Coal Waste Deposition and the Distribution of Freshwater Mussels in the Powell River, Virginia

by

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(ABSTRACT)

A survey of the freshwater mussel fauna was conducted in the Powell River, Virginia, to identify critical habitat for endangered species, quantify substratum composition and coal waste deposition, and to assess population trends during the last half century. Mussels were collected as far upstream as Powell River Mile (PRM) 167.4 near Dryden, Virginia. Endangered species were collected up to PRM 144.6 at Jonesville, Virginia. The sites with greatest diversity were located furthest downstream, and there appeared to be a general decline in the number of species and diversity of mussels from downstream to upstream. Mussel densities also declined proceeding upstream, and specimens were rare above PRM 158.3 near Pennington Gap, Virginia. The highest density occurred at PRM 123.0 near the Tennessee-Virginia border, with 24 mussels/m^2. Collections per unit effort of sampling concurred with quadrat surveys, indicating a decline in abundance and diversity upstream. Length frequency distributions of the muckets *Actinonaias pectorosa* and *A. ligamentina* indicated an absence of smaller mussels at most sites.

Sediment samples, collected in riffles at 10 sites to determine particle size distributions and the amount of coal, showed no apparent trends in waste coal from downstream to upstream; however, there were significant negative correlations between PRM location and various fractions of the substratum, indicating a longitudinal sorting of smaller size fractions. Percentages of very fine to medium sand, silt, and coal show marked increases downstream of the North Fork Powell River confluence (PRM 156.6) at Pennington Gap, Virginia. Mussel density had a slightly positive correlation with percent silt ($r^2=0.346$, $p=0.0736$) but was not correlated with percent coal.

Juvenile mussels of *Villosa iris* were placed on several types of substratum to determine differences in survival. In laboratory experiments, survival of juveniles on coal silt sometimes did not differ from that of juveniles without substratum (survival close to 100%). Survival of juveniles without substratum (93.9%), however, was significantly higher than survival (30.0-63.2%) on three sediment types from the Powell River ($p < .001$). In field experiments, there was a marginally significant difference in survival of juveniles between two sites ($p = .070$), with higher survival (47.7%) in sediments from Poteet Ford (PRM 144.6). Survival of juveniles was similar in all laboratory and field experiments.

A decline in density of the mussel fauna in the Powell River over the past 15 years was apparent when compared to previous data. Contamination and siltation from coal washing facilities and abandoned mine lands are suspected of contributing to this decline.

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Introduction

The Powell River, located in the headwaters of the Tennessee River system, supports a rich and diverse freshwater mussel fauna. However, there has been evidence of recent declines in both densities and species richness of mussels (Ahlstedt and Brown 1979, Neves et al. 1980, Dennis 1981, Ahlstedt 1986, Jenkinson and Ahlstedt 1988). Environmental perturbations from domestic, municipal, industrial, and agricultural activities have occurred in the Powell River watershed, although pollution from coal mining and sewage treatment facilities is most evident.

Pollution from poor coal mining practices in the Powell River headwaters has been suspected as a cause of mussel declines in the last decade (Ahlstedt and Brown 1979, Neves et al. 1980, Dennis 1981, Ahlstedt 1986, Jenkinson and Ahlstedt 1988). The pollution is both physical and chemical in nature and results from mine waste effluents, runoff, and coal washing operations (Neves et al. 1980). At times, the full length of the Powell River was seen running black with coal fines (Ahlstedt 1986). Coal wastes and sediments are prevalent in the substratum throughout the river, yet there are no data on the effects of this material on freshwater mussels (Neves et al. 1980). In 1983 a die-off of mussels was reported from Powell River Mile (PRM) 67.0 to 143.0 and continued at least until 1986 (Ahlstedt and Jenkinson 1987).

This is of great concern to the U.S. Fish and Wildlife Service because the Powell River supports seven endangered species of freshwater mussels.

Freshwater mussels are not the only fauna affected by pollution in the Powell River. Reports of poor fishing in the Powell River from local residents have prompted the Virginia Department of Game and Inland Fisheries to investigate possible causes. These reports may be related to mining violations, including the release of "blackwater" or chemicals into the Powell River, or to other anthropogenic impacts on the terrestrial and aquatic resources of the watershed.

Effects of Siltation on Freshwater Mussels

Erosion material entering waterways can affect the aquatic biota either through alteration of the substratum by siltation or through alteration of the physical and chemical composition of the water by suspended silt (Ellis 1936). Both types of effects need to be considered when investigating possible impacts of sediment inputs to a stream. Suspended silt is very effective in limiting light penetration through the water column. Ellis (1936) found that water carrying large loads of erosion silt transmitted more light of longer wave lengths than the shorter wave lengths. He concluded, however, that the major effect of suspended erosion silt was the formation of an opaque screen that limited light penetration regardless wavelength. Such a decrease in light penetration could possibly dull phototactic responses of mussels and reduce production of phytoplankton used as food by mussels (Fuller 1974).

Suspended silt may alter the temperature regime of water. Ellis (1936) found that if water containing erosion silt was constantly agitated, heat transmission and radiation were not altered. If the mixture was undisturbed, stratification occurred which interfered with heat transmission.

When silt settles out of suspension, it may carry with it suspended organic materials. This organic material is carried into the stream bed where it remains for long periods of time and in high concentrations (Ellis 1936). This could result in increased and localized enrichment of the stream (Fuller 1974). Organic and inorganic materials in the stream bed provide food and shelter in some respects, but can also be destructive through scouring, smothering, and chemical alteration (Dance 1981). Sediment which settled out in riffles below a crushed rock quarry caused a 40 percent decline in macroinvertebrate population densities (Gammon 1970).

Physical injury resulting from suspended material has been reported in mollusks and fish. Ellis (1944) found that particles larger than "those that will pass through a 1,000-mesh (to the inch) screen will cut and injure both fish gills and the mantle and gills of unionid mollusks". Kemp (1949) stated that mud or silt in suspension could clog or cut the gills of fish and mollusks and concluded that concentration of 3,000 mg/l were dangerous if maintained for 10 days.

Several experiments have been conducted to determine the effect of suspended silt on the feeding of mollusks, primarily on marine species. Winter (1978) found that the filter-feeding activity of the blue mussel *Mytilus edulis* increased with low quantities of suspended silt which resulted in better growth per unit time. Dennis (1984) showed that uptake of C-14 was higher in freshwater mussels maintained in low levels of silt. However, higher levels of silt interfered with feeding; food uptake was reduced to approximately 80 percent at silt levels greater than 1,000 mg/l. Dennis (1984) attributed this reduction to dilution of the food source by inorganic particles rather than indirect interference of filtration. This same conclusion was reached by Bricelj (1984) with the hard clam, *Mercenaria mercenaria*. Ellis (1936) concluded that erosion silt interfered with the feeding of freshwater mussels; however, his experiments indicated that mussels in water with suspended silt remained closed a large portion (75-95 percent) of the time. Mussels in silt-free water were closed less than 50 percent of the time. Aldridge et al. (1987) found that intermittent exposure of freshwater mussels to high levels of suspended solids altered physiological energetics and caused shifts from protein based catabolism to non-protein body stores. They concluded that imposed starvation or semistarvation was the major effect of high levels of suspended solids on freshwater mussels through reduced clearance rates.

Growth of mussels may be affected by siltation. Freshwater mussels in deeper water and finer sediments were found to grow slower (Stansbery 1970). Kat (1982) found a reduction in growth of larger freshwater mussels in muddy substrata. A decrease in feeding efficiency or a larger energy expenditure to maintain position in the soft sediments were stated as possible reasons.

Substratum types may have an affect on the distribution of some freshwater mussel species. The character of the substratum is considered to be a primary influence in the distribution of freshwater mussels by Headlee (1906). Lefevre and Curtis (1912) observed that some species adjusted better to different substrata. "Sluggish" species such as *Quadrula spp.* were poorly adapted to sedimentation and were more prone to being smothered in deposits of silt. In contrast, *Lampsilis spp.* were more active and able to adjust to silt deposition. Harmon (1972) observed a definite relationship between mollusk distribution and substratum patterns. Whether this relationship is caused by selection for a particular substratum type, however, is unclear. Lewis and Riebel (1984) observed that righting and burrowing of mussels could be accomplished in a variety of substrata. Therefore, they questioned whether substratum type would be related to distribution and postulated that factors which determine substratum composition (erosion and deposition) may be responsible for local mussel distribution.

Some researchers have found that silt deposition may affect freshwater mussel survival. Ellis (1936) demonstrated that mussels in sand or gravel bottoms showed high mortality when exposed to silt accumulations from 6 to 25 mm deep and that the high mortality was induced by silt-covering. Imlay (1972) questioned whether mussels might be more susceptible to artificial events of siltation rather than natural events. He postulated that "an unnatural covering occurring at an atypical season would not trigger a natural response mechanism for digging out", even though the mussel would have the physical means to do so. He found that mussels displaced in late autumn or summer were not able to recover as well as those displaced in spring and concluded that artificial displacement (substratum smothering, commercial harvesting, or removal and replacement) was more detrimental to mussels than natural displacement (natural sand formation, storm disturbance). Imlay (1972) also noted that "the demonstrated failure of mussels more often than not to climb out of smothering conditions explains in part the devastating effects of dredging, channelization, silt behind dams, quarry washing, or for that matter, of dust storms, and surface runoff." Mussels transplanted into high silt areas have shown lower survival than those transplanted into low silt areas, and reproduction may also be impaired (Dennis 1984).

Marking (1979) exposed specimens of *Lampsilis radiata luteola, L. ventricosa* and *Fusconaia flava* to sand and silt overlays and found that silt overlays of 10 cm prevented emergence of 50 percent of *F. flava*, whereas 17.5 cm prevented emergence of 50 percent of *Lampsilis spp.*. He concluded that adult mussels have the ability to emerge from significant depths after burial from a single deposition of bottom sediments. However, other life stages, such as juveniles, were not tested in these experiments.

Several investigators have reported a change in abundance, diversity or distribution of freshwater mussels in relation to siltation. Stansbery (1964) commented on the changes after impoundment of Muscle Shoals, Alabama, and noted that the Cumberlandian species were most susceptible to the changes from impoundment, whereas Ohioan species were most resistant. Coon et al. (1977) found that mussel species diversity of Pools 8, 9 and 10 of the Mississippi River had decreased from 31 species in 1930 to 23 species in 1975, and they attributed this mostly to sedimentation. Starnes and Starnes (1980) reported that although the little-winged pearlymussel *Pegias fabula* occurred in the Little South Fork Cumberland River, none were expected in the analogous habitat of the Big South Fork Cumberland River because of recent coal mining which had increased siltation and decreased water quality. They noted that the mollusk populations were declining rapidly there and would perhaps soon disappear. Metcalf (1980) attributed the decimation of the unionacean mussel fauna in Hominy Creek, Kansas, to a natural increase in sediment inputs to the river. Cooper (1987) found that degradation of the bottom habitat from sediment run-off caused reduction in both the number of taxa and density of stream organisms when compared to areas not normally subjected to excessive sediment deposition.

Changes in species composition of unionids have been attributed to unfavorable habitat for juvenile mussels. Scruggs (1960) postulated that the reduction of *Pleurobema cordatum* in a recently impounded river was due to the extensive silt deposits which degraded habitat and decreased the survival of young mussels. In the Thames River, England, Negus (1966) observed young mussels in organic sand or loam but very rarely in mud and silt. Ellis (1931) stated that "erosion silt is destroying a large portion of the mussel populations in various streams by directly smothering the animals in localities where a thick deposit of mud is formed; by smothering young mussels even where the adults can maintain themselves." Bates (1962) found that although reproduction was apparent in adults, no juvenile age classes of some mussels were found in the recently impounded Tennessee River (Kentucky Reservoir). He suspected that increased siltation, a decrease in oxygen tension, or a change in fish host availability were responsible.

Effects of Coal Mining on Streams

The Appalachian region is characterized by high topographic relief with steep slopes. Mining in this area includes contour strip mining, mountain-top removal, and limited area mining of small operation size (Starnes 1980). During surface mining, the overburden is stripped away to expose the underlying coal deposits. Mine drainage and devegetation are two significant problems created by strip mining (Ahmad 1973). Strip mining pulverizes overlying rocks which release large quantities of pyrite. Sulfuric acid is formed when pyrite is oxidized in the presence of oxygen and moisture (Ahmad 1973). In some areas, limestone in overlying rocks neutralizes the acid; however, other toxic elements are still produced. Ahmad (1973) estimated that 28,962 km of streams in Appalachia have been destroyed for generations due to mining.

Erosion from mine slopes and haul roads has affected streams by increasing sedimentation and turbidity. These inputs result in decreased 1) light penetration and aquatic plant growth, 2) fish spawning success, and 3) macroinvertebrate populations (Starnes 1980). Numerous studies have investigated changes in stream biota as a result of mining. Branson and Batch (1972) conducted a study on two Kentucky streams receiving low-level acid mine effluents and a high level of siltation and turbidity from the intensive erosion of spoil banks. Their results indicated a 90 percent decrease in numbers and kinds of benthic food organisms. Vaughan (1979) compared an undisturbed watershed to three watersheds impacted by strip mining and reported species diversity of diatoms significantly greater in undisturbed streams. In disturbed streams, the creek chub (*Semotilus atromaculatus*) composed 95-98 percent of the fish populations, and darter species were absent. His conclusions noted a trend toward smaller populations and fewer species of both fish and diatoms and that "changes observed in community structure of organisms in these streams could not be explained by differences in water quality other than those related to increased runoff, sediment load, and siltation caused by mining activity." Vaughan (1979) also stated that in the absence of acid mine drainage, the major impacts to the aquatic community were related to accelerated runoff with substratum disturbance, scouring, and siltation. Matter and Ney (1981) concluded from their investigations on the effects of surface mining on streams in southeastern United States, that continual sedimentation was more serious than acid formation. Curtis (1972) noted that even where acid drainage is not a problem, surface mining could result in chemical pollution of the stream; sulfate, calcium, and magnesium showed the greatest increases after mining. Effects of runoff from alkaline mine drainage can include "osmotic stress due to dissolved constituents, and sedimentation and turbidity effects from addition of solids" (United States Fish and Wildlife Service 1978). Concentrations of dissolved constituents reached a maximum after mining has ceased in an eastern Kentucky stream, and continued for several years, with maximum dissolved salts occurring during low flows (Dyer and Curtis 1977).

Coal washer wastes are produced by cleaning coal to remove non-coal materials; small particles of coal are included in the washings. This material, called "black water", is occasionally discharged into streams illegally. Little work has been done to characterize the effects of coal washings or coal fines on aquatic systems. Pautzke (1937) subjected young steelhead and cutthroat trout to washings produced from semi-bituminous coal and found that fish exposed to the discharge in the stream died within 2.5 hours. He observed solid masses of coal dust and slate particles adhering to heavy mucus secretions on the gills of these fish. Williams (1969) found coal dust deposited on the periostracum of mussels, and although coal dust was found in the digestive tract, he could not determine whether the substance was detrimental to mussels. Charles (1966) concluded that "intermittent coal waste pollution in Martin's Fork (KY) had a greater effect on the viewers aesthetic sensibility than it had on biological productivity." However, his evaluation of macroinvertebrate fauna did not include mussels.

The Powell River

The principle perturbations in the Powell River and its tributaries were reported by the Tennessee Valley Authority (1980) to be suspended solids and acid mine drainage, with "blackwater" being a major problem. They also noted that low pH due to acid mine drainage was restricted to headwater tributaries, although high sulfate levels remained throughout the river. Heffinger (1986) postulated that water quality in the Powell River was degraded by coal mining activities and municipal discharges. Coal waste from processing plants was very obvious in the river from substratum and water quality data (Neves et al. 1980), yet no information was available on possible negative effects from coal particles in the stream. 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."

Ortmann (1918) in his early survey of the Powell River listed 41 species of freshwater mussels and predicted the eventual decline of mussel populations. "In view of the gradual, slow but steady, deterioration of the fauna in consequence of stream pollution, there is great danger that the fauna will largely become destroyed, and that it will be impossible, in the future, to duplicate this collection. At the present time, conditions are fair, some parts splendid; but there are already polluted streams in which the fauna are gone. Such are: the Powell River, for a certain distance below Big Stone Gap, Virginia (wood extracting plant)..."(Ortmann 1918). Although he collected mussels as far upstream as Bigstone Gap (PRM 178.2), recent surveys on the Powell River indicate that collecting sites above PRM 140 have been heavily impacted by coal and silt deposition, and no mussels have been found above PRM 165 (Ahlstedt and Brown 1979, Neves et al. 1980, Dennis 1981, Ahlstedt 1986). Ahlstedt and Brown (1979) were unable to locate nine of the species recorded by Ortmann (1918) and speculated that six of these species were headwater species and may have been eliminated from the upper Powell River due to siltation. The other three species were perhaps eliminated by the impoundment of Norris Reservoir. They postulated that the restricted distribution of mussels in the Powell River was probably due to habitat degradation from the building of dams, stream channelization, pollution and silt from strip mines and coal washing facilities. Dennis (1981) reported a complete elimination of mussels in the upstream reaches of the Powell River (PRM 141-180) and below PRM 141, mussel abundance gradually increased downstream. Few mussels were found above PRM 144.3 by Ahlstedt and Brown (1979), who noted that silt and coal deposits were obvious features in the substratum. Neves et al. (1980) indicated that endangered mussels did not exist above PRM 136.1 and postulated that the major factor accounting for this was habitat degradation from coal waste inputs. Ahlstedt and Brown (1979) concluded that "continued siltation of the river could eventually destroy the remaining mussel assemblage."

Presently, 36 mussel species are reported in the Powell River, including 15 endemic species characteristic of the Cumberland Plateau Region (Ahlstedt 1986). Cumberlandian fauna historically occurred in the Powell, Clinch and Holston rivers in Virginia and Tennessee, the French Broad River and portions of the Duck, Elk, and Tennessee rivers in Tennessee, and the Cumberland River in Kentucky (Dennis 1981). All seven endangered species in the Powell

River are Cumberlandian species: *Dromus dromas* (dromedary pearlymussel), *Fusconaia cor* (shiny pigtoe), *Fusconaia cuneolus* (fine-rayed pigtoe), *Hemistena lata* (crackling pearlymussel), *Lemiox rimosus* (birdwing pearlymussel), *Quadrula intermedia* (Cumberland monkeyface), and *Quadrula sparsa* (Appalachian monkeyface). Collection records by Jenkinson and Ahlstedt (1988) indicated that the seven endangered species may be declining in abundance in the Powell River. Several endangered species were collected in their quadrat surveys; however, *L. rimosus* and *H. lata* were only collected in qualitative surveys in 1979 (Ahlstedt 1986). Quadrat surveys indicated that *F.cor* has decreased significantly since 1979 (Jenkinson and Ahlstedt 1988).

Jenkinson and Ahlstedt (1988) documented a decline in overall mean abundance of freshwater mussels in the Powell River over the past decade: 7.25 mussels/m^2 in 1979, 4.87 mussels/m^2 in 1983, and 2.41 mussels/m^2 in 1988. They found that most species declined between 1979 and 1983, although most populations did not decline statistically between 1983 and 1988. The significant difference between 1979 and 1983 may reflect the die-off that occurred in the Powell River in 1983 (Ahlstedt and Jenkinson 1987). The mucket, *Actinonaias ligamentina*, declined significantly throughout the sampling period. Even though decreases appear to be occurring for many species, the Powell River still contains one of the richest mussel faunas in the United States and needs to be protected from further degradation.

Objectives

This project, funded by the U.S. Fish and Wildlife Service, was initiated to evaluate any changes in distribution and abundance of mussels in the Powell River and to determine whether coal mining wastes are detrimental to the mussel fauna.

Specific objectives of this study were as follows:

1) to compare present abundance, diversity and size distribution of freshwater mussels in the Powell River to that of previous surveys;

2) to evaluate the amount of coal waste and sediment deposits in the substratum of the Powell River, especially in areas which still support mussel populations; and

3) to determine the responses of juvenile mussels to coal and Powell River sediments in laboratory experiments.

Materials and Methods

Study Area

The Powell River, located in the headwaters of the Tennessee River system, flows southwest from near Norton, Virginia, through the Ridge and Valley Province of the Appalachian Mountains into Tennessee, where it joins the Clinch River in Norris Reservoir (Figure 1). This study was conducted in the Virginia portion of the Powell River. Study sites were selected according to suitability of habitat for mussels, similarity among sites (such as riffles and runs and type of substratum), and accessibility (Table 1). Most sites were selected from those previously surveyed by Ahlstedt and Brown (1979), Neves et al. (1980), Dennis (1981), Ahlstedt (1986), and Jenkinson and Ahlstedt (1988). All sites sampled quantitatively were mapped and documented for access (Appendix A). Water quality data were obtained from EPA's STORET data base for the Powell River, 1988 and 1989 and summarized (Appendix B).

