Habitat Suitability and Population Characteristics

of Smallmouth Bass and Rock Bass in the Powell River, Virginia

by

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(ABSTRACT)

A survey of the population characteristics of smallmouth bass (*Micropterus dolomieu*), rock bass (*Ambloplites rupestris*), and habitat conditions were conducted in the Powell River, Virginia, to identify potential habitat limitations for these species. The study area consisted of three reaches, which were determined in 1987. The upstream reach was used to monitor effects of coal mining in the upper watershed on the Powell River. The midstream reach, which was below the North Fork Powell River, was used to monitor the possible effects of this tributary and its watershed. The downstream reach appeared to have been impacted by sedimentation less than either of the other reaches.

Habitat Suitability Index (HSI) models were used to identify habitat variables that were below optimum for these species in the Powell River, Virginia. Habitat sampling yielded HSI scores for smallmouth bass at each site ranging from 0.67 to 0.76, with a mean of 0.72; scores for rock bass ranged from 0.65 to 0.70, with a mean of 0.69. No trends in HSIs from upstream to downstream were evident. However, substratum, of which sand was dominant in pools, was the variable most frequently below optimum for smallmouth bass (SI=0.21) and rock bass (SI=0.20).

Values for sediment depth, embeddedness, waterborne sediment, and coal were collected in riffles, runs, and pools at 10 sites. Mean sediment depth in pools, embeddedness in riffles and runs, and waterborne sediment deposited in traps monthly in pools decreased from upstream to downstream; however, waterborne sediment in runs did not decrease. Content (by weight) of coal wastes in the substratum did not decrease from upstream to downstream. The embeddedness index in pools (=1.0), riffles, and runs was not significantly different among the three river reaches.

No differences in population abundance, biomass estimates, age and growth, or relative weights (Wr) of smallmouth bass and rock bass were found among the three river reaches. Population estimates of smallmouth bass (34.3/ha) and rock bass (116.6/ha) were lower than those in many other streams in the U.S. Catch-per-unit-effort and biomass of smallmouth bass (2.9/h, 2.6 kg/ha) and rock bass (6.6/h, 2.2 kg/ha) also were lower than those in most other streams.

A total of 70 stomachs of smallmouth bass and 166 stomachs of rock bass was examined from fish collected between July 1988 and October 1989. Diets for each species, primarily

crayfish and insects, showed no apparent differences among the three river reaches. Abundance of crayfish and hellgrammites were compared; greatest hellgrammite abundance was in the downstream reach (P = 0.032), and there were no significant differences in crayfish abundance among the three river reaches.

HSI values showed no significant correlation with catch-per-unit-effort for smallmouth bass or rock bass. No significant correlation was found among sediment depth, catch-per-unit-effort, biomass or relative weight of smallmouth bass and rock bass. No correlation was found between the embeddedness index in riffles and biomass of rock bass. There was a significant negative correlation between the embeddedness index in riffles and relative weight of smallmouth bass (P=0.016); however, no correlation existed between the embeddedness index and relative weight of rock bass. There was a significant negative correlation between the embeddedness index in riffles and growth of smallmouth bass (P=0.016); however, there was a significant positive correlation between the embeddedness index and growth of rock bass. There was a significant positive correlation between the embeddedness index in riffles and both hellgrammite abundance (P=0.031) and crayfish abundance (P=0.052) in riffles. No significant correlation was found between the amount of sediment deposited in pools and catch-per-unit-effort of smallmouth bass and rock bass. No significant correlation existed between the amount of sediment deposited in runs and biomass of rock bass. In addition, crayfish density was not correlated with relative weight of smallmouth bass or rock bass. With the available documentation that links population characteristics of smallmouth bass and rock bass to habitat, it is evident that habitat is usually the limiting factor in determining population characteristics; however, there was no significant trend in the correlations presented above.

Habitat for smallmouth bass and rock bass in the Powell River, Virginia was suboptimum and sand was the dominant substratum in pools. Population estimates, catch-per-unit-effort, and biomass of smallmouth bass and rock bass in the Powell River are low compared to other U.S. streams. Although it appears that sedimentation has degraded habitat of smallmouth bass and rock bass and contributed to reduced population levels of these species in the Powell River, Virginia, my results were not statistically different among sites with measurable differences in sedimentation.

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Introduction

Powell River

The Powell River originates near coal fields in Wise County, Virginia, and flows southwest through Lee County for approximately 145 km before entering Tennessee (Wollitz, 1985). It continues for roughly 175 km through Hancock, Claiborne, Campbell, and Union counties before entering Norris Reservoir. The Powell River lies in the Appalachian Mountain section of the Great Ridge and Valley physiographic region (TVA, 1968). Its basin consists of long, parallel ridges and valleys. Powell Mountain forms the southern border of the river, while Cumberland Plateau forms the northern border (Ahlstedt and Brown, 1979; Ayers, 1981). The watershed covers about 1800 km^2 (Helfrich et al., 1986). Forests cover approximately 75% of the watershed, and cropland covers about 10% (TVA, 1968).

This river receives pollution from industrial, agricultural, and residential activities, although wastes from sewage treatment and coal mining facilities are most evident (Ayers, 1981; Heffinger, 1986). According to local anglers and R.E. Wollitz (Virginia Department of Game and Inland Fisheries, pers. comm.), one of the suspected causes of the problems in the Powell River is the high sediment load caused by erosion in coal fields. Most of this sediment from accelerated erosion is believed to enter the Powell River from the North Fork tributary. Sedimentation originates in runoff from strip-mines, refuse piles, haul roads, logging operations, and from row crop and cattle farms that have no erosion control (Neves et al., 1980; Ayers, 1981;

Heffinger, 1986). After coal is washed, coal fines are deposited into settling ponds; these fines have been observed in the river (TVA, 1980). At times the entire length of the Powell River was seen running black with coal fines (TVA, 1980). Recent surveys indicate that the river below the confluence of the North Fork Powell River was heavily impacted by silt and coal deposition (Ahlstedt and Brown, 1979; Neves et al., 1980). Wollitz (1985) stated that "most of the coal fines entering the river are thought to be the result of erosion from abandoned mines and illegal discharges of mine black water from active mines."

In addition to the environmental perturbations from coal mining, the Powell River has many others. Illegal releases of toxic substances, such as hydraulic fluid, may have contributed greatly to the perturbations (R.E. Wollitz, pers. comm.). Several fish kills have occurred in the Powell River, but the latest one occurred in August 1986, when an emulsion of oil and water, released from a coal mine, killed 8,552 fish over a 7.2 km reach (Osborne, 1986). This fish kill prompted the Virginia Department of Game and Inland Fisheries to notify the Virginia Division of Mined Land Reclamation and the Virginia Water Control Board (VWCB) of suspected pollutants.

Contaminants are present in the Powell River system. According to the VWCB (1988), twenty-six percent of water samples taken from the Powell River and its tributaries were in violation of fecal coliform standards. This is because the river receives high levels of raw or partially treated sewage from many small towns in the watershed (Ayers, 1981), which is one reason the water quality in the Powell River is degraded (Heffinger, 1986). Longitudinal gradients in alkalinity, biological oxygen demand, calcium, conductivity, iron, sulfate, and total solids occur in the Powell River (A. Temple, Virginia Polytechnic Institute and State University, pers. comm.). Analysis of metals, herbicides, and pesticides showed trace concentrations (VWCB, 1985). Dissolved oxygen, pH, hardness, and temperatures appear to be optimum when compared to the U.S. Fish and Wildlife Service's habitat suitability criteria for smallmouth bass and rock bass (VWCB, 1988).

During recent years, anglers have become increasingly concerned about poor fishing in the Powell River in Lee and Wise counties, Virginia. Fishing in this river was once outstanding but has produced poor catches for anglers in recent years (R.E. Wollitz, pers. comm.). Native sport fish, which include longear sunfish *(Lepomis megalotis)*, smallmouth bass (*Micropterus dolomieu*), spotted bass (*Micropterus* punctulatus), rock bass (*Ambloplites rupestris*), and channel catfish (*Ictalurus punctatus*) as well as introduced redbreast sunfish (*Lepomis auritus*), sauger (*Stizostedion canadense*), walleye (*Stizostedion vitreum*), muskellunge (*Esox masquinongy*), rainbow trout (*Salmo gairdneri*), and brook trout (*Salvelinus fontinalis*) provide a recreational fishery for anglers in this economically depressed region of the state.

The knowledge gained from understanding the effects of sedimentation on the fish fauna of the Powell River is important not only for the sport fishery but also for the federally threatened slender chub (*Erimystax cahni*) and federally endangered mussels that reside there. According to Wolcott (1990), the river supports one of the greatest diversities of mussel species in the upper Tennessee drainage, to include: the cracking pearlymussel (*Hemistena lata*), Appalachian monkeyface (*Quadrula sparsa*), cumberland monkeyface (*Quadrula* intermedia), birdwing pearlymussel (*Lemiox rimosus*), dromedary pearlymussel (*Dromus dromas*), fine-rayed pigtoe (*Fusconaia cuneolus*), and shiny pigtoe (*Fusconaia cor*). The state endangered species in the Powell River include: elephant-ear mussel (*Elliptio crassidens*), cumberlandian combshell mussel (*Epioblasma brevidens*), oyster mussel (*Epioblasma capsaeformis*), snuffbox mussel (*Epioblasma triquetra*), and deertoe mussel (*Truncilla truncata*).

Coal Mining Effects

Although coal mining is an economically important industry in southwest Virginia, irresponsible coal mining practices have resulted in degradation of streams. According to Ahmad (1973), approximately 29,000 km of streams in Appalachia have been degraded because of mining. Appalachian coal mining includes mountain top removal and contour strip mining (Starnes, 1980). These activities expose not only coal deposits, but also soil and pyrite to wind and water erosion. In the presence of oxygen and water, pyrite is oxidized to form sulfuric acid (Ahmad, 1973; Starnes, 1985). Fortunately, because much of the Powell River basin is underlain by limestone, formation of acid is readily neutralized (TVA, 1968).

In addition to acid mine drainage, mine slopes allow accelerated erosion to take place, thereby increasing sedimentation in streams. According to Judy et al. (1984), sediment is the factor that limits fish communities in 46% of the streams in the U.S. This sediment not only affects fish and fish habitat, but also human usage. Water contaminated with sediment is undesirable for drinking, contact recreation, or aesthetic enjoyment (U.S. Environmental Protection Agency, 1976). Turbidity resulting from mining activities has caused a significant decline in sport fishing in many streams throughout the U.S. (Lloyd et al., 1987). Branson and Batch (1972) studied a Kentucky stream that receive high levels of sedimentation from spoil banks and reported a 90% decrease in benthos abundance. Vaughn (1979) and Matter and Ney (1981) stated that when acid mine drainage was absent, sedimentation from surface mining was the main impact on streams.

Many studies have documented the effects of mining on aquatic ecosystems. Pautzke (1937) observed that discharges of coal washings were lethal to steelhead and cutthroat trout. According to Charles (1966), "intermittent coal waste pollution in Martin's Fork (Kentucky) had a greater effect on the viewers' aesthetic sensibility than it had on biological productivity." Effects of runoff from alkaline mine drainage can induce osmotic stress on fish due to sedimentation, turbidity, and dissolved constituents (U.S. Fish and Wildlife Service, 1978). These constituents reach a maximum concentration after mining has stopped and can continue for several years (Dyer and Curtis, 1977).

Sedimentation Effects

Sedimentation is the process of depositing erosion material into waters. For this study, silt and sand will be referred to as sediment. Sedimentation can affect fish either by altering substratum or by degrading the physical and chemical composition of water (Ellis, 1936). Sedimentation affects physical habitat directly by filling interstitial spaces of hard substrata and reducing interstitial flow in these spaces (Moring, 1982; Berkman and Rabeni, 1987). By shading out rooted aquatic plants, suspended sediments can decrease stability of stream substratum (Muncy et al., 1979). Suspended sediments also influence water quality. Temperature can increase due to suspended solids (Cordone and Kelly, 1961), and dissolved oxygen can decrease (Carlson and Siefert, 1974; Siefert et al., 1974). Because of dissolved oxygen decreases, eggs of smallmouth bass showed a delay in hatching time (Siefert et al., 1974).

Sedimentation can influence population abundance of fish by inhibiting reproduction and growth, to include maturation, fecundity, embryonic development, and larval survival (Muncy et al., 1979). Jones (1964) reported that suspended coal dust can decrease the amount of plankton in the water column, causing a reduction in survival of fish larvae. Suspended sediment also causes a similar effect (Van Oosten, 1948; Cooper and Bacon, 1980; Lloyd et al., 1987). Substrata that are heavily silted can also affect fish reproduction. According to Breder and

Rosen (1966), redbreast sunfish and smallmouth bass made nest cavities approximately 0.6 m in depth in a mud-bottomed pond, but failed to find a firm substratum to spawn. Even if spawning had occurred, continuous parental care would have been needed to prevent the eggs from suffocating (Iwamoto et al., 1978; Muncy et al., 1979).

Long-term exposure to high levels of suspended solids can inhibit growth and reduce fecundity, which could have a substantial impact on the fish population (Muncy et al., 1979). Swingle (1956) found that largemouth bass may spawn up to 30 days later in muddy water than in clear water. Buck (1956) determined that fish growth was greater in clear ponds than in muddy ones. High levels of sediment can also reduce food availability, thereby limiting energy that can be directed toward growth and reproduction (European Inland Fisheries Advisory Committee, 1964; Allen, 1969; Karr and Dudley, 1981). Bulkley (1975) reported that suspended solids reduced available food of largemouth bass until they were not capable of reproduction. According to Wallen (1951) and Cairns (1968), direct exposure of fish to high concentrations of suspended solids can result in death. Gills can become clogged with sediment, and fish suffocate. Also, fish can die as an indirect result of sediment when mucous sloughs off and disease causes death (Cairns, 1968).

Suspended solids and sediment can have a negative impact on food available to fish due to problems with locating food (Ritchie, 1972; Muncy, et al., 1979). Also, suspended solids and sediment can cause a reduction in prey fish and benthos (Cordone and Kelly, 1961; Bingham, 1969; Winger, 1978; Vaughn, 1979; Matter et al., 1981; Cooper, et al., 1982; Cooper and Knight, 1985; Berkman and Rabeni, 1987; Cooper, 1987).

Fish Habitat Assessment

When reviewing implications for proposed projects, legislative mandates (e.g., National Environmental Policy Act) require federal agencies to consider habitat protection (Binns and Eiserman, 1979; Layher et al., 1987). Because of this need for fish habitat evaluation, the Division of Ecological Services of the U.S. Fish and Wildlife Service developed Habitat Evaluation Procedures (HEP). HEP models are used to document the quality and quantity of habitat that is available for fish (Platts, 1980), and to provide information for comparing different stream reaches (United States Fish and Wildlife Service, 1980). They are based on the assumption that habitat for a species can be described by a habitat suitability index (HSI) model (Urich and Graham, 1983). The HSI, a value ranging from 0.0 (unsuitable) to 1.0 (optimum) and a measure of an area's suitability to support a given fish population, is constructed from single or aggregated indices and statistical methods (Terrell and Nickum, 1984; Aho et al., 1986). The main objective of HSI models is to quantify habitat conditions and provide a basis for project modifications to minimize, mitigate, or prevent adverse impacts on fishery resources (Lahyer and Maughan, 1985).

As with any management tool, HSI is not a panacea for impact assessment. Many validation studies have shown that HSI models have poor predictive power in relating fish standing stocks to physicochemical variables (Helm, 1984; Pajak and Neves, 1987; Wesche et al., 1987). Knowledge of a species' requirements is often inadequate, which can have a substantial effect on the predictive power of the model (McClendon and Rabeni, 1987). One assumption critical to the validity of HSI values is that changes in fish biomass can be predicted from changes in physicochemical variables. Limited evidence supports this assumption (Binns and Eiserman, 1979; Orth and Maughan, 1982; McClendon and Rabeni, 1987), and some is in disagreement (Terrell and Nickum, 1984). Another assumption is that habitat availability limits fish populations (Terrell and Nickum, 1984). HSI procedures were designed to reflect habitat quality, not standing stock (Milner et al., 1985). Others say that HSI values were designed to reflect carrying capacity (Aho et al., 1986; Raleigh et al., 1986).

Many techniques have been used to quantify suitability of substratum for fishes, to include calculation of rates by mass balance (Golterman, 1975), sediment coring (Dennis, 1985), and sediment dating (Krishnaswami and Lal, 1978; Cooper and Bacon, 1980). Another approach is to measure sedimentation with sediment traps (Painter, 1972; Welton and Ladle, 1979; Bloesch and Burns, 1980). Sediment traps will not determine rates of sedimentation, but they will determine the amount of available material to settle in a particular area. Embeddedness, an index of the substratum's suitability for spawning and aquatic invertebrate habitat, rates the extent that large particles (e.g. cobble) are surrounded by fine sediment. As embeddedness increases, biotic productivity is thought to decrease (Platts et al., 1983).

Important Sport Fish Species

Smallmouth Bass

The knowledge of age, growth, food, reproduction, and specific habitat requirements of smallmouth bass and rock bass is needed to conduct this study on the habitat and population characteristics of these species in the Powell River, Virginia.

Smallmouth bass tend to be found in cool, clear, deep pools with a gravel substratum (Sanderson, 1958; Coble, 1975; Pflieger, 1975; Rankin, 1986). This species selects cover of boulders, logs, stumps, and undercut banks (Hubert and Lackey, 1980; Probst et al., 1984), and prefers streams greater than 10.5 m in width (Edwards et al., 1983).

Smallmouth bass inhabit waters with a pH of 5.7 to 9.0 (Clady, 1977; Paragamian, 1979), prefer temperatures of 21 to 27 C (Clancey, 1980), and select water velocities between 15 and 20 cm/s (Rankin, 1986). According to Bulkley (1975) and Spoor (1984), smallmouth need at least 6.0 mg/l dissolved oxygen for optimal growth. High turbidity and sedimentation can cause a decline in smallmouth bass populations (Coutant, 1975). Edwards et al. (1983) states that the optimum Jackson Turbidity Units (JTU's) should be less than 25, and the total dissolved solids should be between 100 and 375 mg/l.

Smallmouth bass usually spawn from late-April to mid-July depending on location and water temperature (Graham and Orth, 1986). Nest building occurs on a substratum of stone, rock, or gravel in shoals, shallows, or backwaters (Cleary, 1956; Sanderson, 1958; Coble, 1975). Smallmouth bass start nest excavation around boulders, logs, or stumps when the water temperature reaches 12.8 C (Turner and MacCrimmon, 1970; Scott and Crossman, 1973; Coble, 1975; Shuter et al., 1980).

