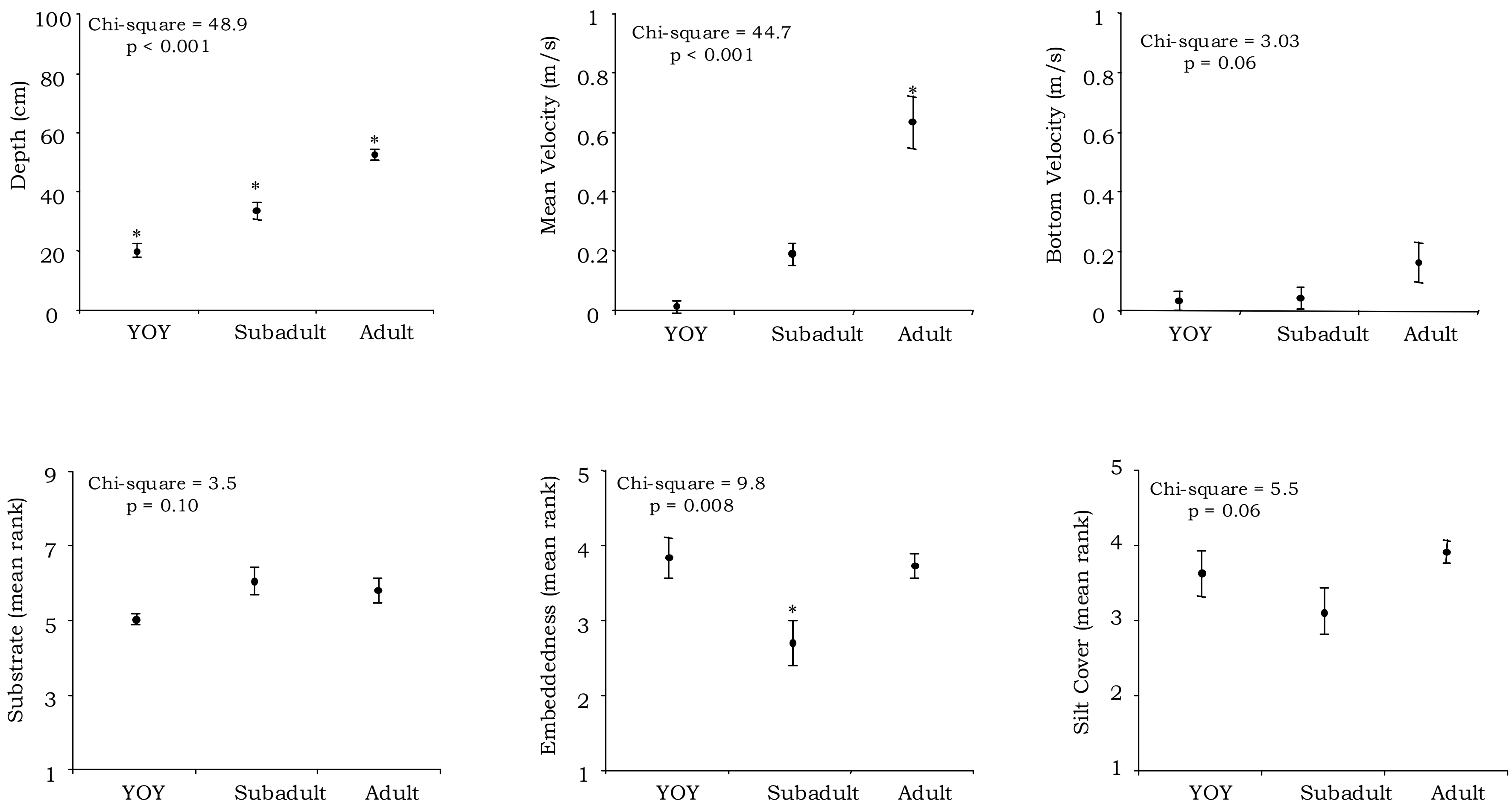
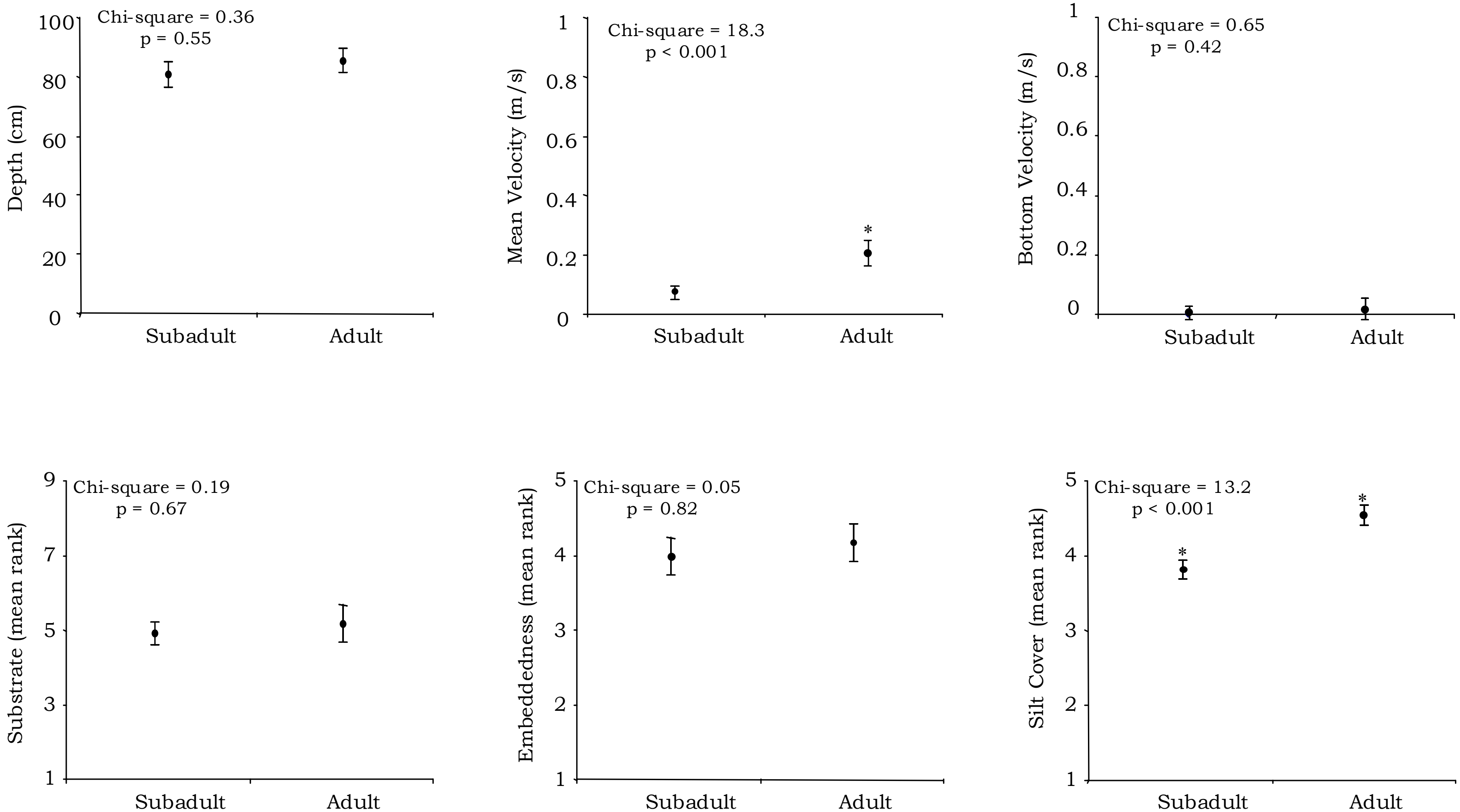


Figure 16. Mean habitat use of adult, subadult and young-of-year Roanoke logperch in the Roanoke River (A) and adult and subadult logperch in the Nottoway River (B). Error bars indicate 95% confidence interval of the mean. * indicates a significant difference in habitat use (non-parametric multiple comparisons, $\alpha = 0.05$).

(B) Nottoway River



Multivariate analysis

Habitat in the Roanoke River can be ordinated as two principal components (Table 15). The first component represented substrate and velocity, while the second component was loaded most heavily by depth (Table 15). One end of the first axis (component 1) represents stagnant, embedded habitats with small substrates, while the other end represents scoured habitats with larger substrate and high water velocities (Figure 17A). The ends of the second axis indicate shallow versus deep habitat (Figure 17A).

Table 15. Loadings of six habitat variables on the first two principal components and percent of total variance accounted for by each component for the Roanoke and Nottoway rivers.

	Principal Components			
	Roanoke River		**Nottoway River**	
	1	**2**	**1**	**2**
Eigenvalues	2.9	1.1	2.4	1.2
Habitat Variables				
Depth	-0.228	0.748	-0.399	0.230
Bottom Velocity	0.703	0.421	0.645	-0.599
Mean Velocity	0.786	0.419	0.719	-0.378
Substrate	0.615	-0.409	0.445	0.561
Embeddedness	0.808	-0.242	0.679	0.490
Silt	0.829	-0.010	0.778	0.215
% Variance	48.0	19.0	39.3	19.3

Plots of logperch locations in the Roanoke River onto two-dimensional principal component space illustrate patterns of habitat selection relative to available habitat (Figure 17A). Segregation among age classes is most marked along the second axis, representing depth characteristics. Adult logperch, however, span a greater range of velocity and substrate characteristics and occupy more scoured and fast flowing habitats than other age classes (Figure 17A). Frequency distributions of habitat availability locations along the two axes indicate that

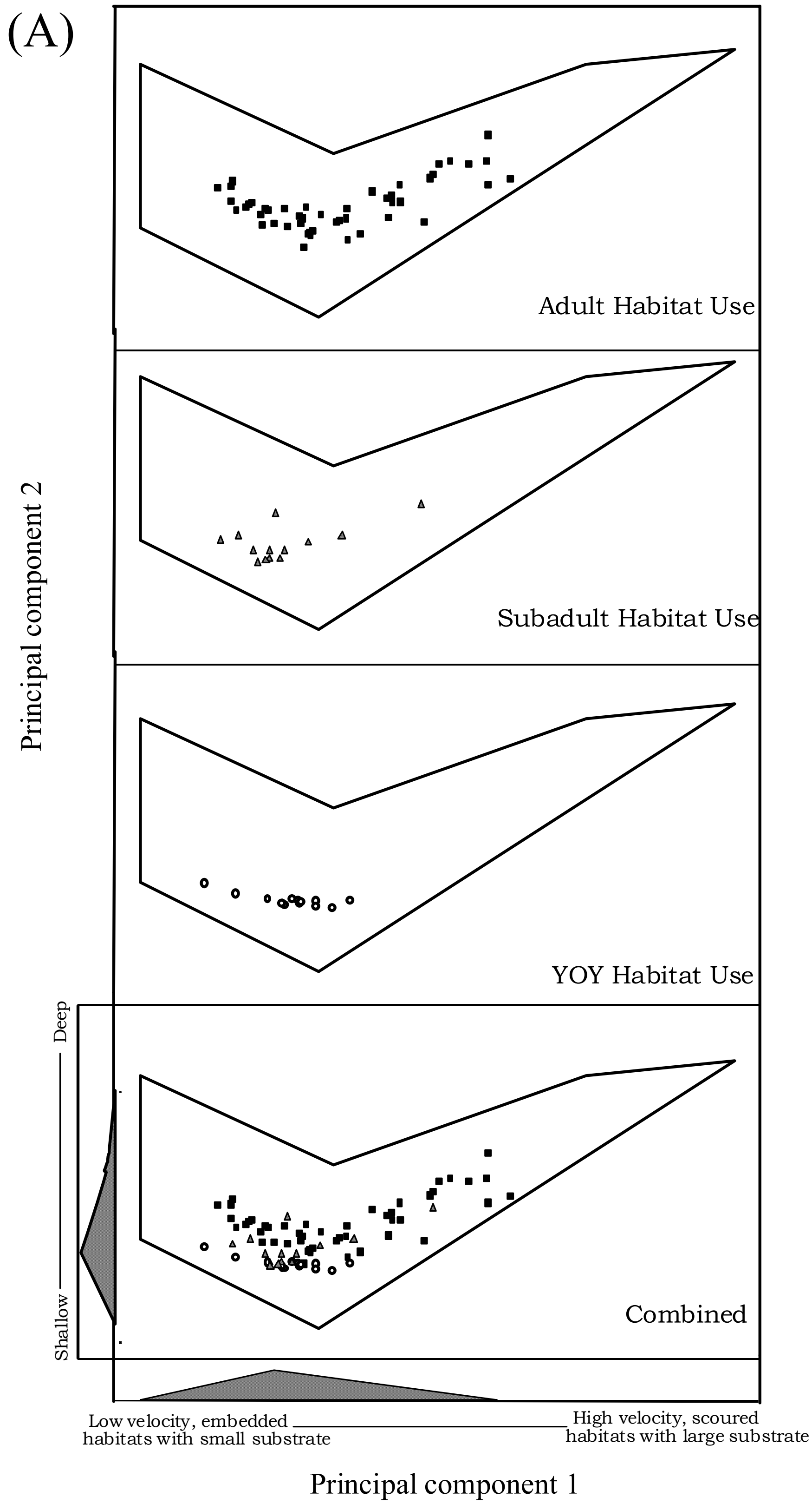
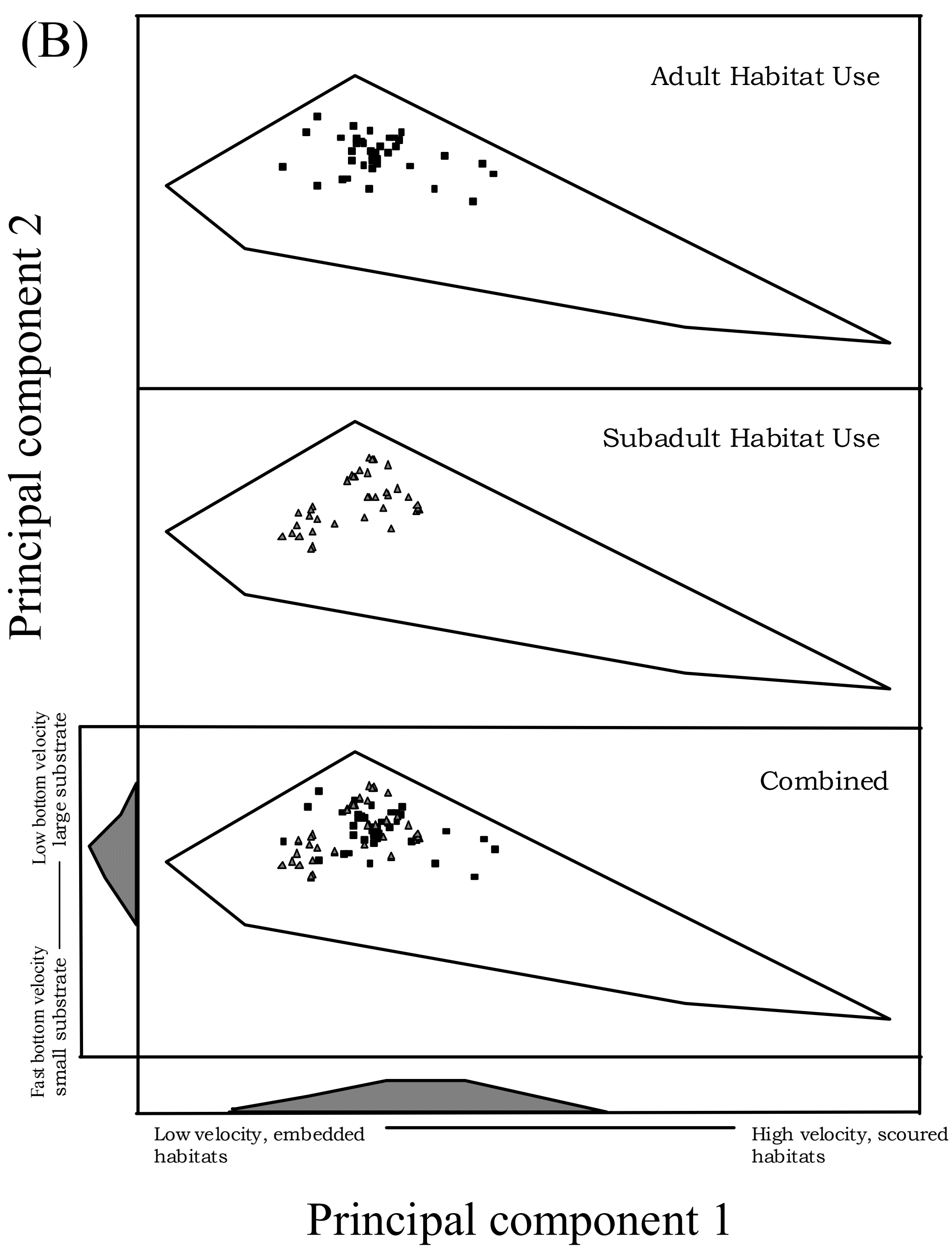