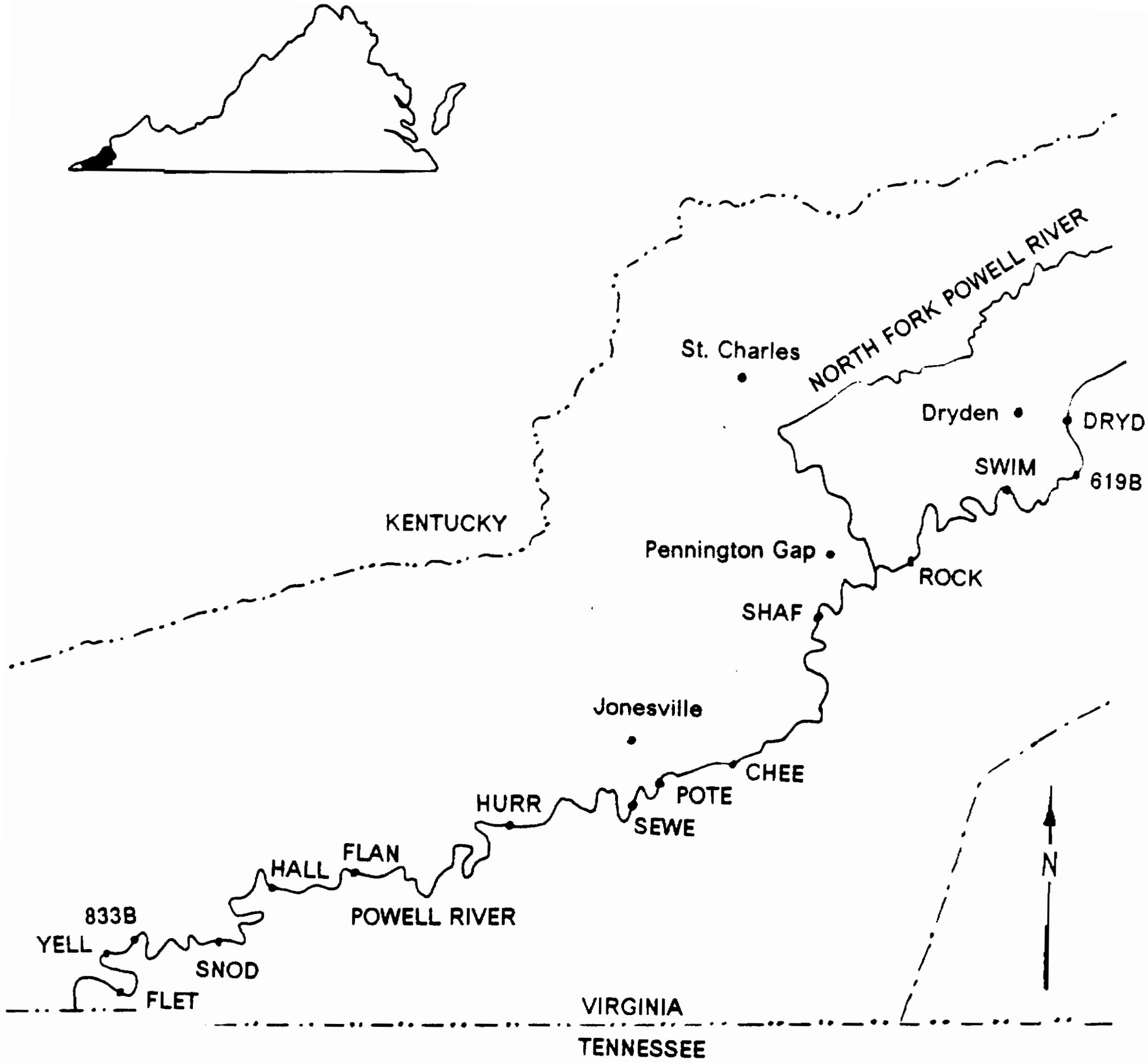

Figure 1. Map of the Powell River, Lee County, Virginia.

TABLE 1. Sites sampled for mussels in the Powell River, 1988-89.

Site (abbreviation)	River Mile	Description
Fletcher Ford (FLET)	117.3	Rte. 678 off Rte. 661; private access,locked gate; 75m run, 21m riffle.
Yellow Creek (YELL)	119.3	Rte. 661, above swinging bridge; long riffle downstream of Yellow Creek confluence.
Rte. 833 Bridge (833B)	120.4	Rte. 833 bridge off Rte. 661; 50m riffle, 100m run.
Snodgrass Ford (SNOD)	123.0	Rte. 667 off Rte. 679; approx. 0.5 mile downstream of swinging bridge; boat access only; 60m run, 30m riffle.
Hall Ford (HALL)	128.4	Gravel road off Rte. 662; under swinging bridge; 31m mixed riffle and run.
Flanary Bridge (FLAN)	130.6	Rte. 758 bridge; downstream of bridge; short, deep run with small riffle areas.
Hurricane Bridge (HURR)	138.3	Rte. 654 bridge; downstream of bridge; short, deep run; no riffles.
Sewell Bridge (SEWE)	143.5	Rte. 70 bridge; small riffle and run.
Poteet Ford (POTE)	144.6	Gravel road off Rte. 783; at ford, downstream of swinging bridge; 100m run and 80m mixed riffle and run.
Cheekspring Ford (CHEE)	146.8	Rte. 783; under swinging bridge; 30m riffle, 30m run.
Shafer Ford (SHAF)	153.4	Rte. 640; channel on eastern side of island; other channel intermittent; 40m run, 10m riffle.
Rock Island (ROCK)	158.3	Gravel road off Rte. 642; poor access; short riffles and runs.
Swimming Hole (SWIM)	163.4	Gravel road off Rte. 642; downstream of swinging bridge; 30m run, 10m riffle.
Rte. 619 Bridge (619B)	165.5	Rte. 619 bridge; downstream of bridge; 15m run, 50m riffle.
Dryden (DRYD)	167.4	Gravel road at Rte. 58 bridge; at island upstream of bridge; 10m riffle, 60m run.

Quantitative Surveys

Quantitative surveys were conducted at 9 sites on the Powell River, identified by Powell River Mile (PRM). Approximately one 0.5 m^2 quadrat was taken for every 100 m^2 of suitable mussel habitat, which included optimal and marginal habitats. A minimum of 10 quadrats and a maximum of 20 quadrats were taken at each site. Quadrat samples were obtained using a 0.5 m^2 metal frame, and allocated among riffles and runs according to area. Quadrat points were located randomly by the following method: a meter tape was placed lengthwise down the middle of the river at each sampling site. Points were then chosen on the tape using a random number table. Random numbers were then used to pace off the appropriate distance from the tape to each quadrat point. The substratum was searched to approximately 15 cm in depth with the aid of a mask and snorkel. All live mussels contained in the 0.5 m^2 area were removed, identified, and measured for length (maximum anterior to posterior distance). Mussels were replaced near their original location in the siphoning position. Numbers were converted to densities per square meter at each site. Densities of the exotic asian clam, *Corbicula fluminea*, and the state-protected spiny riversnail, *Io fluvialis*, also were recorded to determine the abundance of these species. Age estimates of the pheasantshell, *Actinonaias pectorosa*, were obtained by counting external growth lines on shells. Substratum type was characterized visually (cobble, gravel, sand or silt), and water velocity was recorded at mid-depth at each quadrat using a Marsh McBirney Model 201 portable water current meter.

Although chi-square procedures with contingency tables would be the most appropriate analysis to compare sites with count data, insufficient numbers of mussels were collected to use these procedures. Therefore, Kruskal-Wallis procedures were used to compare mean densities among sites. Total densities of mussels, *I. fluvialis*, and *C. fluminea* at sites grouped by river reaches also were compared using Kruskal-Wallis procedures. Sites were grouped as downstream (Fletcher Ford, Rte. 833 Bridge, Snodgrass Ford), midstream (Hall Ford, Poteet Ford, Cheekspring Ford), and upstream (Shafer Ford, Swimming Hole, Rte. 619 Bridge). Differences in average lengths of the pheasantshell, *Actinonaias pectorosa*, and the mucket, *A. ligamentina*, were compared among sites using ANOVA procedures. Chi-square analysis with contingency tables were used to determine differences in size class distributions of *A. pectorosa* among sites. Insufficient numbers of most species in quadrat samples prevented similar comparative analyses of abundance and length data.

Qualitative Surveys

Qualitative sampling was conducted to assess distribution and relative abundance of mussel species. Fifteen sites were surveyed using a combination of waterscopes, snorkeling and wading. Surveying times ranged from 0.5 to 3 h, depending on the amount of suitable habitat at each site. All mussels observed during this time were collected, identified, measured, and replaced in a siphoning position. Numbers of *I. fluvialis* were recorded also.

Qualitative sites were grouped by river reach in order to conduct Kruskal-Wallis tests on the number collected per unit effort (CPUE) data. Sites were grouped as follows: downstream (Fletcher Ford, Yellow Creek, Rte. 833 Bridge, Snodgrass Ford), lower-midstream (Hall Ford, Flanary Bridge, Hurricane Bridge), upper-midstream (Sewell Bridge, Poteet Ford, Cheekspring Ford, Shafer Ford), and upstream (Rocky Road, Swimming Hole, Rte. 619 Bridge, Dryden). Grouped sites were compared to determine differences in numbers of mussels, mussel species, and *I. fluvialis* collected per unit effort. Mussel length data were analyzed in the same manner as length data from sites sampled by quadrats.

Substratum Analysis

Substratum samples were collected at each of the quadrat sites to determine particle size distribution and coal content. A modified 20 cm diameter metal coring device (Figure 2),

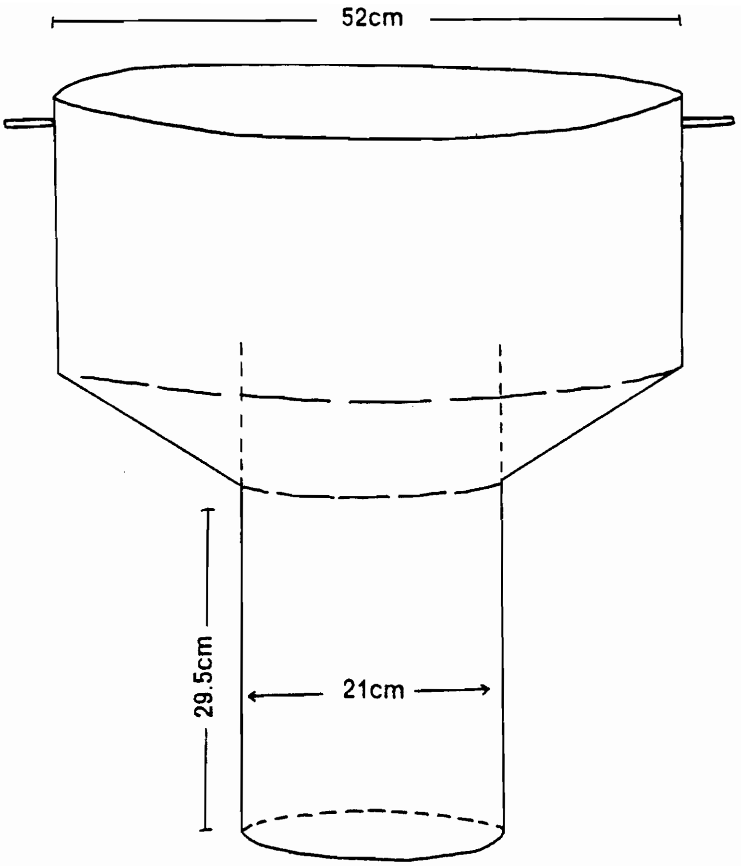

Figure 2. Schematic of a McNeil-Ahnell hollow-core sampler.

similar to a McNeil-Ahnell Hollow Core Sampler, was used (Hamilton and Bergersen 1984). Sample depth averaged approximately 16 cm, and the samples were collected from each riffle and pool at quadrat sites. Sample volume was approximately 300-400 cm^3. Water velocity readings were taken at mid-depth at each sample point. Substratum samples were passed through a 2 mm USGS sieve in the field, and both size fractions were bagged and transported to the laboratory.

In the laboratory, excess water was decanted off the <2 mm fraction after standing for 24 h. Samples were air-dried, passed through a series of USGS sieve screens, and classified according to the Wentworth system; large cobble (128-256 mm), small cobble (64-128 mm), pebble (16-64 mm), gravel (2-16 mm), coarse to very coarse sand (0.5-2 mm), very fine to medium sand (0.063-0.5 mm), and silt (<0.063 mm). Each fraction was weighed to determine percent composition by weight. Coal was separated out of each fraction using float-sink separation methods (American Society for Testing and Materials 1987). High-density organic fluids (perchloroethylene and Hevigrav) were used to achieve a specific gravity of approximately 1.8. When the sediment fractions were added to these media, the coal floated to the top and was screened or filtered off. Coal fractions were dried and weighed. Coal is lighter than other sediments; therefore, sediment weights were adjusted to volume for comparison purposes. A conversion factor of two was obtained by comparing the volumes of water displaced by equal weights of coal and non-coal sediments. Therefore, the volume of coal was approximately twice that of non-coal sediments of equal weight.

The weight data obtained (percent composition) are proportional and an arcsine transformation was used to normalize data (Zar 1984). ANOVA procedures were used to determine if there were any differences in the mean proportions by weight of size fractions and coal among sites. Quadrat sites were compared to determine any trends from upstream to downstream in the amount of coal and silt deposition.

Responses of Juvenile Mussels to Coal and Silt Deposition

Juvenile rainbow mussels, *Villosa iris*, were obtained by infesting a known host fish, rock bass (*Ambloplites rupestris*), with glochidia in the laboratory. Mussels were obtained from the Clinch River, Tazewell County, Virginia. Rockbass were collected from the New River, Montgomery County, Virginia by electrofishing. Procedures for infesting fish with glochidia were as described by Bruenderman (1989), except that glochidia were teased from the marsupia of sacrificed mussels. Newly metamorphosed juveniles were collected as they dropped from the fish host for use in laboratory and field experiments and ranged in age from one to five days.

Several laboratory experiments were conducted by placing juvenile mussels in coal, non-coal, or Powell River silt substrata. Coal silt was obtained by pulverizing large pieces of coal from the Powell River and passing the material through a series of USGS sieves. Powell River silt was obtained by sieving river sediments. Approximately 50 ml of each silt type was measured into 90 x 50 mm Pyrex crystallizing dishes. Juveniles were pipeted into holding chambers constructed of 27 x 50 mm PVC pipe with 6 mm holes drilled in the sides (Figure 3). Strips of 153 μm Nitex were adhered to the sides and one end of the pipe. These chambers were then placed in each crystallizing dish. The crystallizing dishes were covered with 202 μm Nitex screen and placed randomly on the bottom of a 285 l recirculating Living Stream (Frigid Units Inc., Toledo, OH). Water characteristics in the Living Stream were as follows: dissolved oxygen, 8.3 mg/l; pH, 7.2-7.5; temperature, 19-20 C. Two or three repetitions of each treatment were completed, depending on the number of juveniles available (Table 2). Juveniles were not fed during these experiments.

Experiment One

Holding chambers containing 10 juvenile mussels were placed in individual crystallizing dishes with either 50 ml of 100 percent coal silt from the Powell River or no substratum. Three

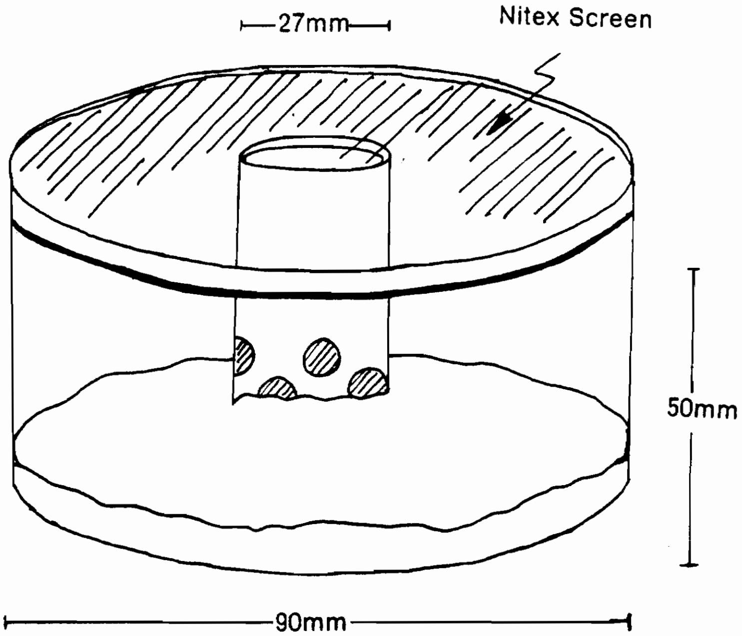

Figure 3. Juvenile holding chamber placed in crystallizing dish.

TABLE 2. Summary of juvenile experiments conducted with several substrata in the laboratory and field, 1989.

Experiment		Date started	Treatment	No. of juveniles	Replicates
Experiment one - Laboratory					
	7-day	06-27-89	coal/none	10	3
		10-31-89	coal/none	10	3
	14-day	05-10-89	coal/none	10	3
		07-04-89	coal/none	10	3
Experiment two - Laboratory					
	7-day	07-17-89	FLET/POTE/DRYD/NONE	20	2
		10-08-89	FLET/POTE/DRYD/NONE	10	3
	14-day	07-17-89	FLET/POTE/DRYD/NONE	20	2
Experiment three - Field					
	7-day	08-23-89	FLET/POTE/DRYD	10	2

repetitions of each treatment were run. Trials were completed for both 7 and 14-day periods in a Living Stream.

Experiment Two

Juveniles were placed in holding chambers which were set in crystallizing dishes containing no substratum or 50 ml of sediments from Fletcher Ford, Poteet Ford, and Dryden. Seven and 14-day trials periods were run with two repetitions per treatment, and 20 juveniles per chamber. A 7-day trial period was run with three repetitions, and 10 juveniles per chamber. All trials were conducted in a Living Stream.

Experiment Three

Holding chambers containing 10 juveniles were placed in crystallizing dishes containing 50 ml of sediment from Fletcher Ford, Poteet Ford, or Dryden. Crystallizing dishes covered with 153 μm Nitex were bound to the bottom of a 16.5 x 16.5 x 60.0 cm wire cage (live trap). Each wire cage was anchored in the river for 7 days at sites corresponding to where the treatment sediment in the crystallizing dish was collected. Survival of juveniles among treatments was compared by chi-square and contingency table analysis.

Results

Species Composition and Distribution

Quantitative and qualitative mussel sampling in 1988 and 1989 yielded 28 mussel species, including five federally-endangered species and four proposed state-endangered species (Table 3). The mussel species *Fusconaia barnesiana* and *Pleurobema oviforme* are difficult to distinguish solely from external characteristics, and because many of these species are rare, mussels were not sacrificed for positive identification. When positive identification could not be made, these specimens were grouped together as *Fusconaia/ Pleurobema* complex. Therefore, the number of species is considered a minimum in my surveys. Endangered mussel species were found at many sites (Table 4), but not above Poteet Ford (PRM 144.6). *I. fluvialis* was also found at most sites but was absent above PRM 163.4. No live mussels or relic shells were found above PRM 167.4. The most diverse sites on the Powell River in Virginia were located furthest downstream, and there appeared to be a general decline in the number of species of mussels from downstream to upstream (Figure 4).

Two of the most diverse sites in the downstream portion of the river are Fletcher Ford (PRM 117.3) and Snodgrass Ford (PRM 123.0). Sampling at Fletcher Ford produced 19 mussel species. Snodgrass Ford, which has never been documented as a mussel bed, proved to

TABLE 3. Mussel species collected in the Powell River, Virginia, 1988 and 1989.

Scientific name[1]	Common name
Actinonaias ligamentina	mucket
Actinonaias pectorosa	pheasantshell
Amblema plicata plicata	three-ridge
Cyclonaias tuberculata	purple wartyback
Dromus dromas[2]	dromedary pearlymussel
Elliptio dilatata	spike
Epioblasma brevidens[3]	cumberlandian combshell
Epioblasma capsaeformis[3]	oyster mussel
Epioblasma triquetra[3]	snuffbox
Fusconaia barnesiana	Tennessee pigtoe
Fusconaia cor[2]	shiny pigtoe
Fusconaia subrotunda	long-solid
Lampsilis fasciola	wavy-rayed lampmussel
Lampsilis ovata	pocketbook
Lasmigona costata	fluted- shell
Lemiox rimosus[2]	birdwing pearlymussel
Ligumia recta	black sandshell
Medionidus conradicus	Cumberland moccasinshell
Plethobasus cyphyus[3]	sheepnose
Pleurobema oviforme	Tennessee clubshell
Potamilus alatus	pink heelsplitter
Ptychobranchus fasciolaris	kidneyshell
Ptychobranchus subtentum	fluted kidneyshell
Quadrula cylindrica strigillata	rough rabbitsfoot
Quadrula intermedia[2]	Cumberland monkeyface
Quadrula sparsa[2]	Appalachian monkeyface
Villosa iris	rainbow
Villosa vanuxemensis vanuxemensis	mountain creekshell

[1] Nomenclature from Turgeon et al. (1988)
[2] Federal endangered species
[3] Proposed state-endangered species

TABLE 4. Locations and diversity of mussel species collected in the Powell River, Virginia, 1988 and 1989.