Adult smallmouth bass feed on crayfish and fish, with crayfish predominating in the diet (Doan, 1940; Reynolds, 1965; Coble, 1975; Miner, 1978; Probst et al., 1984; Austen and Orth, 1985; Roell and Orth, 1988). Juveniles feed on large insects, crayfish, and fish (Lachner, 1950; George and Hadley, 1979), and fry feed on microcrustaceans (Beeman, 1924; Applegate et al., 1967). According to Stein and Magnuson (1976), when crayfish are in the presence of smallmouth bass there is a distinct behavioral change by crayfish. Crayfish decrease their diurnal activity, decrease use of sand substratum, and increase use of gravel and pebble substrata. Smallmouth bass predation on crayfish is partially regulated by handling and searching time, but also by bioenergetic return (Stein, 1977; Probst et al., 1984). Stein (1977) found that smallmouth bass prefer the smallest and least aggressive crayfish such as females, juveniles, and recent molts.

During the first year of study, a reconnaissance of the Powell River was conducted and it was determined that conditions of the river fit into the ranges of habitat variables of smallmouth bass described above.

Rock Bass

Rock bass tend to occur in pools with gravel, sand, or rock substrata in medium-size streams (Gerking, 1953; Cook, 1959). This species prefers a stream gradient of 0.6 to 4.5 m/km (Burton and Odum, 1945; Lee and Nelson, 1987), and a velocity <0.6 m/s (Lee and Nelson, 1987). These fish prefer cover (logs, rootwads, etc.), but vegetation is very important as a nursery area (Bailey, 1955; Lee and Nelson, 1987).

The optimum turbidity for rock bass is <25 JTU. Because of excess turbidity, many spawning and feeding sites have been destroyed in Illinois steams (Smith, 1971). Rock bass reside in streams with pH of 4 to 7, and a pH < or equal to 3 is lethal (Lee and Nelson, 1987). This species prefers a carbonate concentration of 5.0 to 19.0 mg/l (Lee and Nelson, 1987). Dissolved oxygen concentrations < 2.0 mg/l are fatal, but levels > 3.09 mg/l are nonlethal to rock bass (Moore, 1942). This species prefers a temperature of 20 to 30 C (Reynolds and Casterlin, 1978).

Depending on location and water temperature, individuals usually spawn from May to July (Lee and Nelson, 1987). Spawning takes place when water temperature is between 19.5 C and 26.0 C (Tyus, 1970; Gross and Nowell, 1980; Lee and Nelson, 1987). Nest building occurs in shallow water, 30 to 150 cm deep (Carbine, 1939), on a substratum of gravel or sand (Cook, 1959; Gross and Nowell, 1980).

Rock bass grow faster in the southern part of their range. Growth is positively correlated with summer water temperatures, growing season, water hardness, and pH (Hile, 1941a; 1941b; Ryan and Harvey, 1977). Growth is also correlated with gradient; slowest in the headwaters and most rapid downstream (Hile, 1941b). According to Becker (1983), males grow faster than females after the fourth year, and sexual maturity occurs in both sexes at age 3 (Hile, 1941a).

Adults (> 150 mm) feed on crayfish (Probst et al., 1984; Roell and Orth, 1988), whereas younger individuals (75 to 150 mm) feed on Ephemeroptera, Trichoptera, Odonata nymphs, fish fry, and crayfish (George and Hadley, 1979). Individuals between 20 and 75 mm feed primarily on chironomid larvae, Cladocera, Copepoda, and Ephemeroptera (Keast and Webb, 1966; Glessner, 1977; Keast, 1977; Probst et al., 1984). Adult rock bass and smallmouth bass feed on the same size range and species of food (Marteney et al., 1983).

During the initial study of the Powell River it was determined that conditions of the river fit into the ranges of habitat variables of rock bass described above.

Objectives

Much information is needed to document perturbations that are occurring in the Powell River and to formulate solutions. This project, funded by the Virginia Department of Game and Inland Fisheries, was initiated to survey the major sport fish populations and their habitats, evaluate the possible effects of sedimentation on these populations, and quantify the amount of sediment and waterborne material in the Powell River, Virginia.

Specific objectives of this study were as follows:

1. Quantify and compare sediment depth, percent of sediment as coal, embeddedness, and waterborne sediment in pools, runs and riffles of the North Fork Powell River and at 9 selected sites in the Powell River differing in sediment impacts.
2. Determine, compare, and relate sediment characteristics to abundance, age class structure, condition, and growth rates of smallmouth bass and rock bass in the North Fork Powell River and at 9 selected sites in the Powell River.
3. Assess abundance of prey species and diet composition of smallmouth bass and rock bass at 9 selected sites in the Powell River.

Materials and Methods

Study Area

During the summer of 1987, nine sampling sites were selected in the Powell River and one in the North Fork Powell River (Figure 1). Three sites were located upstream of the North Fork to monitor the effects of coal mining in the upper watershed on the main-stem Powell River (upstream reach). Three sites were located below the North Fork (midstream reach) to monitor the possible effects of this tributary and its watershed, which supports an intensive amount of coal mining. Also, three sites were located in the lower Powell River (downstream reach) near the Tennessee state line (Table 1). This reach supports state and federally threatened and endangered species and based upon initial viewing, appeared to have less sedimentation and perturbations than either of the other reaches. Sites were selected on the basis of 1) ease of access, 2) well-developed riffle, run, and long pool habitat types, and 3) low fishing pressure.

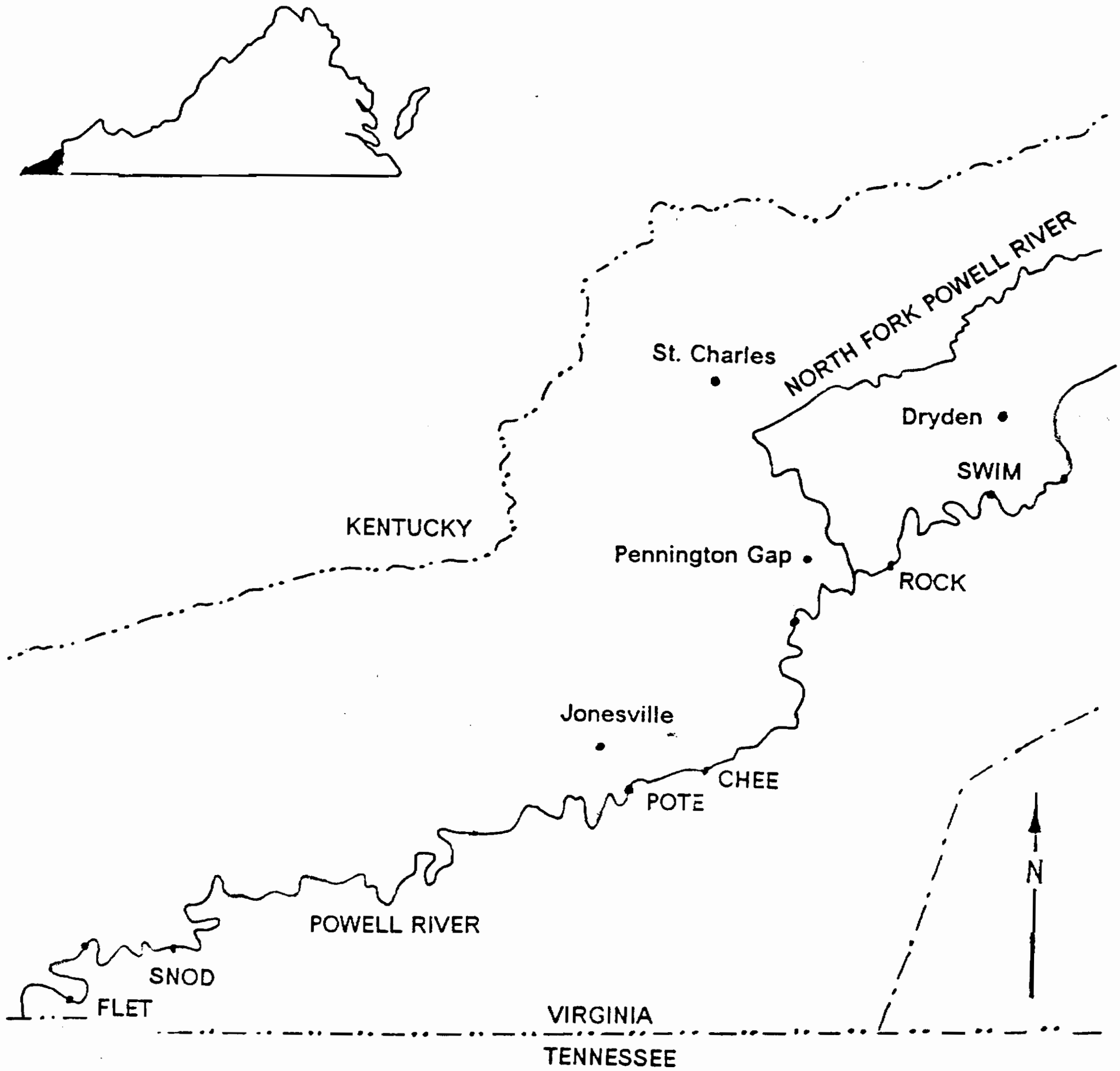

Figure 1. Sampling sites in the Powell River, Virginia.

Table 1. Sampling sites in the Powell River, Virginia.

Name	Reach	Site number	River mile	Stream order	Stream width (m)	Site length (m)	Distance between sites (km)
Olinger	1	1	172.2	5	23.8	389	
							14.8
Swim Hole	1	2	163.0	5	27.1	506	
							6.0
Rock Road	1	3	159.3	5	29.8	646	
							10.1
Trash	2	4	153.0	6	29.2	709	
							14.5
Cheek Spring	2	5	145.8	6	27.7	476	
							3.7
Poteet Ford	2	6	143.5	6	26.7	634	
							32.3
Snodgrass	3	7	123.4	6	36.8	677	
							5.0
Beech Grove	3	8	120.3	6	34.4	599	
							4.8
Fletcher	3	9	117.3	6	34.5	492	

Habitat

HSI models for smallmouth bass and rock bass were used to identify habitat variables that were below optimum for these species in the Powell River. Both of these models are hypotheses of species-habitat relationships that determine the suitability of a measured habitat variable by comparing the variable with an observed optimum for the species and variable in question. HSI models for each species consisted of individual suitability indices (SIs) or life requisites (Tables 2, 3). These components were then combined to calculate a HSI value for each site in the Powell River.

Water quality data were collected in pools at each site during the first week of each month, from September 1988 through August 1989. Total alkalinity (mg/l $CaCO_3$) and turbidity (FTU) were measured in the field using a DR-EL 2000 Hach Kit. A Model DR-EL/2 Hach Kit was used to measure pH (Hach Chemical Company, 1977). Dissolved oxygen and temperature were measured with a Yellow Springs Instrument (YSI) Model 58 oxygen meter and polarographic probe. Water level fluctuations were determined from the Hydrologic Information Storage and Retrieval System (1989) at the Jonesville, Virginia, gauging station.

All physical habitat variables were measured at each of the 9 sites in the Powell River to determine HSIs. Measurements were taken at each site (sites consisted of a pool, run, and a riffle) during low flow in June, 1988, because low flows typically limit habitat availability (Stalnaker, 1981). Lengths of pools, runs, and riffles were measured by meter tape. Three transects were located in each riffle and run habitat, and transects were spaced at 50 m intervals in pools. Five sample points were located on each transect as follows: 0.5 m from each bank, the transect center, and 25% of the transect width out from each bank (Hamilton and Bergensen, 1984). Depth was determined at each sample point, and pool areas were determined from maps

Table 2. Life requisites, habitat variables and equations in the smallmouth bass habitat suitability index model (Edwards et al., 1983).

Life requisite	Habitat variable
food (Cf)	(V_1) dominant substrate type (V_2) percent pools (V_3) percent cover
cover (Cc)	(V_1) dominant substrate type (V_2) percent pools (V_4) average depth of pools during midsummer (V_5) percent cover
water quality (Cwq)	(V_6) average pH level during the year (V_8) minimum dissolved oxygen throughout the year (V_9) maximum monthly average turbidity level during the
summer	
	(V_{10}, V_{12}, V_{13}) water temperature (nonbreeding)
reproduction (Cr)	(V_{11}) water temperature (breeding) (V_{14}) water level fluctûation during and 45 days after spawning (V_1) dominant substrate type (V_5) percent cover (V_8) minimum dissolved oxygen level throughout the year (V_9) maximum monthly average turbidity level during the
summer	
other (Cot)	(V_{15}) stream gradient within representative reach

$$Cf = (V_1 \times V_2 \times V_5)^{1/3}$$

$$Cc = \frac{(V_1 \times V_2 \times V_4 \times V_5)}{4}$$

$$Cwq = \frac{(V_6 \times V_8 \times V_9) + 2\,[(V_{10} \times V_{12} \times V_{13})^{1/3}]}{5}$$

$$Cr = (V_{11}^{\,2} \times V_{14} \times V_1 \times V_5 \times V_8 \times V_9)^{1/7}$$

$$Cot = V_{15}$$

$$HSI = (Cf \times Cc \times Cwq \times Cr \times Cot)^{1/5}$$

Table 3. Life requisites, habitat variables, and equations in the rock bass habitat suitability index model (Lee and Nelson, 1987).

Life requisite	Habitat variable
food cover (Cf/c)	(V_{1a}) percent complex cover
	(V_{1b}) percent simple cover
	(V_2) substrate size
	(V_3) percent pools
water quality (Cwq)	(V_4) average turbidity level during the year
	(V_5) minimum dissolved oxygen throughout the year
	(V_6) water temperature (nonbreeding)
	(V_7) average alkalinity during the year
	(V_8) average pH level during the year
reproduction (Cr)	(V_9) water temperature (breeding)
	(V_{10}) average depth of pools
	(V_{11}) substrate size
other (Cot)	(V_{12}) stream gradient within representative reach
	(V_{13}) average current velocity
	(V_{14}) percent stand

$$Cf/c = (V_{1a} \times V_{1b} \times V_2 \times V_3)^{1/4}$$

$$Cwq = (V_4 \times V_5 \times V_6 \times V_7 \times V_8)^{1/5}$$

$$Cr = (V_9 \times V_{10} \times V_{11})^{1/3}$$

$$Cr = (V_{12} \times V_{13} \times V_{14})^{1/3}$$

$$HSI = (Cf/c \times Cwq \times Cr \times Cot)^{1/4}$$

made for each site (Platts et al., 1983). Average velocity was measured at each sample point using a Marsh McBirney Model 201 portable water current meter at 60% of the water column depth (Pajak and Neves, 1987). Dominant and secondary substrata were visually estimated, by percent, at each point (Platts et al., 1983), and the particle size ranges were defined using a modified Wentworth scale (Cummins, 1962): large cobble (128-256 mm), small cobble (64-128 mm), pebble (16-64 mm), gravel (2-16 mm), coarse sand (0.5-2 mm), fine sand (0.0625-0.5 mm), and silt (< 0.0625 mm). Stream gradient was measured to the nearest 1% with an Abney level and staff. To quantify cover, the cover "item" was identified as either rootwads, logs, log complexes, debris complexes, water willow, *Potamogeton*, other aquatic vegetation, overhanging vegetation, undercut banks, rock wall, or boulders (McClendon and Rabeni, 1987). Areas of each cover type were calculated and converted to a per-hectare and percent basis. Also, percent canopy was determined for each site by recording the distance of vegetation overhang along each transect (Platts et al., 1983).

Suitability curves for smallmouth bass and rock bass were used to assign values to variables measured in this study. The values were used to calculate component SIs, which were then combined to calculate an overall HSI value (Edwards et al., 1983; Lee and Nelson, 1987). HSI values were grouped by reach and compared among the three river reaches with a Kruskal-Wallis test.

Sediment

Sediment depths were measured to the nearest centimeter at each of the 9 sites during June 1988 with a meter stick at each sample point on the transect in pools. The meter stick, which was slightly rounded on one end, was inserted into the sediment, and depth of sediment was determined after the stick reached solid material. Embeddedness was visually estimated at each point during June, 1988, according to the rating system of Platts et al. (1983). The rating consisted of numbers 1 to 5, based on the percentage of surface area covered by fine sediment: >75, 50-75, 25-50, 5-25, and <25%, respectively. To quantify the amount of sediment being deposited in the Powell River, four sediment traps per site were used (Painter, 1972; Welton and Ladle, 1979). Each trap was a steel can 15 cm in diameter and 17 cm in height. To minimize change in the streambed, traps were filled with clean cobble from the sampling site. Before placing each trap in the streambed, velocity at the site of placement was determined in order to select similar velocities among sites (2 traps in runs and 2 in pools). Pool sites had zero velocity, whereas run sites had a velocity of almost 15 cm/s. The top of the trap was arbitrarily placed 7 cm above the streambed, and traps were emptied once per month for 12 months, beginning August 1988. Sediment was removed by washing the cobble in a bucket and placing the sediment in bags. The trap was refilled with the same cobble and replaced in the streambed. In the laboratory, the sample was air dried for one month, sieved, and weighed. Results from these traps were used to compare deposition rates at the ten sampling sites in the Powell River with an analysis of variance (ANOVA) test.

Substratum samples were collected with a McNeil-Ahnell hollow core sampler (Platts et al., 1983). Sample depths averaged approximately 16 cm, and sample volume was approximately 300-400 cm^3. Three samples were taken in each riffle and each pool per site. Excess water was decanted from the samples after standing for 24 h in the laboratory; samples were then air-dried and passed through a series of USGS sieve screens and weighed to determine percent (by weight) silt, sand, gravel, pebbles, and cobble according to the modified Wentworth scale (Cummins, 1962). Coal was separated from each fraction using float-sink separation methods (American Society for Testing and Materials, 1987). High-density liquids (perchloroethylene and Hevigrav) were used to obtain a specific gravity of 1.8. The sediment sample was added to the solution and the coal, which floated to the surface, was screened off, air dried, and weighed.

I compared sediment depth in pools and waterborne sediment upstream, in the North Fork, midstream, and downstream reaches to determine trends in sedimentation. Sediment depth and embeddedness indices were analyzed by a Kruskal-Wallis test. Waterborne sediment, sediment fractions, and percent coal are proportional, and an arcsine transformation was used to normalize data before it was analyzed by ANOVA. The null hypothesis was that there were no differences in sediment depth, embeddedness, waterborne sediment, sediment fractions, and percent coal among the three river reaches and the North Fork.