Figure 17. A graphic presentation of principal component scores for each age class of Roanoke logperch in the Roanoke River (A) and Nottoway River (B). The polygon in each figure circumscribes the area representing available habitat in sampling sites, while the area curves on axes of the bottommost graph represent the relative frequency of availability locations.


(B)
Adult Habitat Use
Subadult Habitat Use
Combined
Principal component 2
Low bottom velocity
large substrate
Fast bottom velocity
small substrate
Low velocity, embedded habitats
High velocity, scoured habitats
Principal component 1

scoured, fast flowing habitat is the rarest in sites in the Roanoke River. Although logperch were not observed in habitat extremes along the axes, all age classes combined occupy a large portion of available habitat, indicating a wide range of habitat types, both common and rare, is used by Roanoke logperch in the Roanoke River over ontogeny (Figure 17A).

PCA illustrates different patterns of ontogenetic habitat use in the Nottoway River than in the Roanoke River. Habitat use can be ordinated as two principal components (Table 15). The first component was loaded heavily by velocity characteristics, silt, and embeddedness, while the second component was loaded most heavily by bottom velocity and substrate size (Table 15). The ends of the first axis (component 1) represent stagnant, embedded habitats with silt cover versus high velocity, scoured habitats. The extremes in the second axis (component 2) represent fast bottom velocity habitats with small substrate versus slow bottom velocity habitat with large substrate (Figure 17B). Although presence of low bottom velocity and large substrate seems counter-intuitive, it follows that smaller substrates, such as sand, create a smaller bottom-velocity boundary layer than larger substrates. Adults were skewed slightly towards the high velocity, scoured extreme of axis 1 relative to subadults. However, there is considerable overlap between age classes and both tend to occur at the end of axis 1 that represents low velocity habitat (Figure 17B). As was observed in the Roanoke River, logperch did not occupy extremes along either axis (Figure 17B). Relative frequencies of habitat availability along the two principal axes indicate that logperch occupy habitat configurations that are common in the Nottoway River (Figure 17B).

Multivariate habitat use differed significantly over logperch ontogeny in the Roanoke River (Wilks' lambda = 0.26, $F = 11.5$, $df = 12$, $P < 0.001$). Further, plots of discriminant analysis scores indicate habitat segregation among logperch age classes (Figure 18). The first

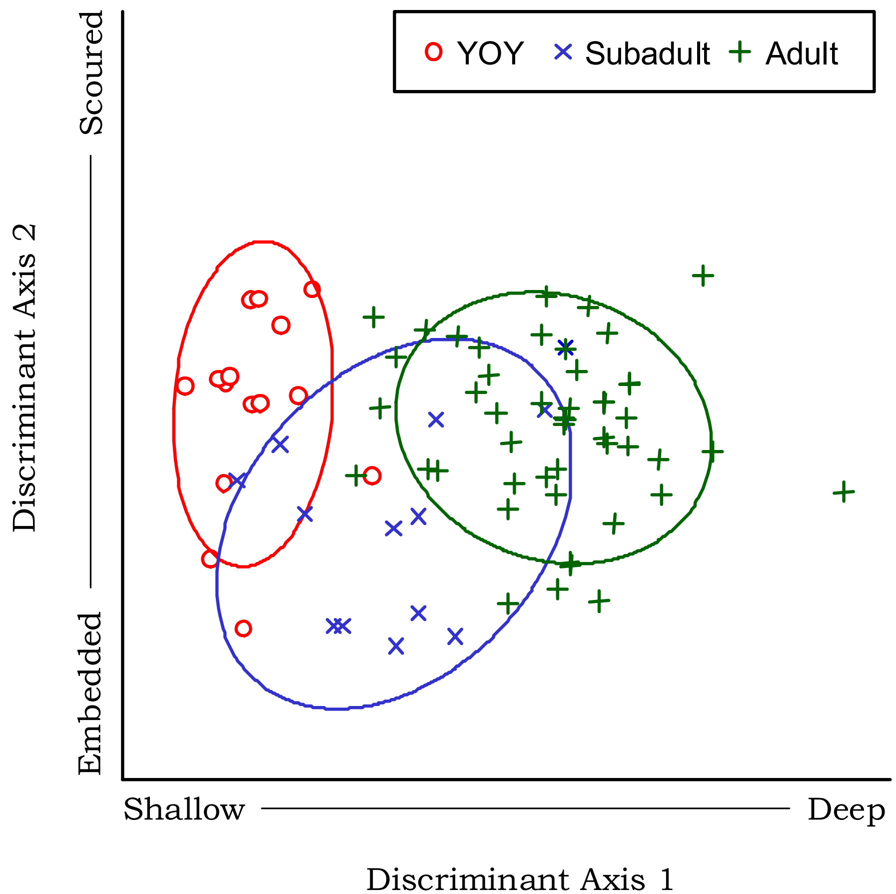


Figure 18. Discriminant analysis of habitat use by three age classes of Roanoke logperch in the Roanoke River. Ellipses around data points are 95% confidence intervals around mean canonical scores.

discriminant axis is loaded primarily by depth, while the second axis is most heavily loaded by embeddedness (Table 16). The discriminant analysis corroborates univariate analyses, indicating that age classes in the Roanoke River separate most markedly by depth, and subadult locations are more embedded than adult and YOY locations.

Table 16. Canonical functions for two discriminant axes representing multivariate habitat use by Roanoke logperch.

Habitat Variables	**Canonical Discriminant Functions** Roanoke River		Nottoway River
	Axis 1	**Axis 2**	**Axis 1**
Depth	0.987	0.174	0.434
Bottom Velocity	0.027	-0.122	-0.227
Mean Velocity	0.224	-0.174	0.818
Substrate	0.259	-0.434	0.190
Embeddedness	-0.303	1.263	-0.563
Silt	0.534	-0.338	0.759

Although subadult and adult logperch differ significantly in multivariate habitat use in the Nottoway River (Wilks' lambda = 0.67, $F = 6.0$, $P < 0.001$), differences are subtle when compared to the Roanoke River, and are confined to one discriminant axis (Figure 19). This primary axis is loaded most heavily by velocity and silt characteristics (Table 16). Again, this follows univariate analyses for the Nottoway River, with adults occupying locations with faster velocities and lower silt cover than subadults.

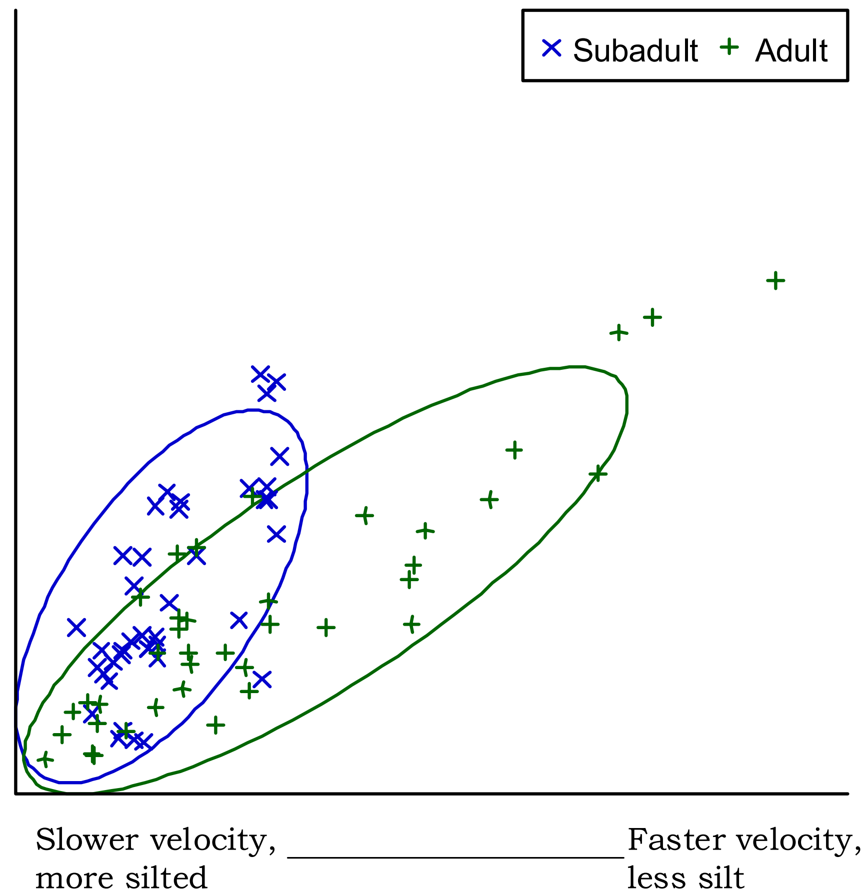


Figure 19. Discriminant analysis of habitat use of adult and subadult Roanoke logperch in the Nottoway River. Ellipses around data points are 95% confidence intervals around mean canonical scores.

Discussion

While Roanoke logperch appear to select specific habitat configurations, this species uses a wide range of habitats in the Roanoke and Nottoway rivers over ontogeny. In the Roanoke River, adult logperch select deep, high velocity riffles and runs, which provide loosely embedded substrate for feeding as well as potential spawning habitat (Burkhead 1983). Subadults in the Roanoke River, however, are found in habitats intermediate in depth, with lower velocities, greater silt loads, and moderately embedded substrate. YOY logperch are also found in low-velocity habitat, yet were not observed in the river thalweg. Instead, small individuals were found in shallow backwaters and river edges feeding over small patches of loosely embedded, silt-free gravel substrate. We also observed YOY in mixed species schools in the Roanoke River, an uncommon behavior in adult and subadult logperch.

Adult and subadult Roanoke logperch in the Nottoway River are found primarily in deep, silt-free, low velocity pools with sand and gravel substrate and occasionally in runs and riffles. Like in the Roanoke River, adult logperch in the Nottoway River were found in faster water velocities than subadults, corresponding ro slightly less silted substrate. However, ontogenetic shifts observed in the Nottoway River were less obvious than in the Roanoke River. No stratification among age classes was observed for depth or embeddedness, as was observed in the Roanoke River. In addition, multivariate analyses indicate a high degree of habitat use overlap between age classes in the Nottoway River. Potential mechanisms of ontogenetic habitat shifts within the rivers include predation pressure, feeding preferences, and swimming ability. Differences between the rivers in ontogenetic habitat use may be due to dissimilarity in habitat availability, predation pressure, and/or stressors related to human activity.

Proposed mechanisms for ontogenetic shifts in habitat use

The ontogenetic shifts in habitat that we observed in the Roanoke and Nottoway rivers may be related to a variety of factors that affect individual survival, growth, and reproductive success; constraints related to these parameters are likely to change over ontogeny (Werner and Gilliam 1984, Schlosser, 1987, 1988). Hypotheses relating habitat use to predation risk generally state that risk in shallow habitats is from non-gape-limited predators (e.g., wading or diving birds), while risk in deep habitats is mostly from gape-limited predators (e.g., piscivorous fishes; Magalhães 1993, Angermeier 1992, Schlosser 1987, 1988, Power 1984). Large predatory fish are rarely observed foraging in shallow water, potentially due to risk of aerial predation or decreased maneuverability and visibility that would lower feeding rates. Angermeier (1992) found that predation rate of rock bass (*Ambloplites rupestris*) on fantail darters (*Etheostoma flabellare*) is less in shallow habitat. In addition, Schlosser (1987) found in an artificial stream that small juvenile and adult fishes with small maximum size are constrained to shallow riffle/raceway habitat when predators are in pools, but when predators are absent, all taxa preferred structurally complex or simple pools, even at the cost of low food availability. Very small individuals are faced with the additional threat from fishes that are ordinarily not predators but will prey on larvae or YOY (Werner and Hall 1988). However, YOY are less likely to be preyed upon by wading or flying predators (Kushlan 1976).

In field conditions such as this study, it is likely that the interaction between predation and habitat is complex and dynamic. The effects of habitat characteristics on predator-prey interactions could vary not only with prey size, but the natural history and behavior of the species under investigation (Angermeier 1992). Fish have low costs of maintenance and can handle some degree of starvation for predator avoidance; therefore, predation may be more immediately important than food for habitat selection (Power 1984); however, this relationship can be dynamic because fishes can facultatively respond to changes in feeding rates and predation risk (Werner and Hall 1988).