SITE	FLET	YELL	833B	SNOD	HALL	FLAN	HURR	SEWE	POTE	CHEE	SHAF	ROCK	SWIM	619B	DRYD
SPECIES RIVER MILE	117.3	119.3	120.4	123.0	128.4	130.6	138.3	143.5	144.6	146.8	153.4	158.3	163.4	165.5	167.4
Actinonaias ligamentina	X	X	X	X	X	X	X	X	X	X	X	-	-	-	-
Actinonaias pectorosa	X	X	X	X	X	X	X	X	X	X	X	X	X	-	X
Amblema plicata	-	-	X	X	X	X	-	X	X	-	-	-	-	-	-
Cyclonaias tuberculata	X	X	X	X	X	-	-	X	X	-	-	-	-	-	-
Dromus dromas[1]	X	X	X	X	-	-	-	-	-	-	-	-	-	-	-
Elliptio dilatata	X	X	X	X	X	-	-	X	X	X	X	X	-	X	-
Epioblasma brevidens[2]	X	-	X	X	X	-	-	X	-	-	-	-	-	-	-
Epioblasma capsaeformis[2]	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-
Epioblasma triquetra[2]	X	-	-	X	X	X	-	-	-	-	-	-	-	-	-
Fusconaia/Pleurobema	X	-	X	X	X	-	-	-	X	X	-	-	-	-	-
Fusconaia cor[1]	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-
Fusconaia subrotunda	X	X	X	X	X	X	X	X	X	X	X	X	-	-	X
Lampsilis fasciola	X	X	X	X	X	-	X	X	X	X	X	X	X	-	X
Lampsilis ovata	-	X	X	X	-	X	X	X	X	-	X	-	-	-	-
Lasmigona costata	X	-	X	X	X	X	X	X	X	X	X	-	-	-	-
Lemiox rimosus[1]	X	-	-	-	-	-	-	-	X	-	-	-	-	-	-
Ligumia recta	X	-	X	X	-	-	-	-	-	X	-	-	-	-	-
Medionidus conradicus	X	X	X	X	X	-	-	X	-	-	-	-	-	X	-
Plethobasus cyphyus[2]	X	-	-	X	-	-	-	-	-	-	-	-	-	-	-
Potamilus alatus	X	-	-	X	-	X	X	X	X	X	X	-	-	-	-
Ptychobranchus fasciolaris	X	X	X	X	-	-	-	X	X	X	X	X	-	-	X
Ptychobranchus subtentum	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-
Quadrula cylindrica strigillata	-	-	X	-	-	X	-	X	X	-	X	X	-	-	-
Quadrula intermedia[1]	X	X	X	X	X	-	-	X	X	-	-	-	-	-	-
Quadrula sparsa[1]	X	X	-	-	-	-	-	-	X	-	-	-	-	-	-
Villosa iris	-	-	-	X	X	-	-	-	-	-	-	-	-	-	X
Villosa v. vanuxemensis	-	-	-	-	-	-	-	-	-	X	X	X	X	X	-
Total species	19	12	18	22	14	9	7	15	16	11	11	7	3	3	5
Federal endangered spp.	4	3	2	3	1	-	-	1	3	-	-	-	-	-	-
Proposed state endangered spp.	3	-	2	3	2	1	-	1	-	-	-	-	-	-	-

[1]Federal endangered species [2]Proposed state-endangered species

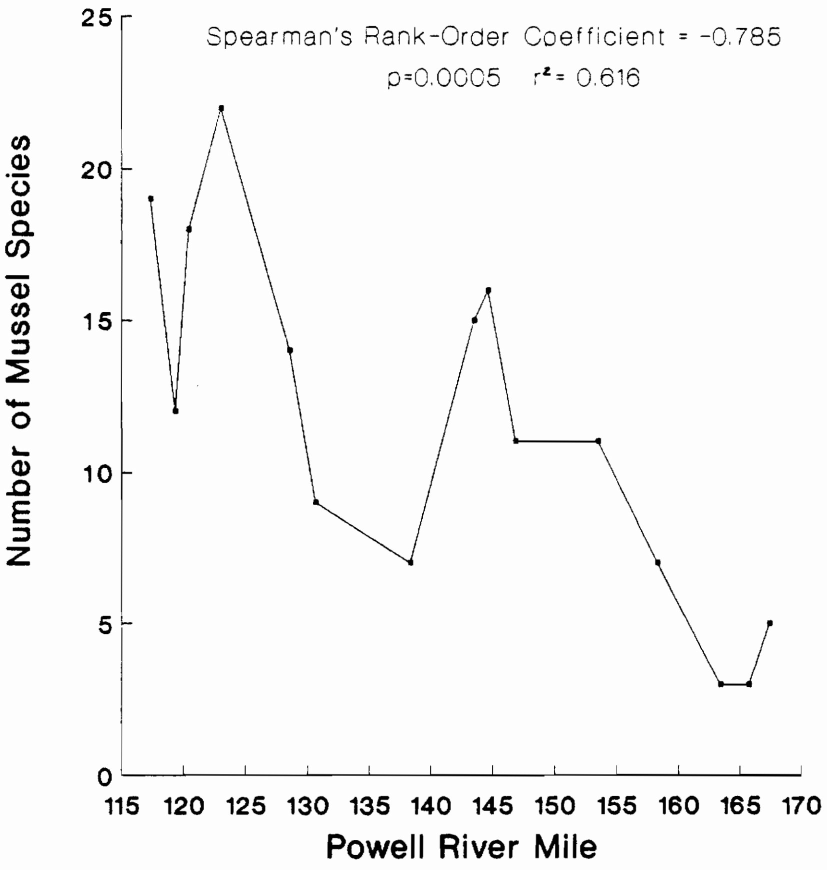

Figure 4. Total number of mussel species collected at sites sampled in the Powell River in 1988 and 1989.

support the most diverse and abundant mussel fauna, including 22 mussel species. Both sites consist of a 75-80 m run section followed by a swift 20-30 m riffle. Bottom substrata consist primarily of a non-compacted mixture of pebble, gravel and sand.

Mussel Densities in Quadrat Samples

Mussel densities declined progressing upstream, and mussels were very rare above PRM 163.4 (Table 5). Mean water velocity in riffles increased progressing upstream (Appendix C). Mussel abundance was too low upstream of PRM 163.4 to be quantified by quadrat sampling; however, mussels were found in qualitative sampling. Comparison of mussel densities by Kruskal-Wallis analysis showed significant differences among sites ($p=.0001$), and multiple comparisons were made using Wilcoxon two-sample tests (Table 6). Snodgrass Ford had significantly higher mussel densities than all of the other sites, with a mean density of 24.0 mussels/m^2. Densities at Fletcher Ford and the Rte. 833 Bridge were not significantly different from each other but were greater than all other sites. Densities of *I. fluvialis* were significantly different among sites ($p=.0001$), with the highest numbers occurring at Snodgrass Ford and Fletcher Ford (Table 6). Densities of *C. fluminea* were also significantly different among sites ($p=.0001$), with the highest numbers occurring at Hall Ford, Snodgrass Ford and Fletcher Ford (Table 6).

When sites were grouped, the Kruskal-Wallis test showed significant differences ($p=0.0001$) in mussel densities among grouped sites, with the greatest densities at downstream sites (Table 7). Densities of *I. fluvialis* showed a significant difference among grouped sites ($p=0.0001$), with downstream sites having higher densities than mid or upstream sites. *C. fluminea* densities were also significantly different among grouped sites ($p=.0020$), with downstream sites having the greatest densities.

Table 5. Number of mussels per square meter in quadrat samples from the Powell River, 1988.

SPECIES	SITE RIVER MILE	FLET 117.3	833B 120.4	SNOD 123.0	HALL 128.4	POTE 144.6	CHEE 146.8	SHAF 153.4	SWIM 163.4	619B 165.7
Actinonaias ligamentina		0.7	0.5	5.0	0.2	-	-	-	-	-
Actinonaias pectorosa		3.7	3.0	13.9	0.6	0.1	0.8	0.2	-	-
Cyclonaias tuberculata		0.1	-	-	-	-	-	-	-	-
Dromus dromas[1]		-	-	0.1	-	-	-	-	-	-
Elliptio dilatata		0.4	0.6	2.2	-	0.1	-	-	-	-
Epioblasma brevidens[2]		0.3	0.1	-	-	-	-	-	-	-
Fusconaia subrotunda		0.6	0.3	1.0	-	0.5	-	-	-	-
Lampsilis fasciola		0.1	-	-	-	-	-	0.2	-	-
Lampsilis ovata		-	-	0.1	-	-	-	-	-	-
Lemiox rimosus[1]		-	-	-	-	0.1	-	-	-	-
Ligumia recta		-	-	0.1	-	-	-	-	-	-
Medionidus conradicus		0.5	0.6	1.4	-	-	-	-	-	-
Plethobasus cyphyus[2]		0.1	-	-	-	-	-	-	-	-
Quadrula intermedia[1]		-	-	0.2	-	-	-	-	-	-
Villosa v. vanuxemensis		-	-	-	-	-	-	-	0.2	-
TOTAL		6.5	5.1	24.0	0.8	0.8	0.8	0.4	0.2	-
TOTAL QUADRATS		20	20	20	10	20	10	10	10	10
TOTAL SPECIES		9	6	9	2	4	1	2	1	-
Corbicula fluminea		201.2	134.2	267.7	266.8	43.4	71.4	100.0	71.4	46.4
Io fluvialis		3.1	2.0	5.0	1.6	0.9	-	0.2	-	-

[1] Federal endangered species

[2] Proposed state-endangered species

TABLE 6. Differences in mollusk densities among sites as determined by the quadrat survey, 1988.

MUSSELS $\chi^2=90.97$, $p=0.0001$			SPINY RIVERSNAIL $\chi^2=49.90$, $p=0.0001$			ASIAN CLAM $\chi^2=49.89$, $p=0.0001$		
Site	Mean[1]	SE	Site	Mean	SE	Site	Mean	SE
SNOD	24.00a[2]	1.63	SNOD	5.00a	0.35	HALL	266.80a	19.14
FLET	6.50b	0.50	FLET	3.10ab	0.42	SNOD	267.70a	23.38
833B	5.10b	0.54	833B	2.00bc	0.33	FLET	201.20ab	22.13
HALL	0.80c	0.22	HALL	1.60bc	0.25	833B	134.20bc	13.26
CHEE	0.80c	0.22	POTE	0.90bc	0.17	SHAF	100.00bc	10.39
POTE	0.80c	0.18	SHAF	0.20cd	0.10	CHEE	71.40cd	10.39
SHAF	0.40c	0.13	CHEE	0.00d	0.00	SWIM	71.40cd	7.53
SWIM	0.20c	0.10	619B	0.00d	0.00	619B	46.40d	4.15
619B	0.00c	0.00	SWIM	0.00d	0.00	POTE	43.40d	3.92

[1] Mean density estimates refer to the number of mollusks/m^2.

[2] Means with the same letter are not significantly different ($p \geq 0.05$) according to Wilcoxon 2-sample tests.

TABLE 7. Differences in mollusk densities among grouped sites, as determined by the quadrat survey, 1988.

MUSSELS		SPINY RIVERSNAIL		ASIAN CLAM	
$\chi^2 = 79.08$, $p = 0.0001$		$\chi^2 = 35.05$, $p = 0.0001$		$\chi^2 = 17.50$, $p = 0.0020$	
Site	Mean[1]	Site	Mean	Site	Mean
DOWNSTREAM	11.867a[2]	DOWNSTREAM	2.133a	DOWNSTREAM	201.03a
MIDSTREAM	0.800b	MIDSTREAM	0.850b	MIDSTREAM	107.14b
UPSTREAM	0.200b	UPSTREAM	0.067c	UPSTREAM	72.60b

[1] Mean density estimates refer to the number of mollusks/m^2.

[2] Means with the same letter are not significantly different ($p \geq 0.05$) according to Wilcoxon 2-sample tests.

CPUE - Qualitative Surveys

The number of mussel species collected was higher in qualitative surveys than quantitative surveys (Table 8). Generally, most of the common species were found during quadrat sampling, while rarer species were found during qualitative sampling. The highest number of species was collected at Fletcher Ford. *Actinonaias pectorosa* and *A. ligamentina* were the most common mussel species at most sites. The number of mussels and species collected per unit effort declined progressing upstream, except at some midstream sites (Table 9). Sites at Flanary Bridge and Hurricane Bridge appeared very silty and had fairly short riffles. Hall Ford also had a very short riffle area. Kruskal-Wallis tests compared differences in mussels collected per unit effort for grouped sites. Significant differences ($p=.0142$) were found among grouped sites (Table 10). Mussels collected per unit effort were significantly lower at upstream sites when compared to other sites. No differences were found among the other site groups. The number of species collected per unit effort was significantly different among grouped sites ($p=.0312$); upstream sites had significantly fewer species per unit effort. Differences in *I. fluvialis* collected per unit effort were not significant among grouped sites ($p=.0722$). Results of CPUE data concur with quadrat data regarding longitudinal trends in abundance; namely, mussel abundance decreased in an upstream direction.

Size Class Differences Among Sites

Lengths of specimens were used to represent age structure of populations at sites. I hypothesized that because the Powell River appeared to be less affected downstream, and survival of juvenile mussels may be affected by siltation or other pollutants, juvenile mortality would be expected to be higher at upstream sites where siltation or pollution is suspected to be greater. A decrease in recruitment of juveniles would affect age and length distributions

Table 8. Numbers of mussels recorded in qualitative sampling of the Powell River, 1988.

	SITE	FLET	YELL	833B	SNOD	HALL	FLAN	HURR	SEWE	POTE	CHEE	SHAF	ROCK	SWIM	619B	DRYD
SPECIES	RIVER MILE	117.3	119.3	120.4	123.0	128.4	130.6	138.3	143.5	144.6	146.8	153.4	158.3	163.4	165.5	167.4
Actinonaias ligamentina		59	58	12	257	32	8	28	36	49	20	5	-	-	-	-
Actinonaias pectorosa		197	125	41	208	38	6	12	42	40	40	3	4	-	-	-
Amblema plicata		-	-	3	3	2	2	-	2	1	-	-	-	-	-	-
Cyclonaias tuberculata		4	1	1	4	1	-	-	1	1	-	-	-	-	-	-
Dromus dromas[1]		3	2	-	2	-	-	-	-	-	-	-	-	-	-	-
Elliptio dilatata		12	9	5	9	4	-	-	3	11	4	2	4	-	1	-
Epioblasma brevidens[2]		2	-	1	1	-	-	-	1	-	-	-	-	-	-	-
Epioblasma capsaeformis[2]		-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
Epioblasma triquetra[2]		-	-	-	-	-	1	-	-	-	-	-	-	-	-	-
Fusconaia/Pleurobema		-	-	1	-	-	-	-	-	1	-	-	-	-	-	-
Fusconaia subrotunda		30	9	4	41	8	2	5	38	24	5	1	7	-	-	-
Lampsilis fasciola		4	5	3	4	1	-	3	3	5	1	-	2	2	-	-
Lampsilis ovata		-	-	1	-	-	1	4	5	4	-	-	-	-	-	-
Lasmigona costata		7	-	2	3	5	2	3	6	2	1	-	-	-	-	-
Lemiox rimosus[1]		1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ligumia recta		-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
Medionidus conradicus		8	8	23	14	-	-	-	1	-	-	-	-	-	1	-
Plethobasus cyphyus[2]		1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Potamilus alatus		1	-	-	-	-	1	8	2	1	1	-	-	-	-	-
Ptychobranchus fasciolaris		1	1	4	5	-	-	-	1	3	1	-	1	-	-	-
Quadrula cylindrica strigillata		-	-	1	-	-	1	-	1	3	-	-	1	-	-	-
Quadrula intermedia[1]		2	1	-	2	-	-	-	1	3	-	-	-	-	-	-
Quadrula sparsa[1]		1	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Villosa iris		-	-	-	1	1	-	-	-	-	-	-	-	-	-	-
Villosa v. vanuxemensis		-	-	-	-	-	-	-	-	-	1	-	1	-	1	-
TOTAL		333	220	103	554	92	24	63	143	148	75	11	20	2	3	-
TOTAL SPECIES		16	11	15	14	9	9	7	15	14	10	4	7	1	3	-
TOTAL *Io fluvialis*		124	13	27	156	23	6	-	6	27	4	25	1	-	-	-

[1] Federal endangered species

[2] Proposed state-endangered species

TABLE 9. Collection per unit effort of mollusks in the Powell River, 1988.

SITE	FLET	YELL	833B	SNOD	HALL	FLAN	HURR	SEWE	POTE	CHEE	SHAF	ROCK	SWIM	619B	DRYD
RIVER MILE	117.3	119.3	120.4	123.0	128.4	130.6	138.3	143.5	144.6	146.8	153.4	158.3	163.4	165.5	167.4
TOTAL MUSSELS	333	220	103	554	92	24	63	143	148	75	11	20	2	3	-
TOTAL SPECIES	16	11	15	14	9	9	7	15	14	10	4	7	1	3	-
HOURS/SITE	3	3	3	3	3	2	2.5	3	3	3	2.5	3	1.25	1.5	.5
MUSSELS/HOUR	111.0	73.3	34.3	184.7	30.7	12	25.2	47.7	49.3	25.0	4.4	6.7	1.6	2.0	-
SPECIES/HOUR	5.3	3.7	5.0	4.7	3.0	4.5	2.8	5.0	4.7	3.3	1.6	2.3	0.8	2.0	-
TOTAL *Io fluvialis*	124	13	27	156	23	6	-	6	27	4	2	25	1	-	-
Io fluvialis/HOUR	41.3	4.3	13.5	52.0	7.7	3.0	-	2.0	10.8	1.3	1.0	8.3	0.8	-	-

TABLE 10. Differences in collection per unit effort of mollusks among grouped sites in the Powell River, 1988.

NO. OF MUSSELS		NO. OF MUSSEL SPECIES		NO. OF SPINY RIVERSNAILS	
$\chi^2 = 10.58$, $p = 0.0142$		$\chi^2 = 8.86$, $p = 0.0312$		$\chi^2 = 6.99$, $p = 0.0722$	
Site	Mean	Site	Mean	Site	Mean
DOWNSTRM	100.82a[1]	DOWNSTRM	4.67a	DOWNSTRM	27.78a
UPPERMID	31.60a	UPPERMID	3.65a	UPPERMID	3.78a
LOWERMID	22.63a	LOWERMID	3.43a	LOWERMID	3.57a
UPSTREAM	2.57b	UPSTREAM	1.27b	UPSTREAM	2.27a

[1] Means with the same letter are not significantly different ($p \geq 0.05$) according to Wilcoxon 2-sample tests.

of a mussel population. Therefore, length measurements taken from a sample of mussels from a highly impacted site should be skewed toward larger mussels and consequently have a greater mean length. Also, size frequency histograms should have fewer mussels in the smaller size classes.

Mean lengths of *A. pectorosa* were compared by ANOVA among three quadrat sites having sufficient sample sizes, and there were significant differences ($p=0.0001$) among sites (Table 11). The mean size (86.7 mm) of *A. pectorosa* was smallest at the Rte. 833 Bridge, and there may be better recruitment or juvenile survival at this site. Snodgrass Ford had the greatest mean length (106.9 mm), and this may imply reduced recruitment. A χ^2 contingency table comparing length frequency distributions among sites indicated that there are differences ($p<0.0001$) in length classes among sites (Table 12). In particular, there were higher numbers of smaller mussels at the Rte. 833 Bridge than expected and fewer larger mussels than expected. Size class distributions of *A. pectorosa* show similar trends (Table 13); however, the lack of smaller individuals is evident at all sites. There also appears to be a missing size group (30-70 mm) at Fletcher Ford, Rte. 833 Bridge and Hall Ford. Although a large sample ($N=139$) of *A. pectorosa* was collected at Snodgrass Ford, no individuals less than 60 mm in length were collected. Age estimates of length data indicate that few individuals are less than 7 years old, further suggesting reduced recruitment (Table 13).

Mean lengths of *A. pectorosa* also were compared using data obtained from qualitative samples. This analysis may be biased because smaller mussels are not as easily seen when not sorting through the substrata as with quadrat samples; however, all qualitative sampling was conducted by me and consistent, therefore, from site to site. ANOVA testing indicated significant length differences ($p=0.0001$) among sites (Table 11). The Rte. 833 Bridge and Yellow Creek sites had the smallest average lengths of mussels. These data agree quite well with quadrat samples, in that the Rte. 833 site had the smallest mean mussel lengths, and Snodgrass Ford was among the sites with greater mean mussel lengths. Chi-square analysis of length distributions showed significant differences ($p<.0001$) among sites (Table 14). Of the three size classes compared, more mussels were found in the larger size class than expected,

TABLE 11. Differences in mean lengths of *Actinonaias pectorosa* among sites, as determined by quadrat and qualitative surveys, 1988.