Population Characteristics

Smallmouth bass, rock bass, spotted bass, redbreast sunfish, and longear sunfish were sampled quantitatively at each of the 9 study sites in the Powell River from mid-July to mid-August 1988. Fish were captured from a 4.6 m jon boat equipped with a 220-V AC electrofishing unit and a hoop anode array. Electrical outputs averaged 9 amps and 300 volts. Electrofishing proceeded from the lower riffle up the right ascending bank, across the upper riffle, and down through the middle. With the electrical field engaged at all times, electrofishing continued across the lower riffle and up the left ascending bank before reshocking the left and right banks. The time spent electrofishing was distributed uniformly over the entire site. Netted fish were placed in a large wash tub and processed every 30 min for a total of approximately 2 h shocking at each site on each date. Each site was sampled twice, with approximately 10 days elapsing between sample dates. This procedure was repeated in October 1989 to determine yearly variation in relative abundance and population size of smallmouth bass and rock bass.

Sampled fish were placed in a 5% benzocaine solution before measuring lengths to the nearest 1 mm and weights to the nearest 1 g. A scale sample was taken at this time for age and growth determination. To obtain population estimates of smallmouth bass and rock bass, a unique fin-ray scar was applied to the fish (Pajak and Neves, 1987). Fish were allowed to recover fully (15 min) prior to release. Virtually no immediate mortality was observed, but fish that did die were eliminated from the Petersen population estimate procedure to avoid violating assumptions. The application of this estimator was justified since the assumptions were met. On the second sample date, the entire process was repeated, and captured fish were examined for fin-ray scars.

Population estimates were determined by Chapman's version of the Petersen estimate (Ricker, 1975):

$$N=(M+1)x\frac{(C+1)}{(R+1)}$$

where N = size of population, M = number of fish marked, C = catch in the second sampling, and R = number of recaptures.

This formula was used to correct for overestimation of population size that may occur when using the Petersen formula (Ricker, 1975). Population estimates (N/ha) were made for smallmouth bass and rock bass in the Powell River, Virginia. Precision of population estimates, as measured by 95% confidence limits, was calculated by treating the recapture samples as having a Poisson distribution (Ricker, 1975).

Age and growth of smallmouth and rock bass was determined by scale analysis. Non-regenerative scales were selected and impressed on plastic slides by hydraulic press (Jearld, 1983). These slides were projected on a digitizing pad, and ages were determined by locating and counting annuli. Growth was back-calculated using the computer program DISBCAL (Frie, 1982).

Relative weight, an index of condition or relative well-being of fish, was determined using the following expression:

$$Wr = \frac{W}{Ws} \, x \, 100$$

where W = actual weight of a fish and Ws = standard weight of a fish of the same length (Wege and Anderson, 1978).

Standard weights were those determined for smallmouth bass (Anderson, 1980) and rock bass (Covington et al., 1983). Relative weights of each species were compared among reaches using a Kruskal-Wallis test.

I compared catch-per-unit-effort and population sizes in the three river reaches and in the North Fork by comparing numbers of smallmouth bass and rock bass collected. Data were analyzed with a Kruskal-Wallis test to test the null hypothesis that there were no differences in catch-per-unit-effort and population size among the three river reaches. Biomass estimates for smallmouth bass and rock bass per hectare were compared among reaches using a Kruskal-Wallis test. The null hypothesis was that there were no differences in biomass among reaches. Relative weight and growth rates also were compared among reaches using a Kruskal-Wallis test. Age-class structure was compared among reaches with Chi-Square contingency table analysis. The null hypothesis was that there were no differences in these traits of fish among reaches.

Prey Abundance and Diet Composition

To determine prey abundance and diet composition of smallmouth bass and rock bass, stomach contents of the two species were collected by inserting a plastic tube into the stomach and removing the contents with forceps (Van den Avyle and Roussel, 1980). Approximately 10 fish representing each size class of each species were sampled at each site on the second sample date. Contents were stored in 95% ethanol and returned to the laboratory for processing. Prey identity, estimated length of ingested prey, and wet weight of stomach contents were determined for each stomach sample. Differences in diet composition were analyzed with Chi-Square contingency table analysis to test the null hypothesis that there were no differences in diet composition among the three river reaches.

I sampled each of the 10 sites in July, 1989, to estimate the relative abundance of crayfish and hellgrammites. Crayfish and hellgrammites were collected in riffle and run habitats at each site by a kick-seining technique using a 5m long, 4-mm mesh minnow seine (Berkman and Rabeni, 1987). Two kick samples, lasting 15 min each, were taken in each riffle and run for a total of 4 samples per site, with each site encompassing 25 square meters. All crayfish were measured (carapace length), and numbers of crayfish per site were recorded and converted to a per square meter basis to provide abundance estimates and size distributions. Differences in abundance of crayfish and hellgrammites were compared by Kruskal-Wallis test to test the null hypothesis that there were no differences in prey abundance among reaches.

Results

Habitat

Although depth and other morphometric characteristics of the study sites were similar within study reaches, they differed in some aspects. Although not significantly different, riffles in the downstream reach appeared to have had a greater mean and maximum current velocity and a greater mean depth than the other reaches (Table 4). Primary substratum type at all sites was cobble, and the gradient was 1%. Percent canopy appeared to have been greater in the upstream reach than the other reaches for riffles, runs, and pools. Runs in the downstream reach appeared to have had greater mean and maximum current velocities and greater mean depths than the other reaches (Table 5). The primary substrata in runs consisted mainly of pebbles and cobbles. Pools in the downstream reach appeared to have had the greatest mean and maximum current velocities, mean widths, and surface areas (Table 6). The primary substratum in pools at all sites was sand, although the primary substratum at site number 8 (Beech Grove) was gravel.

Habitat sampling at study sites yielded HSI scores for smallmouth bass ranging from 0.67 to 0.76, with a mean of 0.72. Scores for rock bass ranged from 0.65 to 0.70, with a mean of 0.69 (Table 7). Analyses of HSI scores, grouped by study reach, exhibited no significant differences

Table 4. Habitat characteristics of riffles at study sites in the Powell River, Virginia, in 1988.

	Study Site								
Variable	1	2	3	4	5	6	7	8	9
Surface area (ha)	0.12	0.33	0.09	0.18	0.11	0.25	0.09	0.18	0.08
Mean depth (m)	0.27	0.19	0.27	0.33	0.26	0.20	0.27	0.46	0.28
Max. depth (m)	0.42	0.35	0.43	1.00	0.41	0.35	0.27	0.46	0.28
Mean width (m)	12.67	40.80	17.00	26.13	25.20	25.03	22.70	22.77	28.90
Length (m)	97	81	50	67	43	99	39	78	28
Mean velocity (cm/s)	30.5	8.3	20.9	15.5	31.9	42.0	47.5	40.8	31.6
Max. velocity (cm/s)	50.0	21.0	52.0	28.0	45.0	64.0	83.0	50.0	51.0
Substratum									
Silt (%)	0.0	43.1	0.0	3.8	2.7	2.7	1.5	0.0	2.3
Sand (%)	0.0	21.1	14.7	0.0	1.3	0.0	0.0	0.0	1.2
Gravel (%)	0.0	0.0	14.7	10.3	30.7	4.0	0.0	1.5	0.0
Pebble (%)	12.0	3.3	3.9	11.5	11.6	30.7	12.9	21.7	11.5
Cobble (%)	54.7	22.0	64.7	33.3	52.5	62.7	72.8	34.8	83.9
Boulder (%)	33.3	10.6	2.0	30.8	1.3	0.0	2.9	31.9	1.2
Bedrock (%)	0.0	0.0	0.0	10.3	0.0	0.0	10.0	10.1	0.0
Mean canopy (%)	100.0	37.9	100.0	46.1	43.1	55.7	72.8	20.9	27.9

Table 5. Habitat characteristics of runs at study sites in the Powell River, Virginia, in 1988.

Variable	Study Site 1	2	3	4	5	6	7	8	9
Surface area (ha)	0.03	0.19	0.20	0.18	0.12	0.19	0.30	0.03	0.17
Mean depth (m)	0.29	0.41	0.43	0.40	0.31	0.28	0.49	0.45	0.55
Max. depth (m)	0.52	0.70	0.67	0.89	0.44	0.50	0.78	0.71	0.77
Mean width (m)	10.43	30.23	25.20	29.17	25.80	30.67	39.03	29.87	22.93
Length (m)	27	63	78	29	47	31	78	30	74
Mean velocity (cm/s)	31.6	9.1	10.8	7.6	23.4	20.6	19.1	22.0	21.1
Max. velocity (cm/s)	58.0	23.0	28.0	13.0	42.0	43.0	42.0	44.0	37.0
Substratum									
Silt (%)	6.4	10.4	2.7	44.8	3.9	34.4	0.9	0.0	13.1
Sand (%)	0.0	1.1	20.5	0.0	0.0	10.4	23.7	14.8	1.5
Gravel (%)	0.0	0.0	0.0	0.0	10.3	2.2	0.0	0.0	0.0
Pebble (%)	9.0	0.0	1.3	32.2	32.0	21.9	21.9	74.8	31.9
Cobble (%)	60.3	33.3	32.0	21.8	53.8	31.2	42.1	10.4	52.2
Boulder (%)	24.4	55.2	20.5	1.1	0.0	0.0	11.4	0.0	0.0
Bedrock (%)	0.0	0.0	23.1	0.0	0.0	0.0	0.0	0.0	1.5
Mean canopy (%)	88.9	37.4	45.0	50.6	38.9	4.7	26.7	24.0	29.6

Table 6. Habitat characteristics of pools at study sites in the Powell River, Virginia, in 1988.

	Study Site								
Variable	1	2	3	4	5	6	7	8	9
Surface area (ha)	0.63	0.98	1.54	1.69	1.07	1.26	2.06	1.75	1.35
Mean depth (m)	0.86	1.16	1.17	1.32	1.25	1.30	1.02	1.08	1.26
Max. depth (m)	1.64	2.46	1.78	2.05	2.41	2.65	2.60	1.97	1.88
Mean width (m)	23.80	27.14	29.82	29.23	27.74	26.74	36.83	34.36	34.50
Length (m)	265	362	518	579	386	472	560	510	390
Mean velocity (cm/s)	5.1	0.8	0.8	0.0	5.6	3.4	8.6	3.5	5.0
Max. velocity (cm/s)	10.0	7.0	6.0	2.0	16.0	12.0	15.0	8.0	14.0
Substratum									
Silt (%)	11.1	16.0	15.3	16.1	7.9	27.7	5.8	0.9	6.5
Sand (%)	55.8	54.7	59.4	43.6	38.7	38.5	28.9	37.2	35.7
Gravel (%)	6.1	4.5	0.0	0.3	11.6	0.0	8.6	37.7	31.4
Pebble (%)	0.0	0.4	0.0	5.8	3.9	6.9	3.4	18.8	7.9
Cobble (%)	6.1	0.0	4.1	0.6	12.1	4.7	17.4	0.9	5.4
Boulder (%)	13.1	4.9	15.4	11.9	21.1	7.7	20.3	4.0	12.5
Bedrock (%)	7.8	19.5	6.0	21.6	4.8	14.5	15.6	0.6	0.7
Vegetation (m^2/ha)	140.9	111.6	69.3	209.7	69.0	54.2	215.7	127.0	164.6
Woody structure (m^2/ha)	368.7	73.5	888.7	706.6	252.1	501.3	379.5	321.4	767.2
Mean cover (%)	19.1	7.8	25.3	21.3	24.4	14.0	26.4	8.5	21.9
Simple (%)	14.5	6.1	16.2	14.2	22.0	8.3	22.7	5.5	14.3
Complex (%)	4.6	1.7	9.1	7.1	2.4	5.7	3.7	3.0	7.6
Mean canopy (%)	31.3	49.9	58.0	34.7	29.2	37.5	40.8	27.3	42.3

Table 7. HSI values and model component suitability indices for smallmouth bass and rock bass at each study site in the Powell River, Virginia, in 1988.

Variable	Study Site 1	2	3	4	5	6	7	8	9
Smallmouth bass									
HSI	0.71	0.67	0.71	0.74	0.76	0.72	0.75	0.67	0.74
Component SI									
Food	0.51	0.40	0.51	0.50	0.53	0.48	0.51	0.39	0.49
Cover	0.60	0.64	0.55	0.70	0.74	0.69	0.72	0.56	0.69
Water Quality	0.97	0.97	0.97	0.98	0.97	0.99	0.99	0.98	0.98
Reproduction	0.63	0.56	0.66	0.64	0.66	0.61	0.66	0.61	0.65
Other	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Rock bass									
HSI	0.70	0.69	0.70	0.70	0.70	0.69	0.70	0.65	0.69
Component SI									
Food/Cover	0.35	0.33	0.36	0.35	0.34	0.35	0.34	0.26	0.35
Water Quality	0.91	0.93	0.92	0.96	0.96	0.92	0.93	0.92	0.92
Reproduction	0.77	0.74	0.74	0.70	0.72	0.70	0.77	0.76	0.72
Other	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

among reaches for either smallmouth bass (P=0.298) or rock bass (P=0.434). The component mean (range SIs for smallmouth bass were as follows: 1) food, x = 0.48 (0.39-0.53); 2) cover x = 0.65 (0.55-0.75); 3) water quality, x = 0.98 (0.97-0.99); 4) reproduction, x = 0.63 (0.56-0.66); and 5) other, 1.00. Rock bass SI means (ranges) were: 1) food/cover, x = 0.34 (0.26-0.36); 2) water quality, x = 0.93 (0.91-0.96); 3) reproduction, x = 0.74 (0.70-0.77); and 4) other, 1.00. The suitability index for substratum, of which sand was dominant in pools, was 0.21 for smallmouth bass and 0.20 for rock bass. These were the lowest suitability values among the variables measured (see Appendices A and B).

Mean discharge (7.96 m^3/s) during 1988 near Jonesville, Virginia, was much lower than the mean (16.00 m^3/s) from 1968 to 1988 according to hydrologic data available for the Powell River (Hydrologic Information Storage an Retrieval System, 1989). Water level fluctuations in pools ranged from 0 to approximately 2 meters during the April, May, and June 1989 sampling periods, and the suitability index for water level fluctuation was 0.30.

Maximum water temperatures (23.0 - 27.0 C) occurred in July, while minimum water temperatures (3.5-5.0 C) did not occur until December (Table 8). Although not significantly different, dissolved oxygen and pH regimes appeared to be similar among sites, alkalinity appeared to have increased and turbidity appeared to have decreased in the downstream reach. Turbidity was underestimated because sampling did not occur during high flows when discharge was greater than 28.32 m^3/s.

Sediment

Kruskal-Wallis tests indicated no significant differences among reaches for sediment depth in pools (P=0.061). Although not significantly different, depth of pool sediment appeared

Table 8. Annual means and ranges (in parentheses) of selected water quality parameters in the Powell River, Virginia, from September 1988 through August 1989.

	Study Site									
Variable	1	2	3	NF	4	5	6	7	8	9
Temperature (°C)	11.3 (3.5-23.8)	11.4 (3.5-23.0)	12.2 (4.0-25.3)	11.3 (4.0-24.1)	12.2 (4.0-25.2)	12.4 (4.5-25.0)	12.4 (4.5-27.0)	12.4 (5.0-27.0)	12.7 (5.0-26.5)	12.8 (5.0-26.5)
Dissolved oxygen (mg/l)	11.7 (7.9-13.2)	11.3 (7.4-13.1)	11.5 (7.6-12.0)	11.1 (8.5-11.8)	11.2 (7.4-11.8)	11.3 (7.8-11.7)	11.3 (7.5-11.2)	11.2 (8.4-12.1)	10.9 (8.2-12.1)	10.5 (8.0-11.8)
Alkalinity (mg/l $CaCO_3$)	89.8 (54.0-98.0)	86.9 (64.0-91.0)	86.3 (71.0-84.0)	61.4 (39.0-90.0)	79.5 (78.0-91.0)	84..6 (81.0-97.0)	86.9 (80.0-93.0)	98.5 81.0-112.0)	100.5 (82.0-113.0)	101.6 (85.0-112.0)
pH	8.0 (7.0-8.9)	7.9 (7.1-8.3)	8.0 (7.2-8.3)	7.8 (7.0-8.1)	7.8 (7.1-8.0)	7.9 (7.3-8.2)	8.1 (7.3-8.3)	8.0 (7.4-8.4)	8.1 (7.4-8.4)	8.1 (7.4-8.5)
Turbidity (FTU)	7.0 (0-17.0)	4.9 (0-10.0)	3.1 (0-7.0)	5.5 (0-13.0)	4.4 (0-6.0)	4.4 (0-12.0)	4.3 (0-9.0)	5.0 (0-25.0)	4.2 (0-18.0)	3.6 (0-14.0)

NF - North Fork Powell River

Table 9. Mean sediment depth (cm) in pools and embeddedness (1-5 scale) in the Powell River, Virginia, 1988.

Variable	Study Site 1	2	3	4	5	6	7	8	9
Sediment depth	25.5	26.5	16.4	14.7	17.7	25.9	3.2	12.6	7.4
Embeddedness									
Pool	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Run	1.00	1.00	1.01	1.00	1.00	1.11	2.16	2.16	2.13
Riffle	1.21	1.00	2.21	1.00	2.11	3.36	3.51	3.52	3.90

to decline downstream, except for site 8 (Table 9). This site appeared to have had a greater sediment depth than all other downstream sites, with a mean of 12.6 cm. Site 2 (PRM 163.0) appeared to have had the greatest sediment depth of any site. Site 7 (Snodgrass Ford) appeared to have had the lowest sediment depth in pools; however, pool velocity appeared to have been greater than at any other site, and mean depth was extremely low. It appeared that site 9 (Fletcher Ford) had the second lowest sediment depth. The embeddedness index in pools (=1.0), riffles (P=0.063) and runs (P=0.051) was not significantly different among the three river reaches.

Since much of the river's substratum appears to be unstable, many sediment traps were dislodged and never retrieved after periods of heavy rainfall that occurred in the winter and spring of 1989. Therefore, only the summer and fall seasons were used for data analysis (Table 10). ANOVA tests showed significant differences among reaches in total sediment deposited in pools (P=0.036), but no differences in runs (P=0.399).

The McNiel-Ahnell substrate sampler was inadequate for effectively sampling substratum. Sampling problems occurred in pools where deep areas were sampled, and in riffles where large substrata were encountered. Overall, silt and sand measurements may be slightly underestimated because of losses from the sampler. However, methods were consistent among sites and were adequate for comparison (Table 11). No significant differences were found among riffles in percent small cobble (P=0.600), pebble (P=0.257), or gravel (P=0.635). ANOVA tests showed significant differences among sites for coarse sand (P=0.020), fine sand (P=0.001), and silt (P=0.006); however, coarse sand, fine sand, and silt showed no significant differences among reaches. In pools, no significant differences were found among sites for percent small cobble (P=0.133) and pebble (P=0.197). ANOVA tests showed significant differences among sites for gravel (P=0.001), coarse sand (P=0.005), fine sand (P=0.002), and silt (P=0.011), but none

Table 10. Mean dry weight (g) of waterborne material deposited in sediment traps (15-cm diameter) by month in the Powell River, Virginia, in 1989.