Other habitat-related factors that may play a role in shifts over ontogeny in Roanoke logperch include competition and swimming ability. Evidence for the importance of competition in habitat associations for darter species (Percidae) has been varied, and studies have been confined to comparisons between species rather than comparisons between individuals of the same species (Greenberg 1988, Schlosser and Toth 1984). These studies indicate that the physical environment had a strong effect on the degree of competitive interaction (Greenberg 1988) and shifts in habitat use by darters are more likely related to fluctuations in habitat availability rather than species interactions (Schlosser and Toth 1984). Finally, body size has been directly related to the ability of fishes to hold station under high water velocities (Mann and Bass 1997), with larger individuals having greater swimming abilities than small individuals. This phenomenon has been observed in juveniles of fantail darters in the Roanoke River (Matthews 1985).

These findings may be helpful for considering mechanisms accounting for ontogenetic habitat preferences of Roanoke logperch in the Roanoke River. For adult logperch, deep, fast riffle and run habitats may be silt-free refugia from aquatic predators and provide suitable feeding and spawning substrate. The depth and turbulence of these riffles may provide additional cover from wading or flying predators. Subadult logperch, however, may be unable to exploit these high velocity areas due to limited swimming ability. Shallow habitats may provide refugia from fish predators and slow water velocities; however, subadults in the Roanoke River were not observed in backwaters or channel edges, but rather in runs and riffles of intermediate depth and velocity, corresponding to greater substrate embeddedness. A slight shift into shallower waters may be a defense against predation; however, complicating this mechanism of depth stratification of logperch is the distribution of heavily silted substrate in the Roanoke River. Habitats with slow water velocities (i.e. pools) are covered with a heavy blanket of silt. Deep pools, in particular, are heavily embedded. Aquatic predators such as rock bass and smallmouth bass also inhabit these areas; therefore, it is difficult to separate the effects of predation from the effects of heavy silt on depth and velocity preferences of subadult Roanoke logperch. A controlled experiment on logperch depth preferences with and without the presence of aquatic predators would be useful for exploring this mechanism.

YOY logperch in the Roanoke River may find refugia from large, gape-limited predators in backwaters and unit edges and, due to their small size, are unlikely targets of wading predators (Kushlan 1976). The schooling behavior of young logperch in these shallow areas indicates risk of aquatic predation, even in shallow waters. On one occasion, a redbreast sunfish (*Lepomis auritus*) was observed pursuing a school of YOY in a backwater area. Shifts from shallow to deep water over ontogeny have been observed in other stream fishes (Magnan and Fitzgerald 1984). Nursery habitat is commonly described as shallow, off-channel habitat without velocities that would limit swimming abilities of small individuals and offer shelter from large aquatic predators (Copp 1991, 1997; Leslie and Timmins 1991; Scheidegger and Bain 1995; Baras and Nindaba 1999; Bell et al. 2001; Gadomski et al. 2001).

Roanoke logperch in the Nottoway River showed different ontogenetic patterns of habitat use than what was observed in the Roanoke River. No segregation in depth or embeddedness characteristics was observed; however, like in the Roanoke River, adult and subadult logperch in the Nottoway River segregated by velocity. This supports the notion that subadult logperch have less ability than adults to navigate successfully in fast moving water. This preference corresponded to a slight increase in silt cover for subadult logperch in the Nottoway River; however, cover was low for both age classes. The lack of segregation along depth and embeddedness gradients in the Nottoway River, as was seen in the Roanoke River, indicate that different mechanisms are at work in the two rivers. Further, ontogenetic shifts observed in the Nottoway River were subtler than in the Roanoke River. Discriminant analysis, though significant, indicates a high degree of habitat use overlap between age classes. Correlations between habitat variables and the presence/ absence or abundance of a species do not warrant causality conclusions; however, comparison among rivers may offer some insight into mechanisms contributing to the habitat use patterns of Roanoke logperch. Differences between the rivers in ontogenetic habitat use may be due to a variety of factors, including differences in population densities, predation pressure, habitat availability, and severity of human impacts.

Comparison between the two rivers indicates that size segregation as a result of competition is an unlikely mechanism. Subadult logperch were found at greater densities in the Nottoway River than in the Roanoke River (see previous section). If competition between adults and subadults led to the stratification observed in the Roanoke River, it would follow that ontogenetic shifts would be more apparent in the Nottoway River, yet this was not so. The Nottoway River also has a greater diversity of aquatic predators (e.g., longnose gar, bowfin, American eel, and Roanoke bass in addition to largemouth and smallmouth basses); however, both adult and subadult logperch used deep pool habitats inhabited by these predators. The relative importance of predatory risk in the two systems may differ, accounting for differences in pool use; however, the relative density of predators in the two systems is unknown. In addition, individuals found in deep pools in the Nottoway River were often observed near large woody debris, which may serve as cover from these predators and as a source of food (Angermeier 1985). Woody debris is much less common in the Roanoke River (see previous sections) and rarely available in pools. The lack of cover and foraging opportunities afforded by woody debris in Roanoke River pools may render them unsuitable for logperch.

Although our proposed explanations of habitat use remain speculative, comparison between the two rivers reveals generalities about Roanoke logperch habitat use over life history. Habitat that is free of heavy siltation and contains moderately to loosely embedded substrate is preferentially used in the two systems. Subadults in both rivers were found in slower velocity habitats than adults, indicating that water velocity may be an important limitation for this life stage. The Nottoway River sites sampled in this study are in relatively pristine condition, and pools without heavy silt loads are common. It is possible that logperch prefer low velocity, deeper habitats without silt, but that type of habitat is rare in the Roanoke River. Roanoke logperch in the Roanoke River inhabit a range of habitat types from rare to relatively common (Figure 17A). Adults, in particular, seem capable of exploiting rare habitat that is deep, fast moving, and free of silt. In contrast, Roanoke logperch in the Nottoway River occupy habitat that is common and widespread, and habitat overlap between the two age classes is extensive. This indicates a potential habitat bottleneck in the Roanoke River for subadult logperch, which may require low-velocity habitat; subadults may be forced into microhabitats with embedded substrate suboptimal for foraging. This hypothesis is supported by evidence that subadult logperch are less common in the Roanoke River than in the Nottoway River.

<u>Conservation and management implications</u>

Typically, protection of species has been based a single life stage, usually the adult stage, ignoring potential for spatial variation in demographic processes over multiple scales. Each size class of Roanoke logperch selected particular habitat configurations, yet the species uses a wide range of habitats over ontogeny. Successful conservation of this species will involve the preservation of the ecological processes that maintain the connected habitat mosaics required over logperch life history. The distribution of habitat types and pathways of dispersal will be critical for completion of the logperch life cycle, and habitat heterogeneity at multiple scales will contribute to its continued persistence in the Nottoway and Roanoke rivers (e.g. formation of mesohabitat types such as backwaters, pools, riffles, and runs as well as microhabitats with large substrate, silt-free microhabitat, and intermediate water velocities).

Streamflow strongly influences the geomorphology and chemistry of streams and rivers, thus limiting the distribution and abundance of stream fishes and determining the ecological integrity of the system (Poff et al. 1997). Environmental dynamism as seen under natural streamflow conditions is now considered essential for sustaining and conserving native species. Variation in flow magnitude, frequency, duration, timing, and rate of change can destroy and create habitat patches required by stream fishes over their life cycle. Natural flow regimes favor native inhabitants that have evolved under these conditions and can exploit a variety of habitats created and maintained by hydrologic variability (Poff et al. 1997). Flow regulation has been linked to declines in larval fish in nursery habitats, particularly margins and backwaters that are largely ignored in studies of adults (Scheidegger and Bain 1995). Human modifications of channel morphology can reduce habitat diversity and the gradual sloping shoreline, thereby increasing the area of unsuitable habitat with velocities greater than YOY swimming speeds (Copp 1991, 1997; Scheidegger and Bain 1995; Mann and Bass 1997; Mérigoux and Ponton 1999; Meng and Matern 2001).

Our understanding of Roanoke logperch microhabitat use indicates that loosely embedded sediment free of heavy silt cover is critical for this endangered species. Management programs that enhance the natural streamflow of the Nottoway and Roanoke rivers should include protection of the streambank from agricultural and construction practices that contribute silt loads. Scouring flow during natural flood events should also enhance habitat through removal of small sediments, particularly in backwaters that are rarely exposed to scouring water velocities. Historic and ongoing floodplain development, especially in the Roanoke River, can threaten logperch habitat, particularly backwaters and shorelines that appear to be important for YOY logperch. However, it seems evident that a natural flow regime will not be sufficient to provide needed habitats if sediment loading remains or becomes elevated in systems occupied by logperch. Evidence that Roanoke logperch requires a low-silt, complex habitat mosaic over multiple spatial scales indicates that reach-specific management approaches will not ensure the recovery and persistence of this species in the Roanoke and Nottoway Rivers. We instead recommend a watershed-level approach that addresses sediment loading and preserves natural flow regimes that provide ephemeral, seasonal, and persistent types of habitat required over logperch ontogeny.

Objective 4: Logperch movement

A major gap in our knowledge of Roanoke logperch is the lack of information on movements by individual fish. This information is crucial to understanding habitat needs, and to understanding the implications of local extincition for regional persistence of logperch. Recovery of logperch populations after catastrophic fish kills indicate that this species is capable of long-distance movements that contribute to recolonizations (Ensign et al. 1997), indicating that dispersal behavior may play an important (but unexamined) role in population persistence.

More information regarding which ages are better dispersers and where they disperse would greatly improve our understanding of logperch population dynamics.

Methods

A fluorescent elastomer implant that is specifically designed for marking fishes that may be too small to tag by traditional methods (Northwest Marine Technology, Inc) was selected for mark-recapture studies to investigate movement of *Percina rex*. We experimented with different combinations of colors and marking positions on *Percina caprodes* from the New River. Twenty-one *P. caprodes* individuals were marked July 1, 1998 and held in a Living Stream aquarium in Cheatham Hall at Virginia Tech until September, 1999. Mark retention in these experimental fish was high (> 95%). In addition, no mortality was observed in these specimens. Sixteen appropriate and distinguishable body locations for tagging were identified; by using two of these locations per individual, we were able to tag logperch as individuals. Because our study on the habitat use of Roanoke logperch used snorkeling methods (see above sections), we did not capture logperch for tagging purposes. Instead, logperch captured during monitoring for the Roanoke River Flood Reduction project for the Army Corps of Engineers (Ensign and Angermeier 1994) in the summer and fall of 1998 were marked with elastomer tags. A new technique for marking, photonic tagging, (New West Technologies, Inc.) was used for the same body locations in the summer and fall of 1999 and 2000. Low recapture success rates for these years indicated that mark retention is not as high using this method; therefore, we returned to elastomer tags for the summer and fall of 2001.

Results

A total of 347 logperch were marked in the summers and falls of 1998-2001. Of these, only 13 individuals were recaptured despite multiple resampling of marking sites. The maximum movement distance detected was 45m (Table 17). One hundred five logperch were marked with elastomer tagging between 7/9/1998 and 10/7/1998; of these, 8 were recaptured (Table 17). None of these individuals moved a distance greater than 30m (Table 17). In the summer and fall (6/22/99-10/14/99) of 1999, 92 individuals were marked with photonic tags. None of these individuals have been recaptured. In 2000, between 7/10/00 and 10/30/00, we marked 67 logperch with photonic tags, and only 2 of these were recaptured. Both of these individuals moved 45m (Table 17). Our low recapture rate for 1999 and 2000 indicates that mark retention for photonic tags may be lower than elastomer tags. Therefore, in the summer and fall of 2001, we marked 83 logperch with elastomer tags. Of these, two were recaptured after moving 0 and 30m, respectively.

Table 17. Summary of recaptured Roanoke logperch individuals marked during monitoring for the Roanoke River Flood Reduction Project.

Date marked	Recapture date	TL when marked	TL when recaptured	Site	Color	Mark 1	Mark 2	Method	Distance moved
7/10/1998	9/23/1999	116	127	CR2	Orange	LAA	LPA	elastomer	30
7/28/1998	7/18/2000	124	133	RR6	Blue	LAA	LBL	elastomer	30
9/7/1998	10/6/1999	111	120	CR3	Green	LAA	LBL	elastomer	0
9/14/1998	7/24/1999	116	109	RR4	Yellow	LAA	LBL	elastomer	15
9/14/1998	7/24/1999	136	138	RR4	Yellow	LAA	LBR	elastomer	30
9/24/1998	6/29/1999	119	126	RR3	Orange	LMA	RABL	elastomer	0
9/30/1998	9/23/1999	112	127	CR2	Orange	RPA	LMCP	elastomer	15
10/2/1998	7/22/1999	128	125	RR1	Yellow	LAA	LMA	elastomer	15
7/11/2000	10/18/2000	117	119	CR4	Orange	RBR	LBR	photonic	45
7/12/2000	10/30/2000	135	136	RR2	Orange	RBR	RAA	photonic	45
8/7/2001	10/17/2001	135	135	CR2	Red	LMA	LPCP	elastomer	0
8/15/2001	10/8/2001	135	135	RR5	Red	RMCP	LMCP	elastomer	30

Discussion

We were unable to detect any long-distance movement by Roanoke logperch during this study. However, our recapture design is inherently biased towards short-distance movements. The sites where logperch densities are monitored for the Roanoke River Flood Reduction Project are separated by several river kilometers, and we did not search for marked individuals outside of these sites. Thus, marked logperch leaving the sites have very low probability of recapture. Although the recaptured fish moved only short distances, the low recapture rates indicate that most logperch regularly move beyond the study site boundaries. A study design that uses more extensive recapture sites would be needed to provide more precise information regarding the distribution of logperch movement-distances.

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APPENDIX I

Portions of topographic maps indicating sites sampled on the Roanoke, Pigg, and Nottoway rivers, moving from the most upstream sites to the most downstream sites for each river. Each map contains information about the sites, including:

Length sampled -	The length of the transect line stretched along the pool-riffle-run sequence at the site
Water quality parameters -	pH, Temperature (Temp °C), Dissolved Oxygen (mg/L), and Conductivity (µS)
Species observed -	Species noted during snorkeling surveys. We could not identify all *Notropis*, *Moxostoma*, *Nocomis*, and YOY individuals to species during the snorkeling surveys.