QUADRAT SURVEYS F=17.63, p=0.0001		QUALITATIVE SURVEYS F=11.96, p=0.0001	
Site	Mean	Site	Mean
833B	86.68a[1]	833B	101.76a
FLET	100.10b	YELL	104.64ab
SNOD	106.91c	POTE	107.84bc
		FLET	109.66c
		HALL	109.66c
		SNOD	114.43d
		CHEE	114.88d
		SEWE	116.83d
		HURR	119.32d

[1] Means with the same letter are not significantly different ($p \geq 0.05$) according to Fisher's protected least-significant-difference procedure (LSD).

Table 12. Differences in size classes of *Actinonaias pectorosa* among sites, as determined by quadrat surveys, 1988.

	0-89.9mm	90-109.9mm	≥110mm	TOTAL
FLET	11[1] 6.8 2.55 29.73	12 15.3 0.70 32.43	14 14.9 0.06 37.84	37
SNOD	16 25.6 3.62 11.51	56 57.4 0.03 40.29	67 56.0 2.16 48.20	139
833B	11 5.5 5.40 36.67	17 12.4 1.72 56.67	2 12.1 8.42 6.67	30
TOTAL	38	85	83	206

[1] Numbers (in order) are observed count, expected count, cell χ^2, and row percent. Overall $\chi^2=24.666$, df$=4$, $p<.0001$

Table 13. Median size class distribution and estimated age of *Actinonaias pectorosa*, as determined by quadrat and qualitative surveys, 1988.

	Median size class (mm) (Estimate of age)														
SITE	5 (1)	15 (2)	25 (3)	35 (4)	45 (5)	55 (6)	65 (7)	75 (8)	85 (9-10)	95 (11-12)	105	115	125	135	145
QUADRATS															
FLET	-	-	1	-	-	-	-	3	7	5	7	10	3	1	-
833B	2	1	-	-	-	-	-	3	5	11	6	2	-	-	-
SNOD	-	-	-	-	-	-	1	5	10	27	37	42	20	2	-
HALL	-	-	1	-	-	-	-	-	-	-	3	-	-	-	-
CHEE	-	-	-	-	-	-	-	-	-	-	1	2	1	-	-
SHAF	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
QUALITATIVE															
FLET	-	-	-	-	-	-	-	1	17	25	39	80	30	4	1
YELL	-	-	-	-	-	-	2	1	13	22	40	44	3	-	-
833B	-	-	-	-	-	-	-	1	8	6	15	9	2	-	-
SNOD	-	-	-	-	-	-	-	2	1	17	40	84	58	4	2
HALL	-	-	-	-	-	-	-	-	1	7	5	13	12	-	-
FLAN	-	-	-	-	-	-	-	-	-	1	1	3	1	-	-
HURR	-	-	-	-	-	-	-	-	-	-	-	7	3	2	-
SEWE	-	-	-	-	-	-	-	-	-	2	10	15	11	4	-
POTE	-	-	-	-	-	-	-	-	-	2	23	15	1	-	-
CHEE	-	-	-	-	-	-	-	-	1	1	9	19	9	1	-
SHAF	-	-	-	-	-	-	-	-	-	1	1	1	-	-	-
ROCK	-	-	-	-	-	-	-	-	-	-	3	1	-	-	-

Table 14. Differences in size classes of *Actinonaias pectorosa* among sites, as determined by qualitative surveys, 1988.

	0-99.9mm	100-119.9mm	≥120mm	TOTAL
FLET	43[1] 35.0 1.81 21.83	119 123.7 0.18 60.41	35 38.3 0.28 17.77	197
YELL	38 22.2 11.19 30.40	84 78.5 0.39 67.20	3 24.3 18.65 2.40	125
833B	15 7.3 8.15 36.59	24 25.7 0.12 58.54	2 8.0 4.47 4.88	41
SNOD	20 37.0 7.80 9.62	124 130.6 0.33 59.62	64 40.4 13.78 30.77	208
HALL	8 6.8 0.23 21.05	18 23.9 1.44 47.37	12 7.4 2.89 31.58	38
SEWE	2 7.5 4.00 4.76	25 26.4 0.07 59.52	15 8.2 5.74 35.71	42
POTE	2 7.1 3.68 5.00	37 25.1 5.62 92.50	1 7.8 5.90 2.50	40
CHEE	2 7.1 3.68 5.00	28 25.1 0.33 70.00	10 7.8 0.64 25.00	40
TOTAL	130	459	142	731

[1] Numbers (in order) are observed count, expected count, cell χ^2, and row percent. Overall $\chi^2 = 101.361$, df = 14, $p < 0.0001$

and fewer mussels were found in the smaller size class than expected at Snodgrass Ford. At the Rte. 833 Bridge, more mussels were found than expected in the smaller size class. In contrast, fewer large mussels and more small mussels were found than expected at Yellow Creek. Size class tables for each site again illustrate the lack of smaller mussels, although as stated previously, qualitative sampling may be biased against smaller mussels (Table 13). However, conclusions regarding size classes present at sites appear to concur in both qualitative and quantitative samples.

Shell lengths of *A. pectorosa* at Fletcher Ford in 1988 were compared to those taken in 1978 (Neves et al. 1980). A t-test indicated no significant differences in average lengths of *A. pectorosa* between the two years ($p=.5388$). A χ^2 test indicated there may be some differences between length class distributions, but the significance is marginal ($p=.073$). Analysis by contingency table indicated that there were fewer individuals than expected in the smallest length class in 1988 sampling, when compared to samples from 1978 (Table 15). This is further suggested in comparing median length classes between these years (Table 16). There was an obvious decline in the number of smaller mussels at this site; only one specimen in the first 7 median size classes in 1988 implies reduced recruitment over time.

Differences in average lengths of *A. ligamentina* among sites in quadrat data were not significant ($p=0.0963$) among sites (Table 17). However, using qualitative data, the ANOVA test showed significant differences in mean lengths of *A. ligamentina* among sites ($p=.0001$). Fletcher Ford, Yellow Creek, and the Rte. 833 Bridge sites appear to have the smallest mean lengths of mussels. Size class distributions of *A. ligamentina* collected in both surveys indicated few mussels in the smaller size classes (Table 18). Size class distributions for *Fusconaia subrotunda* and *Elliptio dilatata* also illustrate the lack of individuals in smaller size classes (Tables 19 and 20). Although other species were collected in quantitative and qualitative sampling, sample sizes were too small for statistical analysis. Length distributions for these species are included in Appendix D.

Table 15. Differences in size classes of *Actinonaias pectorosa* at Fletcher Ford, 1978 versus 1988.

	0-49.9mm	50-89.9mm	90-119.9mm	≥120mm	TOTAL
1978	12[1] 9.5 0.68 12.12	18 20.4 0.28 18.18	45 48.8 0.29 45.45	24 20.4 0.64 24.24	99
1988	1 3.5 1.82 2.70	10 7.6 0.74 27.03	22 18.2 .78 59.46	4 7.6 1.72 10.81	37
TOTAL	13	28	67	28	136

[1] Numbers (in order) are observed count, expected count, cell χ^2, and row percent. Overall $\chi^2 = 6.955$, df=3, p=0.073.

Table 16. Median size class distribution of *Actinonaias pectorosa*, as determined by quadrat surveys at Fletcher Ford, 1978 and 1988.

	Median size class (mm)														
YEAR	5	15	25	35	45	55	65	75	85	95	105	115	125	135	145
1978	-	2	4	1	5	3	-	7	8	12	16	17	17	6	1
1988	-	-	1	-	-	-	-	3	7	5	7	10	3	1	-

TABLE 17. Differences in mean lengths of *Actinonaias ligamentina* among sites, as determined by quadrat and qualitative surveys, 1988.

QUADRAT SURVEYS F=2.44, p=0.0963		QUALITATIVE SURVEYS F=5.37, p=0.0001	
Site	Mean	Site	Mean
833B	82.28a[1]	FLET	99.78a
SNOD	97.77a	YELL	101.30ab
FLET	101.70a	833B	103.29abc
		POTE	104.98bc
		HALL	105.96bc
		SNOD	106.88c
		SEWE	107.11c
		CHEE	111.31cd
		HURR	115.53d

[1] Means with the same letter are not significantly different ($p \geq 0.05$) according to Fisher's protected least-significant-difference procedure (LSD).

Table 18. Median size class distribution of *Actinonaias ligamentina*, as determined by quantitative and qualitative surveys, 1988.

	Median size class (mm)														
SITE	5	15	25	35	45	55	65	75	85	95	105	115	125	135	145
QUADRATS															
FLET	-	-	-	-	-	-	-	-	2	2	1	1	1	-	-
833B	-	-	-	-	-	-	-	2	2	1	-	-	-	-	-
SNOD	-	-	-	-	-	-	2	5	12	13	11	3	7	-	-
QUALITATIVE															
FLET	-	-	-	-	-	-	-	5	13	7	21	9	5	-	-
YELL	-	-	-	-	-	-	-	3	6	14	22	11	2	-	-
833B	-	-	-	-	-	-	-	-	3	1	5	1	1	1	-
SNOD	-	-	-	-	-	1	2	10	32	39	45	74	45	7	2
HALL	-	-	-	-	-	-	-	3	4	2	4	16	2	1	-
FLAN	-	-	-	-	-	-	-	-	-	2	3	1	1	1	-
HURR	-	-	-	-	-	-	-	-	-	2	3	10	10	2	-
SEWE	-	-	-	-	-	-	2	-	3	5	9	8	7	2	-
POTE	-	-	-	-	-	-	-	1	4	6	23	13	2	-	-
CHEE	-	-	-	-	-	-	-	-	-	3	5	7	5	-	-
SHAF	-	-	-	-	-	-	-	-	-	-	3	-	2	-	-

Table 19. Median size class distribution of *Fusconaia subrotunda*, as determined by quantitative and qualitative surveys, 1988.

	Median size class (mm)												
SITE	5	15	25	35	45	55	65	75	85	95	105	115	125
QUADRATS													
FLET	-	-	-	-	-	-	1	-	2	3	-	-	-
833B	-	-	-	-	1	-	1	-	1	-	-	-	-
SNOD	-	-	-	-	-	-	-	-	2	4	4	-	-
POTE	-	-	-	-	-	-	1	-	2	2	-	-	-
QUALITATIVE													
FLET	-	-	-	-	-	1	2	3	6	10	6	2	-
YELL	-	-	-	-	-	-	1	-	5	2	-	-	-
833B	-	-	-	-	-	-	-	2	2	1	-	-	-
SNOD	-	-	-	-	-	-	1	-	8	21	8	2	1
HALL	-	-	-	-	-	-	-	-	1	1	4	2	-
FLAN	-	-	-	-	-	-	1	-	1	-	-	-	-
HURR	-	-	-	-	-	-	-	2	1	1	1	-	-
SEWE	-	-	-	-	-	-	1	9	7	10	11	-	-
POTE	-	-	-	-	-	-	-	-	6	12	7	-	-
CHEE	-	-	-	-	-	-	-	2	3	-	-	-	-
ROCK	-	-	-	-	-	1	1	-	4	1	-	-	-

Table 20. Median size class distribution of *Elliptio dilatata*, as determined by quantitative and qualitative surveys, 1988.

	Median size class (mm)											
SITE	5	15	25	35	45	55	65	75	85	95	105	115
QUADRATS												
FLET	-	1	-	-	1	1	1	-	-	-	-	-
833B	-	-	-	-	-	1	2	3	-	-	-	-
SNOD	-	-	-	1	4	5	6	3	3	-	-	-
POTE	-	-	-	-	-	-	-	1	-	-	-	-
QUALITATIVE												
FLET	-	-	-	-	-	1	3	2	4	2	-	-
YELL	-	-	-	-	-	2	2	2	3	-	-	-
833B	-	-	-	-	-	-	3	3	-	-	-	-
SNOD	-	-	-	-	-	-	2	6	1	-	-	-
HALL	-	-	-	-	1	-	1	1	1	-	-	-
SEWE	-	-	-	-	-	-	-	2	1	-	-	-
POTE	-	-	-	-	-	-	4	5	1	-	-	1
CHEE	-	-	-	-	-	-	-	3	-	1	-	-
SHAF	-	-	-	-	-	-	-	-	-	2	-	-
ROCK	-	-	-	-	-	1	-	-	1	1	1	-
619B	-	-	-	-	-	-	-	-	1	-	-	-

Substratum Analysis

The McNeil-Ahnell sampler was effective in sampling riffles but was inadequate for sampling deep pools. The large size of the sample was difficult to sort and transport, although sieving the sample into two fractions in the field made transportation easier. The sampler was adequate for collecting sediment fractions larger than silt, but less so for extremely small fractions. However, sampling methods were consistent from site to site, and these data were adequate for comparative purposes. Water velocity data obtained during substratum sampling is summarized in Appendix E.

Separation techniques (float-sink analysis) worked well; however, the coal silt fraction included some fine particulate organic matter that floated off with the coal and thus increased the weight of the coal silt fraction. Coarse particulate matter in larger fractions was floated off with water. This proved ineffective with silt fractions because coal silt floated in water.

The primary constituent of sediment samples taken from riffles and pools was usually pebbles (Table 21). Silt represented the smallest fraction in all samples. Generally, gravel was the secondary component of sediment samples taken from downstream riffle sites, whereas small cobble was the secondary component of samples from upstream riffle sites. The secondary component of sediment samples taken from pools varied among sites.

In riffle areas, no significant differences were found among sites for percent small cobble ($p=.0528$), pebble ($p=.1961$), or gravel ($p=.2976$). However, ANOVA tests showed differences among sites for coarse to very coarse sand ($p=.0025$), very fine to medium sand ($p=.0001$), and silt ($p=.0078$) (Table 22). A sorting of substrata longitudinally is evident for smaller size fractions. There was a longitudinal trend in the amount of coarse to very coarse sand; namely, a decrease progressing upstream (Figure 5). Spearman's rank correlation confirmed a significant negative correlation between sand and Powell River mile ($p=.0008$). A positive correlation between percent coarse to very coarse sand and mussel density ($p=.0004$, $r^2=.8074$) was also found. A significant negative correlation was found between river mile and very fine

Table 21. Mean percent of size fractions in sediment samples, calculated from total sample weight. Numbers in parentheses refer to percent of the fraction that is coal.

	SIZE FRACTION						
SITE	Small cobble	Pebble	Gravel	Coarse to very coarse sand	Very fine to medium sand	Silt	Total coal
<u>RIFFLES</u>							
FLET	9.2(0)	30.3(1.3)	28.0(5.7)	14.9(6.5)	17.4(0.4)	0.3(1.0)	2.9
833B	16.4(0)	31.1(0.5)	25.1(4.7)	19.7(2.1)	7.8(0.4)	0.2(0.8)	1.7
SNOD	5.3(0)	19.9(0.8)	23.5(15.0)	19.8(10.7)	31.2(0.3)	0.3(0.8)	5.4
HALL	11.4(0)	28.9(0.8)	23.2(5.4)	18.7(5.3)	17.7(0.3)	0.2(1.8)	2.5
POTE	23.5(0)	35.2(0.6)	23.7(3.0)	11.2(1.7)	6.2(0.4)	0.1(3.0)	1.1
CHEE	12.9(0)	43.5(0.8)	19.5(2.7)	10.6(2.7)	13.2(0.7)	0.3(1.1)	1.3
SHAF	9.6(0)	42.8(0.6)	28.0(6.5)	9.0(6.2)	10.4(0.3)	0.2(1.5)	2.9
SWIM	31.8(0)	40.5(0.6)	20.5(2.3)	5.0(1.2)	2.1(0.4)	0.1(6.4)	0.9
619B	29.4(0)	40.7(0.8)	19.3(7.8)	6.2(3.6)	4.3(0.5)	0.2(8.3)	2.0
DRYD	29.2(0)	41.5(0.3)	19.6(9.2)	5.8(5.3)	3.7(0.6)	0.1(1.9)	2.1
<u>POOLS</u>							
FLET	2.2(0)	36.1(0)	25.2(2.1)	7.8(16.4)	28.2(0.5)	0.5(0.9)	1.9
833B	7.7(0)	36.8(0.2)	19.5(4.5)	8.4(25.0)	26.8(1.1)	0.8(1.4)	3.3
SNOD	3.2(0)	17.9(67.0)	53.6(62.0)	18.0(8.2)	6.8(1.7)	0.4(1.9)	47.5
HALL	14.2(0)	43.6(0.8)	20.9(1.2)	6.4(10.9)	13.0(3.3)	1.8(1.3)	1.8
POTE	10.0(0)	43.3(0.8)	32.8(3.3)	5.1(7.1)	8.4(1.0)	0.3(1.3)	1.8
CHEE	21.6(0)	18.3(2.3)	21.0(5.6)	11.1(9.3)	27.3(0.9)	0.7(0.7)	2.6
SHAF	21.1(0)	38.9(3.3)	24.7(12.7)	11.0(3.9)	4.1(0.7)	0.2(1.9)	4.7
SWIM	12.7(0)	23.0(1.0)	9.2(39.3)	6.9(29.6)	47.7(0.6)	0.4(2.1)	4.2
619B	23.2(0)	30.9(1.8)	13.7(9.3)	7.3(7.1)	24.2(1.1)	0.7(1.2)	2.5
DRYD	9.7(0)	26.9(10.9)	34.0(42.9)	11.6(12.5)	17.6(0.5)	0.2(8.8)	19.3

TABLE 22. Differences in the proportions of riffle sediment fractions among sites in the Powell River, 1988.

COARSE TO VERY COARSE SAND		VERY FINE TO MEDIUM SAND		SILT		TOTAL COAL	
F=4.47, p=0.0025		F=15.65, p=0.0001		F=3.63, p=0.0078		F=2.84, p=0.0249	
Site	Mean	Site	Mean	Site	Mean	Site	Mean
833B	0.197a[1]	SNOD	0.312a	CHEE	0.0033a	SNOD	0.054a
SNOD	0.198a	HALL	0.177b	SNOD	0.0030a	FLET	0.029ab
HALL	0.187a	FLET	0.174bc	FLET	0.0027ab	SHAF	0.029ab
FLET	0.149ab	CHEE	0.132bcd	833B	0.0023abc	HALL	0.025bc
POTE	0.112abc	SHAF	0.104cde	619B	0.0020abcd	DRYD	0.022bc
CHEE	0.106abc	833B	0.078def	HALL	0.0017bcd	619B	0.020bc
SHAF	0.090bc	POTE	0.062ef	SHAF	0.0017bcd	833b	0.017bc
619B	0.062c	619B	0.043fg	DRYD	0.0013cd	CHEE	0.013bc
DRYD	0.058c	DRYD	0.037fg	POTE	0.0010d	POTE	0.011bc
SWIM	0.050c	SWIM	0.021g	SWIM	0.0010d	SWIM	0.009c

[1] Means with the same letter are not significantly different ($p \geq 0.05$) according to Fisher's protected least-significant-difference procedure (LSD).

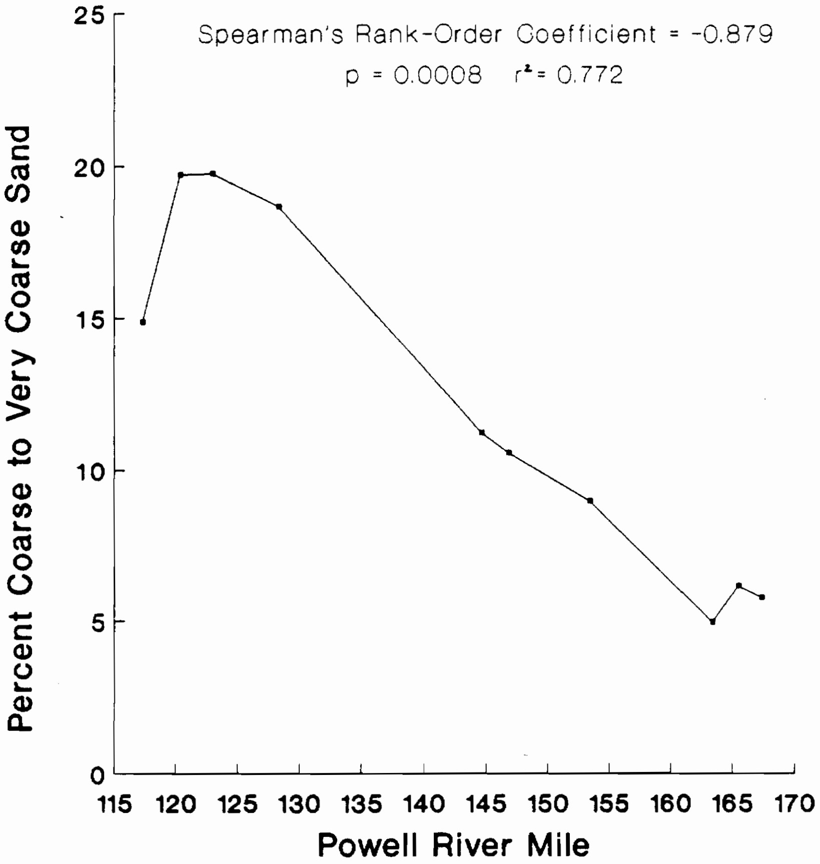

Figure 5. Percent coarse to very coarse sand by weight in riffles at river mile locations in the Powell River, 1988.

to medium sand ($p=.0186$). Large amounts of this fraction occur at Snodgrass Ford (PRM 123.0), and it was significantly higher than at all of the other sites (Figure 6). This fraction was also positively correlated with mussel density ($p=.0068$, $r^2=.6206$). No significant correlation ($p=.1468$) existed between percent silt and river mile (Figure 7); however, there was a slight positive correlation between silt and mussel density ($p=.0736$), although the correlation coefficient was quite low ($r^2=.3460$).