Site	Month Aug.	Sept.	Oct.	Nov.	Dec.
Pool					
1	264	173	93	52	91
2	157	111	61	45	81
3	217	99	56	*	*
NF	137	378	318	25	283
4	287	234	61	21	80
5	510	107	104	21	184
6	148	115	80	16	629
7	73	100	44	12	77
8	141	73	61	18	253
9	93	87	59	17	354
Run					
1	447	260	142	119	574
2	221	158	74	40	321
3	706	124	151	*	*
NF	153	261	476	32	491
4	471	234	73	42	419
5	165	141	44	56	777
6	145	230	139	43	708
7	90	65	161	21	514
8	518	153	66	34	509
9	203	199	59	30	618

NF = North Fork Powell River
*Sample not taken

Table 11. Means percent of size fractions in substratum samples, calculated from total sample weight in the Powell River, Virginia, in 1989.

	Study Site									
Variable	1	2	3	NF	4	5	6	7	8	9
Riffle										
Small cobble	27.2	31.8	11.4	25.7	9.6	12.9	23.5	5.3	16.3	9.2
Pebble	30.6	40.5	29.5	36.1	42.8	43.5	35.2	19.9	31.0	30.2
Gravel	23.2	20.5	26.2	23.1	28.0	19.5	23.7	23.5	25.0	28.0
Coarse sand	18.5	5.0	32.2	14.0	9.0	10.6	11.2	19.8	19.7	14.9
Fine sand	0.4	2.1	0.6	0.9	10.4	13.2	6.3	31.2	7.8	17.4
Silt	0.1	0.1	0.1	0.2	0.2	0.3	0.1	0.3	0.2	0.2
Total coal*	8.1	0.9	7.2	1.3	2.9	1.3	1.1	5.4	1.7	2.9
Pool										
Small cobble	8.0	12.7	0.0	16.2	21.1	21.6	10.0	3.3	7.7	2.2
Pebble	31.3	23.0	31.0	32.6	38.9	18.3	43.3	17.9	36.8	36.1
Gravel	24.0	9.3	38.2	27.3	24.7	21.1	32.8	53.6	19.5	25.2
Coarse sand	33.4	6.9	27.3	27.2	11.0	11.1	5.1	18.0	8.4	7.8
Fine sand	2.9	47.7	3.2	1.5	4.1	27.3	8.4	6.8	26.8	28.2
Silt	0.4	0.4	0.3	0.2	0.2	0.6	0.4	0.4	0.8	0.5
Total coal*	10.6	2.5	37.9	2.7	4.7	2.6	1.8	47.5	3.3	1.9

NF - North Fork Powell River

* - total coal is included in all fractions

of the fractions differed among reaches. The primary size fraction in substratum samples by weight was cobble for riffle and run samples, and sand for pool samples. Although not significantly different, site 7 appeared to have had the greatest amount of fine sand in riffle samples, and site 2 appeared to have had the greatest amount in pools. The percent of total coal among sites was significantly different in pools (P=0.034) and riffles (P=0.048). Site 7 appeared to have had the greatest amount of coal in the pool sample, and site 1 (Olinger) appeared to have had the greatest in the riffle sample. Coal was found in all fractions, but most often in the gravel fraction, ranging from 26.7 to 77.1% of total coal in pool samples and 17.0 to 67.6% in riffle samples (Table 12). Because coal is approximately half the weight of non-coal substrata of equal volume, weight data underestimated the volume of coal in the substratum, and this should be noted when interpreting coal waste data presented by weight.

Population Characteristics

No significant differences were found in catch-per-unit-effort of rock bass (P=0.411) or smallmouth bass (P=0.924) among reaches in either year (Tables 13, 14). Values for catch-per-unit-effort and population estimates taken in 1988 and 1989 were pooled. Although not significantly different, a trend was apparent, however, in mean catch-per-unit-effort of smallmouth bass and rock bass; namely, greatest values appeared to have occurred downstream (smallmouth bass = 2.6/h, rock bass = 15.2/h) and lowest in the midstream reach (smallmouth bass = 2.2/h, rock bass = 9.0/h). It appeared that the greatest catch-per-unit-effort of smallmouth bass (6.9/h) occurred at site 2, where the greatest sediment depth was observed. It appeared that the greatest catch-per-unit-effort of rock bass (25.6/h) occurred at site 9, where the the second lowest sediment depth among sites was observed. The greatest catch-per-unit-effort of spotted bass (4.7/h) and redbreast sunfish (43.0/h) appeared to have occurred in the upstream

Table 12. Means percent of size fractions of coal from substratum samples calculated from total sample weight in the Powell River, Virginia, 1988.

	Study Site									
Variable	1	2	3	NF	4	5	6	7	8	9
Riffle										
Pebble	29.4	23.6	22.0	30.1	8.6	28.3	18.6	3.6	6.0	14.1
Gravel	50.0	66.9	29.9	17.0	67.9	42.1	62.4	61.1	67.6	54.6
Coarse sand	20.2	7.8	47.7	50.7	22.0	21.6	16.7	33.7	24.5	28.8
Fine sand	0.3	1.2	0.4	2.0	1.4	7.7	2.3	1.6	1.8	2.4
Silt	0.1	0.5	0.0	0.2	0.1	0.3	0.2	0.0	0.1	0.1
Pool										
Pebble	17.0	10.2	32.4	22.4	23.0	17.1	14.1	16.1	2.3	0.0
Gravel	48.5	34.5	44.6	48.2	65.8	41.7	59.5	77.1	26.7	27.9
Coarse sand	32.3	48.8	21.5	28.6	10.5	31.6	21.3	6.0	61.5	64.1
Fine sand	2.2	6.3	1.4	0.8	0.6	9.4	4.9	0.7	9.3	7.8
Silt	0.0	0.2	0.1	0.0	0.1	0.2	0.2	0.1	0.2	0.2

NF - North Fork Powell River

Table 13. Catch-per-unit-effort (CPUE) and 95% confidence intervals (C.I.) of smallmouth bass in the Powell River, Virginia, 1988-89.

Study site	Sample time (h)	Life stage	July 1988			October 1989			Combined 1988-89		
			(N)	(CPUE)	(C.I.)	(N)	(CPUE)	(C.I.)	(N)	(CPUE)	(C.I.)
1	3.00	A	1	0.3	0.1-0.9	2	0.7	0.3-1.4	2	0.5	0.2-1.2
		T	4	1.3	0.7-2.2	6	2.0	0.2-7.2	5	1.7	1.0-2.7
2	3.75	A	14	3.7	2.6-5.1	4	1.1	0.5-2.0	9	2.4	1.5-3.6
		T	26	6.9	2.8-14.4	18	4.8	3.5-6.4	22	5.9	2.1-13.0
3	4.25	A	1	0.2	0.0-0.7	*	*	N/A	N/A	N/A	N/A
		T	16	3.8	2.7-5.2	*	*	N/A	N/A	N/A	N/A
4	4.25	A	1	0.2	0.0-0.7	1	0.2	0.0-0.7	1	0.2	0.0-0.7
		T	8	1.9	1.2-3.0	12	2.8	1.9-4.0	10	2.4	1.5-3.6
5	3.75	A	7	1.9	1.2-3.0	*	*	N/A	N/A	N/A	N/A
		T	10	2.7	1.8-3.9	*	*	N/A	N/A	N/A	N/A
6	3.75	A	4	1.1	0.5-2.0	13	3.5	2.4-4.9	9	2.3	1.5-3.4
		T	8	2.1	1.3-3.2	32	8.5	3.6-15.9	20	5.3	1.8-11.9
7	4.50	A	4	0.9	0.4-1.7	*	*	N/A	N/A	N/A	N/A
		T	8	1.8	1.1-2.8	*	*	N/A	N/A	N/A	N/A
8	4.50	A	5	1.1	0.5-2.0	4	0.9	0.4-1.7	5	1.0	0.1-5.6
		T	9	2.0	0.2-7.2	20	4.4	3.2-5.9	15	3.2	2.2-4.5
9	4.50	A	11	2.4	1.5-3.6	11	2.4	1.5-3.6	11	2.4	1.5-3.6
		T	17	3.9	2.8-5.3	39	8.7	3.7-16.0	28	6.3	2.6-13.4

A - adult fish only ($\geq$ age 3)
T - total
* - sample not taken
N/A - not applicable

Table 14. Catch-per-unit-effort (CPUE) and 95% confidence intervals (C.I.) of rock bass in the Powell River, Virginia, 1988-89.

Study site	Sample time (h)	Life stage	July 1988			October 1989			Combined 1988-89		
			(N)	(CPUE)	(C.I.)	(N)	(CPUE)	(C.I.)	(N)	(CPUE)	(C.I.)
1	3.00	A	8	2.7	1.8-3.9	5	1.6	0.9-2.6	7	2.2	1.4-3.3
		T	12	4.0	1.0-10.2	6	2.0	0.2-7.2	9	3.0	2.0-4.3
2	3.75	A	43	11.5	5.8-20.2	31	8.3	4.2-16.2	37	9.9	4.6-18.3
		T	49	13.1	6.9-22.4	45	12.0	6.2-21.0	47	12.6	6.6-21.8
3	4.25	A	30	7.1	2.8-14.5	*	*	N/A	N/A	N/A	N/A
		T	46	10.8	5.3-19.5	*	*	N/A	N/A	N/A	N/A
4	4.25	A	16	3.8	2.7-5.2	31	7.3	3.0-14.7	24	5.6	1.9-12.6
		T	46	10.8	5.3-19.5	41	9.7	4.5-18.1	44	10.3	4.9-18.8
5	3.75	A	36	9.6	4.4-17.8	*	*	N/A	N/A	N/A	N/A
		T	43	11.5	5.8-20.2	*	*	N/A	N/A	N/A	N/A
6	3.75	A	14	3.7	2.6-5.1	25	6.7	2.7-14.2	20	5.2	1.7-11.9
		T	18	4.8	3.5-6.4	33	8.8	3.8-16.1	26	6.8	2.7-14.2
7	4.50	A	43	9.6	4.4-17.8	*	*	N/A	N/A	N/A	N/A
		T	52	11.6	5.8-20.3	*	*	N/A	N/A	N/A	N/A
8	4.50	A	29	6.4	2.7-13.5	23	5.1	1.7-11.9	26	5.8	2.0-12.9
		T	38	8.4	4.3-16.3	37	8.2	3.6-16.1	38	8.3	3.6-16.2
9	4.50	A	89	19.8	12.8-30.6	47	10.4	12.4-19.0	68	15.1	8.5-25.0
		T	115	25.6	17.4-37.6	81	17.9	9.4-28.3	98	21.8	14.3-33.1

A - adult fish only (≥ age 3)
T - total
* - sample not taken
N/A - not applicable

Table 15. Catch-per-unit-effort (CPUE) and 95% confidence intervals (C.I.) of spotted bass in the Powell River, Virginia, 1988-89.

Study site	Sample time (h)	Life stage	July 1988			October 1989			Combined 1988-89		
			(N)	(CPUE)	(C.I.)	(N)	(CPUE)	(C.I.)	(N)	(CPUE)	(C.I.)
1	3.00	A	4	1.3	0.3-6.1	12	4.0	1.0-10.2	8	2.7	0.7-8.2
		T	14	4.7	1.9-9.4	23	7.6	3.8-15.2	19	6.2	2.8-13.4
2	3.75	A	5	1.3	0.3-6.2	5	1.4	0.3-6.3	5	1.4	0.4-6.4
		T	15	4.0	1.0-10.2	10	2.6	0.8-8.2	13	3.3	3.1-7.3
3	4.25	A	1	0.2	0.0-4.3	*	*	N/A	N/A	N/A	N/A
		T	2	0.5	0.0-4.4	*	*	N/A	N/A	N/A	N/A
4	4.25	A	4	0.9	0.1-5.5	6	1.4	0.3-6.3	5	1.3	0.3-6.2
		T	7	1.7	0.4-6.8	13	3.1	3.0-5.0	10	2.4	0.6-7.9
5	3.75	A	2	0.5	0.0-4.4	*	*	N/A	N/A	N/A	N/A
		T	4	2.1	0.5-7.5	*	*	N/A	N/A	N/A	N/A
6	3.75	A	3	0.8	0.0-5.2	5	1.3	0.3-6.2	4	1.1	0.2-5.7
		T	8	2.1	0.5-7.5	21	5.6	4.9-8.1	15	3.9	0.0-10.0
7	4.50	A	3	0.7	0.0-5.0	*	*	N/A	N/A	N/A	N/A
		T	3	0.7	0.0-5.0	*	*	N/A	N/A	N/A	N/A
8	4.50	A	2	0.4	0.0-4.6	3	0.7	0.0-5.0	3	0.6	0.0-4.7
		T	5	1.1	0.2-5.7	10	2.2	0.6-7.7	2	1.7	0.4-6.8
9	4.50	A	2	0.4	0.0-4.6	4	0.9	0.1-5.5	3	0.7	0.0-5.0
		T	4	0.9	0.1-5.5	4	0.9	0.1-5.5	4	0.7	0.0-5.0

A - adult fish only ($\geq$ age 3)
T - total
* - sample not taken
N/A - not applicable

Table 16. Catch-per-unit-effort (CPUE) and 95% confidence intervals (C.I.) of redbreast sunfish in the Powell River, Virginia, 1988-89.

Study site	Sample time (h)	Life stage	July 1988 (N)	July 1988 (CPUE)	July 1988 (C.I.)	October 1989 (N)	October 1989 (CPUE)	October 1989 (C.I.)	Combined 1988-89 (N)	Combined 1988-89 (CPUE)	Combined 1988-89 (C.I.)
1	3.00	A	86	28.7	19.9-41.3	26	8.8	2.7-14.9	106	18.8	11.2-29.2
		T	129	43.0	31.1-57.9	61	20.4	11.3-29.5	95	31.7	20.5-42.9
2	3.75	A	44	11.7	6.6-20.6	69	18.3	11.0-28.8	57	15.0	8.4-24.8
		T	75	20.0	12.2-30.8	135	36.0	25.1-49.8	105	28.0	18.6-40.4
3	4.25	A	47	11.1	5.5-19.9	*	*	N/A	N/A	N/A	N/A
		T	64	15.1	8.5-30.0	*	*	N/A	N/A	N/A	N/A
4	4.25	A	16	3.8	1.4-10.0	36	8.5	3.7-16.5	26	6.2	2.8-13.4
		T	82	19.3	12.4-30.0	91	21.4	13.3-32.5	44	20.4	12.6-30.4
5	3.75	A	36	9.6	5.1-17.9	*	*	N/A	N/A	N/A	N/A
		T	58	15.5	8.8-25.4	*	*	N/A	N/A	N/A	N/A
6	3.75	A	14	3.7	1.4-9.8	20	5.3	1.9-12.4	17	4.5	1.3-11.0
		T	24	6.4	2.5-13.8	44	11.7	5.9-20.6	34	9.1	4.1-17.3
7	4.50	A	1	0.2	0.0-4.3	*	*	N/A	N/A	N/A	N/A
		T	1	0.2	0.0-4.3	*	*	N/A	N/A	N/A	N/A
8	4.50	A	1	0.2	0.0-4.3	7	1.6	0.4-6.6	4	0.9	0.1-5.5
		T	1	0.2	0.0-4.3	16	3.6	0.8-9.6	9	1.9	0.2-7.0
9	4.50	A	2	0.4	0.0-4.6	6	1.4	0.4-6.4	4	0.9	0.1-5.5
		T	4	0.9	0.1-5.5	20	4.5	1.3-11.0	12	2.7	0.6-8.6

A - adult fish only ($\geq$ age 3)
T - total
* - sample not taken
N/A - not applicable

Table 17. Catch-per-unit-effort (CPUE) and 95% confidence intervals (C.I.) of longear sunfish in the Powell River, Virginia, 1988-89.

Study site	Sample time (h)	Life stage	July 1988 (N)	July 1988 (CPUE)	July 1988 (C.I.)	October 1989 (N)	October 1989 (CPUE)	October 1989 (C.I.)	Combined 1988-89 (N)	Combined 1988-89 (CPUE)	Combined 1988-89 (C.I.)
1	3.00	A	4	1.3	0.1-6.2	8	2.8	0.6-8.5	6	2.1	0.5-7.5
		T	5	1.7	0.2-6.7	8	2.8	0.6-8.5	7	2.3	0.6-7.8
2	3.75	A	31	8.3	3.6-16.3	26	6.9	2.8-14.2	29	7.6	3.1-15.1
		T	38	10.1	4.7-18.6	63	16.9	9.8-27.0	51	13.5	7.3-22.8
3	4.25	A	43	10.1	4.7-18.6	*	*	N/A	N/A	N/A	N/A
		T	61	14.4	8.1-24.1	*	*	N/A	N/A	N/A	N/A
4	4.25	A	49	11.5	5.0-19.1	44	10.4	5.0-19.0	47	11.0	5.4-19.7
		T	86	20.2	12.3-31.2	141	33.2	22.8-46.5	114	26.7	17.5-38.9
5	3.75	A	40	10.7	5.2-19.4	*	*	N/A	N/A	N/A	N/A
		T	69	18.4	11.0-28.9	*	*	N/A	N/A	N/A	N/A
6	3.75	A	22	5.9	2.1-12.9	23	6.1	2.3-13.3	23	6.0	2.2-13.1
		T	42	11.2	5.6-20.1	52	13.9	7.6-23.2	47	12.6	6.6-21.7
7	4.50	A	43	9.6	5.1-17.9	*	*	N/A	N/A	N/A	N/A
		T	62	13.8	7.6-23.2	*	*	N/A	N/A	N/A	N/A
8	4.50	A	53	11.8	6.1-20.8	77	17.1	10.0-27.4	65	14.5	8.1-24.2
		T	92	20.4	12.7-31.3	197	43.8	31.9-58.8	145	32.1	21.9-45.3
9	4.50	A	65	14.4	8.1-24.1	99	21.9	13.7-33.0	82	18.2	10.8-28.6
		T	111	24.7	16.0-36.5	189	42.1	30.4-60.0	150	33.4	23.0-45.9

A - adult fish only ($\geq$ age 3)
T - total
* - sample not taken
N/A - not applicable

reach at site 1 (Tables 15, 16). The greatest catch-per-unit-effort of longear sunfish appeared to have occurred at site 10 (Table 17). In general, the abundance of smallmouth bass and rock bass was similar throughout the Powell River, Virginia.