Map Quadrangles (Scale 1:24000; 7.5-minute series):

Roanoke River:
- Map 1 - Elliston
- Map 2 - Elliston
- Map 3 - Elliston
- Map 4 - Elliston
- Map 5 - Glenvar
- Map 6 - Elliston
- Map 7 - Elliston

Pigg River:
- Map 8 - Gladehill
- Map 9 - Gladehill
- Map 10 - Redwood
- Map 11 - Gladehill
- Map 12 - Penhook
- Map 13 - Penhook

Nottoway River:
- Map 14 - McKenney
- Map 15 - McKenney
- Map 16 - McKenney
- Map 17 - McKenney
- Map 18 - Cherry Hill
- Map 19 - Purdy
- Map 20 - Purdy
- Map 21 - Purdy

Roanoke River

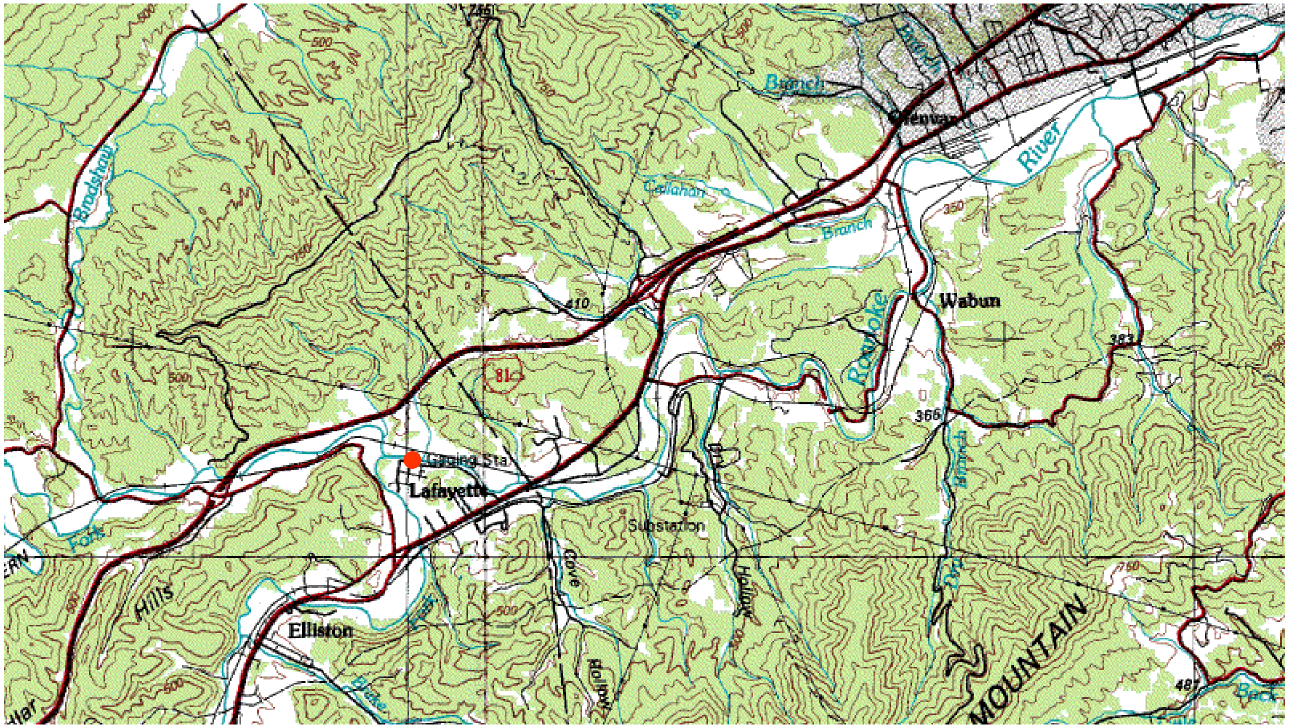
Map 1

- RRH-5/30/00

Length sampled: 75m
pH: 8.3
Temp: 16.6
Dissolved Oxygen: 8.15 mg/L
Conductivity: 353.1 µS

Species observed

Hypentelium nigricans
Campostoma anomalum
Catostomus commersoni
Cyprinus carpio
Notropis sp.
Luxilus albeolus
Micropterus salmoides
Nocomis raneyi
Percina rex
Micropterus dolomieu
Percina roanoka
Scartomyzon cervinus
Lythrurus ardens
Nocomis leptocephalus
Moxostoma sp.



Roanoke River

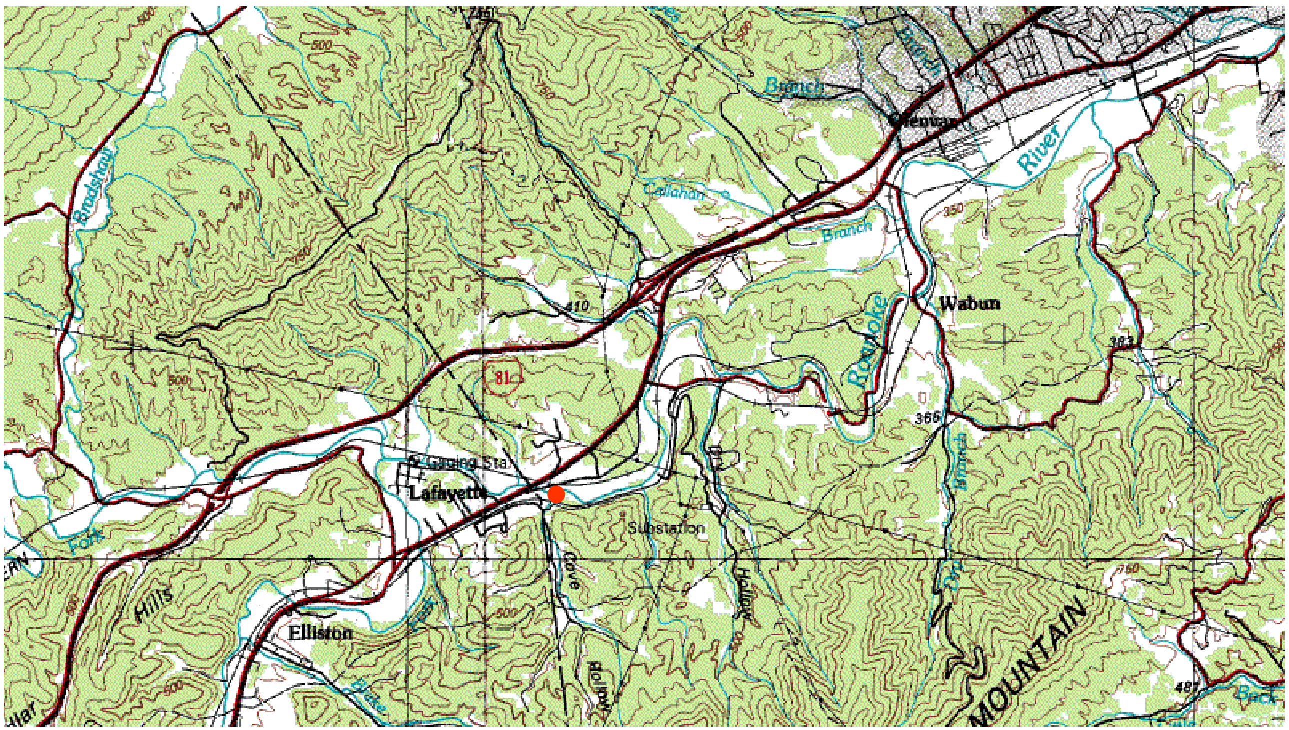
Map 2

Species observed

Etheostoma podostemone
Luxilus albeolus
Percina roanoka
Percina rex
Etheostoma nigrum
Luxilus cerasinus
Nocomis sp.
Hypentelium nigricans
Scartomyzon ariommum
Micropterus dolomieu
Moxostoma sp.

- RRH-6/1/00

Length sampled: 63m
pH: 8.2
Temp: 19.5
Dissolved Oxygen: 9.14 mg/L
Conductivity: 327.2 µS



Roanoke River

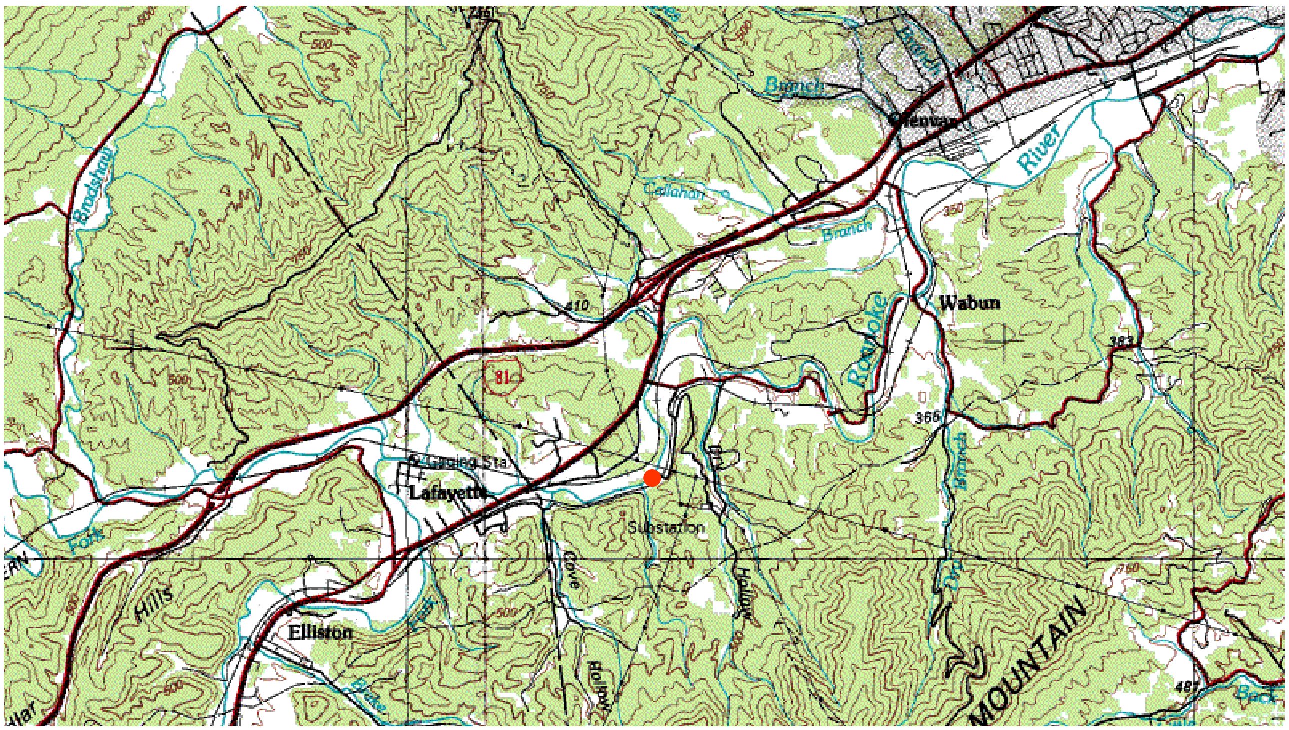
Map 3

● RRH-6/27/00

Length sampled: 90.5
pH: 8.3
Temp: 23.6
Dissolved Oxygen: 8.68 mg/L
Conductivity: 398.8 µS

Species observed

Luxilus albeolus
Percina roanoka
Percina rex
Nocomis sp.
Etheostoma podostemone
Cyprinella analostana
Percina navisense
Lepomis auritus
Micropterus dolomieu
Lythrurus ardens
Scartomyzon cervinus
Etheostoma nigrum
Hypentelium nigricans



Roanoke River

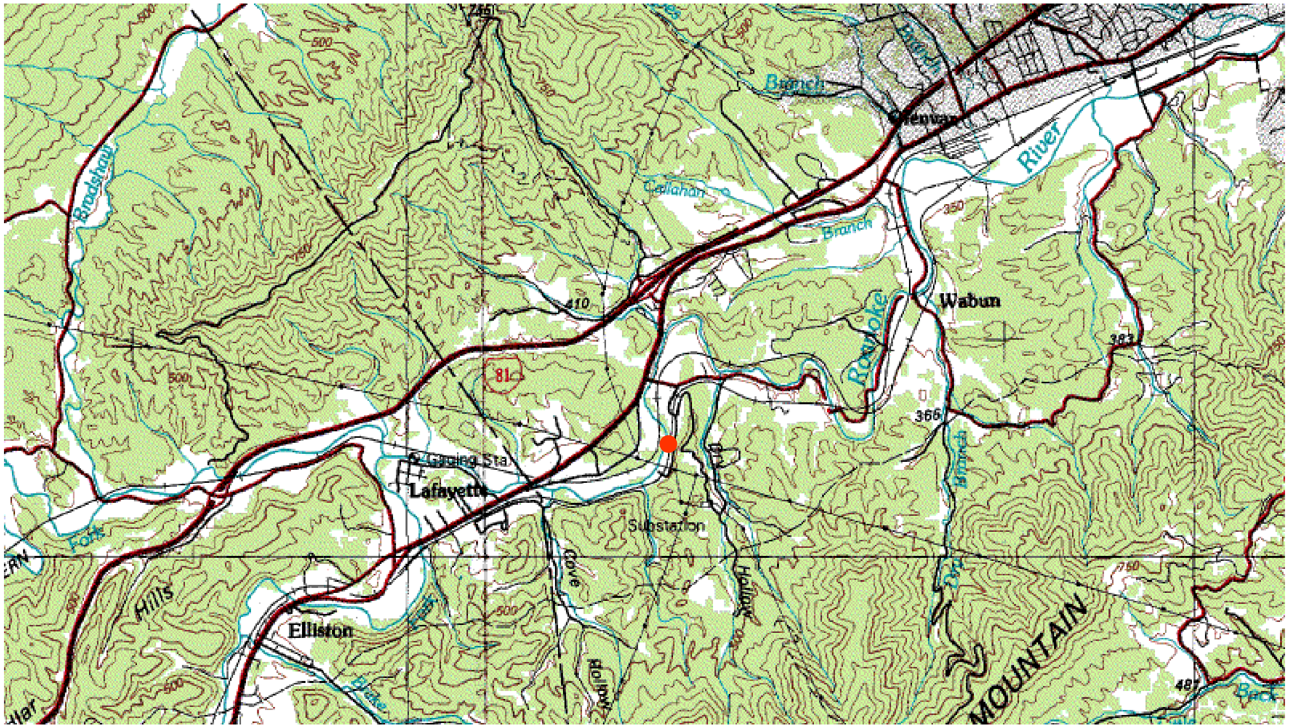
Map 4

- RRH-6/12/01

Length sampled: 102.7m
pH: 9.1
Temp: 22.8
Dissolved Oxygen: 9.27 mg/L
Conductivity: 315.8 µS

Species observed

Luxilus albeolus
Percina roanoka
Percina rex
Etheostoma nigrum
Nocomis sp.
Hypentelium roanokense
Micropterus dolomieu
Moxostoma sp.
Lythrurus ardens
Thoburnia rhothoeca
Campostoma anomalum
Etheostoma flabellare