The percent of total coal in samples was significantly different ($p=.0249$) among sites (Table 22). Snodgrass Ford, the site with the largest amount of coal, also supported the highest number of mussels. However, no correlation was found between percent coal and mussel density ($p=.2667$). The pool immediately upstream of this riffle contained large amounts of coal (Table 21) and may be contributing to the greater amounts of coal found at this site. No significant correlation ($p=.3450$) was found between PRM and percent coal (Figure 8), although it appears that the North Fork of the Powell River, located just upstream of Shafer Ford (PRM 153.4), may be contributing coal waste to the river. No coal was collected in the small cobble fraction, although pieces of coal were observed in this size range. Coal was found in all other fractions (Table 21); however, most of the coal in the sample occurred in the gravel fraction, ranging from 42.1 to 81.3 percent of the total coal in the sample (Table 23). Percentages of very fine to medium sand, silt and coal show a marked increase at or just downstream of Shafer Ford at PRM 153.4 (Figures 6, 7, and 8). Increases of these sediment fractions probably reflect inputs from the North Fork Powell River (confluence at PRM 156.6). Because coal is lighter than other substratum components, weight data underestimate the amount of coal in the substratum by volume. Coal volume is approximately twice that of non-coal substrata of equal weight, and this difference should be noted when interpreting data presented by weight.

For pool areas (Table 24), ANOVA testing showed no significant differences among sites for small cobble ($p=.1768$) or pebble fractions ($p=.1137$). Significant differences were found among sites for gravel ($p=.0001$), coarse to very coarse sand ($p=.0014$), very fine to medium sand ($p=.0040$), silt ($p=.0005$), and total coal ($p=.0008$) (Table 24). No significant correlations

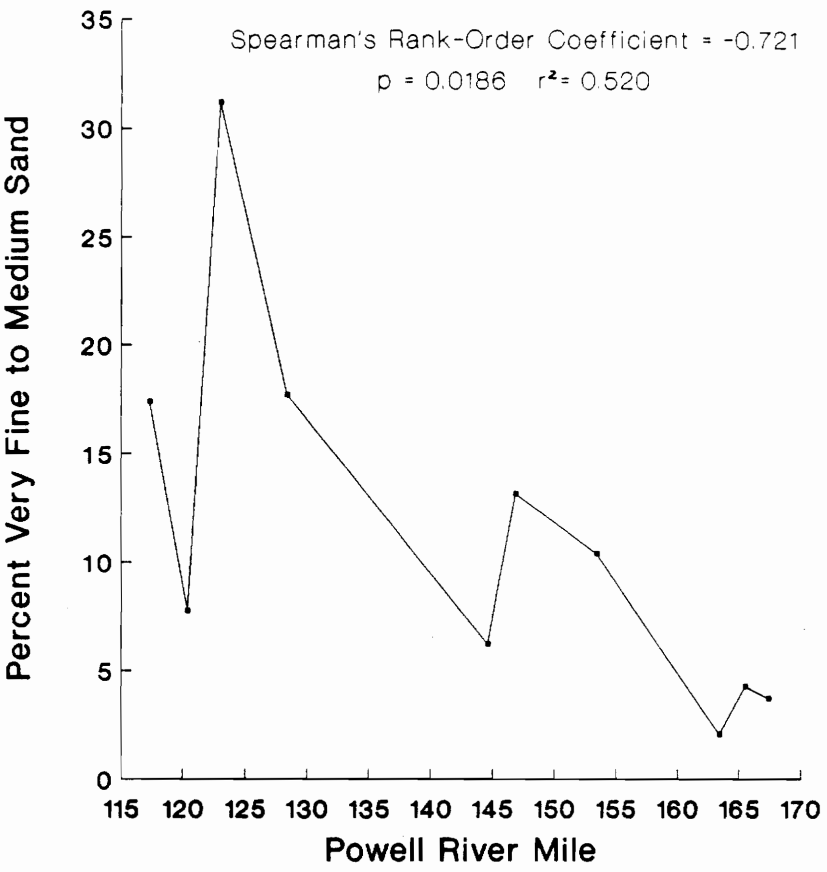

Figure 6. Percent very fine to medium sand by weight in riffles at river mile locations in the Powell River, 1988.

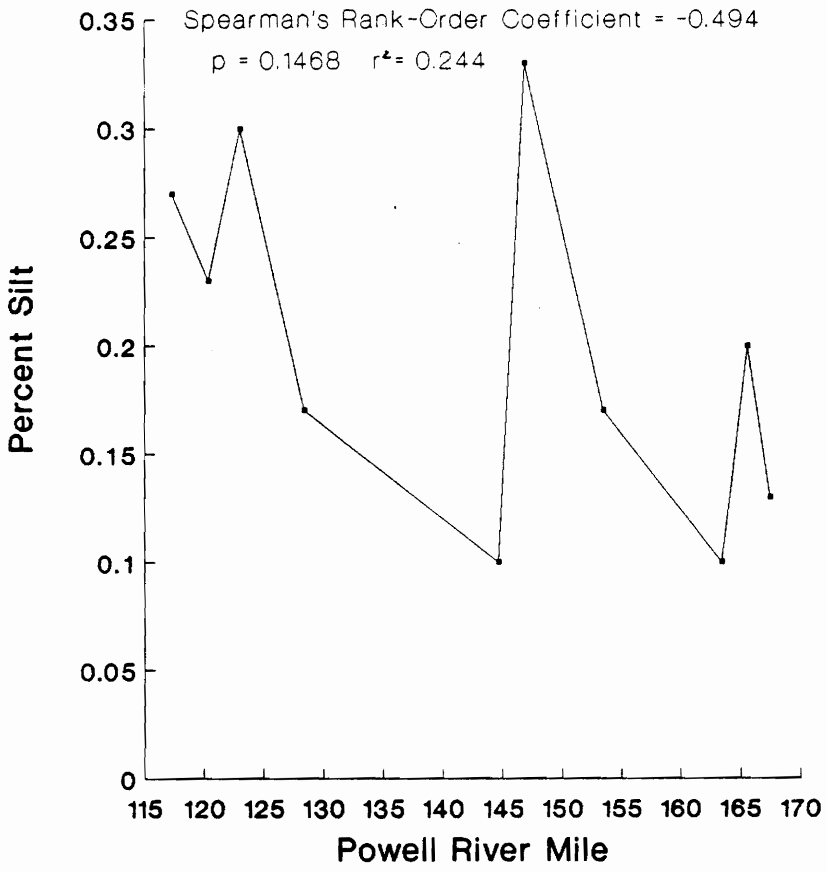

Figure 7. Percent silt by weight in riffles at river mile locations in the Powell River, 1988.

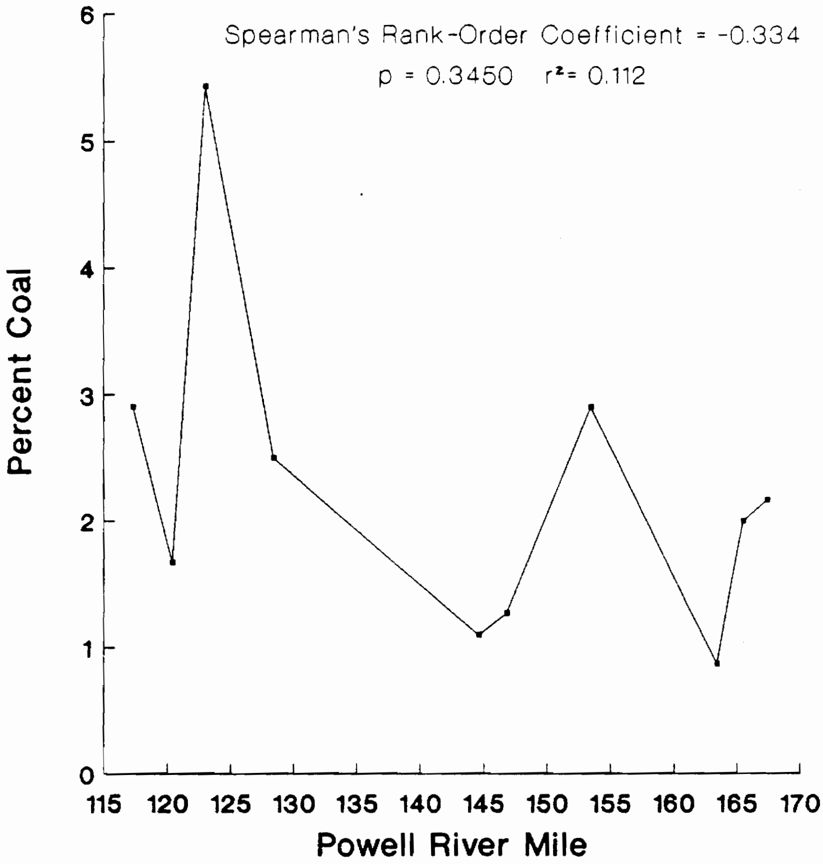

Figure 8. Percent coal by weight in riffles at river mile locations in the Powell River, 1988.

Table 23. Mean percent of coal in sediment fractions, calculated from total weight of coal.

	Size fraction				
SITE	Pebble	Gravel	Coarse to very coarse sand	Very fine to medium sand	Silt
RIFFLES					
FLET	14.1	54.5	28.8	2.4	0.1
833B	6.0	67.6	24.5	1.8	0.1
SNOD	3.6	61.1	33.7	1.6	0.03
HALL	9.2	49.9	38.8	2.0	0.1
POTE	18.6	62.3	16.7	2.3	0.2
CHEE	28.3	42.1	21.6	7.7	0.3
SHAF	8.6	67.9	22.0	1.4	0.1
SWIM	23.6	66.9	7.8	1.2	0.5
619B	9.1	75.8	13.3	1.5	0.3
DRYD	2.2	81.3	15.2	1.2	0.2
POOLS					
FLET	0.0	27.9	64.1	7.8	0.3
833B	2.3	26.7	61.5	9.3	0.2
SNOD	16.1	77.1	6.0	0.7	0.03
HALL	17.7	13.6	42.6	24.8	1.4
POTE	14.1	59.5	21.3	4.9	0.2
CHEE	17.1	41.8	31.6	9.4	0.2
SHAF	23.0	65.9	10.5	0.6	0.1
SWIM	10.2	34.5	48.8	6.3	0.2
619B	22.5	46.2	21.8	9.1	0.5
DRYD	16.6	74.7	8.0	0.6	0.1

TABLE 24. Differences in the proportions of pool sediment fractions among sites in the Powell River, 1988.

GRAVEL		COARSE TO VERY COARSE SAND		VERY FINE TO MEDIUM SAND		SILT		TOTAL COAL	
F=7.89, p=0.0001		F=4.98, p=0.0014		F=4.13, p=0.0040		F=5.77, p=0.0005		F=5.45, p=0.0008	
Site	Mean	Site	Mean	Site	Mean	Site	Mean	Site	Mean
SNOD	0.536a[1]	SNOD	0.180a	SWIM	0.477a	HALL	0.018a	SNOD	0.475a
DRYD	0.340b	DRYD	0.116b	FLET	0.282ab	833B	0.083b	DRYD	0.193b
POTE	0.328bc	SHAF	0.110bc	833B	0.268ab	619B	0.007b	SHAF	0.047bc
FLET	0.252bcd	CHEE	0.111bcd	CHEE	0.274ab	CHEE	0.007b	SWIM	0.042bc
SHAF	0.247bcd	833B	0.084bcde	619B	0.242bc	FLET	0.005bc	833B	0.033c
CHEE	0.210bcd	FLET	0.077bcde	DRYD	0.176bcd	SNOD	0.004bc	CHEE	0.026c
HALL	0.209bcd	619B	0.073bcde	HALL	0.130bcd	SWIM	0.004bc	619B	0.025c
833B	0.195cd	SWIM	0.069cde	POTE	0.084cd	POTE	0.003bc	FLET	0.020c
619B	0.137de	HALL	0.064de	SNOD	0.068cd	SHAF	0.002c	HALL	0.018c
SWIM	0.092e	POTE	0.051e	SHAF	0.041d	DRYD	0.002c	POTE	0.018c

[1] Means with the same letter are not significantly different ($p \geq 0.05$) according to Fisher's protected least-significant-difference procedure (LSD).

using Spearman's rank correlation were found between sediment fractions and Powell River Mile ($p = .0248$). Most of the coal occurred in the gravel and coarse to very coarse sand fractions (Table 23).

Responses of Juvenile Mussels to Coal and Silt Substrata

The holding chambers designed for these experiments were very efficient for retrieving juveniles, and the design worked well for testing sediments with diameters less than that of the juveniles (202 μm). Attempts were made to find an inert substratum to sieve as a control; however, all juveniles died when tested on glass beads (100 μm diameter). The glass beads settled out very quickly when mixed with water, and I suspect they may have been too heavy for the juveniles to maneuver through them. A known uncontaminated silt was not readily available, so a control of no substratum, suggested by the Food and Agriculture Organization of the United Nations (1987) when testing contaminated sediments, was used. Juveniles exhibited shell growth and survived with no substratum for at least 14 days, and some survived up to 47 days in preliminary tests. Therefore, no substratum was used as a control.

In all experiments, juveniles that did not survive showed little or no shell development and apparently died soon after the experiments started. Those that survived showed inconsistent growth within treatments. At the end of experiments, live juveniles were active, exhibiting frequent foot and valve movement.

Experiment One

I obtained inconsistent results in two separate 7-day trials of juvenile survival on 100 percent coal and no substratum. Using χ^2 analysis, the first trial showed no significant differences ($p = 0.150$) between survival on coal and no substratum (Table 25). Survival was nearly 100 percent in this trial. Results of the second trial, however, showed significant differences between treatments, with lower survival (40.0 percent) on coal ($p = .001$). The second trial was

Table 25. Contingency table of differences in percent survival of juvenile mussels on coal and no substratum in 7-day trials.

Trial 1

$\chi^2 = 2.069$, df=1, p=0.500

	COAL	NONE	TOTAL
DEAD	2[1] 1.0 1.00 6.67	0 1.0 1.00 0	2
LIVE	28 29.0 0.03 93.33	30 29.0 0.03 100.00	58
TOTAL	30	30	60

Trial 2

$\chi^2 = 11.334$, df=1, p=0.001

	COAL	NONE	TOTAL
DEAD	18 11.7 3.40 60.00	5 11.3 3.52 17.24	23
LIVE	12 18.3 2.172 40.00	24 17.7 2.247 82.76	36
TOTAL	30	29	59

[1] Numbers (in order) are observed count, expected count, cell χ^2, and column percent (percent survival and mortality).

conducted with Nitex placed directly on top of the chamber as well as the crystallizing dish. Although there did not appear to be any differences in growth, I suspect that the extra layer of Nitex may have reduced the flow of water through the dishes and resulted in problems with dissolved oxygen. A 14-day trial of this experiment gave similar conflicting results. The first trial showed significant differences ($p=0.016$) between treatments (Table 26), with lower survival (35.7 percent) on coal. Conversely, the second trial showed no significant differences ($p=.554$), with almost 100 percent survival for both treatments.

Despite conflicting results, juveniles were still able to survive in some trials for 7 days on coal with little effect. Shell growth in surviving juveniles was evident in both treatments for surviving juveniles. Coal particles were observed in the mantle cavity, although I did not determine whether coal was ingested.

Experiment Two

In 7-day trials, survival (93.9 percent) on no substratum was significantly higher ($p<0.001$) than survival on sediments from Fletcher Ford (34.2 percent), Poteet Ford (63.2 percent), or Dryden Ford (29.7 percent) (Table 27). Survival among the sediment types did not appear to differ from each other, although survival was higher in the first trial than the second. Again, Nitex was used on the chamber during the second trial and could have affected results.

One 14-day trial was conducted, and results were similar to 7-day trials. Survival was significantly different ($p<0.001$) among treatments (Table 28), with survival higher than expected in the treatment with no substratum (95.0 percent). Survival in Dryden Ford sediment was much lower than expected (5.7 percent). The results of this experiment suggest that survival may be affected by some component in Powell River sediments, and survival may be lower in Dryden (upstream) sediments.

Experiment Three

Field conditions during this experiment were poor. Water conditions were high and turbid, and large amounts of silt settled in the crystallizing dishes and chambers. Despite

Table 26. Contingency table of differences in percent survival of juvenile mussels on coal and no substratum in 14-day trials.

Trial 1

$\chi^2=5.790$, df=1, p=0.016

	COAL	NONE	TOTAL
DEAD	18[1] 13.7 1.33 64.29	7 11.3 1.62 30.43	25
LIVE	10 14.3 1.28 35.71	16 11.7 1.56 69.57	26
TOTAL	28	23	51

Trial 2

$\chi^2=0.351$, df=1, p=0.554

	COAL	NONE	TOTAL
DEAD	2[1] 1.5 0.17 6.67	1 1.5 0.17 3.33	3
LIVE	28 28.5 0.01 93.33	29 28.5 0.01 96.67	57
TOTAL	30	30	60

[1] Numbers (in order) are observed count, expected count, cell χ^2, and column percent (percent survival and mortality).

Table 27. Contingency table of differences in 7-day survival of juvenile mussels in no substratum and sediments from three sites in the Powell River.

Trial 1

$\chi^2 = 37.252$, df=3, $p < 0.001$

	FLET	POTE	DRYD	NONE	TOTAL
DEAD	25[1] 17.4 3.28 65.79	14 17.4 0.69 36.84	26 17.0 4.79 70.27	2 15.1 11.41 6.06	67
LIVE	13 20.6 2.78 34.21	24 20.6 0.58 63.16	11 20.0 4.06 29.73	31 17.9 9.68 93.94	79
TOTAL	38	38	37	33	146

Trial 2

$\chi^2 = 71.885$, df=3, $p < 0.001$

	FLET	POTE	DRYD	NONE	TOTAL
DEAD	27 22.6 0.84 90.00	28 21.9 1.71 96.60	26 19.6 2.08 100.00	5 21.9 13.02 17.24	86
LIVE	3 7.4 2.59 10.00	1 7.1 5.26 3.40	0 6.4 6.39 0	24 7.1 39.99 82.76	28
TOTAL	30	29	26	29	114

[1] Numbers (in order) are observed count, expected count, cell χ^2, and column percent (percent survival and mortality).

Table 28. Contingency table of differences in 14-day survival of juvenile mussels in no substratum and sediments from three sites in the Powell River.

	FLET	POTE	DRYD	NONE	TOTAL
DEAD	31[1] 21.5 4.17 79.49	19 22.1 0.43 47.50	33 19.3 9.69 94.29	2 22.1 18.26 5.00	85
LIVE	8 17.5 5.14 20.51	21 17.9 0.53 52.50	2 15.7 11.94 5.71	38 17.9 22.49 95.00	69
TOTAL	39	40	35	40	154

[1] Numbers (in order) are observed count, expected count, cell χ^2, and column percent (percent survival and mortality). Overall $\chi^2 = 72.643$, df=3, $p < 0.001$.

poor conditions, the dishes inside the cages were not disturbed and field methods worked very well. The Dryden treatment could not be retrieved from the river due to high water at the end of 7 days. However, it was retrieved 24 days after the start of the experiment and although no juveniles survived, shell development was evident on several juvenile valves, indicating that they survived for some time period. Marginally significant differences ($p = 0.070$) in survival were found between Fletcher Ford and Poteet Ford (Table 29), with survival being greater on Poteet Ford sediments (47.4 percent). Survival of juveniles did not differ between laboratory and field experiments.

Table 29. Contingency table of differences in survival of juvenile mussels at two sites in the Powell River.

	FLET	POTE	TOTAL
DEAD	16[1] 13.3 0.53 80.00	10 12.7 0.56 52.63	26
LIVE	4 6.7 1.07 20.00	9 6.3 1.12 47.37	13
TOTAL	20	19	39

[1] Numbers (in order) are observed count, expected count, cell χ^2, and column percent (percent survival and mortality). Overall $\chi^2 = 3.284$, df=1, p=0.070.