Mark and recapture data are summarized in Appendices C and D. Population estimates for smallmouth bass and rock bass were not determined for some sites because of 0 recaptures. Of the sites that population estimates were determined, it was apparent that the greatest population estimate of smallmouth bass (54.2/ha) occurred in the upstream reach at site 2, even though this site seemed to have had the greatest sediment depth; the lowest estimate (16.3/ha) appeared to have occurred in the midstream reach at site 5 (Table 18). It was apparent that the greatest population estimate of rock bass (299.4/ha) occurred downstream at site 9, whereas the lowest estimate (35.7/ha) occurred upstream at site 1 (Table 19). It appeared that site 9 had the lowest sediment depth among sites. Population estimates of smallmouth bass and rock bass were not compared due to the low number of population estimates obtained.

Mean biomass estimates of smallmouth bass were not compared due to no recaptures at some sites; however, mean biomass estimates of rock bass per hectare were compared among reaches for the sample taken in 1988 (Table 20). Although not significantly different, the lowest (1.266 kg/ha) and greatest (5.059 kg/ha) biomass estimates of smallmouth bass were obtained from sites 5 and 2, respectively. It was apparent that the greatest (4.976 kg/ha) and lowest (0.522 kg/ha) biomass estimates of rock bass occurred at sites 9 and 1, respectively. There were no significant differences in biomass of rock bass for 1988 ($P=0.56$) among reaches using the Kruskal-Wallis test. Results of biomass data concur with population data; namely, biomass of smallmouth bass and rock bass was similar throughout the river.

Relative weights (Wr) of smallmouth bass ($P=0.144$) and rock bass ($P=0.128$) were not significantly different among reaches. Although not significantly different, median relative weight

Table 18. Population estimates (N), 95% confidence intervals (C.I.) and densities (N/ha) of smallmouth bass in the Powell River, Virginia, 1988-89.

Study site (N/ha)	Area sample (m^2)	Life stage	July 1988 (N)	July 1988 (C.I.)	July 1988 (N/ha)	October 1989 (N)	October 1989 (C.I.)	October 1989 (N/ha)	Combined 1988-89 (N)	Combined 1988-89 (C.I.)	Combined 1988-89
1	6,307	A	*	N/A	*	*	N/A	*	N/A	N/A	N/A
		T	*	N/A	*	*	N/A	*	N/A	N/A	N/A
2	9,826	A	28	19-40	28.1	5	2-12	4.6	17	12-23	16.4
		T	68	54-86	68.6	39	28-53	39.8	54	45-65	54.2
3	15,446	A	*	N/A	*	**	N/A	**	N/A	N/A	N/A
		T	28	19-40	18.1	**	N/A	**	N/A	N/A	N/A
4	16,923	A	*	N/A	*	*	N/A	*	N/A	N/A	N/A
		T	*	N/A	*	*	N/A	*	N/A	N/A	N/A
5	10,707	A	9	4-17	8.4	**	N/A	**	N/A	N/A	N/A
		T	18	11-28	16.3	**	N/A	**	N/A	N/A	N/A
6	12,623	A	*	N/A	*	*	N/A	*	N/A	N/A	N/A
		T	*	N/A	*	*	N/A	*	N/A	N/A	N/A
7	20,623	A	*	N/A	*	**	N/A	**	N/A	N/A	N/A
		T	*	N/A	*	**	N/A	**	N/A	N/A	N/A
8	17,524	A	*	N/A	*	*	N/A	*	N/A	N/A	N/A
		T	*	N/A	*	*	N/A	*	N/A	N/A	N/A
9	13,455	A	*	N/A	*	18	11-28	13.0	N/A	N/A	N/A
		T	*	N/A	*	95	78-116	70.0	N/A	N/A	N/A

A - adult fish only (≥ age 3)
T - total
* - population estimate not obtainable, no recaptures
**- sample not taken
N/A - not applicable

Table 19. Population estimates (N), 95% confidence intervals (C.I.) and densities (N/ha) of rock bass in the Powell River, Virginia, 1988-89.

Study site	Area sample (m^2)	Life stage	July 1988 (N)	July 1988 (C.I.)	July 1988 (N/ha)	October 1989 (N)	October 1989 (C.I.)	October 1989 (N/ha)	Combined 1988-89 (N)	Combined 1988-89 (C.I.)	Combined 1988-89 (N/ha)
1	6,307	A	13	7-22	19.8	*	N/A	*	N/A	N/A	N/A
		T	23	15-34	35.7	*	N/A	*	N/A	N/A	N/A
2	9,826	A	63	48-80	64.3	59	46-74	59.7	61	50-72	62.0
		T	77	62-96	78.4	81	64-101	82.3	79	68-93	80.4
3	15,446	A	124	104-148	80.2	**	N/A	**	N/A	N/A	N/A
		T	168	144-196	108.8	**	N/A	**	N/A	N/A	N/A
4	16,923	A	111	92-134	65.4	126	106-150	74.6	119	105-135	70.0
		T	180	156-208	106.4	203	175-235	120.1	192	173-212	113.3
5	10,707	A	86	79-97	80.6	**	N/A	**	N/A	N/A	N/A
		T	94	77-115	87.4	**	N/A	**	N/A	N/A	N/A
6	12,623	A	30	20-43	23.8	76	61-96	60.3	53	44-64	42.1
		T	42	30-57	33.3	78	62-97	61.9	60	50-72	47.6
7	20,623	A	127	123-171	61.4	**	N/A	**	N/A	N/A	N/A
		T	145	123-171	70.3	**	N/A	**	N/A	N/A	N/A
8	17,524	A	59	46-74	33.4	39	28-53	22.0	49	41-60	27.7
		T	72	57-91	41.1	76	61-96	43.4	74	63-87	42.3
9	13,455	A	413	375-455	305.8	132	111-157	97.8	273	251-297	201.8
		T	428	389-471	317.9	379	343-419	280.9	404	377-433	299.4

A - adult fish only ($\geq$ age 3)
T - total
* - population estimate not obtainable, no recaptures
**- sample not taken
N/A - not applicable

Table 20. Biomass (kg/ha) of fish at each study site in the Powell River, Virginia, in 1988.

Reach	Site	Smallmouth bass	Rock bass
1	1	*	0.522
1	2	5.059	4.056
1	3	1.666	1.831
	$\bar{X}$	*	2.136
2	4	*	0.941
2	5	1.266	2.828
2	6	*	0.921
	$\bar{X}$	*	1.563
3	7	*	1.874
3	8	*	1.762
3	9	*	4.976
	$\bar{X}$	*	2.871

* - biomass not obtainable, no recaptures

appeared to decrease from upstream (92.44) to midstream (90.05) to downstream (84.37) for smallmouth bass (Table 21). Relative weights appeared to increase from upstream (94.58) to midstream (95.57) to downstream (96.43) for rock bass (Table 22). Relative weights of smallmouth bass (P=0.072) and rock bass (P=0.092) were not significantly different than the standard weight value (100.0). Overall, relative weights of smallmouth bass and rock bass were similar throughout the Powell River.

Ages of 89 smallmouth bass and 331 rock bass were determined by scale analysis, and age class structures were compared among reaches using Chi-Square contingency table analysis (Tables 23, 24). Because the Powell River appeared to be less affected in the downstream reach, and survival of age 1 fish may be affected by sedimentation or other pollutants, mortality of age 1 fish would be expected to be greater at the upstream and midstream reaches where sedimentation or pollutants was suspected to be greater. However, neither smallmouth bass (P=0.871) nor rock bass (P=0.197) differed in age class structure among reaches.

Growth rates were computed for each species and compared by length-at-age among reaches. Von Bertalanffy growth equations were used to visually depict growth rates for each species by reach (Figures 2 and 3) and are presented in Appendix E. There were no significant differences between length-at-age for smallmouth bass among reaches for age 1 (P=0.380) and age 2 (P=0.326), but lengths differed significantly among reaches for ages 3 and 4. Lengths of age 3 fish were greater in the upstream (P=0.030) and midstream reach (P=0.009), when compared to those in the downstream reach. There were no significant differences between lengths of age 3 smallmouth bass in the upstream and midstream reaches (P=0.153). When lengths of age 4 smallmouth bass were compared among reaches, only lengths in the upstream reach were greater than lengths in the downstream reach (P=0.019). There were no significant differences between length-at-age of rock bass among reaches for age 1 fish (P=0.378). Lengths of age 2 rock bass were greater in the downstream reach versus the midstream reach (P=0.072);

Table 21. Median relative weights (Wr) for each size class of smallmouth bass in the Powell River, Virginia, in 1988.

Size class	Number of observations	Median relative weight
Upstream reach		
< 193 mm	23	97.1
193-292 mm	10	83.3
> 292 mm	8	90.5
Pooled	41	92.4
Midstream reach		
< 193 mm	14	92.1
193-292 mm	7	88.7
> 292 mm	3	83.8
Pooled	24	90.1
Downstream reach		
< 193 mm	17	82.2
193-292 mm	13	87.4
> 292 mm	8	81.1
Pooled	38	84.4

Table 22. Median relative weights (Wr) for each size class of rock bass in the Powell River, Virginia, in 1988.

Size class	Number of observations	Median relative weight
Upstream reach		
< 91 mm	11	97.4
91-140 mm	31	98.0
>140 mm	45	91.6
Pooled	87	94.6
Midstream reach		
< 91 mm	17	98.6
91-140 mm	40	99.5
> 140 mm	42	90.6
Pooled	99	95.6
Downstream reach		
< 91 mm	10	114.3
91-140 mm	49	96.7
> 140 mm	86	94.2
Pooled	145	96.4

Table 23. Back-calculated lengths (mm) of smallmouth bass in study reaches of the Powell River, Virginia, in 1988.

		Length at age							
Age class	N	1	2	3	4	5	6	7	8
Upstream reach									
1	14	81.5							
2	7	84.4	155.8						
3	7	84.5	148.3	197.7					
4	4	85.2	149.2	201.9	243.4				
5	3	86.6	148.4	215.0	255.7	290.9			
6	0	0.0	0.0	0.0	0.0	0.0	0.0		
7	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
8	1	81.6	117.2	185.5	235.2	275.5	329.8	374.8	409.0
Pooled	36	83.5	147.0	201.5	247.0	287.1	329.8	374.8	409.0
Midstream reach									
1	10	75.9							
2	4	86.4	131.3						
3	6	88.0	128.5	177.2					
4	1	67.3	1206	167.5	232.1				
5	2	75.9	119.4	194.7	242.5	294.6			
Pooled	23	80.4	126.8	178.0	232.6	294.6			
Downstream reach									
1	7	75.8							
2	9	84.9	132.8						
3	7	77.8	120.0	160.5					
4	5	78.0	126.9	174.1	219.2				
5	2	67.4	124.2	169.9	224.5	264.0			
Pooled	30	78.8	126.9	166.7	220.7	264.0			

Table 24. Back-calculated lengths (mm) of rock bass in study reaches of the Powell River, Virginia, in 1988.

		Length at age					
Age class	N	1	2	3	4	5	6
Upstream reach							
1	10	41.1					
2	32	49.0	80.1				
3	12	53.4	84.7	122.0			
4	18	49.3	77.8	111.9	142.7		
5	10	45.1	68.1	95.6	131.3	162.9	
6	5	49.6	72.1	112.4	150.6	183.0	210.6
Pooled	87	49.5	78.2	111.0	140.4	169.6	210.6
Midstream reach							
1	16	52.7					
2	37	49.3	83.6				
3	17	47.6	80.1	114.5			
4	16	48.0	75.9	111.2	144.4		
5	11	49.8	72.9	101.4	132.8	159.0	
6	2	47.4	67.3	99.5	124.1	154.6	187.2
Pooled	99	49.4	79.6	109.6	138.6	158.3	187.2
Downstream reach							
1	11	54.2					
2	48	53.4	86.6				
3	20	50.3	84.0	120.7			
4	33	51.1	80.5	116.5	149.2		
5	31	49.5	76.0	107.5	142.0	168.8	
6	2	49.8	75.3	113.4	143.8	181.7	203.8
Pooled	145	51.6	82.1	114.2	145.7	169.6	203.8

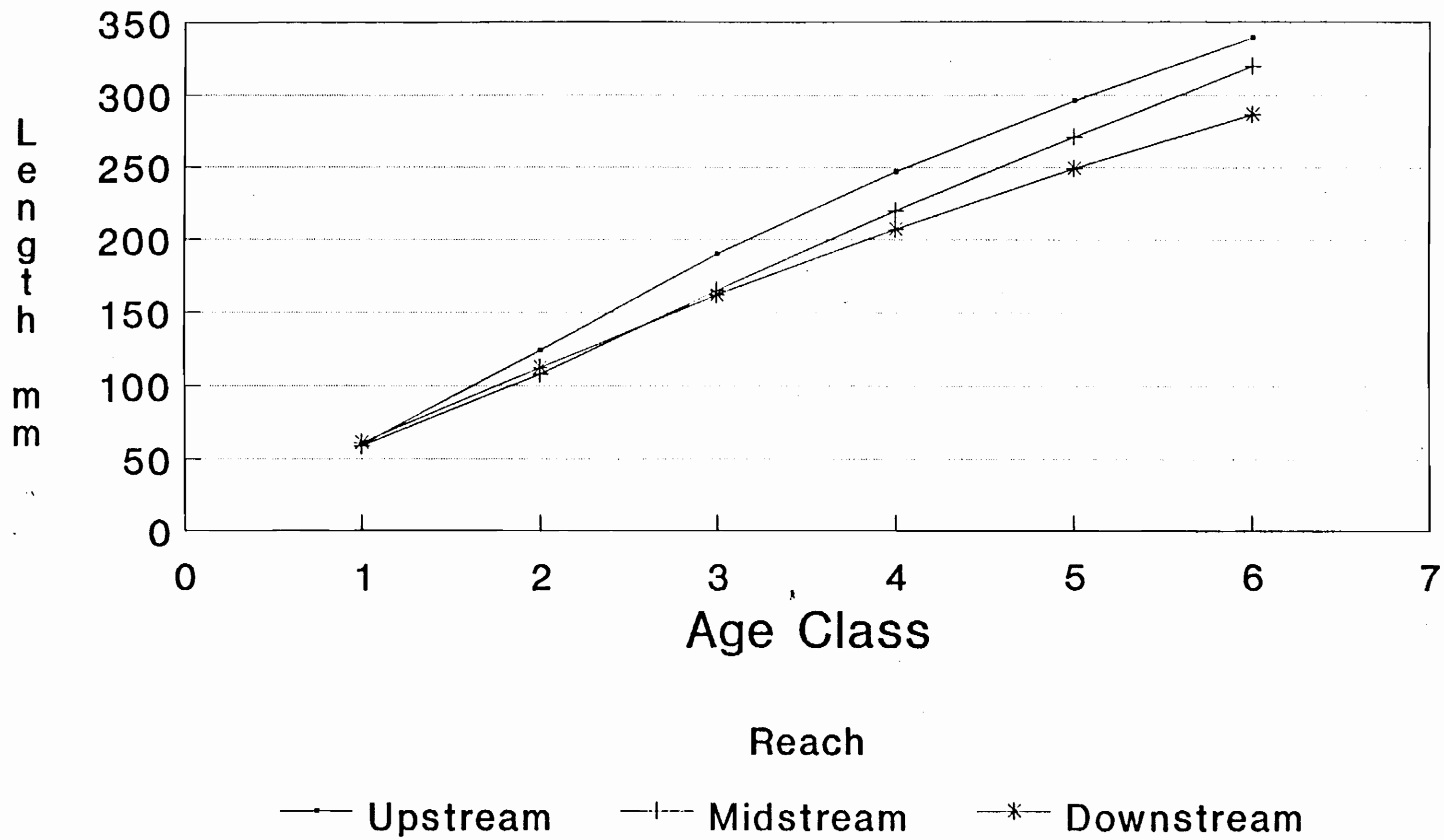

Figure 2. Growth of smallmouth bass in the Powell River, Virginia, in 1988, as calculated by the Von Bertalanffy equation. Lengths of age 3 fish were greater in the upstream and midstream reachs compared to the downstream reach. Lengths of age 4 fish were greater in the upstream reach compared to the downstream reach.

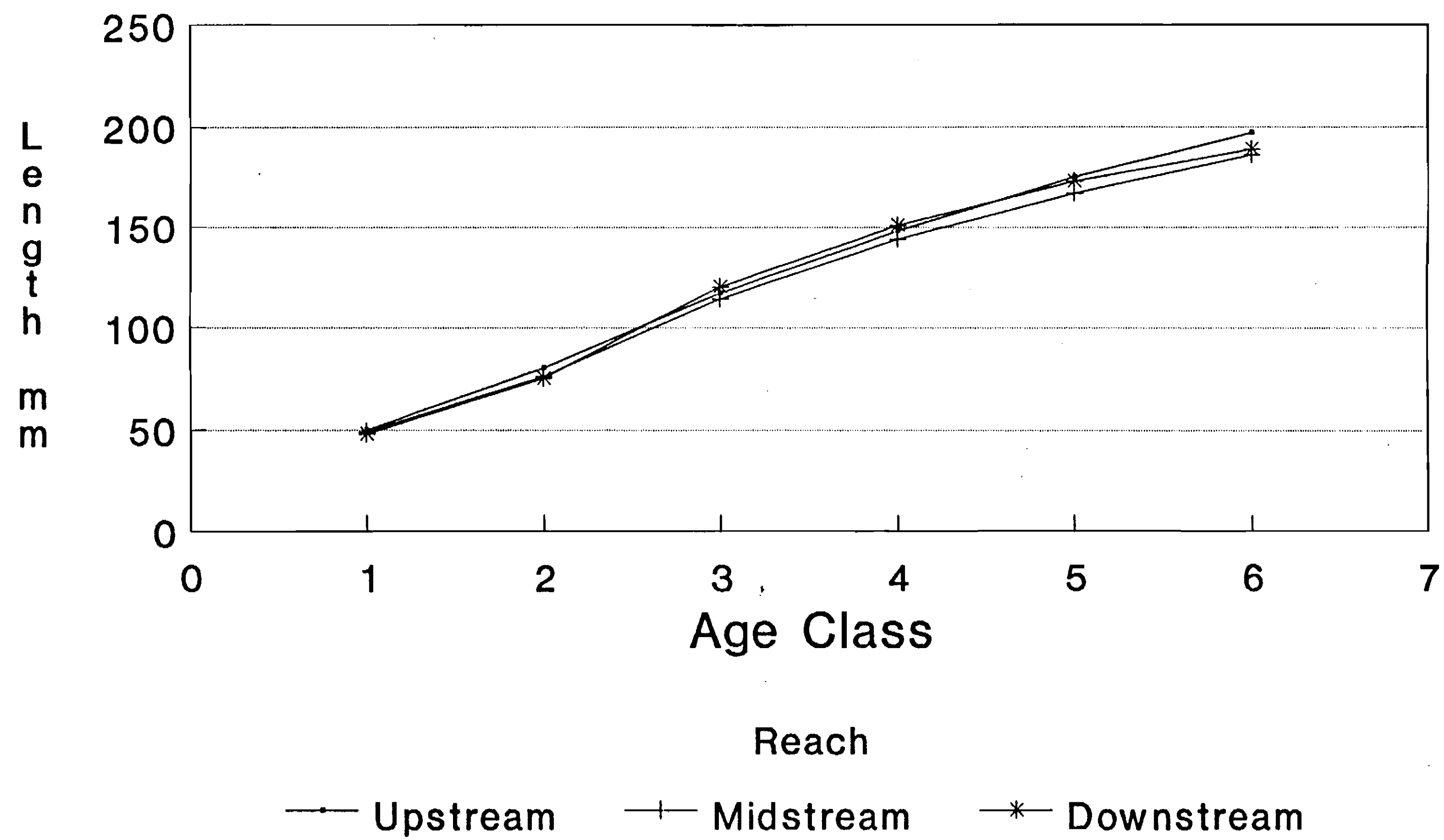

Figure 3. Growth of rock bass in the Powell River, Virginia, in 1988, as calculated by the Von Bertalanffy equation. Lengths of age 2 fish were greater in the downstream reach compared to midstream reach. Lengths of age 3 fish were greater in the upstream reach compared to the midstream reach.

however, lengths of age 2 fish in the upstream and downstream reach were similar (P=0.141). Lengths of age 3 rock bass in the upstream reach were significantly greater than those in the midstream reach (P=0.018), but lengths in the downstream reach were not significantly different than lengths of rock bass in the midstream reach (P=0.072). Also, lengths of age 3 rock bass in the upstream reach were not significantly different than lengths in the downstream reach (P=0.089). Lengths of age 4 rock bass were not significantly different among reaches (P=0.112). In general, length at age of smallmouth bass and rock bass varied among ages and reaches in the Powell River, but no consistent trends were evident.