Roanoke River

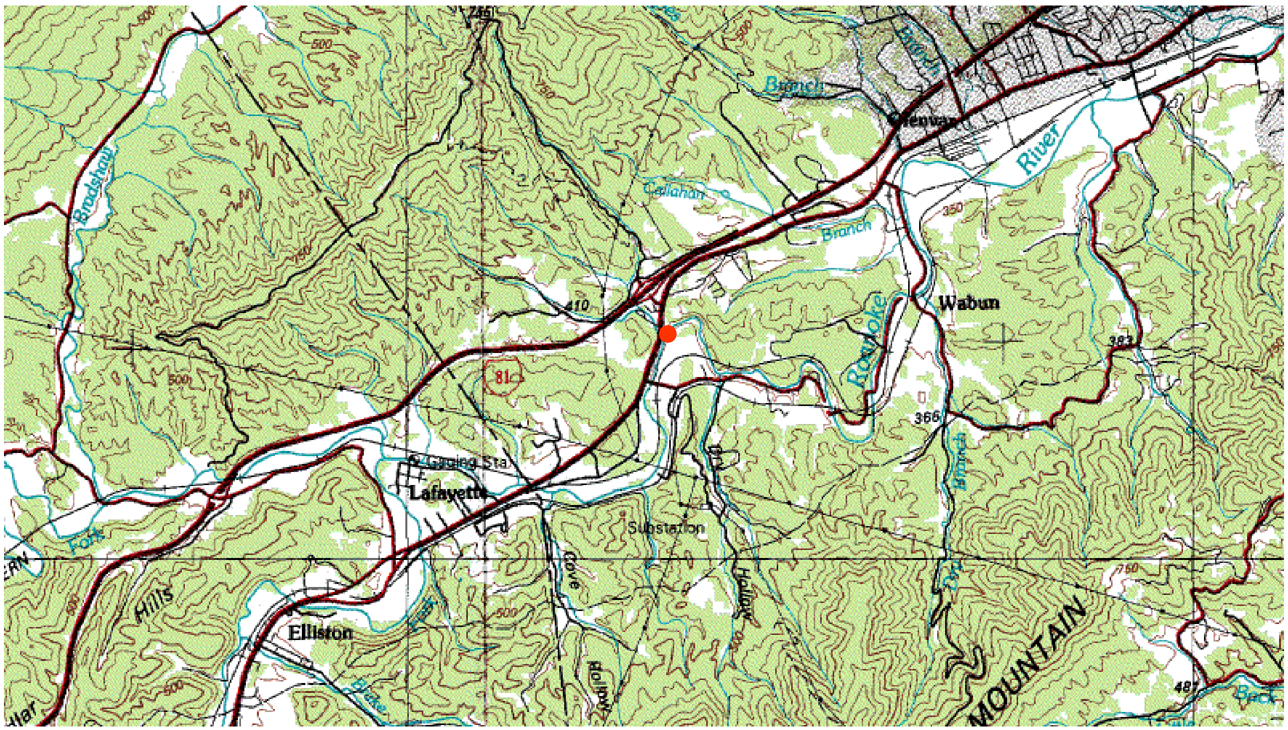
Map 5

● RRH-6/14/01

Length sampled: 141.2m
pH: 8.3
Temp: 21.1
Dissolved Oxygen: 11.96 mg/L
Conductivity: 318.3 µS

Species observed

Luxilus albeolus
Percina roanoka
Percina rex
Nocomis sp.
Notropis sp.
Etheostoma podostemone
Nocomis leptocephalus
Micropterus dolomieu
Lythrurus ardens
Campostoma anomalum
Etheostoma flabellare
Luxilus cerasinus
Scartomyzon cervinus



Roanoke River

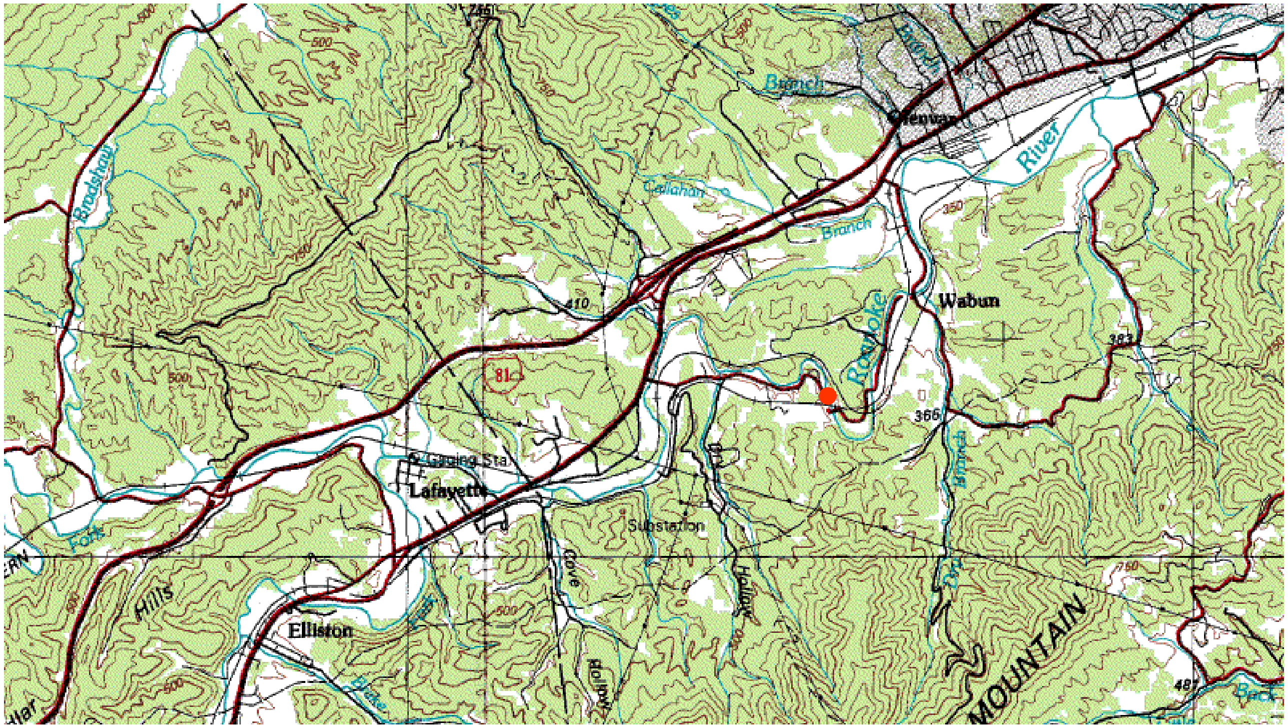
Map 6

● RRH-7/17/01

Length sampled: 130m
pH: 8.2
Temp: 20.7°
Dissolved Oxygen: 10.7 mg/L
Conductivity: 353.8 µS

Species observed:

Micropterus dolomieu
Etheostoma nigrum
Etheostoma podostemone
YOY *Scartomyzon* sp.
YOY *Nocomis* sp.
YOY *Notropis* sp.
Percina roanoka
Scartomyzon cervinus



Roanoke River

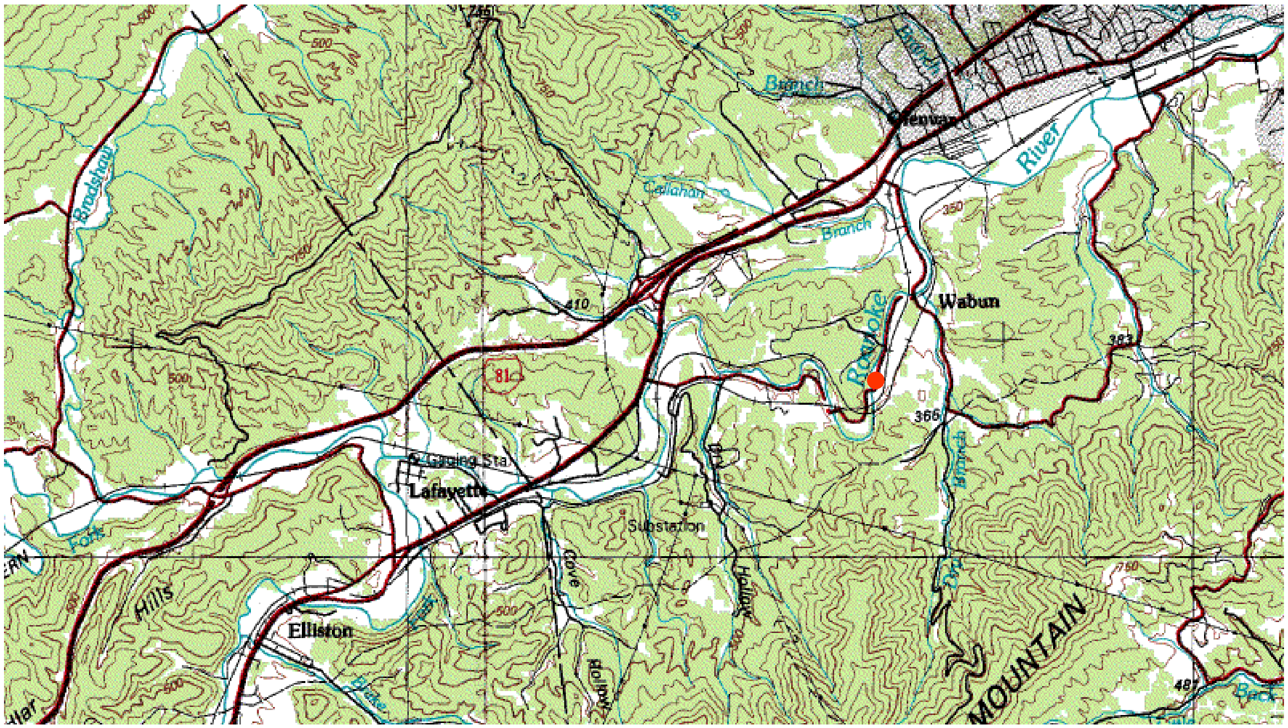
Map 7

Species observed

- RRH-7/23/01

Length sampled: 122.8m
pH: 8
Temp: 18.9
Dissolved Oxygen: 9.51 mg/L
Conductivity: 358.1 µS

Hypentelium nigricans
Campostoma anomalum
Luxilus albeolus
Micropterus salmoides
Nocomis raneyi
Percina roanoka
Percina rex
Micropterus dolomieu
Etheostoma podostemone
Percina roanoka
Scartomyzon cervinus
Nocomis sp.
Ambloplites rupestris
Luxilus cerasinus
Lythrurus ardens
Cyprinella analostana
Notropis sp.

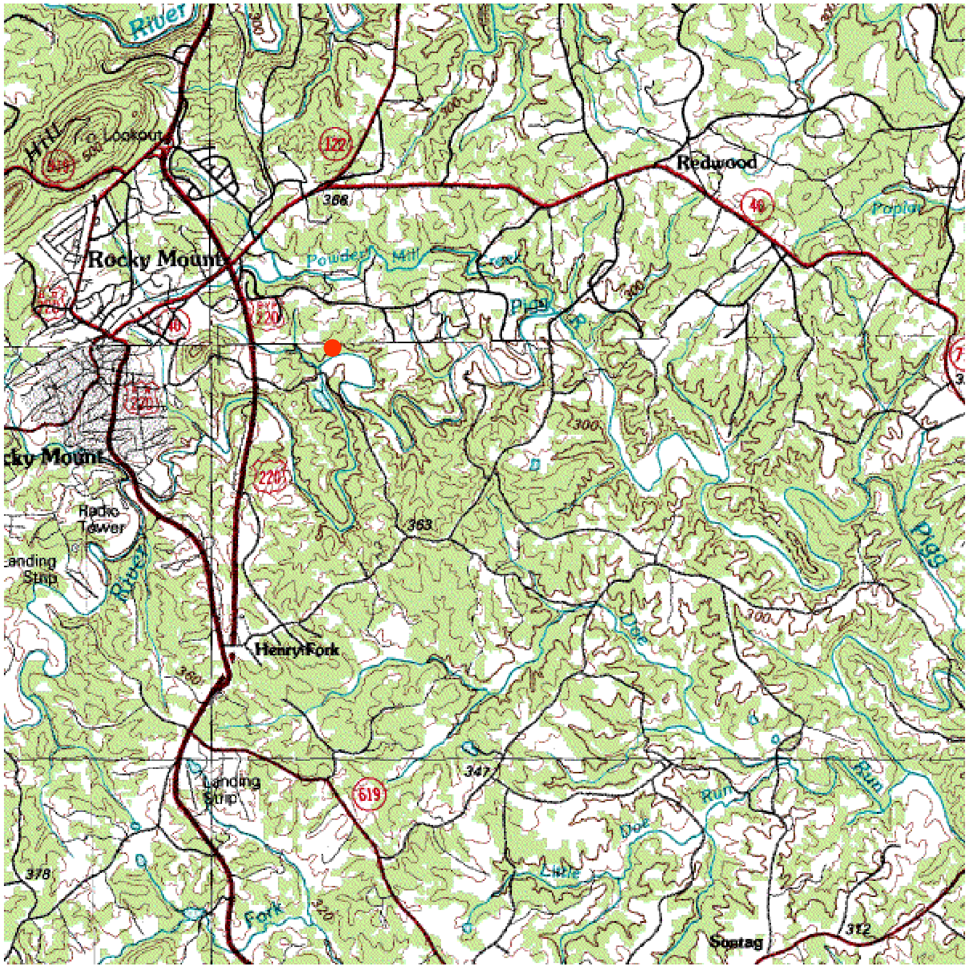


Pigg River

- PRH 8-8-01

Length sampled: 73.9
pH: 7.5
Temp: 24.4
Dissolved Oxygen: 10.8 mg/L
Conductivity: 106.1 µS

Map 8



Species observed

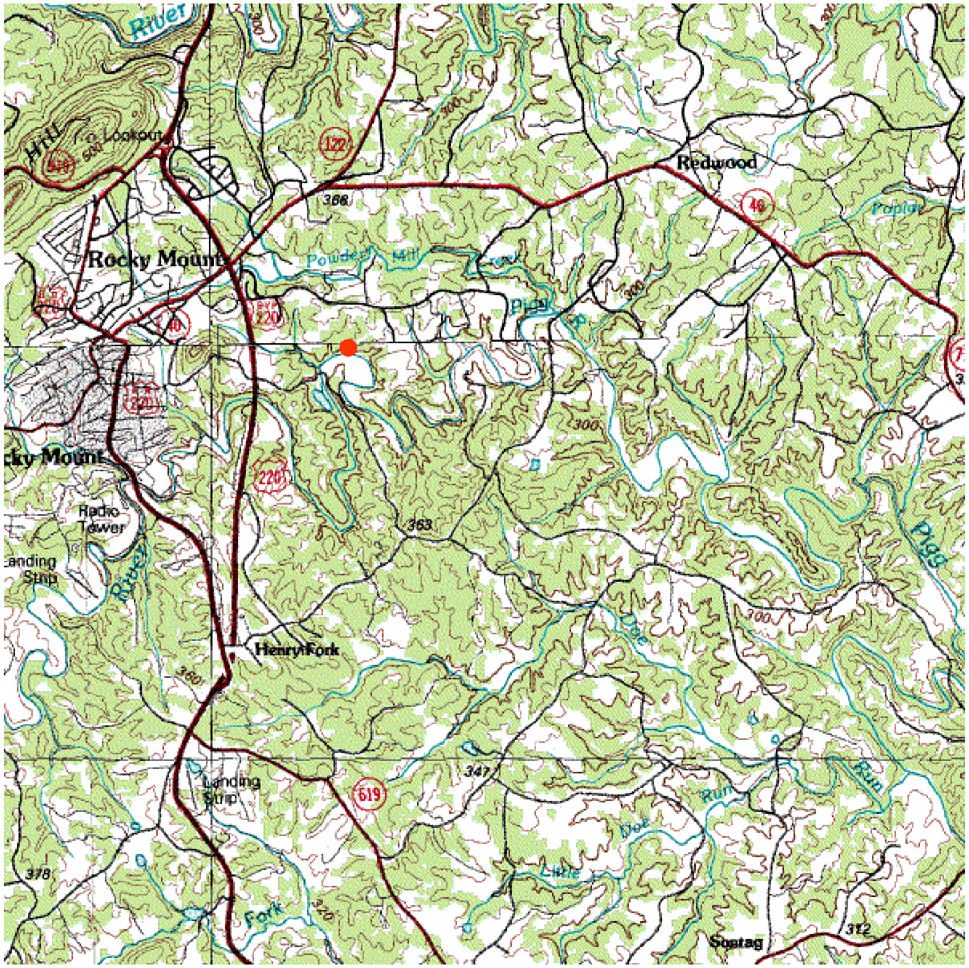
Luxilus albeolus
Percina roanoka
Percina rex
Etheostoma podostemone
Percina navisense
Lepomis auritus
Etheostoma nigrum
Luxilus cerasinus
Notropis sp.