Discussion

Mussel Species Composition and Distribution

Species and distribution differences are apparent when my survey data are compared with surveys of the last 16 years (Ahlstedt and Brown 1979, Neves et al. 1980, Dennis 1981, Ahlstedt 1986, Jenkinson and Ahlstedt 1988) (Table 30). More mussel species were found at sites above PRM 130.6 than surveys of the past 16 years. In 1988, I found no live mussels at Dryden Ford (PRM 167.4). In 1989, a resurvey of that site during very clear water conditions produced five species. This illustrates the variability of survey results, which are very dependent on water conditions. Also, considerable effort was required to find mussels in upstream sites because they were dispersed and occurred in very low densities. Therefore, I believe discrepancies in species densities and richness in upstream sites is due primarily to ineffective sampling in previous surveys and not recovery of mussel populations. Generally, species richness has decreased at lower sites (below PRM 130.6) since earlier surveys. During my survey, several sites were sampled repeatedly, searching for specific species not collected during previous visits, but these species could not be found. Loss of species richness, therefore, is likely due to extirpations of some species at lower sites.

TABLE 30. Comparison of collection records of mussels at selected sites in the Powell River, 1975-1989.

SITE	FLET	FLEC	YELL	833B	SNOD
SPECIES RIVER MILE	117.3	117.9	119.3	120.4	123.0
Actinonaias ligamentina	ABCDEFG	CDG	CG	ABCDG	G
Actinonaias pectorosa	ABCDEFG	CDG	CG	ABCDG	G
Amblema plicata plicata	ACDF	C	C	ABCG	G
Cyclonaias tuberculata	ACDFG	C	G	ABCG	G
Dromus dromas	ABCDG	C	CG	ABDG	G
Elliptio crassidens	AE	-	-	-	-
Elliptio dilatata	ABCDEFG	CD	CG	ABCG	G
Epioblasma brevidens	ABCDEG	CD	C	ABCDG	G
Epioblasma capsaeformis	ACDE	C	-	ABG	-
Epioblasma triquetra	ACDEFG	C	-	AB	G
Fusconaia/Pleurobema	G	-	-	G	G
Fusconaia barnesiana	ABCDE	C	C	ABCD	-
Fusconaia cor	ABD	CD	-	AC	G
Fusconaia subrotunda	ACEFG	C	CG	ACG	G
Hemistena lata	AD	C	-	-	-
Lampsilis fasciola	ABCDEG	CD	CG	ABCDG	G
Lampsilis ovata	ADE	C	CG	ABCDG	G
Lasmigona costata	ADEG	CD	C	ABCG	G
Lemiox rimosus	DG	D	-	C	
Leptodea fragilis	ABCD	C	-	ACD	-
Lexingtonia dolabelloides	-	C	-	-	-
Ligumia recta	ACDG	C	C	G	G
Medionidus conradicus	ACDEFG	CDG	CG	ABCG	G
Plethobasus cyphyus	ABDG	C	-	ABD	G
Pleurobema oviforme	BF	-	-	-	-
Potamilus alatus	ADG	C	C	ABCD	G
Ptychobranchus fasciolaris	ACDEFG	C	CG	ABCG	G
Ptychobranchus subtentum	ADE	C	C	ABD	G
Quadrula cylindrica strigillata	AD	-	-	ABG	-
Quadrula intermedia	ABCDG	CD	CG	G	G
Quadrula pustulosa pustulosa	-	-	-	-	-
Quadrula sparsa	FG	-	G	-	-
Villosa iris	AD	C	-	ABC	-
Villosa vanuxemensis vanuxemensis	AD	-	-	AB	-
SURVEY	A B C D E F G	C D G	C G	A B C D G	G
TOTAL SPECIES	28 12 17 27 15 10 19	26 10 3	17 12	24 21 18 11 18	22

A = 1973-1978 (Dennis 1981)
B = 1975-1978 (Ahlstedt and Brown 1979)
C = 1979 (Ahlstedt 1986)
D = 1980 (Neves et al. 1980)
E = 1983 (Jenkinson and Ahlstedt 1988)
F = 1988 (Jenkinson and Ahlstedt 1988)
G = 1988-1989 (present study)

TABLE 30. (Continued)

SPECIES	SITE RIVER MILE	HALL 128.5	FLAN 130.6	HURR 138.3	SEWE 143.5	POTE 144.6
Actinonaias ligamentina		CDG	ABCEG	BG	G	ABCG
Actinonaias pectorosa		CDG	CEFG	CG	G	ABCG
Amblema plicata plicata		DG	G	-	G	BG
Cyclonaias tuberculata		G	-	-	G	G
Dromus dromas		-	-	-	G	-
Elliptio crassidens		-	-	-	-	-
Elliptio dilatata		DG	CE	C	G	ABG
Epioblasma brevidens		DG	F	-	-	-
Epioblasma capsaeformis		-	-	-	-	-
Epioblasma triquetra		G	G	-	-	-
Fusconaia/Pleurobema		G	-	-	-	G
Fusconaia barnesiana		D	AB	-	-	AB
Fusconaia cor		D	BC	-	-	-
Fusconaia subrotunda		G	CEFG	CG	G	BCG
Hemistena lata		-	C	-	-	-
Lampsilis fasciola		DG	EF	G	G	ABG
Lampsilis ovata		C	ABCG	G	CG	ABCG
Lasmigona costata		CDG	CEFG	G	G	G
Lemiox rimosus		-	-	-	-	G
Leptodea fragilis		D	-	C	-	AB
Lexingtonia dolabelloides		-	-	-	-	-
Ligumia recta		-	-	-	-	-
Medionidus conradicus		DG	C	-	G	-
Plethobasus cyphyus		D	-	-	-	-
Pleurobema oviforme		-	-	-	-	-
Potamilus alatus		CD	BCG	G	CG	BG
Ptychobranchus fasciolaris		D	C	-	G	CG
Ptychobranchus subtentum		D	-	-	-	-
Quadrula cylindrica strigillata		D	ABG	C	G	ABG
Quadrula intermedia		G	B	-	G	G
Quadrula pustulosa pustulosa		-	-	C	-	-
Quadrula sparsa		-	C	-	-	G
Villosa iris		DG	-	-	-	-
Villosa vanuxemensis vanuxemensis		D	BC	-	-	AB
SURVEY TOTAL SPECIES		C D G 5 18 14	A B C E F G 4 8 13 6 5 9	B C G 1 6 7	C G 2 15	A B C G 9 12 5 16

A = 1973-1978 (Dennis 1981)
B = 1975-1978 (Ahlstedt and Brown 1979)
C = 1979 (Ahlstedt 1986)
D = 1980 (Neves et al. 1980)
E = 1983 (Jenkinson and Ahlstedt 1988)
F = 1988 (Jenkinson and Ahlstedt 1988)
G = 1988-1989 (present study)

TABLE 30. (Continued)

SPECIES	SITE RIVER MILE	CHEE 146.8	TRAS 153.4	ROCK 158.3	SWIM 163.4	619B 165.7	DRYD 167.4
Actinonaias ligamentina		G	G	-	-	A	-
Actinonaias pectorosa		G	G	G	G	-	G
Amblema plicata plicata		-	-	-	-	-	AB
Cyclonaias tuberculata		-	-	-	-	-	-
Dromus dromas		-	-	-	-	-	-
Elliptio crassidens		-	-	-	-	-	-
Elliptio dilatata		G	G	G	-	G	-
Epioblasma brevidens		-	-	-	-	-	-
Epioblasma capsaeformis		-	-	-	-	-	-
Epioblasma triquetra		-	-	-	-	-	-
Fusconaia/Pleurobema		G	-	-	-	-	-
Fusconaia barnesiana		-	-	-	-	-	-
Fusconaia cor		-	-	-	-	-	-
Fusconaia subrotunda		G	CG	G	-	-	G
Hemistena lata		-	-	-	-	-	-
Lampsilis fasciola		G	G	G	G	-	CG
Lampsilis ovata		-	G	-	-	AB	-
Lasmigona costata		G	G	-	-	-	-
Lemiox rimosus		-	-	-	-	-	-
Leptodea fragilis		-	-	-	-	-	C
Lexingtonia dolabelloides		-	-	-	-	-	-
Ligumia recta		G	-	-	-	-	-
Medionidus conradicus		-	-	-	-	G	-
Plethobasus cyphyus		-	-	-	-	-	-
Pleurobema oviforme		-	-	-	-	-	-
Potamilus alatus		G	G	-	-	-	CE
Ptychobranchus fasciolaris		G	G	G	-	-	G
Ptychobranchus subtentum		-	-	-	-	-	-
Quadrula cylindrica strigillata		-	G	G	-	-	-
Quadrula intermedia		-	-	-	-	-	-
Quadrula pustulosa pustulosa		-	-	-	-	-	-
Quadrula sparsa		-	-	-	-	-	-
Villosa iris		-	C	-	-	-	G
Villosa vanuxemensis vanuxemensis		G	G	G	CG	G	C
SURVEY		A G	C G	C G	C G	A B G	A B C G
TOTAL SPECIES		0 11	2 11	0 7	1 3	2 1 3	1 1 4 5

A = 1973-1978 (Dennis 1981)
B = 1975-1978 (Ahlstedt and Brown 1979)
C = 1979 (Ahlstedt 1986)
D = 1980 (Neves et al. 1980)
E = 1983 (Jenkinson and Ahlstedt 1988)
F = 1988 (Jenkinson and Ahlstedt 1988)
G = 1988-1989 (present study)

Changes in mussel distribution are obvious when compared to surveys of the early 1900's (Ortmann 1918). Particularly noticeable is the absence of mussels upstream of Dryden (PRM 167.4). Ortmann (1918) collected mussels at least up to PRM 177.8 at Big Stone Gap (Table 31). Mussels have not been found above PRM 167.4, at least as far back as 1973 (Dennis 1981). No records are available before that time to verify when they first disappeared from the upstream reaches of the Powell River, although effects from mining and industrialization have been ongoing for the last 50 years (Dennis 1981). Mussels are thought to have been eliminated from the Big Stone Gap area because of acid mine drainage (Wollitz 1985).

Nine mussel species have been extirpated from the Powell River since 1918 (Table 32). Several species are considered headwater species and likely were affected by upstream siltation; others are lower river species and were affected by the impoundment of Norris reservoir (Ahlstedt and Brown 1979, Dennis 1981). There are several species that may have extended their range into the Virginia portion of the Powell River in the last 70 years (Table 32). *A. ligamentina*, abundant at most Virginia sites, was never collected by Ortmann (1918) above the Tennessee border. Several species are uncommon and may have been overlooked by him. Some species reported in recent surveys were never documented by Ortmann (1918) in the Powell River in Tennessee or Virginia (Table 32), although most of them are rare and likely were missed in his early surveys. *C. tuberculata* is quite common and may be a recent introduction (Ahlstedt and Brown 1979). Most discrepancies can probably be attributed to ineffective sampling by Ortmann (1918) because of limited access to the Powell River, which in turn, resulted in underestimates of species richness.

Sharp declines in mussel densities are evident when compared to previous collections. During 1978, Neves et al. (1980) conducted density estimates of mussels at Fletcher Ford. They estimated densities at this site to be 24.2 mussels/m^2. Quadrat surveys by Jenkinson and Ahlstedt (1988) at Fletcher Ford estimated abundance to be 11.14 mussels/m^2 in 1979, 10.29 mussels/m^2 in 1983, and 5.52 mussels/m^2 in 1988. My surveys estimated abundance to be 6.5 mussels/m^2 in 1988. While densities may vary between similar sites in a river, they

TABLE 31. Mussel species collected by Ortmann (1918) in the Powell River, Virginia.

SITE[1]	SFP	BSG	OLIN	DRYD	PENN	JONE	ROSE
SPECIES APPX. RIVER MILE	178	177	172	167	154	143	117
Actinonaias pectorosa	-	-	-	-	X	-	X
Alasmidonta marginata	-	-	X	X	-	-	X
Alasmidonta viridis	X	-	-	-	-	-	-
Elliptio crassidens	-	-	-	-	-	X	-
Elliptio dilatata	-	-	X	X	X	-	X
Epioblasma brevidens	-	-	-	-	-	-	X
Epioblasma haysiana	-	-	-	-	X	-	-
Fusconaia barnesiana	X	X	X	X	X	-	X
Fusconaia cor	-	-	-	-	X	-	X
Fusconaia cuneolus	-	-	X	-	-	-	-
Fusconaia subrotunda	X	X	X	X	X	X	X
Lampsilis fasciola	-	X	-	X	X	-	X
Lampsilis ovata	-	-	X	X	-	-	-
Lasmigona costata	-	-	X	X	X	-	-
Lasmigona holstonia	X	-	-	X	-	-	-
Lemiox rimosus	-	-	-	-	-	X	X
Lexingtonia dolabelloides	X	-	X	X	X	-	-
Medionidus conradicus	X	X	X	X	-	-	X
Pegias fabula	-	-	-	X	-	-	-
Pleurobema oviforme	X	-	X	X	X	X	X
Ptychobranchus fasciolaris	-	-	-	-	X	-	X
Ptychobranchus subtentum	X	-	X	X	-	X	-
Quadrula cylindrica strigillata	-	-	-	-	X	-	-
Strophitus undulatus	X	-	-	X	-	-	-
Toxolasma lividus	X	-	-	-	-	X	-
Villosa nebulosa (=iris)	X	X	X	X	X	-	X
Villosa perpurpurea	-	-	X	-	-	-	-
Villosa vanuxemensis vanuxemensis	X	-	-	X	X	-	-
TOTAL NUMBER OF SPECIES	12	5	13	16	14	6	13

[1] SFP=South Fork Powell River (river mile refers to confluence with the Powell River)
BSG=Bigstone Gap
OLIN=Olinger
PENN=Pennington Gap

TABLE 32. Summary of unreported and extirpated species in the Powell River, Virginia, as judged by Ortmann's (1918) collection records versus those of recent surveys.

Species unreported in 1918	Species reported in 1918 but now extirpated
Actinonaias ligamentina[3]	*Alasmidonta viridis*
Amblema plicata plicata[3]	*Epioblasma haysiana*
Cyclonaias tuberculata	*Epioblasma lewisii*[1]
Dromus dromas[3]	*Epioblasma torulosa gubernaculum*[1]
Epioblasma capsaeformis[3]	*Lasmigona holstonia*
Epioblasma triquetra[3]	*Pegias fabula*
Hemistena lata[3]	*Strophitus undulatus*[2]
Leptodea fragilis[3]	*Toxolasma lividus*
Ligumia recta[3]	*Villosa fabalis*[1]
Plethobasus cyphyus[3]	*Villosa perpurpurea*
Potamilus alatus[3]	
Quadrula intermedia	
Quadrula pustulosa pustulosa[3]	
Quadrula sparsa	
Villosa taeniata	

[1] Collected in Tennessee by Ortmann (1918) but never collected in Virginia.

[2] Collected in Virginia and Tennessee by Ortmann (1918) but now only occurs in Tennessee.

[3] Collected in Tennessee by Ortmann (1918).

rarely vary on a temporal basis (Dennis 1984). These estimates represent a substantial decline in mussel abundance at this site and likely are explained by some form of perturbation.

The distribution of the spiny riversnail *I. fluvialis* has also declined. Historically, *I. fluvialis* was collected 3.22 km above Olinger, Virginia (PRM 172.0) by Adams (1915). He noted that *I. fluvialis* was "living in abundance" at Olinger. Clearly, the distribution of *I. fluvialis* has decreased since Adams' survey. The spiny riversnail was found to occur up to PRM 163.4 in my surveys; however, densities decreased markedly above PRM 128.4. In 1979, *I. fluvialis* was collected up to PRM 156.8, with densities ranging up to 5.7/m^2 (Tennessee Valley Authority 1979). The highest densities, 5.0/m^2, of *I. fluvialis* in my survey were found at Snodgrass Ford (PRM 123.0). The range of *I. fluvialis* has decreased roughly 15.5 km since 1915.

Much of the data used in this thesis compares sites longitudinally along the Powell River. Researchers have noted an increase in the number of species as stream size increases (Coker et al. 1921, Strayer 1983). This phenomenon likely occurs to some degree in the Powell River, because the Powell River increases substantially in size, especially below the confluence of the North Fork Powell River. Ortmann's (1918) records did not show an increase in the number of mussel species proceeding downstream in the Powell River, Virginia (Table 31). However, this lack of a longitudinal trend was probably attributed to omission of prime or sufficient sites for mussels on the Powell River.

Length Frequency Distributions

Generally, a growing population would have a large number of younger individuals; a stable population would have a more even distribution of age classes; and a declining population would have a larger proportion of old individuals (Odum 1971). Unfortunately, few historical length frequency data are available to compare changes in size or age class structure over time. Only one set of data exists from quadrat surveys that recorded mussel lengths (Neves et al. 1980). It is readily apparent that the number of smaller individuals has decreased in the last 10 years at Fletcher Ford. Recruitment is likely not equal annually in mussel populations; for example, Zale (1980) found varying representation of age classes for *Medionidus conradicus*. Dominant year classes are sometimes found in populations of long-lived species (Krebs 1978), and probably occur in mussel populations. Sometimes, dominant year classes are followed by low survival in subsequent years (Odum 1971). However, the lack of individuals in six of the smallest length classes in 1988 indicates that the lack of recruitment has been long term and is related to something other than variable recruitment of age classes. The fact that smaller individuals were collected in the previous survey indicates that these individuals can be sampled by quadrat sampling methods. The lack of smaller individuals implies that recruitment at this site is not occurring, and the populations are declining. Reasons for this decline are only speculative in nature; however, the result could be devastating for the mussel fauna of the Powell River.

Length frequency distributions were also used to identify poor recruitment at other sites. Mean lengths of *A. pectorosa*, the most abundant mussel in the Powell River, were smallest at the Rte. 833 Bridge. This site was the only place where smaller (juvenile) mussels were collected. At Snodgrass Ford, no evidence of recruitment was found, and old age individuals comprised the entire assemblage. Snodgrass Ford had the highest densities of all the sites sampled (24 mussels/m^2). Dennis (1984) stated that densities of 20-30 mussels/m^2 were unusually high when compared to other densities in comparable rivers of the Interior Basin, with 2-8 mussels/m^2 being common in areas harvested commercially. Densities found at Snodgrass Ford were very close to those found at Fletcher Ford in 1978 (Neves et al. 1980). Snodgrass Ford should be monitored closely to document reproduction because it is a very diverse site, and several *D. dromas* and *Q. sparsa* were collected there. The fact that this site had not been sampled extensively in the past may indicate that repeated disturbances or overcollecting may affect mussel populations adversely and contribute to a decline in abundance.

Mussel Declines

Because mussels are long-lived, effects of environmental changes may not be obvious for many years (Dennis 1984). Only 20 years ago, no environmental regulations were in place. The National Environmental Policy of 1969 was enacted in 1970 and the Clean Water Act was enacted in 1972. Important legislation to control mine wastes and reclamation were not enacted until 1977 (Surface Mining Control and Reclamation Act of 1977). Improvements in water quality have occurred since municipal and industrial wastes have come under regulation; however, the mussel fauna may still be suffering from the effects of events many years ago. Several factors could lead to the decline of freshwater mussels, such as siltation, contamination, predation, loss of fish hosts, disease, parasites, overcollecting, and even the introduction of the Asian clam, *Corbicula fluminea*. These factors could result in direct and differential mortality of adults and juveniles or inhibit reproduction.

Researchers believe that one reason the the mussel fauna disappeared from upstream reaches of the Powell River is because of siltation of the substratum (Ahlstedt and Brown 1979, Dennis 1980, Neves et al. 1980, Ahlstedt 1986, Jenkinson and Ahlstedt 1988). However, some mussels considered to be "silt tolerant" have also been affected. *Alasmidonta viridis* and *Toxolasma lividus*, reported as locally abundant in upstream areas of the Powell River by Ortmann (1918), no longer occur there. These species are considered headwater species and may occur in mud, sand or gravel in slow and swift currents (Gordon and Layzer 1989). Although indirect effects of silt, such as the elimination of necessary fish hosts, should be considered, it is possible that pollutants other than silt may have been an important factor in the elimination of these species.

Conclusions from length frequency distribution data indicate almost no recruitment of mussels in the Powell River. Reasons for reduced recruitment into the populations could be from impaired or lack of reproduction, mortality of juveniles, loss of host fish, or a combination of these factors. I regret not having checked gravidity of mussels during my surveys, as this information may have been useful in determining whether fertilization occurs.

A comparison of fish surveys in 1988 (Alan Temple, Department of Fisheries and Wildlife Sciences, VPI&SU, Blacksburg, VA, pers. comm.) to those of Tennessee Valley Authority (1970), Masnik (1974), and Neves et al. (1980) did not show major reductions or changes in fish species over time. Therefore, it does not appear that host fish species availability has declined in the Powell River. However, the relative numbers of these fish species over time has not been determined.

Another factor to consider when evaluating causes of mussel declines is the invasion of *C. fluminea*. Mussel declines in Atlantic drainage rivers have been attributed to the development of dense *C. fluminea* populations (Clarke 1988). *C. fluminea* first appeared in the Powell River in 1979 (Ahlstedt 1986), and by 1983 it was considered common. It is now widespread in the river, but does not occur in high densities relative to those in other rivers. The effects of *C. fluminea* on the mussel fauna in the Powell River is unknown.