Prey Abundance and Diet Composition

When mean abundance of hellgrammites in the upstream, midstream, and downstream reaches was compared (Table 25), the downstream reach had significantly more hellgrammites (P=0.032). Abundance of crayfish in the upstream, midstream, and downstream reaches was not significantly different among reaches in riffles (P=0.659).

A total of 236 stomachs were examined from smallmouth bass and rock bass ($\geq$ age 3) collected between July 1988 and October 1989 (Tables 26, 27). Diet composition, when compared by a Chi-Square test, was not significantly different for either smallmouth bass (P=0.644) or rock bass (P=0.124) among reaches (Figures 4, 5). Crayfish (*Orconectes* spp.) were by far the dominant food items in stomachs of smallmouth bass, comprising 54.1% of prey items by number and 60.2% of stomach contents by wet weight. Unidentified insects comprised 23.9% of prey items by number and 26.0% of total food weight. Unidentified fish comprised 22.0% by number and 13.8% by weight. Although not significantly different among reaches, the percentage

Table 25. Number collected (N), densities (N/m²), and 95% confidence intervals (C.I.) of hellgrammites and crayfish at study sites in the Powell River, Virginia, in 1988.

Study site	Hellgrammites (N)	Hellgrammites (N/m²)	Hellgrammites (C.I.)	Crayfish (N)	Crayfish (N/m²)	Crayfish (C.I.)
1	3	0.10	0.02-0.29	4	0.13	0.03-0.34
2	2	0.07	0.01-0.24	5	0.17	0.05-0.39
3	4	0.13	0.030.34	7	0.23	0.09-0.48
4	3	0.10	0.02-0.29	2	0.08	0.01-0.24
5	1	0.03	0.00-0.19	2	0.08	0.01-0.24
6	3	0.10	0.02-0.29	5	0.17	0.05-0.39
7	6	0.20	0.07-0.44	4	0.13	0.03-0.34
8	7	0.23	0.09-0.48	7	0.23	0.09-0.48
9	7	0.23	0.09-0.48	7	0.23	0.09-0.48

Table 26. Percent of total number (N) and wet weight (W) of prey items consumed by adult smallmouth bass in the Powell River, Virginia, in 1989.

Site	No. examined	With food (%)	Crayfish		Fish		Insects	
			N	W	N	W	N	W
1	6	83.3	60	93	0	0	40	7
2	12	50.0	50	84	33	9	17	7
3	5	100.0	60	52	20	29	20	19
4	3	33.3	100	100	0	0	0	0
5	5	80.0	75	90	25	10	0	0
6	12	25.0	34	30	33	6	33	64
7	3	100.0	50	57	25	13	25	30
8	9	44.4	25	20	25	30	50	50
9	15	33.3	71	62	15	19	14	19
Total	70							

Table 27. Percent of total number (N) and wet weight (W) of prey items consumed by adult rock bass in the Powell River, Virginia, in 1989.

Site	No. examined	With food (%)	Crayfish N	Crayfish W	Fish N	Fish W	Insects N	Insects W	Other N	Other W
1	2	100.0	67	41	33	59	0	0	0	0
2	19	16.0	67	87	0	0	33	13	0	0
3	9	67.0	83	78	0	0	17	22	0	0
4	23	30.3	63	58	25	41	12	1	0	0
5	6	33.0	50	60	0	0	50	40	0	0
6	23	30.0	40	68	10	3	40	25	10	4
7	16	56.0	45	25	0	0	45	73	10	2
8	24	29.1	14	8	0	0	86	92	0	0
9	44	55.4	46	70	0	0	50	28	4	2
Total	166									

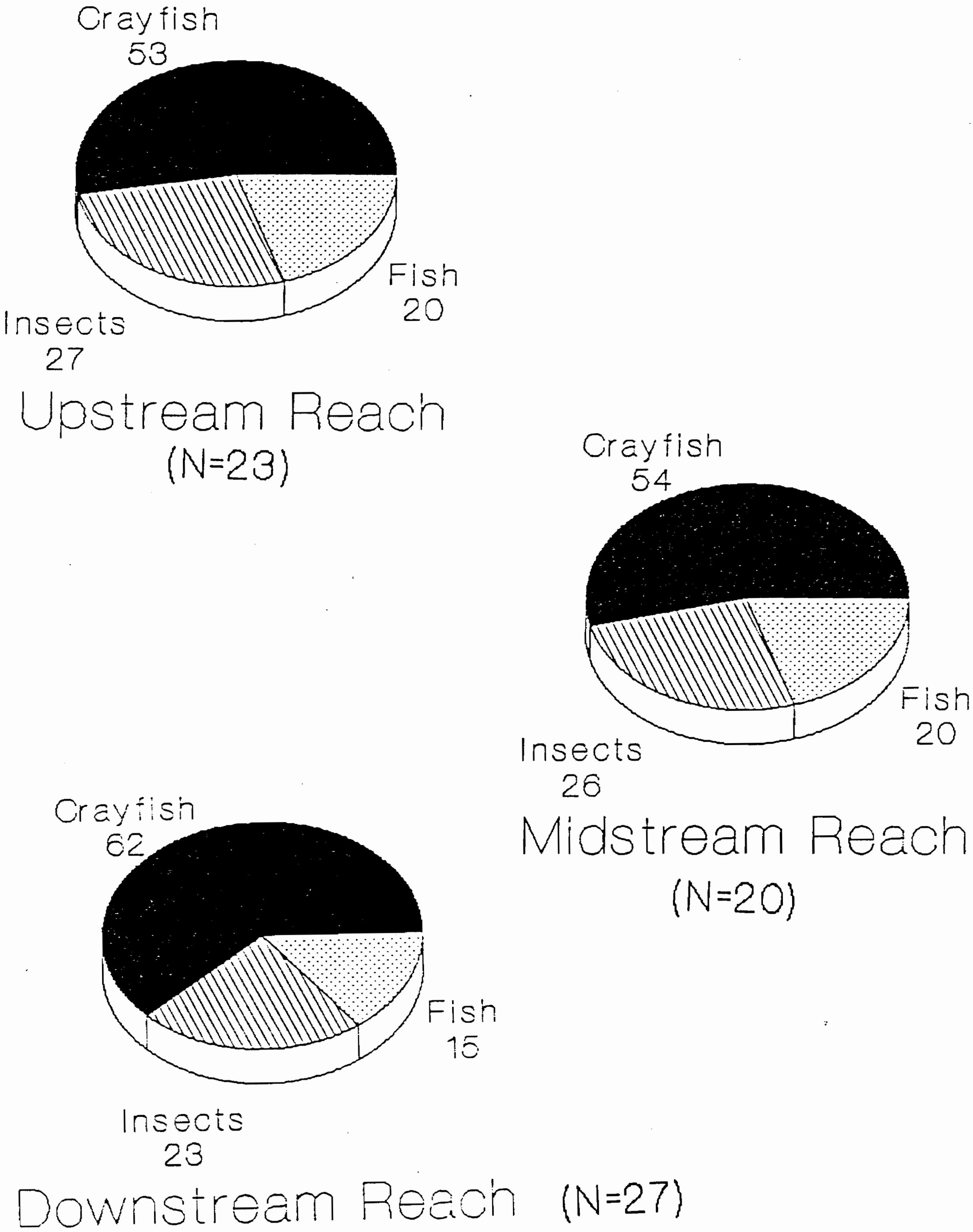

Figure 4. Percent composition (by number) of the diet of smallmouth bass in the Powell River, Virginia, in 1988.

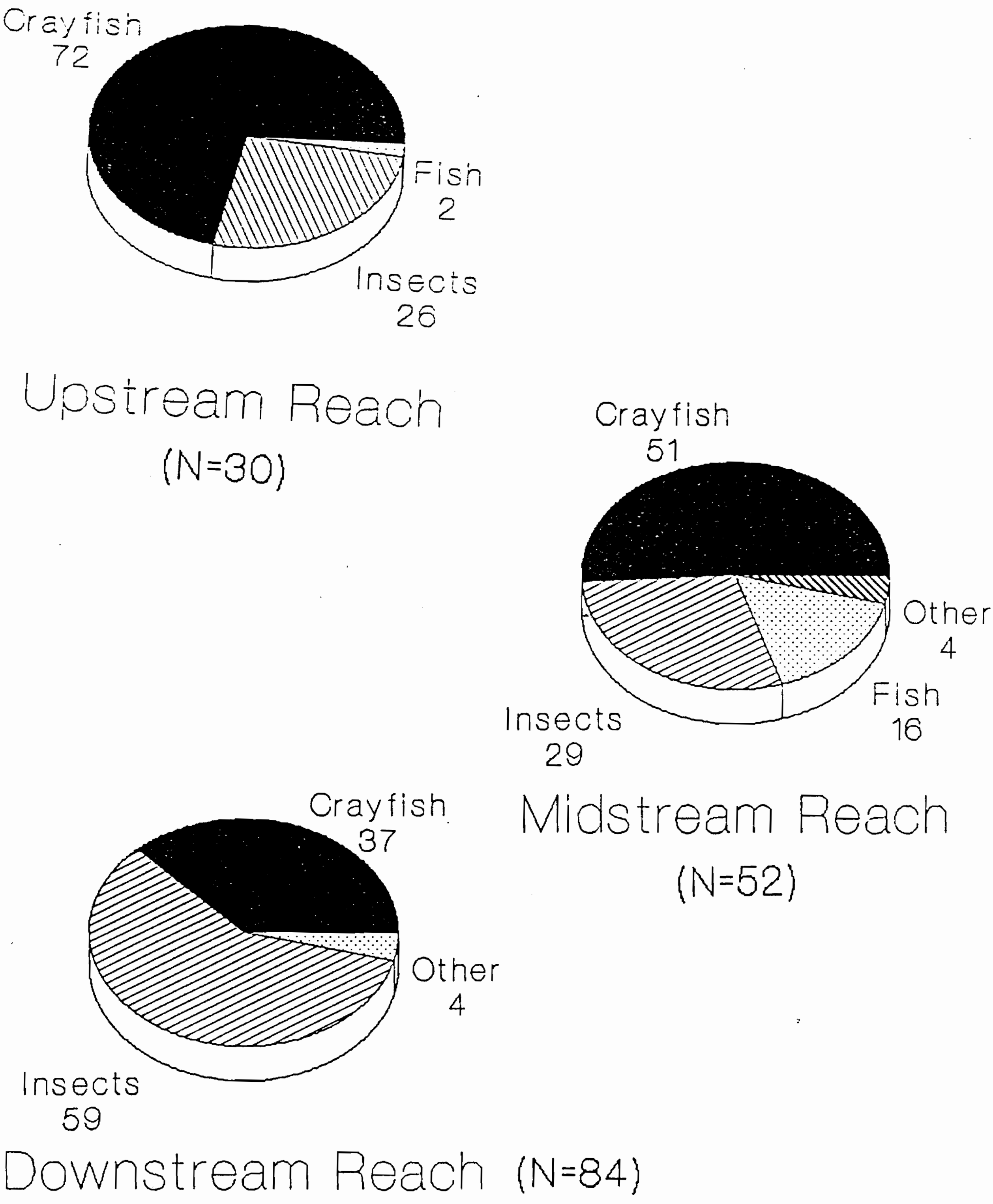

Figure 5. Percent composition (by number) of the diet of rock bass in the Powell River, Virginia, in 1988.

of crayfish in the diet of smallmouth bass increased downstream, whereas the percentage of insects in the diet decreased downstream. Crayfish eaten by smallmouth bass ranged from 8 mm carapace length (CL) to a maximum size of 38 mm CL. Sizes of crayfish consumed were correlated positively with sizes of smallmouth bass (P=0.025, r=0.924).

Crayfish were also the dominant food items in stomachs of rock bass and represented 47.6% of prey items by number and 56.4% by wet weight. The comparable values for insects were 43.7% and 35.5%, respectively. Unidentified fish comprised 5.3% of food items and 6.8% of total food weight. Relatively infrequent diet items included frog parts and Asian clams, *Corbicula fluminea*. Crayfish consumed by rock bass ranged in size from 7 mm CL to 34 mm CL. Sizes of crayfish consumed were positively correlated with sizes of rock bass (P=0.019, r=0.936).

Relationships Among Habitat, Sediment and Population Characteristics

HSI values for each site showed no significant correlation with catch-per-unit-effort for each site for smallmouth bass (P=0.828, r=-0.085) or rock bass (P=0.631, r=-0.186) (Table 28). The SI value for substratum also showed no significant correlation with catch-per-unit-effort of smallmouth bass (P=0.897, r=0.025) or rock bass (P=0.888, r=0.022). In addition, catch-per-unit-effort of smallmouth bass was not correlated with percent sand (P=0.318, r=-0.377), cobble (P=0.926, r=-0.036), or boulder (P=0.435, r=-0.299). Catch-per-unit-effort of rock bass was not correlated with percent sand (P=0.434, r=-0.299), cobble (P=0.480, r=0.271), or boulder (P=0.763, r=0.118). Overall, catch-per-unit-effort of smallmouth bass and rock bass did not correlate with measured habitat values in the Powell River.

Table 28. Relationships among habitat, sediment and population characteristics in the Powell River, Virginia, 1988-89.

	CPUE (SMB)	CPUE (RKB)	Biomass (SMB)	Biomass (RKB)	Wr (SMB)	Wr (RKB)	Growth** (SMB)	Growth** (RKB)	Hellgramite Abundance	Crayfish Abundance
HSI (smallmouth bass)	P=0.83 r=-0.85	N/A	*	N/A	*	N/A	*	N/A	*	*
HSI (rock bass)	NA	P=0.63 r=0.19	N/A	*	N/A	*	N/A	*	*	*
Substratum SI (smallmouth bass)	P=0.90 r=0.02	N/A	*	N/A	*	N/A	*	N/A	*	*
Substratum SI (rock bass)	N/A	P=0.89 r=0.02	N/A	*	N/A	*	N/A	*	*	*
Percent sand	P=0.32 r=-0.38	P=0.44 r=-0.30	*	*	*	*	*	*	*	*
Percent cobble	P=0.93 r=-0.04	P-0.48 r=0.27	*	*	*	*	*	*	*	*
Percent boulder	P=0.44 r=-0.30	P=0.76 r=0.12	*	*	*	*	*	*	*	*
Sediment depth	P=0.69 r=0.15	P-0.20 r=-0.47	P=0.31 r=0.38	P=0.52 r=-0.25	P=0.01 r=0.79	P=0.68 r=0.16	*	*	*	*
Embeddedness index (riffle)	*	*	P=0.78 r=0.11	P=0.53 r=0.24	P=0.02 r=-0.76	P=0.79 r=-0.11	P=0.02 r=-0.77	P=0.05 r=0.66	P=0.03 r=0.71	P=0.05 r=0.66
Sediment can (run)	*	*	P=0.68 r=-0.16	P=0.43 r=-0.30	*	*	*	*	*	*
Sediment can (pool)	P=0.59 r=-0.21	P=0.30 r=-0.39	*	*	*	*	*	*	*	*
Hellgrammite abundance	*	*	*	*	*	*	*	*	*	*
Crayfish abundance	*	*	*	*	P=0.45 r=-0.29	P=0.23 r=-0.45	*	*	*	*

SMB = Smallmouth bass. RKB = Rock bass. N/A = not applicable. * = correlation not determined.
** = Growth rate, all ages.

No significant correlation was found between sediment depth and catch-per-unit-effort of smallmouth bass (P=0.694, r=0.153), rock bass (P=0.197, r=-0.474), spotted bass (P=0.087, r=0.601), or redbreast sunfish (P=0.057, r=0.653) at sampled sites. However, a significant negative correlation was found between catch-per-unit-effort of longear sunfish and sediment depth (P=0.036, r=-0.698). There was no significant correlation between sediment depth and biomass of rock bass (P=0.519, r=-0.249). No correlation existed between sediment depth and relative weight of smallmouth bass (P=0.112, r=0.791) or relative weight of rock bass (P=0.685, r=0.158). The lack of significant correlations between sediment depth and certain population characteristics indicates that sediment depth may not be affecting many of the population characteristics of smallmouth bass and rock bass in the Powell River.