Pigg River

- PRH 8-9-01*

Length sampled: 109.3
pH: 7.5
Temp: 24.3
Dissolved Oxygen: 9.2 mg/L
Conductivity: 107.3 µS

Map 9



Species observed

Luxilus albeolus
Percina roanoka
Percina rex
Nocomis sp.
Etheostoma podostemone
Cyprinella analostana
Percina navisense
Micropterus dolomieu
Etheostoma nigrum
Campostoma anomalum
Noturus insignis
Luxilus cerasinus
Etheostoma flabellare
Lepomis macrochirus
Notropis sp.
Hypentelium nigricans

* freshwater sponges observed at this site

Pigg River

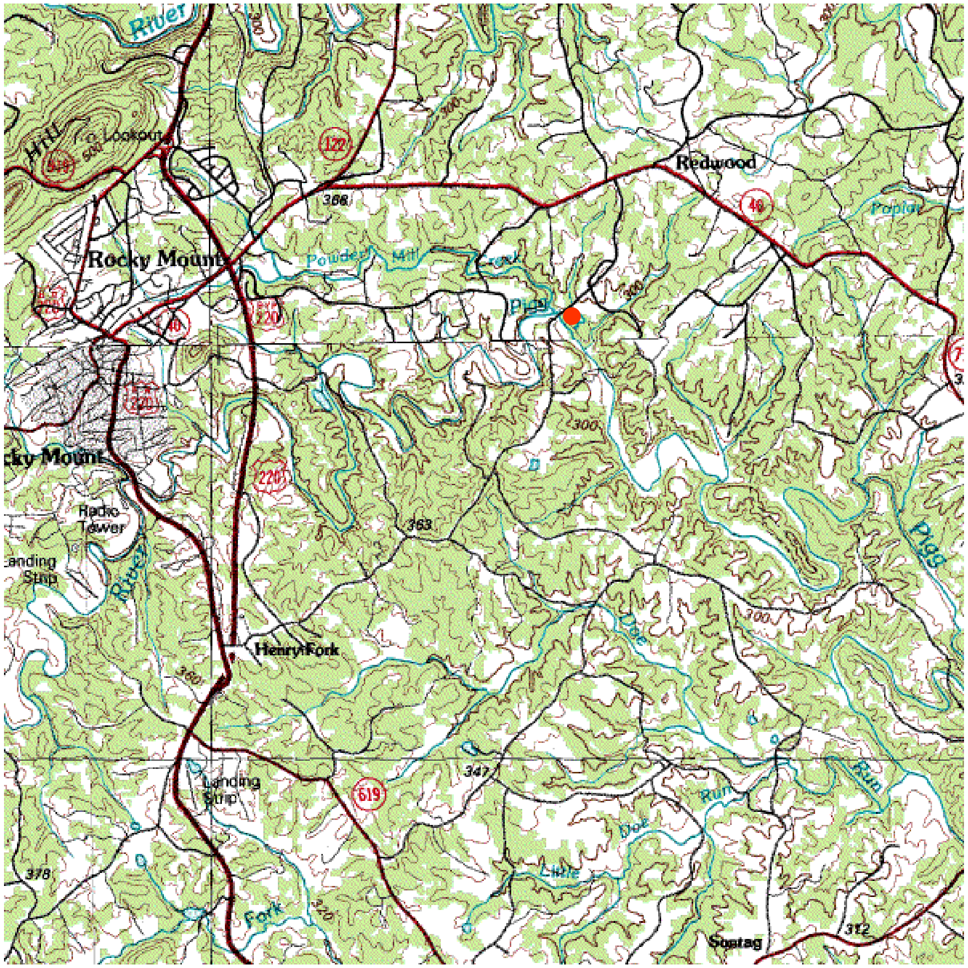
● PRH 9-22-01

Length sampled: 121.3
pH: 7.8
Temp: 18.5
Dissolved Oxygen: 8.1 mg/L
Conductivity: 111.8 µS

Map 10

Species observed

Etheostoma nigrum
Etheostoma podostemone
Luxilus albeolus
Etheostoma vitreum
Micropterus salmoides
Campostoma anomalum
Nocomis sp.
Notropis sp.
Percina navisense
Etheostoma flabellare
Luxilus cerasinus
Hypentelium nigricans
Lepomis auritus
Percina rex
Percina roanoka

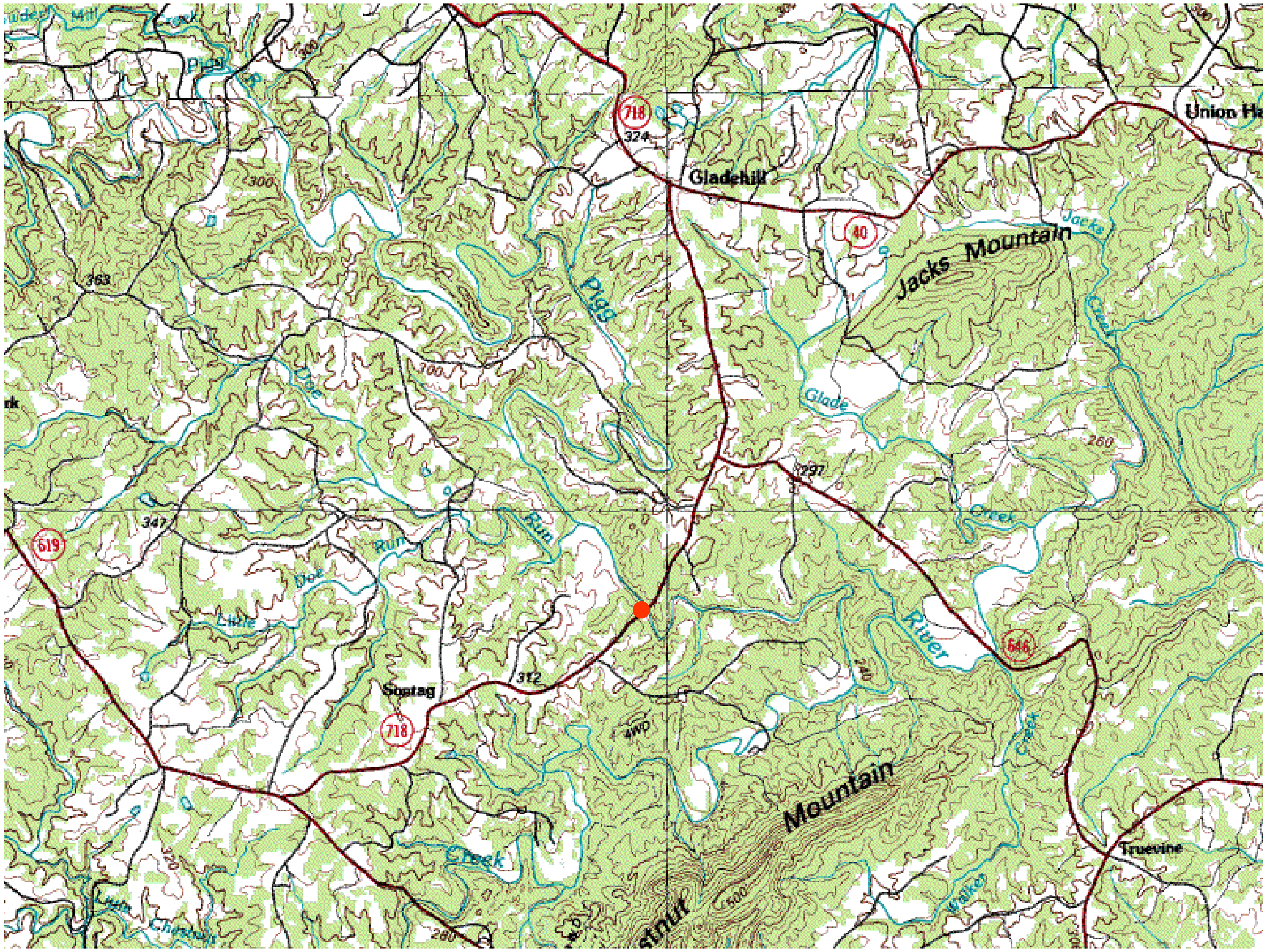


Pigg River

● PRH 8-10-01

Length sampled: 95.4
pH: 7.5
Temp: 24.4
Dissolved Oxygen: 10.8 mg/L
Conductivity: 106.1 µS

Map 11



Species observed

Luxilus albeolus
Percina roanoka
Percina rex
Nocomis sp.
Etheostoma podostemone
Cyprinella analostana
Percina navisense
Lepomis auritus
Micropterus dolomieu
Etheostoma nigrum
Campostoma anomalum
Noturus insignis
Luxilus cerasinus
Etheostoma flabellare
Moxostoma sp.
Lepomis macrochirus

Pigg River

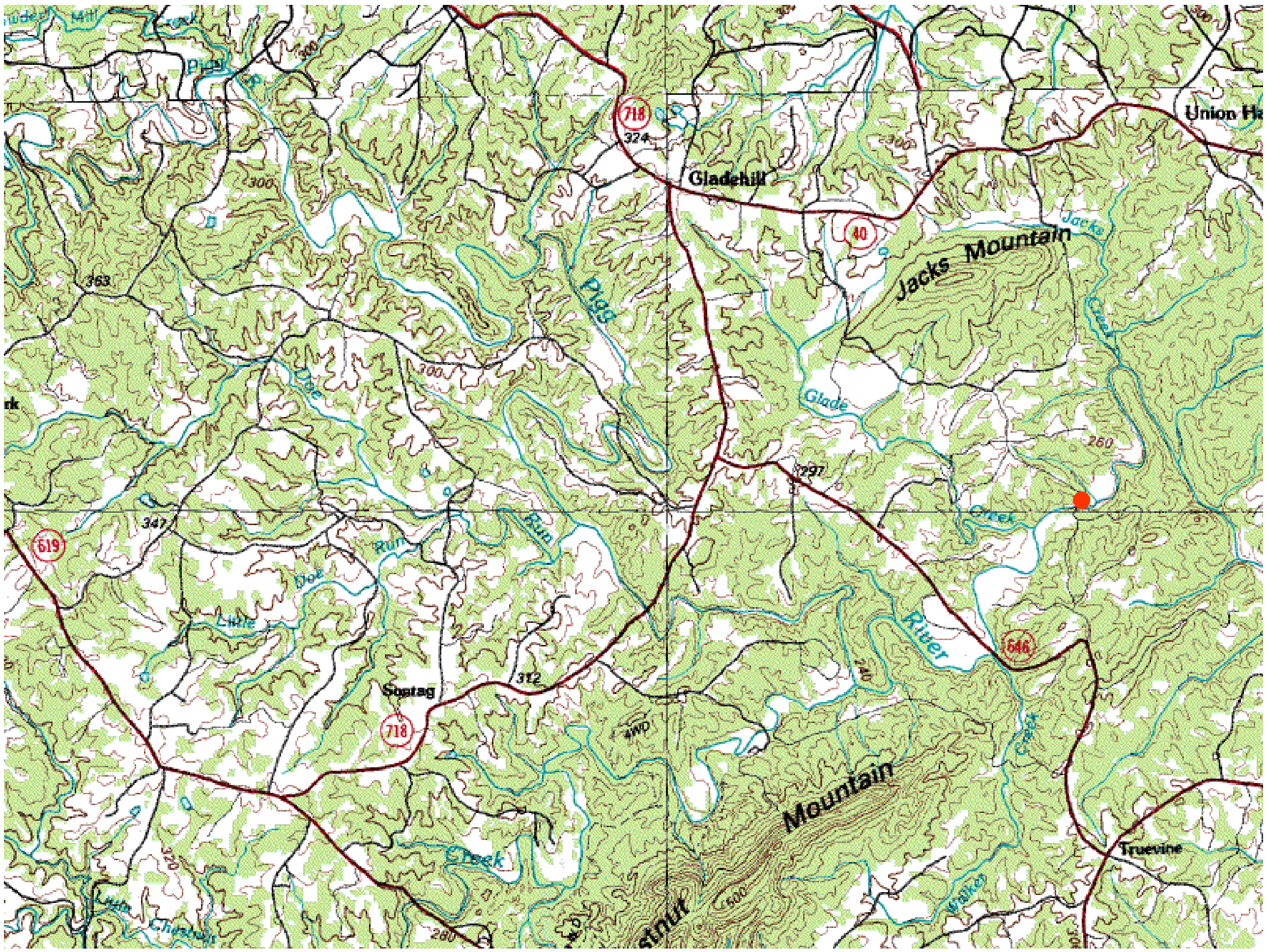
● PRH 9-7-01

Length sampled: 94.8
pH: 7.9
Temp: 22.6
Dissolved Oxygen: 8.6 mg/L
Conductivity: 89.9 µS

Map 12

Species observed

Notropis sp.
Noturus insignis
Nocomis sp.
Moxostoma sp.
Etheostoma podostemone
Percina navisense
Luxilus albeolus
L. cerasinus
Percina roanoka
Percina rex