Substratum Analysis

Quantification of sediment conditions in a river is very difficult. Many factors can influence the amount of fines in a river at one point in time, including storm events, gradient, and geology. The same factors can influence the amount of coal in the substratum. Because of natural fluctuations of sediment fines, gravel permeability may be a better indicator of the effects of land use practices (Adams and Beschta 1980, Moring 1982). Permeability is related to the porosity of the streambed, and the size, shape, and arrangement of materials (McNeil and Ahnell 1964). A decrease in permeability can reflect poor intergravel conditions for developing salmon eggs and alevins when other factors, such as the amount of fines in the gravel, do not appear detrimental (McNeil and Ahnell 1964, Moring 1982). This measurement may be more appropriate for determining effects of substratum on juvenile mussels which likely live in interstitial spaces(Neves and Widlak 1987).

Pool samples probably were not very indicative of the true conditions of pool substrata because of the sampling equipment used. Preliminary analysis of samples taken from pool areas in the Powell River by the Tennessee Valley Authority (1986) indicated that sand was the major component of pool sediments. They found that size fractions smaller than 0.075mm (silt and clay) comprised between 0 and 11 percent of the substratum. Percentages of silt (including clay) in my samples ranged from 0.2 to 1.8 and may be underestimates. They concluded that large amounts of sediments were available in pool areas and could move downstream. They reported unexpectedly high organic content values for sediment samples using loss-on-ignition analysis, likely reflecting the large amounts of coal present in the substratum.

Riffle habitats are probably altered the most by sedimentation because the addition of fines can substantially change the composition of this substratum (Berkman and Rabeni 1987). Some size fractions in riffles correlated well with river mile location, especially coarse to very coarse sand which increased in downstream areas. Relating mussel density or occurrence to substratum composition is difficult, especially when considering the instability of bed material over time. It is also difficult to distinguish whether mussel densities change because of mussel bed materials or other factors related to changes in river hydrology, gradient, morphology, or geology (Strayer 1983). Substratum type is generally considered a factor in predicting mussel distribution among microhabitats (Coker et al. 1921, Harman 1972, Vannote and Minshall 1982); however, species-specific relations to substrata are variable (Coker et al. 1921, Kat 1982).

Most of the downstream sites contained relatively large amounts of the smaller size fractions, and also had higher percentages of coal than upstream sites. Silt and coal deposits may be gradually moving downstream (Ahlstedt 1986), and this may be reflected in the high levels of smaller fractions at lower sites, especially Snodgrass Ford. Channel alteration and sedimentation of mussel habitat could be a factor in the decrease or extirpation of mussels in the Powell River. Decreased retention capacities of the watershed, due to loss of vegetation from strip mining, may have enhanced periodic high flows. If shear stress is high enough, substratum materials can be carried in suspension along the stream (Newbury 1984). Mussels may have been washed away, especially in areas that were already highly unstable from aggradation (Vannote and Minshall 1982). Scour forces would also have been higher with large sediment loads. Ahlstedt (1986) speculated that mussel habitat was scoured away during high stream flows in upstream areas of the Powell River.

Juvenile Survival on Coal and Powell River Sediments

Juvenile mussels had better survival on no substratum when compared to Powell River sediments. This does not mean, however, that contaminants detrimental to juveniles are necessarily in the sediments. Sediment from the Powell River would have contained organic matter, which may have caused low oxygen conditions within the holding chambers. Future experiments on river sediments should determine organic content of the sediments and dissolved oxygen in the chambers to control these factors. An uncontaminated sediment should be included as a control. Also, experiments should be conducted simultaneously with standard organisms in sediment bioassays.

Survival of juvenile mussels appeared to be highest in Poteet Ford sediments when compared to those from the other two sites. Length frequency data did not show any indication of better recruitment at Poteet Ford. I hypothesized that if survival differed between sites, it would be highest at the lower most site, Fletcher Ford, because it occurs furthest from the likely sources of pollution in the headwaters. However, there may be sediment conditions at Dryden Ford and Fletcher Ford that are reducing juvenile survival. Again, other factors such as organic content may have affected results.

Survival of juveniles did not appear to be affected by coal silt in 7 and 14-day laboratory experiments, although conflicting results occurred. Many factors may have contributed to conflicting results in laboratory trials, including bacterial or fungal infections, water contamination, low dissolved oxygen in the chambers, or poor initial health of the juveniles. Coal as a possible contaminant in the substratum should not be dismissed, however. Although the coal may not affect juveniles over a short period, more long-term chronic effects need to be determined. Juvenile mussels, which may be deposit feeders, could be affected by particle-bound contaminants if ingested (Swartz et al. 1988). Although there is no conclusive evidence that juveniles ingest particles of coal, it seems likely that they would be deposit feeders.

Plausible feeding modes for juveniles would be normal suspension feeding of overlying water, deposit feeding, uptake of dissolved organic matter, or interstitial suspension feeding. Churchill and Lewis (1924) observed 0.20-0.25 mm juveniles ingesting small particles and speculated that they were feeding on protozoa, diatoms, and minute particles of detritus. Churchill and Lewis (1924) observed juveniles in the laboratory drawing material in through the valves by creating a current with cilia on the gills. I also observed material being drawn into the valves in this manner. Material was also seen adhering to the ciliated foot which could facilitate entry into the mantle chamber. Deposit feeding has been a suggested feeding mode for sphaeriid clams (Hornbach et al. 1984, Way 1989). Way (1989) observed *Musculium transversum* using ciliary tracts on the foot to move particles to the labial palps. He postulated that the potential for deposit feeding would exist in areas of rich, organic substrata, especially when low quantities or quality of suspended food were available. Because filter feeding provided only 35 percent of the energy needs of *Sphaerium striatinum* populations, deposit feeding was suggested as an alternate feeding mode for these organisms (Hornbach et al. 1984). Mortality of juvenile *Anodonta imbecillis* sometimes exceeded 90 percent within 5 to 6 weeks when reared in containers of river water containing naturally occurring plankton (Hudson and Isom 1984). The addition of silt from pond and lake substrata increased survival nearly 90 percent. They postulated that the added particulate matter may have provided an added food source for the juveniles, although they did not speculate on the feeding mode used. Interstitial suspension feeding in littoral muds was proposed as a feeding mode for *Pisidium casertanum* and *P.conventus* (Lopez and Holopainen 1987). They postulated that this could be a possible feeding mode for very small animals where a concentrated food source was available.

Very little information is available in the literature regarding the distribution and habitat use by juveniles (Gordon and Layzer 1989). The paucity of information is because they are difficult to locate in the field. Juveniles are probably located in the interstitial spaces of the substratum rather than on the surface. I observed juveniles (200 μm - 210 μm) in the laboratory to burrow immediately when placed on fine sand. In an artificial stream system, juveniles burrowed up to 8 cm into the substratum (Greg Church, Department of Biology, VPI&SU, Blacksburg, VA, pers. comm.) In the field, larger juveniles were observed in sandy pockets, or crevices in bedrock which were filled with sand, several centimeters in the substratum (Greg Church, pers. comm.). Neves and Widlak (1987) collected most juveniles in the upper 8 cm of the substratum behind boulders in riffles and runs. There are several advantages of living interstitially, including protection from predatory species, spates, and droughts (Williams 1981)

Contaminants

Contaminants are present in the Powell River system and may be a cause of mussel die-offs and declines. As with other systems, however, most evidence of contamination contributing to decreases in density, range or diversity of mussels is largely circumstantial (Havlik and Marking 1987). Twenty-six percent of samples taken from four ambient water quality monitoring stations, two on the Powell River and two on tributaries to the Powell River, were not in compliance with fecal coliform criteria (Virginia Water Control Board 1988). All samples taken below the Pennington Gap STP on the North Fork Powell River were in violation of fecal coliform standards. The EPA's National Municipal Policy requires that a new wastewater treatment plant be built in Pennington Gap. This action will likely bring the water quality stations below Pennington Gap STP into compliance (Virginia Water Control Board 1988). In addition, biological monitoring stations located in tributaries to the North Fork Powell River indicated poor to fair water quality, probably resulting from active and abandoned mining activities and poorly or untreated domestic wastes (Virginia Water Control Board 1988).

Major trends from 10 year averages in the Powell River showed decreases in BOD from Big Stone Gap (PRM 181) to Jonesville (PRM 143), stable dissolved oxygen and pH, and a significant reduction downstream in suspended solids (Virginia Water Control Board 1985). Chemical analysis of priority pollutant metals, herbicides, and pesticides showed low (trace) concentrations. Sediment concentrations were higher, but were not considered detrimental to water quality. Gradients in sulfate, iron, alkalinity, calcium, conductivity, and total solids occur in the Powell River, Virginia (Alan Temple, pers. comm.).

Overall, Powell River waters exceed water quality standards established by the Virginia Water Control Board (1985). However, there are only two ambient water quality stations on the main-stem of the Powell River at this time. Also, ambient water quality monitoring stations are only sampled monthly. Sampling should be continuous or at least during high flow events because many types of pollution episodes occur in pulses, such as during storm events or illegal dumping incidents. This potential problem is being evaluated by a high flow sampling program in the Powell River, Tennessee (United States Geological Survey 1989).

Pollution from agriculture, logging, domestic sewage, coal mining and other industries has increased since Ortmann (1918) collected in the Powell River, and as he predicted, the mussel fauna has declined. Although several sources of pollution exist, coal mining is the major point and non-point source affecting the Powell River drainage. Coal mines have been in southwest Virginia since the 1850's (Holm 1955). However, surface mining did not occur in the Powell River drainage until 1944 and reached its peak in 1976 (Hibbard in prep.) (Figure 9). With the advent of coal mining, sediment erosion from mined lands and contaminant leaching from spoil banks and gob piles resulted in severe damage to several watersheds of this area. Unfortunately, there were no reclamation laws requiring operators to permit, bond, or reclaim mined areas until 1966. Stricter regulations for surface mining and reclamation were added with the enactment of the Federal Surface Mining Control Act of 1977. This act

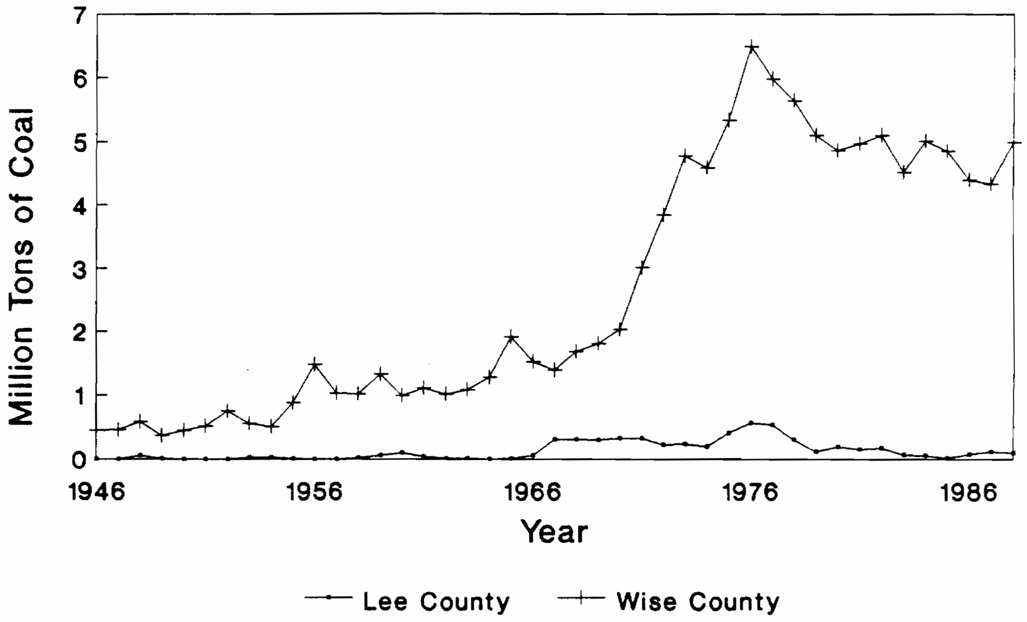

Figure 9. Coal production from surface mines in Lee and Wise counties, Virginia, 1946-1988.

required erosion control measures during mining and also provided funds for reclamation of abandoned mines.

Coal processing wastes (gob piles) constitute a major hazard in coal-producing areas. Potentially toxic contaminants in coal wastes include iron, aluminum, and manganese which generally leach out of coal refuse in high amounts (Wewerka et al. 1976). Contaminants from coal preparation wastes vary, depending on the age of the gob pile, origination of the coal, and chemicals used for cleaning the coal (Stewart and Daniels 1989). Runoff from gob piles and accidental releases from settling ponds may result in large influxes of unknown contaminants to the Powell River.

Abandoned mine lands are probably contributing the most significant amounts of coal waste to the Powell River (Carl Zipper, Coal and Energy Research Laboratory, VPI&SU, Blacksburg, VA, pers. comm.). These lands can contain large areas of spoil banks and gob piles. Unfortunately, many abandoned mines have not undergone reclamation and conservation measures for lack of funding. Reclamation efforts or naturally established vegetation can decrease the amount of sediments entering the river; however, researchers have found that even if sediment inputs are controlled, some water quality aspects, such as sulfate levels, are slow to recover (Dyer and Curtis 1977, Matter and Ney 1981).

Contaminant information available for mussels consists primarily of uptake, storage, and elimination data, but information regarding toxicity is limited (Havlik and Marking 1987). Manganese, a common contaminant in coal mining waste, is readily taken up and stored in adult mussel tissue in high concentrations, with apparently no adverse affects (Havlik and Marking 1987). Manganese levels in soft tissues of *A. pectorosa* in the Powell River range from 5,600 to 7,760 μg/g (Richard J. Neves, 1986, unpublished data). These levels do not appear to be unusual when compared to other manganese data (Havlik and Marking 1987). However, recent studies have concluded that manganese may be toxic to juvenile mussels. Under low oxygen conditions, the LC50 concentration for manganese was 19.6 mg/l (ppm) (Wade et al. 1989). The Powell River has had manganese concentrations in water up to 1.70 mg/l (ppm) in the upstream areas (EPA STORET database). Sediment levels of manganese have been recorded as high as 450 $\mu g/g$ (ppm)(R. J. Neves, 1986, unpublished). Although manganese concentrations in the water of the Powell River are much lower than LC50 concentrations, chronic effect concentrations have not been determined. Levels of manganese in sediments appear high and require further investigation to determine its availability to juveniles. Aluminum and iron appear in soft tissues of mussels of the Powell River in concentration ranges close to or less than those found in other areas (R. J. Neves, 1986, unpublished data; Havlik and Marking 1987). A discharge of Solcenic oil caused a fish kill in 1986 in the Powell River (Osborne 1986), and this material may affect mussels as well. Because two or more factors may result in stress that adversely affect mussel populations (Havlik and Marking 1987), synergistic effects must be considered when determining effects of certain contaminants.

Declines in mussel densities and distributions most likely stem from the impacts of coal mining in the Powell River watershed. Regulations are in place to improve water quality from point sources; however, stricter enforcement of these regulations is needed. Non-point sources of pollution are not as easily remedied. Presently, funds are limited and allocated only to areas where public health and safety are seriously threatened (Spangler 1989). At the current rate of funding, it will take 55 years just to reclaim these high priority sites in Virginia (Spangler 1989).

Expediting the reclamation of abandoned mines is essential for the continued existence of the diverse fauna occurring in the Powell River. Obviously, environmental concerns are not being fully addressed by existing regulations, and funding and other solutions are needed. For instance, remining abandoned mined lands may provide cost-effective reclamation to sites that otherwise may not be reclaimed until the mid to late twenty-first century (Spangler 1989). Another potentially viable approach is being addressed by the Powell River Project. This cooperative research and education program sponsors programs in economic, land use, environmental, and social areas (Powell River Project 1989). The research generated by these programs will be very useful in providing creative, systematic, and innovative solutions to environmental problems in the Powell River area.

Biological recovery of the Powell River is the best indicator of the success of reclamation efforts in the watershed. The Powell River should be monitored very closely to determine if biological recovery is occurring in response to reclamation efforts. Surveys should be conducted at least every five years, repeating quadrat sampling and qualitative sampling. Limited qualitative sampling should be conducted to minimize the impact or disturbance of mussels. Because mussels generally are distributed in a clumped manner, it is essential to sample the same area or mussel bed. Close monitoring of these sites will detect the occurrence of recovery or further declines of mollusks in the Powell River. Also, identification of contaminants that are toxic to mussels is imperative. Intensive research in this area is needed in order to determine if industrial, municipal or other types of river inputs are the cause(s) of mussel declines. Preservation and protection of the diverse mussel fauna in the Powell River is dependent on identification of those environmental factors detrimental to mollusk survival and reproduction.

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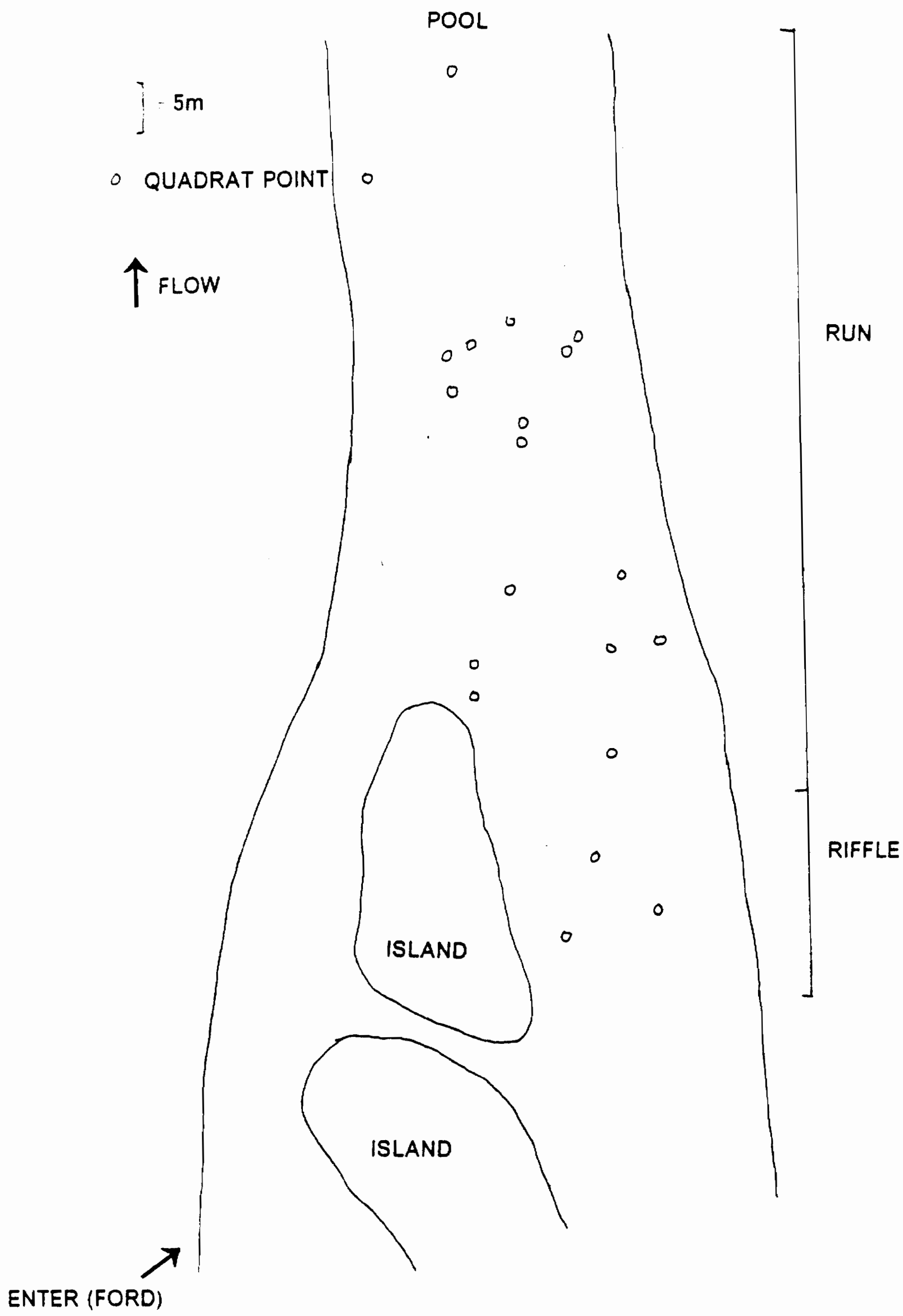
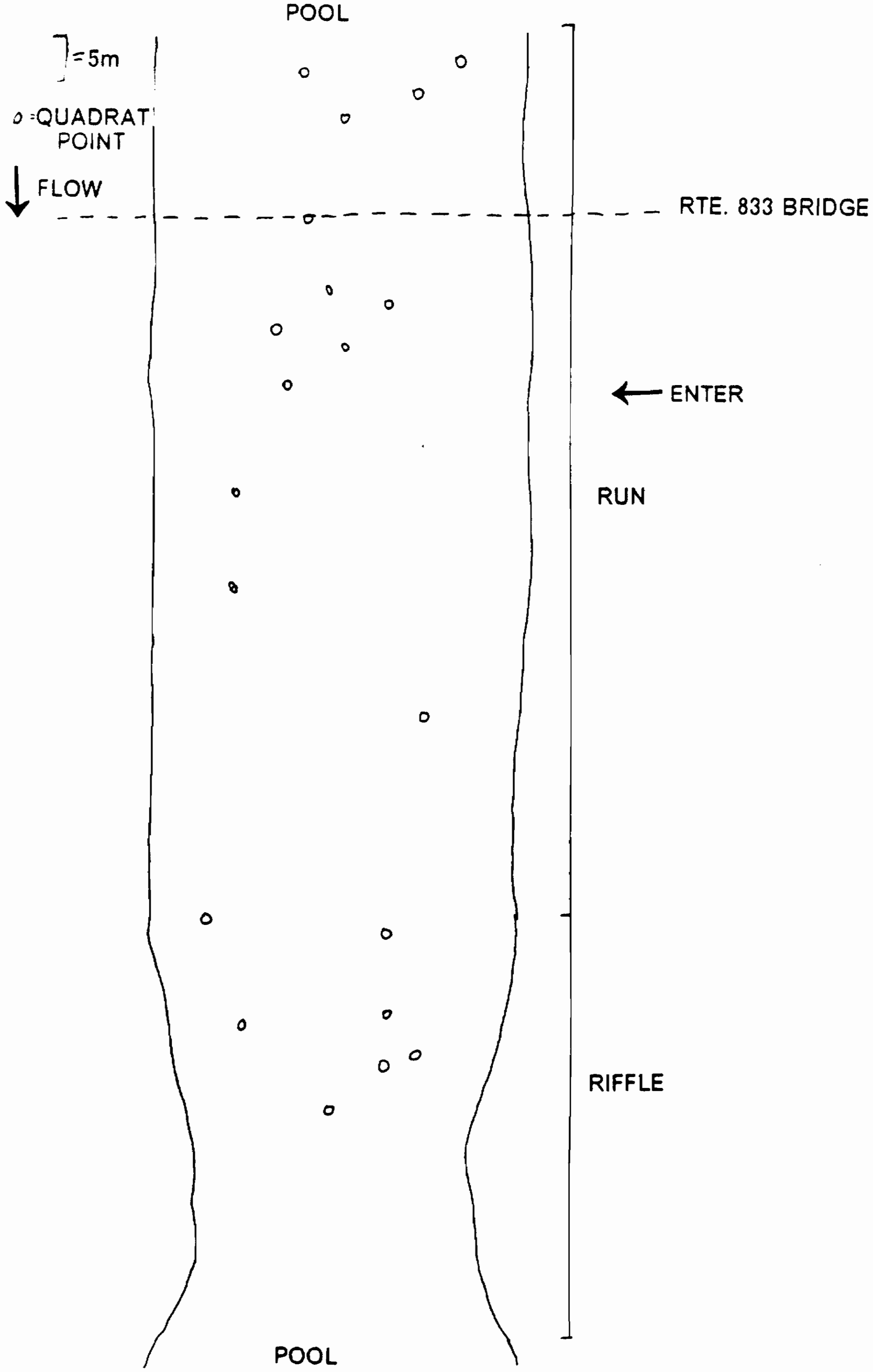
Appendix A. Maps of sites sampled by quadrats on the Powell River, Virginia.