No correlation was found between the embeddedness index in riffles and biomass of rock bass (P=0.529, r=0.243). There was a significant negative correlation between the embeddedness index in riffles and relative weight of smallmouth bass (P=0.016, r=-0.767); however, no correlation existed between the embeddedness index and relative weight of rock bass (P=0.786, r=-0.106). There was a significant negative correlation between the embeddedness index in riffles and growth of smallmouth bass (P=0.016, r=-0.767); however, there was a significant positive correlation between the embeddedness index and growth of rock bass (P=0.052, r=0.662). There was a significant positive correlation between the embeddedness index in riffles and both hellgrammite abundance (P=0.031, r=0.714) and crayfish abundance (P=0.052, r=0.662) in riffles. These significant correlations suggest that embeddedness may be affecting growth of smallmouth bass and rock bass, and abundance of crayfish and hellgrammites.

No significant correlation was found between the amount of sediment deposited in sediment traps in pools and catch-per-unit-effort of smallmouth bass (P=0.589, r=-0.210) and rock bass (P=0.297, r=-0.392) in those pools. No significant correlation existed between the amount of sediment deposited in sediment traps in runs and biomass of rock bass (P=0.430, r=-

0.302) in those pools. In general, the amount of sediment deposited in sediment traps did not correlate with population characteristics of smallmouth bass and rock bass at each site.

In addition, crayfish density was not correlated with relative weight of smallmouth bass ($P=0.451$, $r=-0.289$) or rock bass ($P=0.228$, $r=0.446$).

Discussion

Results of this study allow an evaluation of several aspects of habitat suitability and population characteristics of smallmouth bass and rock bass in rivers. The effects of sedimentation on both species are discussed.

Habitat

Results of the habitat survey for smallmouth bass and rock bass in the Powell River, Virginia, indicated that habitat suitability for these species was similar among sites. The relative homogeneity of habitat among sites was reflected in the nearly identical HSI values assigned to them. To determine whether population characteristics were related to substratum type, HSI models of smallmouth bass and rock bass were applied in hopes of finding a site or reach in which the only suboptimum variable was substratum. Although substrata and other measured habitat components were equal among sites, variables below optimum for each species were identified.

The food, cover, and reproductive component SIs were below optimum for smallmouth bass at all sampled sites. Substratum was below optimum in the food and cover SIs, and substratum and water level fluctuation were below optimum in the reproduction SI. Water quality and other component SIs were not below optimum. The food/cover component SI for rock bass was below optimum at all sampled sites, and the variable most below optimum in this group, again, was substratum, due to excess sand. Other component SIs, such as water quality, reproduction, and other factors, were not limiting.

Substratum composition was the variable most frequently below optimum for smallmouth bass and rock bass in the Powell River. McClendon and Rabeni (1987) determined that biomass and density of smallmouth bass were positively correlated with cobble and boulder substratum. This was supported by a significant positive correlation between the embeddedness index in riffles and both hellgrammite abundance and crayfish abundance in riffles. Silt and sand, the types of substratum contributing to the low embeddedness rating at sample sites in the Powell River, affects food by not providing habitat and intersticial spaces needed for most invertebrates, especially crayfish (Ellis, 1936; Cordone and Kelly,1961; Keast and Webb, 1966; Glessner, 1977; Keast, 1977), the predominant prey of these species. Crayfish have been found to be closely associated with cobble and boulder substrata with adequate interstitial spaces (Murphy et al., 1981; Edwards et al., 1983; Berkman and Rabeni, 1987; Lee and Nelson, 1987). Crayfish densities in the Powell River were low compared to other streams in the U.S. (Brown and Fitzpatrick, 1978; DiStefano, 1987; McClendon and Rabeni, 1987; Roell, 1989). Substratum type was also important in the cover component because these species prefer cobble and boulder substrata with interstitial spaces available for shelter, unlike sand, the dominant substrata in pools (Cleary, 1956; Sanderson, 1958; Scott and Crossman, 1973; Coble, 1975; Pflieger, 1975; Paragamian, 1981; Probst et al., 1984; McClendon and Rabeni, 1987; Todd and Rabeni, 1989). Substratum is important in reproduction because smallmouth bass only spawn over coarse substrata, and great amounts of sediment in coarse substrata can inhibit embryonic development and larval survival (Sanderson, 1958; Coble, 1975; Muncy et al., 1979; Paragamian, 1981;

Berkman and Rabeni, 1987). Paragamian (1981) and McClendon and Rabeni (1987) were able to relate smallmouth bass abundance to substratum type. Orth and Maughan (1982) were not successful in correlating substratum with smallmouth bass abundance; however, the substratum in their study consisted of little or no sand. I also did not observe a correlation between smallmouth bass or rock bass abundance and substratum type. For smallmouth bass, water level fluctuation during spawning was the second variable below optimum, according to the HSI model. This can affect reproductive success by exposing nest areas and causing nest desertion (Pflieger, 1975). Stark and Zale (1989) concluded that extreme water level fluctuations limit smallmouth bass populations in southeastern Oklahoma. Of the variables measured, substratum and water level fluctuation were most significant in decreasing habitat quality for smallmouth bass in the Powell River.

The other variable below optimum for rock bass in the Powell River was percent cover, which consisted of percent complex structure, percent simple structure and substratum composition. The low value for simple cover probably has minor effects on the population because fish can shift from this cover type to what is available, but this could have some effect on recruitment (Probst, 1983). The low value for complex structure could have a substantial effect on the species (Bailey, 1955; Probst, 1983). On the other hand, Probst et al. (1984) stated that a relatively small amount of woody structure can serve as habitat for a substantial fish biomass. McClendon and Rabeni (1987) determined that cover was important in the prediction of biomass and density of rock bass. Substratum composition is important because crayfish is an important food source (Keast and Webb, 1966; Glessner, 1977; Keast, 1977) and have been found to be associated with boulders (Lee and Nelson, 1987). Substratum composition, which is low in percent boulders, and percent cover were the variables most significant in decreasing habitat quality for rock bass in the Powell River.

With the available documentation that links smallmouth bass and rock bass to habitat, it is evident that habitat usually is the limiting factor in determining species presence and abundance (McClendon and Rabeni, 1987). However, competition and exploitation by anglers may alter population characteristics. Habitat enhancement for smallmouth bass and rock bass populations has not been a standard procedure for fisheries managers, but it could be as important as it has been for trout (Paragamian, 1981). In order to improve fishable populations of smallmouth bass and rock bass in the Powell River, Virginia, some improvement in substratum composition appears necessary. This could be accomplished by implementing best management practices in the watershed to further control silt and sand entering the Powell River, Virginia.

Sedimentation

Accurate measurement of sediment and coal in a river bottom is difficult. Factors that can influence the amount and size of sediment include geology, morphology, gradient, and flow. Embeddedness, which rates the amount that larger particles are covered by fine sediment, allowed evaluation of the Powell River's suitability for spawning, egg incubation, habitats for aquatic invertebrates such as hellgrammites and crayfish and young overwintering fish (Platts et al., 1983). As embeddedness increases, biological productivity is also thought to increase (Platts et al., 1983). An increase in embeddedness can reflect poor intragravel conditions for spawning, egg incubation, and habitats for aquatic invertebrates, when other factors, such as the amount of fines present, do not appear detrimental (Platts et al., 1983). Also, this measurement may be more appropriate for determining effects of sedimentation on organisms that require interstitial spaces.

No differences in sediment depth were found among reaches. Correlations were found among sediment depth and abundance of longear sunfish, and relative weight of smallmouth bass;

however, they are not consistent with other correlations between sediment variables and population characteristics. Although no correlations were found between catch-per-unit-effort, population estimates, or biomass of smallmouth bass or rock bass and sediment depth, many other studies have documented that increased sedimentation reduced fish abundance (Ellis, 1936; Cordone and Kelly, 1961; Cairns, 1968; Muncy et al., 1979; Cooper et al., 1982; Berkman and Rabeni, 1987). Paragamian (1981) determined that the abundance of smallmouth bass was negatively associated with increased silt levels. Paragamian (1989) found that no smallmouth bass were in silt-laden areas in Iowa rivers, and he concluded that sediment appears to be a major habitat factor in the viability of smallmouth bass populations. Paragamian (1981) and McClendon and Rabeni (1987) found that greater biomass of smallmouth bass and rock bass was associated with high amounts of coarse substrata; however, this association was not evident in the Powell River. Sediment depths in the Powell River were similar to those determined by TVA (1986), who reported that sediment depths at sites 1, 4, and 5 were 25, 20, and 20 cm, respectively. Sediment depth at site 9 ranged from 3 to 8 cm. The large amounts of sediment were deposited in pools and would likely move downstream (Ahlstedt, 1979; TVA, 1986).

The embeddedness index was the same (=1.0) in pools at all sites. Pools were totally covered and, therefore, fully embedded. Embeddedness in riffles was similar among reaches. Embeddedness in runs upstream and midstream were similar, but were more embedded than runs in the downstream reach. The embeddedness index in riffles showed a negative correlation with growth of smallmouth bass; however, the embeddedness index showed a positive correlation with growth of rock bass. This could be because the confidence around the embeddedness index mean was quite low and accuracy was fair. However, year-to-year precision was rated good and Platts et al. (1983) rated this as a fairly dependable measurement. Crouse et al. (1981) found that a significant decrease in growth and biomass of juvenile coho salmon occurred when the embeddedness rating was 1 or 2. The embeddedness index in riffles also correlated well with crayfish abundance and hellgrammite abundance. Embedded riffles results in the filling of interstitial spaces that are needed as habitat for crayfish (Ellis, 1936; Cordone and Kelly, 1961; Glessner, 1977; Keast, 1977) and fish (Breder and Rosen, 1966; Muncy et al., 1979; Alexander and Hansen, 1983). Embedded riffles and runs affected crayfish abundance, the predominant prey of smallmouth bass and rock bass.

The sediment traps were effective in pools but not in runs, probably due to high velocities. Although no differences were found in sediment deposited in traps placed in runs, significant differences were detected in sediment deposited in traps set in pools. Quantities of sediment deposited in traps in the upstream and midstream reaches were not significantly different from each other, but were greater than levels of sediment deposited in traps in the downstream reach. This is probably due to sediment entering both the headwaters of the Powell River and the North Fork Powell River. One problem experienced with sediment traps is that they can be biased by differential bedload movement. Gravel was found in some samples from each reach, and bedload movement occurred to some extent throughout the river (Ahlstedt, 1986; TVA, 1986), thereby minimizing potential for bias in results. Wesche et al. (1989) determined that the small size and low cost of this type of sediment trap made it well-suited for field use.

The McNiel-Ahnell sampler was ineffective in sampling fine substrata, and silt and sand measurements probably were underestimated because of losses from the sampler. TVA (1986) used a sediment coring device to conclude that silt in pools comprised between 0 and 6% by dry weight of the substratum, and my values ranged from 0.1 to 0.8%. TVA also found that sand in pools comprised between 64 and 94% of the substratum, and values in my study ranged from 13.5 to 54.6%. There were no differences in percent silt or sand among reaches. Riffles are often most altered by sedimentation (Berkman and Rabeni, 1987); however, no percent sand or silt differences were evident in riffles among reaches in the Powell River. Percentage of coal present at sites was highly variable, especially in pools, which were highly variable in depth. It may be that coal deposits were slowly moving downstream (Ahlstedt, 1986), causing the high quantities measured at site 7. The large content of coal wastes in the substratum indicate that the Powell River has been degraded due to human-induced activities. This includes illegal dumping of coal wastes during high flow periods and erosion of coal fields.

Abandoned mine lands probably contribute the greatest amount of sediment and coal waste to the Powell River (Wolcott, 1990). These lands sometimes contain large amounts of coal refuse and spoil banks because many abandoned mine lands have not been reclaimed for lack of funding. Limited funds are only being allocated to areas where public safety and health are threatened, and at the current rate, it will take over 50 years to reclaim high priority sites in Virginia (Spangler, 1989). The Powell River Project (1989) sponsors programs in economic, social, and environmental areas of land use to provide solutions to the abandoned mine land problem in the Powell River Valley.

Overall, sediment depth, embeddedness in riffles and runs, and sediment deposited in traps in runs did not significantly decrease proceeding downstream. The North Fork Powell River is heavily sedimented, probably contributing sediments to the main-stem Powell River. It is suspected that the sediment in the Powell River, because of coal fine presence, is largely a result of mining operations in the upper Powell River and North Fork Powell River watersheds.

Population Characteristics

Valid estimates of population size and catch-per-unit-effort are needed to describe characteristics of a fish population. As judged by wide confidence intervals, population estimates and catch-per-unit-effort of smallmouth bass and rock bass were highly variable. In addition, only a few recaptures were found in some sites and in others, no recaptures were found. Growth and age class structure were probably more accurately measured attributes because populations were comprised mainly of non-adult fish (< age 3), which are more accurately aged than adult fish. Also, estimates of relative weight were considered reliable because the estimate is less likely to be influenced by factors such as age, no recaptures or other variables that would make interpretation speculative.

Gear selectivity probably affected equal capture for all size classes of individuals and contributed to errors in population estimates (Larimore, 1961; Reynolds, 1983). Incomplete galvanotaxis of smaller individuals was observed, but even when stunned, some fish were not retrieved due to dense cover, sampling-induced turbidity, or leaf packs. However, adult smallmouth bass and rock bass were fully recruited to the electrofishing gear.

It appears that population levels of smallmouth bass and rock bass in the Powell River, Virginia, are low throughout the study reach (PRM 117 to PRM 172). In addition, few harvestable-sized smallmouth bass (> 29.2 cm) or rock-bass (> 14.0 cm) were captured during the sampling period. Population estimates of smallmouth bass in the Powell River were lower than those reported for seven other populations of smallmouth bass from selected U.S. streams (Table 29). The highest population estimate of smallmouth bass was reported in the Galena River, Wisconsin, which had a HSI score for smallmouth bass of 0.96. Catch-per-unit-effort of smallmouth bass in the Powell River was lower than values reported for seven other stream-dwelling populations of smallmouth bass, but higher than three other populations, including a previous sampling of the Powell River (Wollitz, 1967). Catch-per-unit-effort of smallmouth bass in the Powell River, Tennessee, was greater than that reported for the Powell River, Virginia (Saylor et al., 1988). This difference could be attributed to the lower sediment depth in the Powell River in Tennessee (TVA, 1986).

Table 29. Population estimates and catch-per-unit-effort (CPUE) of smallmouth bass from selected streams in the U.S.

Locality	Population estimate (N/ha)	CPUE (N/h)	Source
Galena R.,Wi.	361	N/A	Forbes, 1989
Maquoketa R., Ia.	197.0	N/A	Paragamian, 1984
Big Buffalo Cr., Mo.	138	N/A	Reed and Rabeni, 1990
Jacks Fork R., Mo.	134	N/A	McClendon and Rabeni, 1987
Elkhorn Cr., Ky.	133.4	N/A	Crowell, 1984
Red Cedar Cr., Wi.	132	N/A	Paragamian and Coble, 1975
Current R., Mo.	53	N/A	Covington, 1982
Powell R., Va.	34.3	2.9	This study
Big Piney R., Mo.	30	N/A	Russell, 1974
S. Fork Flambeau R., Wi.	27.9	N/A	Lyons, 1990
Little R., Ok.	22.2	N/A	Stark and Zale, 1989
James R., Va.	N/A	28.8	Garman et al., 1988
Clinch R., Va.	N/A	15.3	Temple, unpubl. data
Clinch R., Tenn.	N/A	14.4	Saylor et al., 1988
Powell R., Tenn. (1987)	N/A	13.4	Saylor et al., 1988
Clinch R., Va.	N/A	7.1	Wollitz, 1968
Powell R., Tenn. (1986)	N/A	5.5	Saylor et al., 1988
N. F. Holston R., Va.	N/A	3.1	Temple, unpubl. data
Emory R., Tenn.	N/A	1.5	Saylor et al., 1988
Powell R., Va.	N/A	0.7	Wollitz, 1967
Sequatchie R., Tenn.	N/A	0.6	Saylor et al., 1988

N/A - Not applicable

Population estimates of rock bass in the Powell River were lower than those reported for rock bass in the South Fork Flambeau River, Wisconsin, which was similar in stream width (Lyons, 1990). Catch-per-unit-effort values of rock bass in the Powell River were lower than those reported for ten other populations of rock bass from selected U.S. streams (Table 30), but were greater than those reported for rock bass populations in the Powell River in 1967 (Wollitz, 1967), and the similar-sized Russell Fork River (Carroll, 1989). However, data from these studies of smallmouth bass and rock bass are difficult to compare because of differences in effort, sampling equipment, size of the stream, and habitat.

Biomass estimates of rock bass were compared among reaches, and no significant differences were found. Mean biomass at all sites likely was underestimated because observed sampling biases and population data indicate that younger age classes were not fully recruited to the electrofishing gear. However, methods were consistent among sites and were adequate for comparisons. Mean biomass estimates (2.6 kg/ha) for smallmouth bass in the Powell River, Virginia, were lower than those reported for fourteen other populations of smallmouth bass from selected streams in the U.S. (Table 31). Similarly, the mean biomass estimate (2.2 kg/ha) for rock bass in the Powell River was lower than that (4.5 kg/ha) reported for rock bass in Courtois Creek, Missouri (Fajen, 1975).

Population and biomass estimates are potentially influenced by several factors, and are inherently difficult to obtain, especially in a large river. Rock bass are able to thrive under adverse conditions where other species cannot (Lee and Nelson, 1987), and this may explain why it was the most abundant species. Population estimates of smallmouth bass were low compared to other selected U.S. streams. One or more factors may account for the disparity: 1) low prey abundance may affect population size, 2) small sample sizes and no recaptures in this study may make interpretation speculative, and 3) over-exploitation by anglers. Although a creel survey was not conducted in the Powell River, fishing pressure appeared to have been similar

Table 30. Population estimates and catch-per-unit-effort (CPUE) of rock bass from selected streams in the U.S.

Locality	Population estimate (N/ha)	CPUE (N/h)	Source
S. Fork Flambeau R., Wi.	496.7	N/A	Lyons, 1990
James R., Va.	N/A	47.4	Garman et al., 1988
Powell R., Tenn. (1987)	N/A	40.2	Saylor et al., 1988
Clinch R., Tenn.	N/A	16.8	Saylor et al., 1988
Clinch R., Va.	N/A	16.0	Temple, unpubl. data
Sequatchie R., Tenn.	N/A	13.8	Saylor et al., 1988
Clinch R., Va.	N/A	11.1	Wollitz, 1966
N.F. Holston R., Va.	N/A	10.8	Temple, unpubl. data
Powell R., Tenn. (1986)	N/A	8.3	Saylor et al., 1988
Emory R., Tenn.	N/A	7.5	Saylor et al., 1988
Licking R., Ky.	N/A	7.2	Kornman, 1989
Powell R., Va.	116.6	6.6	This study
Russell Fork R., Ky.	N/A	5.7	Carroll, 1989
Powell R., Va.	N/A	1.0	Wollitz, 1967

N/A - Not applicable

Table 31. Mean biomass (kg/ha) of smallmouth bass from selected streams in the U.S.