Pigg River

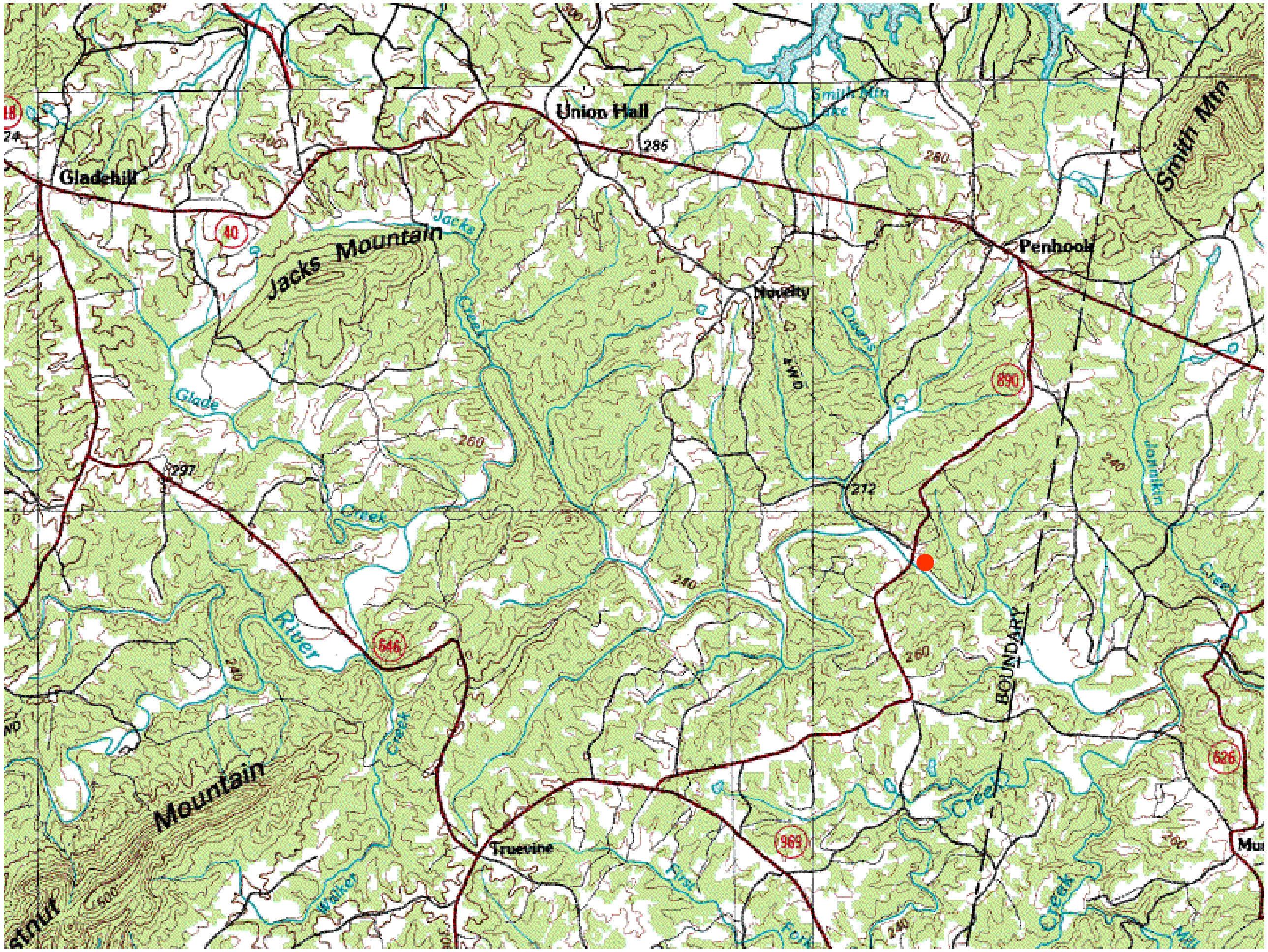
- PRH 9-21-01

Length sampled: 89.8
pH: 8.2
Temp: 20.0
Dissolved Oxygen: 9.0 mg/L
Conductivity: 81.0 µS

Map 13

Species observed

Luxilus albeolus
Percina roanoka
Percina rex
Etheostoma podostemone
Cyprinella analostana
Percina navisense
Micropterus dolomieu
Campostoma anomalum
Noturus insignis
Notropis sp.
Hypentelium nigricans
Scartomyzon cervinus
Etheostoma vitreum

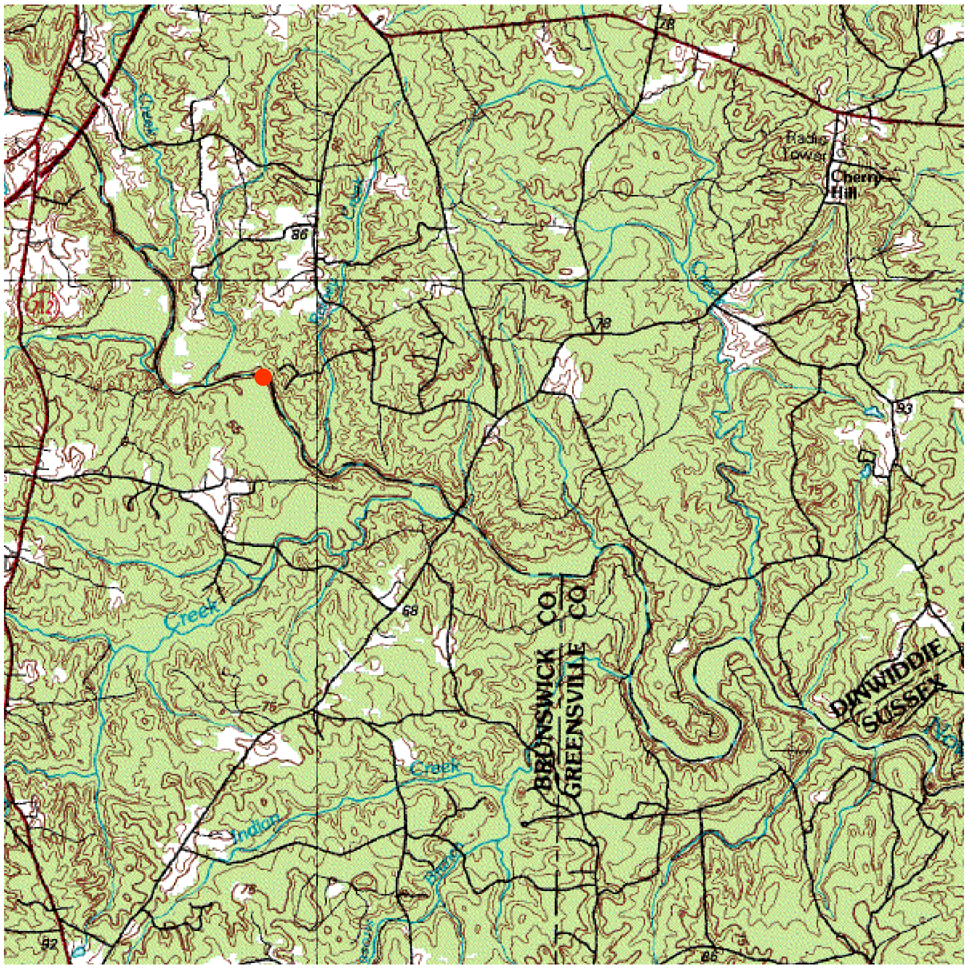


Map 14

Nottoway River

● NRH 7-19-00

Length sampled: 127.4
pH: 6.8
Temp: 26.1
Dissolved Oxygen: 6.3 mg/L
Conductivity: 81.2 µS



Species observed

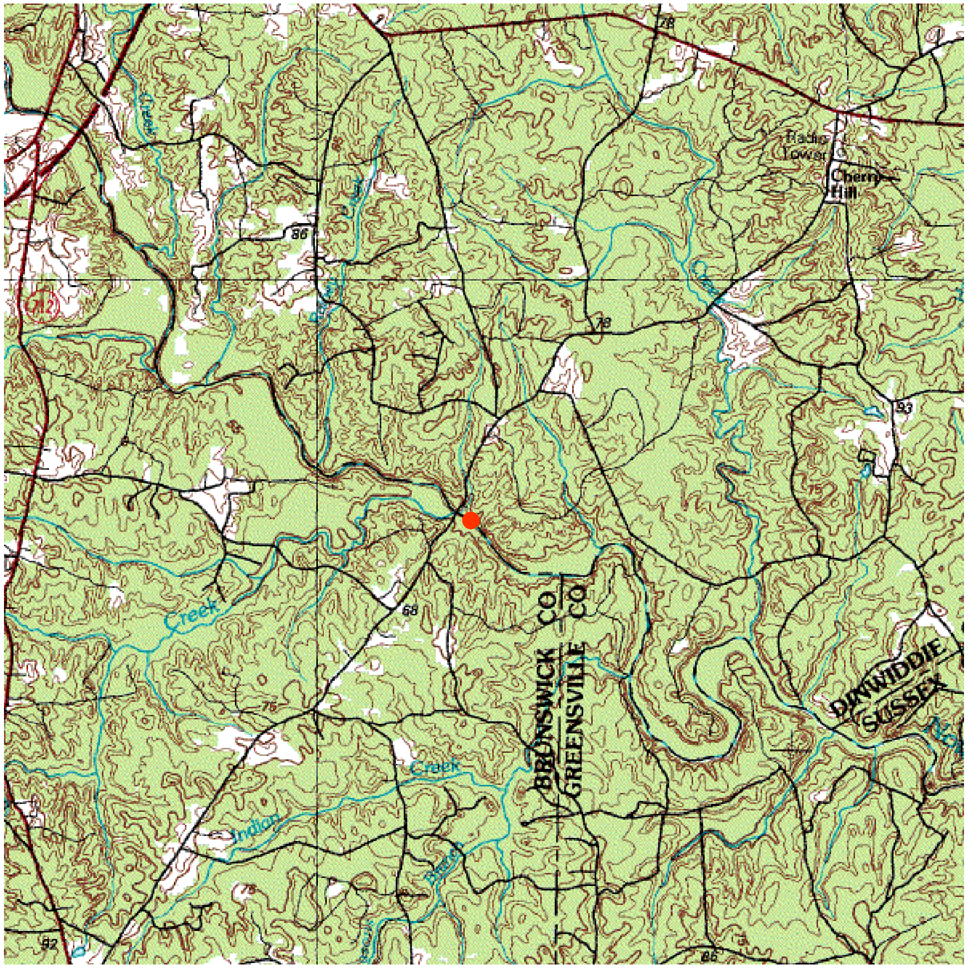
Percina roanoka
Percina rex
Micropterus dolomieu
Scartomyzon cervinus
Etheostoma vitreum
Percina navisense
Luxilus albeolus
Cyprinella analostana
Nocomis sp.
Notropis sp.
Micropterus salmoides
Lythrurus ardens
Lepomis auritus

Map 15

Nottoway River

● NRH 7-20-00

Length sampled: 100
pH: 7.1
Temp: 25.4
Dissolved Oxygen: 6.5 mg/L
Conductivity: 74.7 µS



Species observed

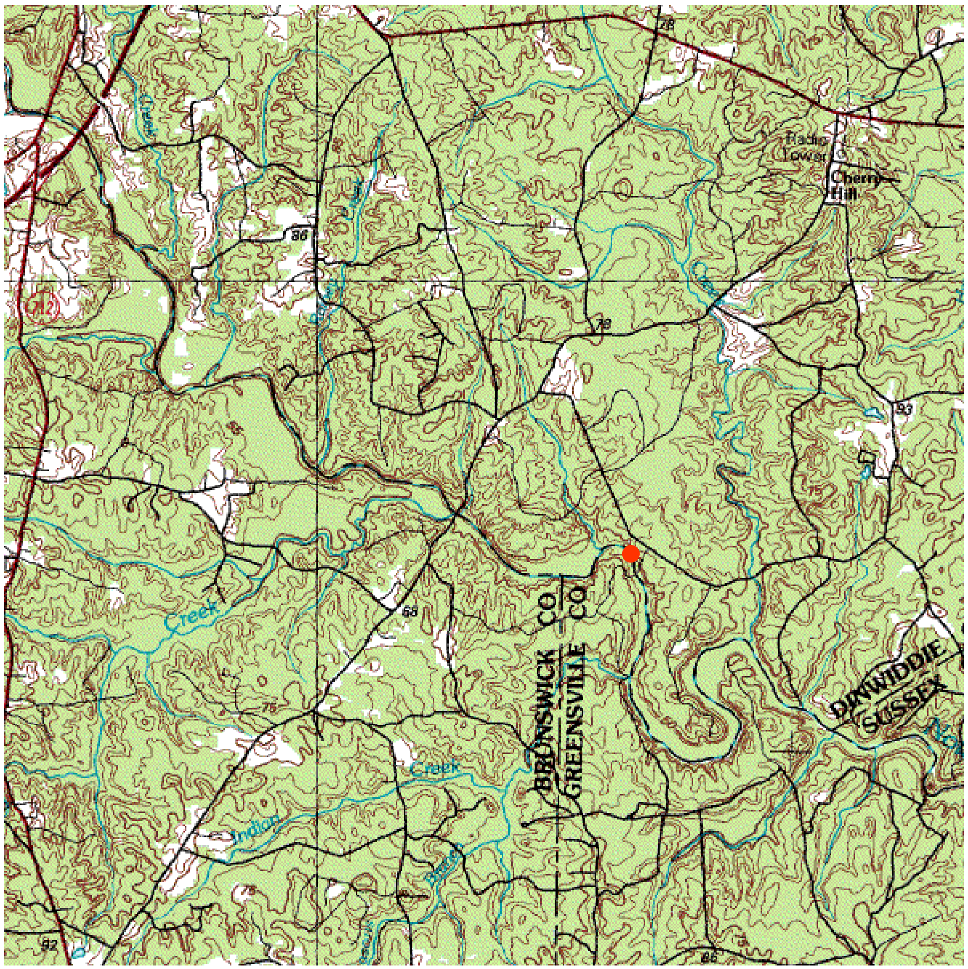
Percina roanoka
Percina rex
Etheostoma vitreum
Percina navisense
Luxilus albeolus
Lepomis macrochirus
Lepomis auritus
Notropis sp.
Nocomis sp.

Map 16

Nottoway River

● NRH 7-10-01

Length sampled: 113
pH: 8.4
Temp: 25.1
Dissolved Oxygen: 8.4 mg/L
Conductivity: 81.4 µS



Species observed

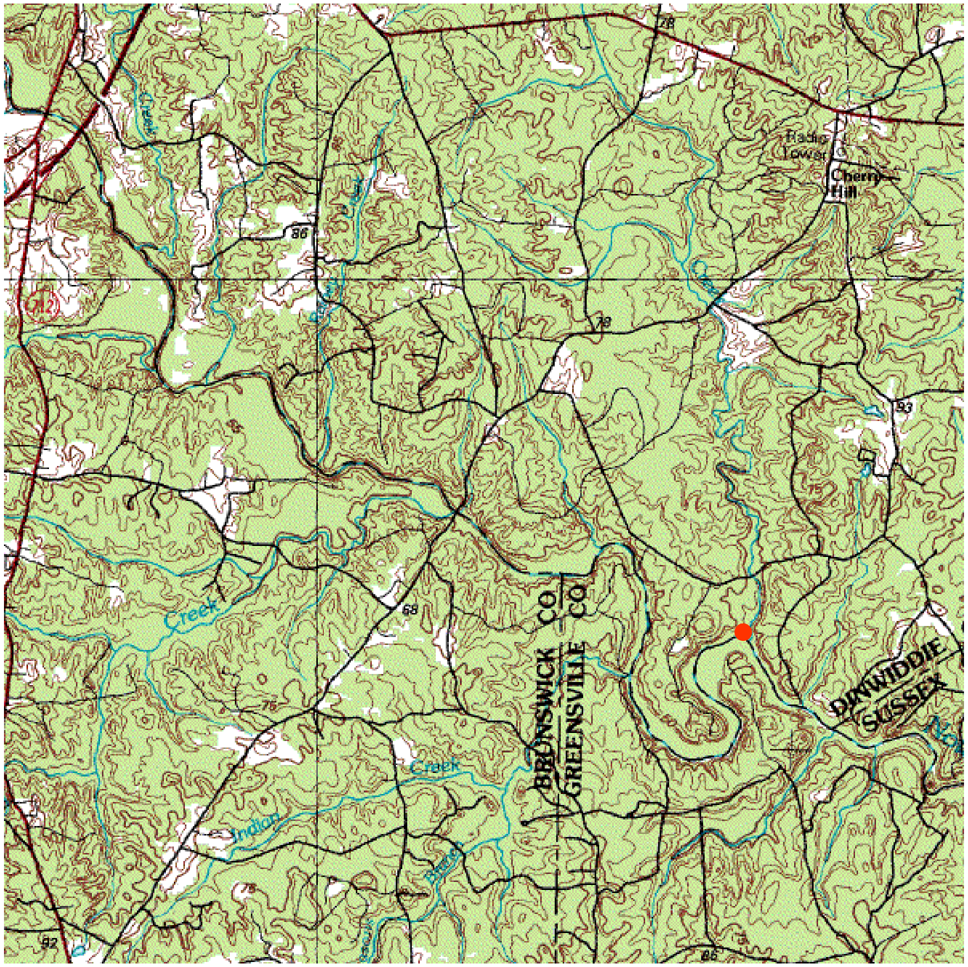
Percina roanoka
Percina rex
Scartomyzon cervinus
Etheostoma vitreum
Esox niger
Moxostoma sp.
Cyprinella analostana
Percina navisense
Notropis procne
Micropterus salmoides
Hypentelium nigricans
Luxilus albeolus
Lythrurus ardens
Ambloplites cavifrons
Lepomis auritus

Nottoway River

Map 17

● NRH 8-1-01

Length sampled: 125.7
pH: 7.6
Temp: 19.7
Dissolved Oxygen: 8.1 mg/L
Conductivity: 69.8 µS



Species observed

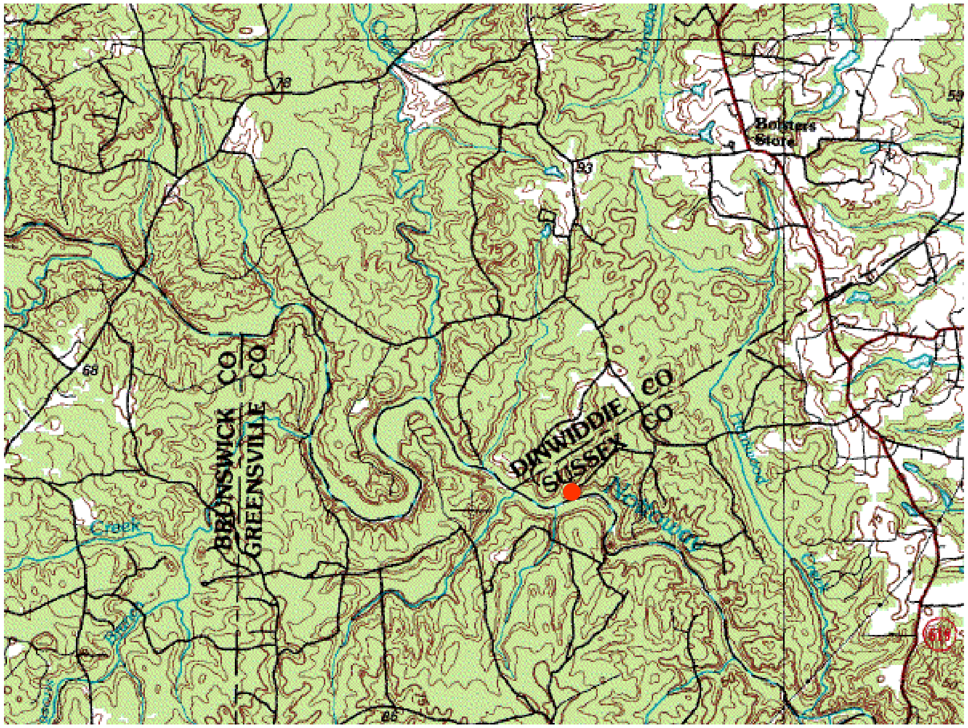
Percina roanoka
Percina rex
Scartomyzon cervinus
Etheostoma vitreum
Luxilus albeolus
Hybognathus regius
Percina navisense
Lepomis auritus
Nocomis sp.
Moxostoma sp.
Anguilla rostrata
Hypentelium nigricans
Notropis sp.
Cyprinella analostana

Map 18

Nottoway River

● NRH 7-7-01

Length sampled: 248.6
pH: 7.1
Temp: 23.8
Dissolved Oxygen: 7.5 mg/L
Conductivity: 84.9 µS



Species observed

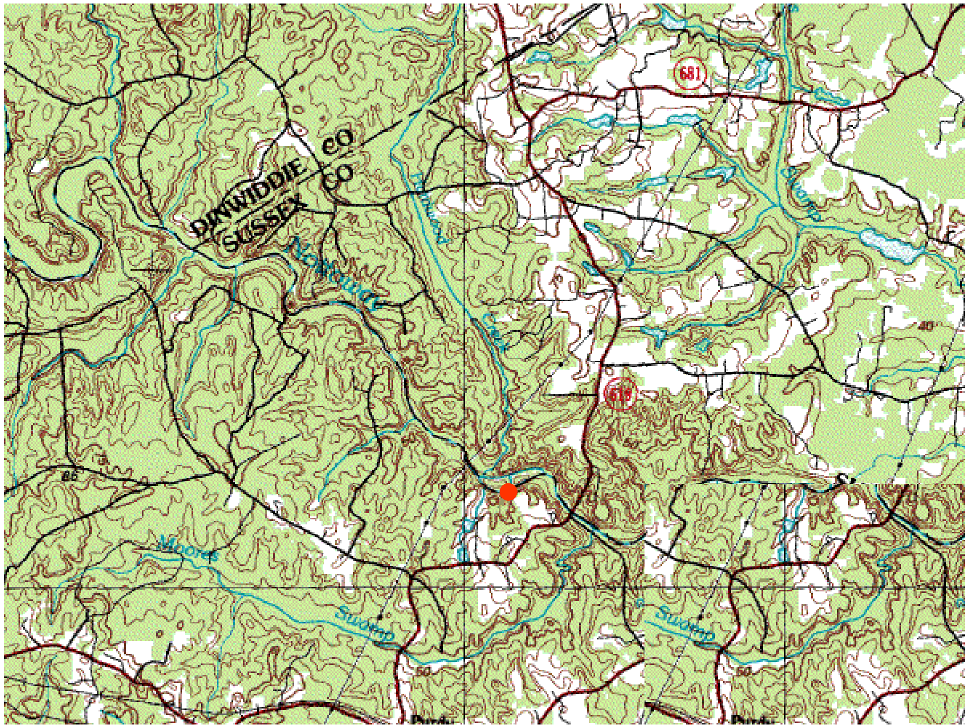
Percina roanoka
Percina rex
Noturus insignis
Ambloplites cavifrons
Percina navisense
Etheostoma vitreum
Lythrurus ardens
Hypentelium nigricans
Cyprinella analostana
Lepomis auritus
Nocomis sp.
Micropterus salmoides
Micropterus dolomeiu

Map 19

Nottoway River

● NRH 5-31-01

Length sampled: 91.3
pH: 8.1
Temp: 21.7
Dissolved Oxygen: 9.0 mg/L
Conductivity: 99.2 µS



Species observed

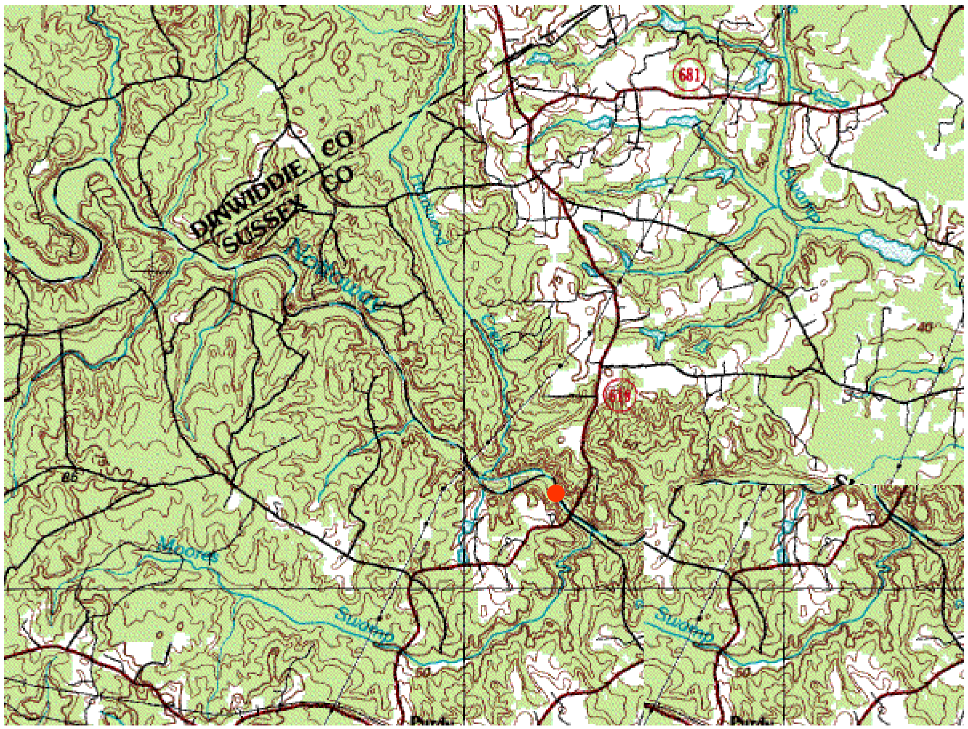
Percina navisense
Etheostoma vitreum
Micropterus salmoides
Mictopterus dolomieu
Lepomis macrochirus
Lepomis gibbosus
Luxilus cerasinus
Lythrurus ardens
Lepisosteus osseus
Nocomis raneyi
Luxilus albeolus
Notropis sp.
Percina roanoka
Percina rex

Map 20

Nottoway River

● NRH 7-12-01

Length sampled: 124.7
pH: 7.4
Temp: 26.2
Dissolved Oxygen: 8.4 mg/L
Conductivity: 81.4 µS



Species observed

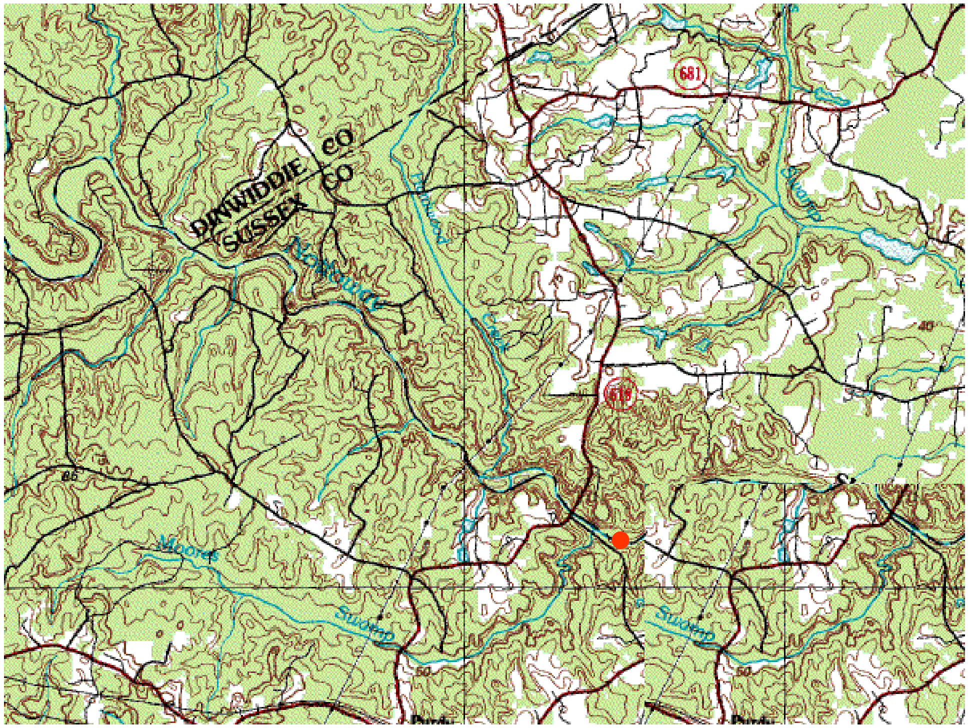
Micropterus dolomieu
Micropterus salmoides
Etheostoma vitreum
Nocomis sp.
Moxostoma sp.
Lepomis auritus
Luxilus albeolus
Hypentelium nigricans
Notropis sp.
Lythrurus ardens

Map 21

Nottoway River

● NRH 6-12-00

Length sampled: 150
pH: 8.0
Temp: 26.0
Dissolved Oxygen: 9.8 mg/L
Conductivity: 79.5 µS



Species observed

Percina roanoka
Percina rex
Micropterus dolomieu
Scartomyzon cervinus
Ambloplites rupestris
Etheostoma vitreum
Luxilus albeolus
Lepomis macrochirus
Lepomis auritus
Nocomis sp.
Lythrurus ardens
Cyprinella analostana
Percina navisense
Micropterus salmoides