Locality	Biomass	Source
Elkhorn Cr., Ky.	50.1	Crowell, 1984
Otter Cr., Ok.	46.3	Finnell et al., 1956
Galena R., Wi.	29.2	Forbes, 1989
Big Buffalo Cr., Mo.	28.9	Reed and Rabeni, 1990
Jacks Fork R., Mo.	27.2	McClendon and Rabeni, 1987
Potomac R., Md.	18.0	Sanderson, 1958
Plover R., Wi.	17.5	Paragamian and Coble, 1975
Red Cedar R., Wi.	15.1	Paragamian and Coble, 1975
Maquoketa R., Ia.	12.5	Paragamian, 1982
Current R., Mo.	10.2	Covington, 1982
Courtois Cr., Mo.	8.6	Fajen, 1975
L. Miami R., Oh.	6.4	Brown, 1960
Glover Cr., Ok.	3.8	Orth and Maughan, 1984
Big Piney R., Mo.	3.5	Russell, 1974
Powell R., Va.	2.6	This study
Little R., Ok.	2.2	Stark and Zale, 1989
Jordan Cr., Il.	1.9	Larimore, 1961

throughout the river and was considered low because of the number of anglers, access, refuse, and use observed along the river.

The usefulness of the relative weight index is that variation in relative weight should reflect ecological conditions, and values can be compared between fish of different lengths and from different populations (Wege and Anderson, 1978). In the Powell River, relative weights of smallmouth bass and rock bass did not differ significantly among reaches. Relative weights were not significantly different than standard weights; however, when compared to other rivers, relative weights of both species were low (Wege and Anderson, 1978). McClendon and Rabeni (1987) determined that relative weights of smallmouth bass and rock bass were correlated with maximum summer water temperature and crayfish density. However, I found no correlation between relative weight of smallmouth bass or rock bass, and crayfish density in the Powell River. Crayfish densities in the Powell River were lower than those of other U.S. streams (DiStefano, 1987; McClendon and Rabeni, 1987; Roell, 1989). Water temperatures in the Powell River were optimum according to the HSI model for these two species. Also, the food and food/cover SIs for smallmouth bass and rock bass, respectively, were low, and the variable most below optimum for these SIs was substratum.

Statistical differences in growth of smallmouth bass and rock bass varied among ages and reaches in the Powell River. Smallmouth bass and rock bass grew at rates slightly slower than the means for these species throughout the U.S. Growth of smallmouth bass in the Powell River was greater than that reported for the North Fork Holston River (Wollitz, 1967), and Elkhorn Creek (Crowell, 1984). It was lower than that reported for the Clinch River (Wollitz, 1967), Duck River (TVA, 1975), James River (Garman et al., 1988), other Virginia streams (Banach, 1989), Wisconsin streams (Forbes, 1985), and seven other streams (Table 32). Growth of smallmouth bass in the Powell River was approximately equal to that reported for the Lost River, West Virginia (Brown, 1960). Growth of rock bass in the Powell River was greater than that reported

Table 32. Mean calculated total length (mm) at each annulus for smallmouth bass from selected streams in the U.S.

Locality	Mean length at each annulus								Source
	1	2	3	4	5	6	7	8	
Duck R., Tenn.	114	203							TVA, 1975
Wisconsin streams	89	178	246	307	353	396	432	452	Forbes, 1985
Galena R., Wi.	84	173	239	302	368	394	424	445	Forbes, 1989
Iowa streams	91	175	224	282	348	432			Clearly, 1951
Missouri streams	81	175	251	300	358	391	406	414	Lowry, 1953
Sandusky R., Oh.	86	170	234	302	363	381			Brown, 1960
Little R., Ok.	99	188	241	290	338	371			Finnell, 1955
Clinch R., Va.	71	165	251	320	381				Wollitz, 1967
Maquoketa R., Ia.	97	159	226	284	332	378	452		Paragamian, 1982
Virginia streams	96	168	221	267	305	368	416	458	Banach, 1989
Little Miami R., Oh.	74	150	224	279	323	353	368	384	Brown, 1960
James R., Va.	97	162	227	267	308	328			Garman et al., 1988
Powell R., Va.	82	139	188	246	280	330	375	409	This study
Lost R., W.V.	79	140	188						Brown, 1960
Elkhorn Cr., Ky.	69	109	152	206	257	305	333	356	Crowell, 1984
N.F. Holston R., Va.	51	112							Wollitz, 1967

for the North Fork Holston River (Wollitz, 1967), but lower than that reported for the Clinch River (Wollitz, 1967), James River (Garman et al., 1988), other Virginia streams (Banach, 1989), Missouri streams (Purkett, 1958), and five other streams (Table 33). Growth of rock bass in the Powell River was approximately equal to that reported for the Duck River (TVA, 1975).

High levels of sediment can reduce food availability, thereby limiting the amount of energy that can be directed toward fish growth (European Inland Fisheries Advisory Committee, 1964; Allen, 1969; Karr and Dudly, 1981). From my results and those of other studies, it appears that growth of smallmouth bass and rock bass in the Powell River, Virginia, was slow. It does not appear that densities of crayfish influenced relative weights and growth of smallmouth bass and rock bass.

Relating fish population characteristics to sedimentation is difficult, especially when the instability of sediment is considered. Sedimentation is generally considered to be a factor in the prediction of population characteristics of smallmouth bass and rock bass (Paragamian, 1981; Probst et al., 1984; McClendon and Raben, 1987; Todd and Rabeni, 1989). Population numbers and biomass of smallmouth bass and rock bass in the Powell River are low when compared to other streams in the U.S. Previous studies comparing population abundance of fish and sedimentation show that sedimentation could limit population characteristics of smallmouth bass and rock bass; however, the population characteristics in this study were not significantly different among sites with measurable differences in sedimentation.

Prey Abundance and Diet Composition

In general, food habits of smallmouth bass and rock bass in the Powell River agreed with diet data collected for these two species in other rivers; namely, the dominance of crayfish in

Table 33. Mean calculated total length (mm) at each annulus for smallmouth bass from selected streams in the U.S.

Locality	Mean length at each annulus								Source
	1	2	3	4	5	6	7	8	
James R., Va.	*	139	169	191	203				Garman et al., 1988
Little Miami R., Oh.	79	132	173	198	211	221			Brown, 1960
Sandusky R., Oh.	51	117	175	185					Clark, 1956
Illinois R., Ok.	43	107	147	188	206				Jenkins et al., 1952
Potomac R., Va.	48	104	142	163	193	213			Sanderson, 1958
Missouri streams	41	86	140	178	203	216			Purkett, 1958
Virginia streams	58	104	133	162	175	200	223	233	Banach, 1989
Kentucky streams	36	89	145	168	180	185	216	211	Charles, 1957
Clinch R., Va.	33	74	124	168	198	246			Wollitz, 1967
Powell R., Va.	51	80	112	142	167	204			This study
Duck R., Tenn.	30	64	114	155	183	213			TVA, 1975
N.F. Holston R., Va.	23	51	81	117	142	168	191	218	Wollitz, 1967

* - sample not taken.

their diets (Doan, 1940; Reynolds, 1965; Coble, 1975; Miner, 1978; Probst et al., 1984; Austen and Orth, 1985; Roell and Orth, 1988; Roell, 1989). Density of crayfish in riffles was compared among reaches and no significant differences were found; however, density of hellgrammites was significantly greater in the downstream reach. The abundance of crayfish (0.16 per m^2) in riffles was less than that (6.20 per m^2) reported for an Ozark stream (McClendon and Rabeni, 1987), the New River (1.6 per m^2) (Roell, 1989), Ball Creek (9.2 to 23.6 per m^2) (DiStefano, 1987), and Pinnacle Branch (16.7 to 24.6 per m^2) (DiStefano, 1987). Hellgrammite abundance (0.13 per m^2) in riffles was less than that reported for the New River (2.5 per m^2) (Roell, 1989) and five Texas streams (Brown and Fitzpatrick, 1978; Short et al., 1987). The Ozark stream, Ball Creek, Pinnacle Branch, and the New River had low amounts of sedimentation (DiStefano, 1987; McClendon and Rabeni, 1987; Roell, 1989); however, estimates for hellgrammites and crayfish in these streams were based on a sampling technique using a 1 m^2 sampling device and could have resulted in better and greater estimates.

It has been well documented that increased sedimentation reduces insect abundance (Cordone and Kelly, 1961; Captor, 1969; Berkman and Rabeni, 1987; Cooper, 1987). The food and food/cover SIs for smallmouth bass and rock bass, respectively, were below optimum in the Powell River. Sand, the dominant substratum and the variable most below optimum in the two SIs, affects food by not providing habitat needed for crayfish and insects (Ellis, 1936; Cordone and Kelly, 1961; Keast and Webb, 1961; Glessner, 1977; Keast, 1977). Although these previous studies suggest that sedimentation may be affecting the abundance of crayfish, insects, and other invertebrates, my results were not statistically significant among sites with measurable differences in sedimentation.

Conclusion

Documentation of cause and effect relationships between population characteristics of smallmouth bass and rock bass, and habitat is difficult in field studies. Evidence from river sampling indicated that sediment-related habitat characteristics varied from upstream to downstream. From the watershed activities, it is logical to presume that this was caused by human-induced activities. Although population characteristics were not directly related to sedimentation in the Powell River, evidence suggests that something has affected populations of smallmouth bass and rock bass for several reasons: 1) populations in the Powell River are low relative to other rivers, including the Powell River in Tennessee, 2) population characteristics are related to river mile in the same way as sedimentation, and 3) habitat suitability indices suggest that substrata is suboptimal.

It appears that as far downstream as the Virginia/Tennessee state line, the Powell River, Virginia, has experienced sedimentation to the extent that it has equally influenced the habitat and population characteristics of smallmouth bass and rock bass. A reach in Tennessee composed of sampling sites that had less sedimentation may have proved beneficial in determining the cause and effect of the low quality of habitat and population characteristics.

The fishery in the Powell River may be degraded because of unregulated, human-induced activities, such as poor erosion control practices, that occurred many years ago. Although indirect effects of sedimentation, such as reduced quality and quantity of fish food should be considered, other factors may have contributed to the decline of sport fish populations. Many types of pollution can occur, such as illegal dumping of wastes during high flow periods. This potential problem is being evaluated by a high flow sampling program in the Powell River (U.S. Geological Survey, 1989). Regulations exist to improve water quality in the river, but more strict enforcement is needed if the fish fauna is to recover. Efforts to recover the Powell River and results of reclamation efforts in the watershed must be monitored closely to determine whether biological recovery occurs. It is imperative that existing environmental regulations are enforced by the appropriate agencies. Monitoring of sport fish populations to follow trends in recovery or further declines should be repeated every 5 years. A creel survey would be necessary to estimate harvest rates of sport fish in the Powell River, Virginia, and to determine whether over-exploitation might be limiting abundance. Moreover, recreational and economic questions could be easily incorporated into the creel survey, providing estimates of the monetary and recreational values of the Powell River to the region.

Summary

1. Habitat Suitability Indices (HSI) for smallmouth bass and rock bass were determined at 10 sites in June and July, 1988. Substratum, dominated by sand in pools, was the variable most frequently below optimum for both species in this river. HSI values were not significantly different among sites or river reaches.

2. Greater levels of sediment depth in pools, embeddedness in riffles and runs, and waterborne sediment in pools occurred upstream than downstream. Content (by weight) of coal wastes in the substratum was not different among reaches.

3. Catch-per-unit-effort of smallmouth bass (2.9/h) and rock bass (6.6/h) was not significantly different among river reaches. Abundances and population estimates of these two species, however, were lower than those in most other U.S. streams.

4. The biomass estimate of smallmouth bass was 2.7 kg/ha. The biomass estimates for rock bass (2.2 kg/ha) was not significantly different among river reaches; however, biomass estimates for both species were lower than those in most other U.S. streams.

5. Relative weights (Wr) of smallmouth bass (89.2) and rock bass (95.7) were not significantly different among river reaches or from standard weights of these species.

6. Growth of smallmouth bass and rock bass varied among ages and reaches, and was slightly slower than those reported for other U.S. streams.

7. Crayfish were the most important food item by number in the diets of smallmouth bass (54.1%) and rock bass (47.6%).

8. Densities of crayfish were not significantly different among river reaches; however, densities of hellgrammites were greater downstream than those upstream and may have been affected by lack of suitable benthic habitats. Densities were lower than those in other U.S. streams.

9. Although it appears that sedimentation has degraded habitat of smallmouth bass and rock bass and contributed to reduced population levels of these species in the Powell River, Virginia, my results were not statistically significant among sites with measurable differences in sedimentation.

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Appendix

Appendix A. HSI values for smallmouth bass in the Powell River, Virginia.

Variable	Study Site SI								
	1	2	3	4	5	6	7	8	9
(V_1) substrate type	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.30	0.20
(V_2) percent pools	0.86	1.00	0.65	0.75	0.78	1.00	0.68	0.57	0.68
(V_4) average depth (m)	0.60	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
(V_5) percent cover	0.75	0.33	1.00	0.85	0.96	0.57	1.00	0.36	0.87
(V_6) pH	1.00	1.00	1.00	0.95	1.00	0.97	1.00	1.00	0.98
(V_8) dissolved oxygen	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
(V_9) turbidity	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
(V_{10}) water temperature (adult)	0.93	0.93	0.93	0.95	0.95	0.95	0.97	0.97	0.97
(V_{11}) water temperature (embryo)	0.93	0.93	0.93	0.95	0.95	0.95	0.97	0.97	0.97
(V_{10}) water temperature (fry)	0.93	0.93	0.93	0.95	0.95	0.95	0.97	0.97	0.97
(V_{10}) water temperature (juvenile)	0.93	0.93	0.93	0.95	0.95	0.95	0.97	0.97	0.97
(V_{14}) water level fluctuations (m)	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
(V_{15}) gradient (m/km)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Appendix B. HSI values for rock bass in the Powell River, Virginia.

Variable	Study Site SI 1	2	3	4	5	6	7	8	9
(V_{1a}) percent complex cover	0.32	0.23	0.48	0.39	0.25	0.31	0.27	0.26	0.40
(V_{1b}) percent simple cover	0.42	0.30	0.45	0.42	0.55	0.34	0.55	0.29	0.42
(V_2) substrate size	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
(V_3) percent pools	0.55	0.90	0.40	0.47	0.51	0.73	0.45	0.30	0.45
(V_4) turbidity	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
(V_5) dissolved oxygen	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
(V_6) water temperature (nonbreeding)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
(V_7) alkalinity	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
(V_8) pH	0.63	0.70	0.65	0.80	0.80	0.65	0.68	0.67	0.65
(V_9) water temperature (breeding)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
(V_{10}) average depth (m)	0.92	0.80	0.80	0.70	0.75	0.70	0.90	0.87	0.75
(V_{11}) substrate size	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
(V_{12}) gradient (m/km)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
(V_{13}) current velocity	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
(V_{14}) percent sand	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Appendix C. Number and percent recapture of adult smallmouth bass by study site and year in the Powell River, Virginia.

Site	Year	Number marked (M)	Recapture sample (C)	Marks recaptured (R)	% recapture (R/M)	Total % recapture
1	1988	0	1	0	N/A	
	1989	1	1	0	N/A	N/A
2	1988	10	4	1	10.0	
	1989	2	2	1	50.0	16.7
3	1988	1	0	0	0	
	1989	*	*	*	N/A	N/A
4	1988	0	1	0	0	
	1989	1	0	0	N/A	N/A
5	1988	2	5	1	50.0	
	1989	*	*	*	N/A	50.0
6	1988	3	1	1	N/A	
	1989	5	8	0	N/A	N/A
7	1988	2	2	0	N/A	
	1989	*	*	*	N/A	N/A
8	1988	2	3	0	N/A	
	1989	2	2	0	0	N/A
9	1988	6	5	0	0	
	1989	4	6	1	25.0	10.0

* - Sample not taken.
N/A - not applicable.

Appendix D. Number and percent recapture of adult rock bass by study site and year in the Powell River, Virginia.

Site	Year	Number marked (M)	Recapture sample (C)	Marks recaptured (R)	% recapture (R/M)	Total % recapture
1	1988	4	4	1	25.0	
	1989	2	2	0	N/A	16.7
2	1988	23	20	7	30.0	
	1989	17	12	3	18.0	25.0
3	1988	18	12	1	6.0	
	1989	*	*	*	N/A	6.0
4	1988	16	12	1	6.0	
	1989	11	20	1	9.0	7.4
5	1988	22	14	3	14.0	
	1989	*	*	*	N/A	13.6
6	1988	5	9	1	20.0	
	1989	7	18	1	14.0	16.7
7	1988	22	21	3	14.0	
	1989	*	*	*	N/A	13.6
8	1988	17	12	3	18.0	
	1989	10	13	3	30.0	22.2
9	1988	47	42	4	9.0	
	1989	21	23	3	14.0	10.3

* - Sample not taken.
N/A - not applicable.

Appendix E. Von-Bertalanffy growth equations of smallmouth bass and rock bass in the Powell River, Virginia.

Rock bass (upstream) L_t	=	$227.23\ (1 - e^{-.34\ (t+.28)})$
Rock bass (midstream) L_t	=	$252.35\ (1 - e^{-.24\ (t+.48)})$
Rock bass (downstream) L_t	=	$310.27\ (1 - e^{-.18\ (t+.68)})$
Smallmouth bass (upstream) L_t	=	$630.02\ (1 - e^{-.14\ (t+.59)})$
Smallmouth bass (midstream) L_t	=	$679.90\ (1 - e^{-.06\ (t+.73)})$
Smallmouth bass (upstream) L_t	=	$676.16\ (1 - e^{-.09\ (t+.94)})$

Vita

James L. Cummins, Jr. was born on November 20, 1965, in Greenville, Mississippi. He attended Greenville High School and graduated in May, 1983. Upon graduating, he worked for Fulmer Electric Company. That fall he enrolled in Mississippi State University, where he received his B.S. degree in Fisheries Management in May, 1987. During summers between semesters, he worked for the Mississippi Department of Wildlife, Fisheries and Parks at Turcotte Research Laboratory. In August, 1987, he entered the M.S. degree program in Fisheries and Wildlife Sciences at Virginia Polytechnic Institute and State University (VPI & SU). While attending VPI & SU he was secretary of the Graduate Student Assembly and worked for the USDA Forest Service and U.S. Senator Thad Cochran in Washington, D.C. He is currently Executive Director of both Delta Wildlife Foundation and Delta Outfitters Association in Stoneville, Mississippi.