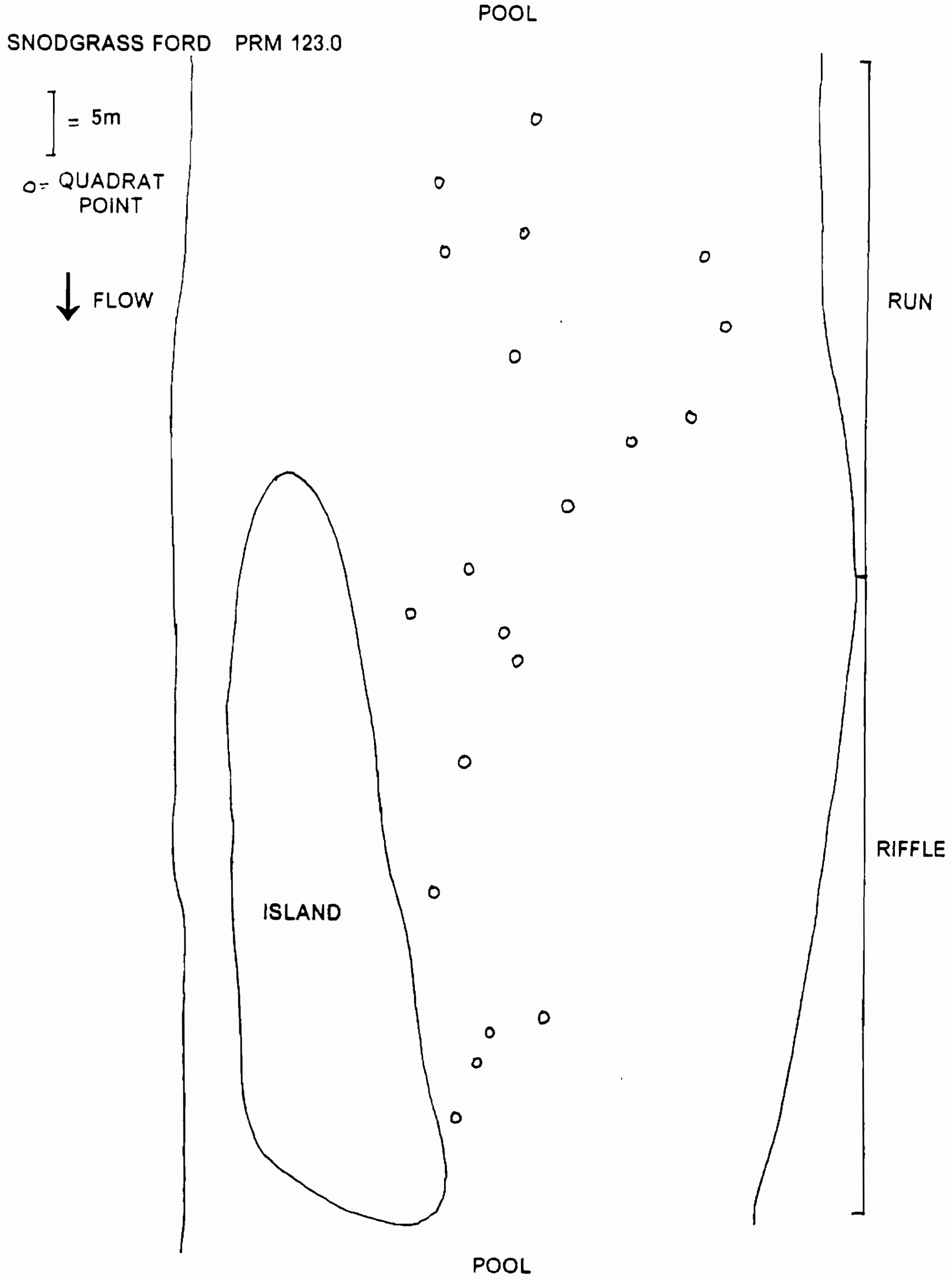
FLETCHER FORD PRM 117.3



Appendix A. Maps of sites sampled by quadrats on the Powell River, Virginia.

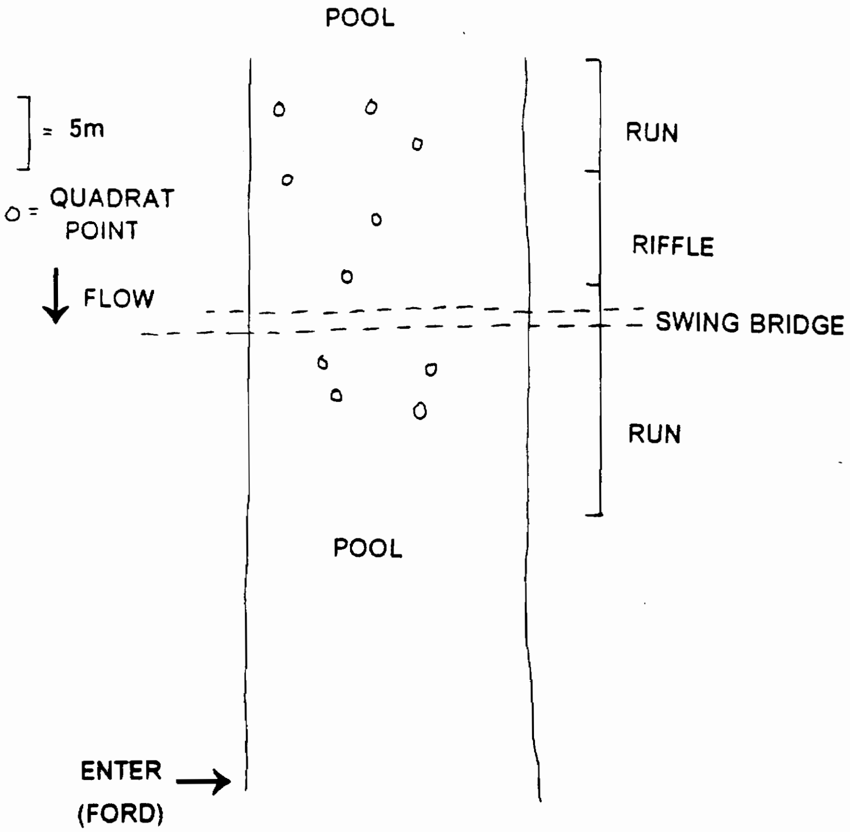
RTE. 833 BRIDGE PRM 120.4



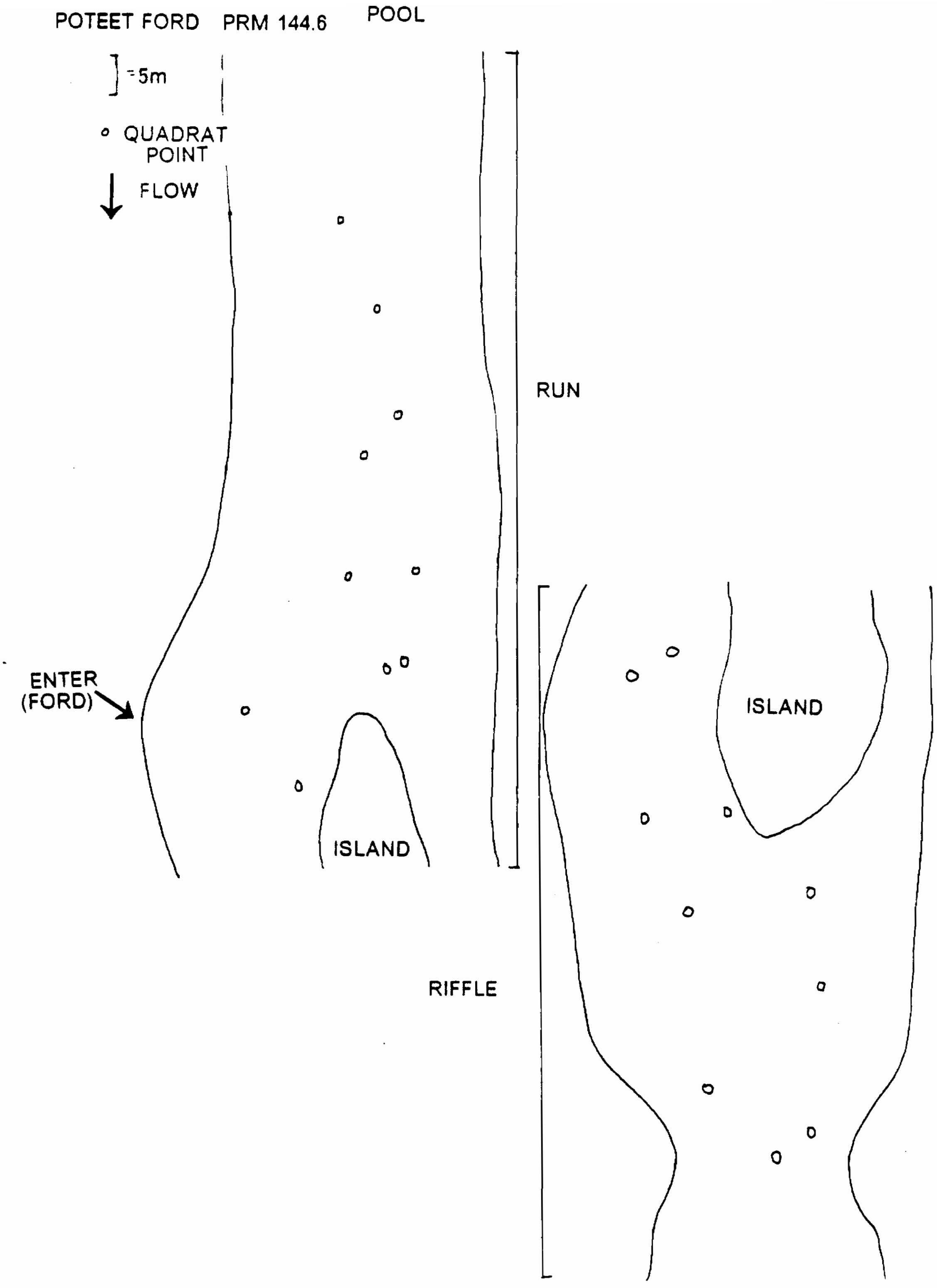


Appendix A. Maps of sites sampled by quadrats on the Powell River, Virginia.

HALL FORD PRM 128.4



Appendix A. Maps of sites sampled by quadrats on the Powell River, Virginia.



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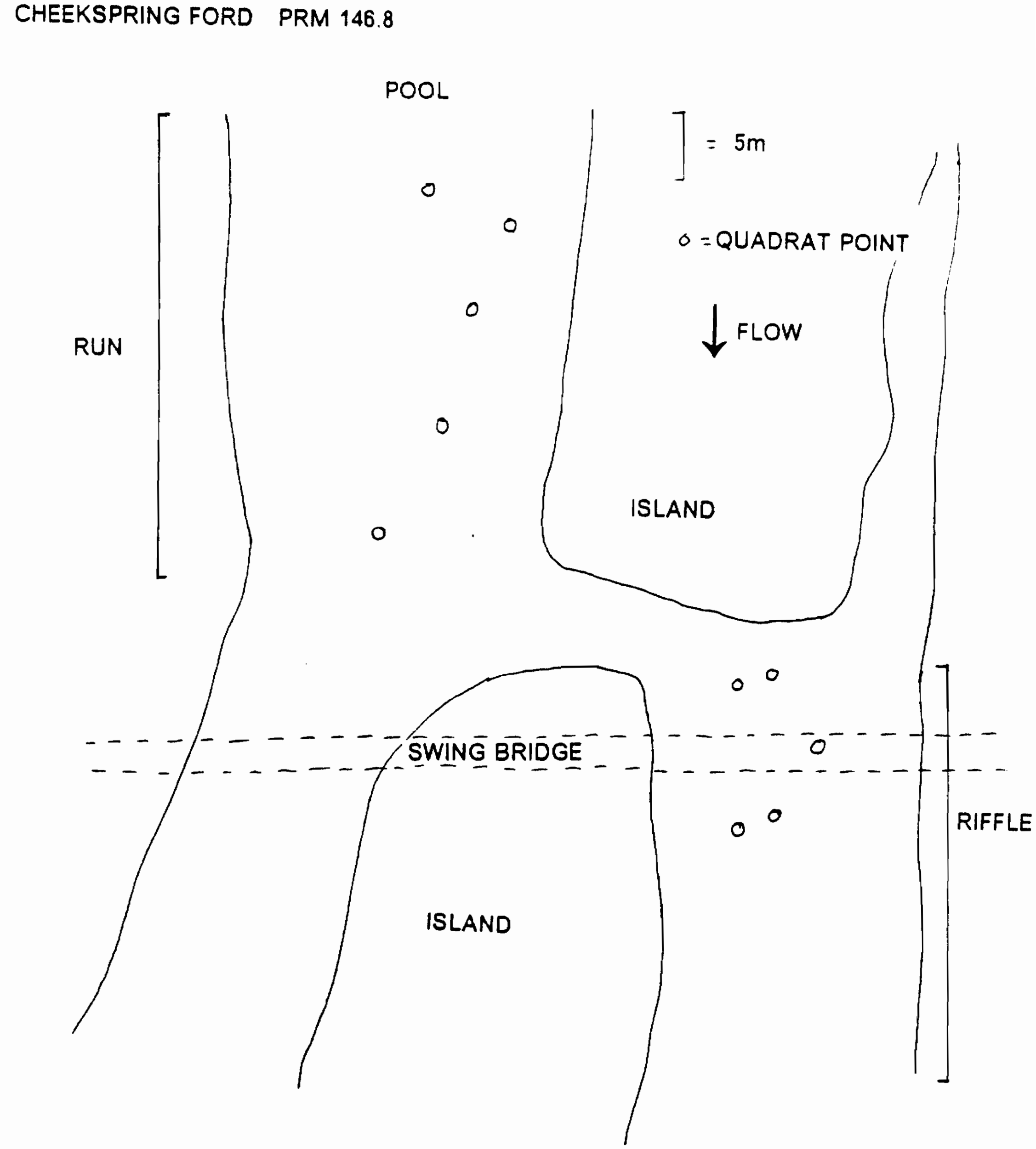

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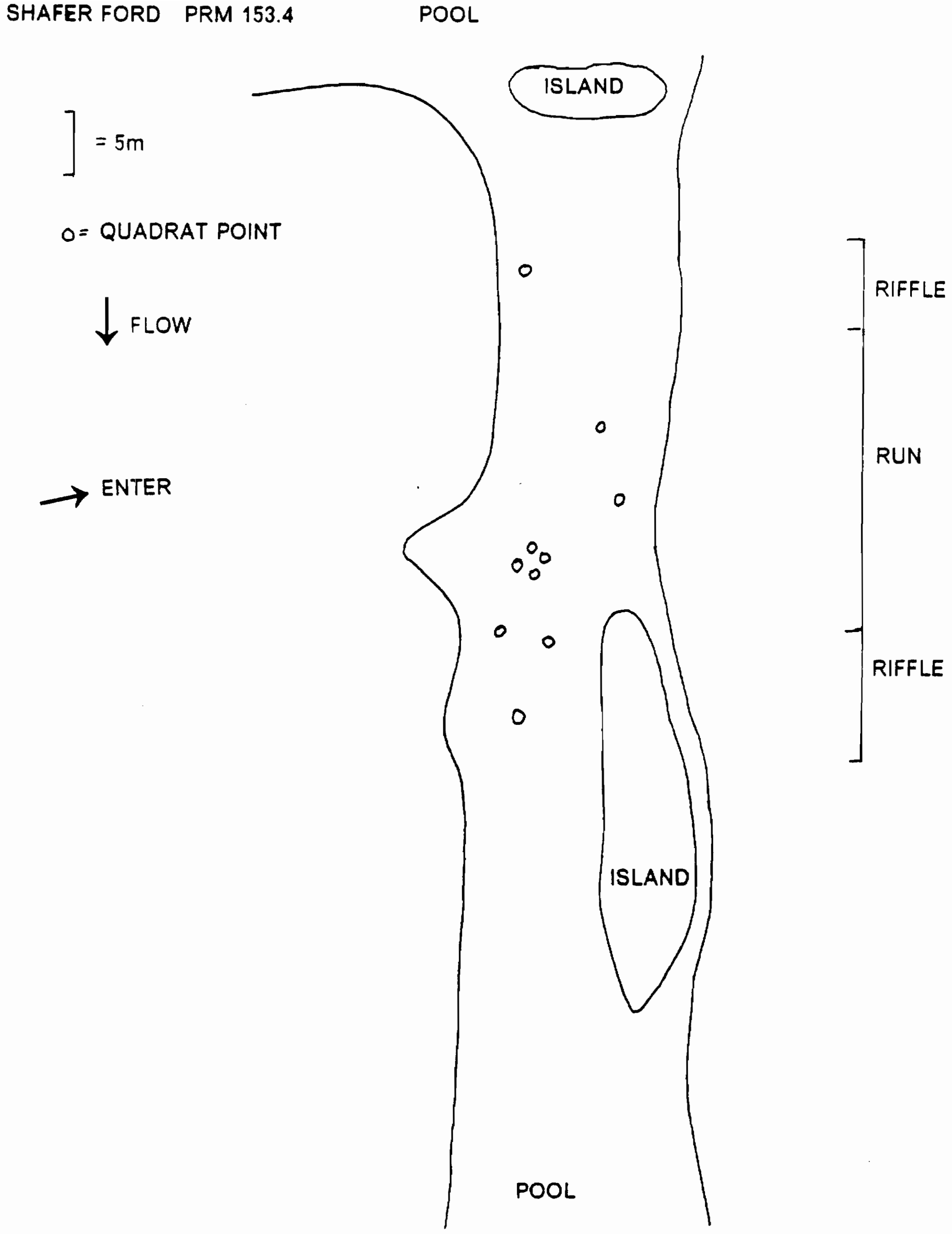

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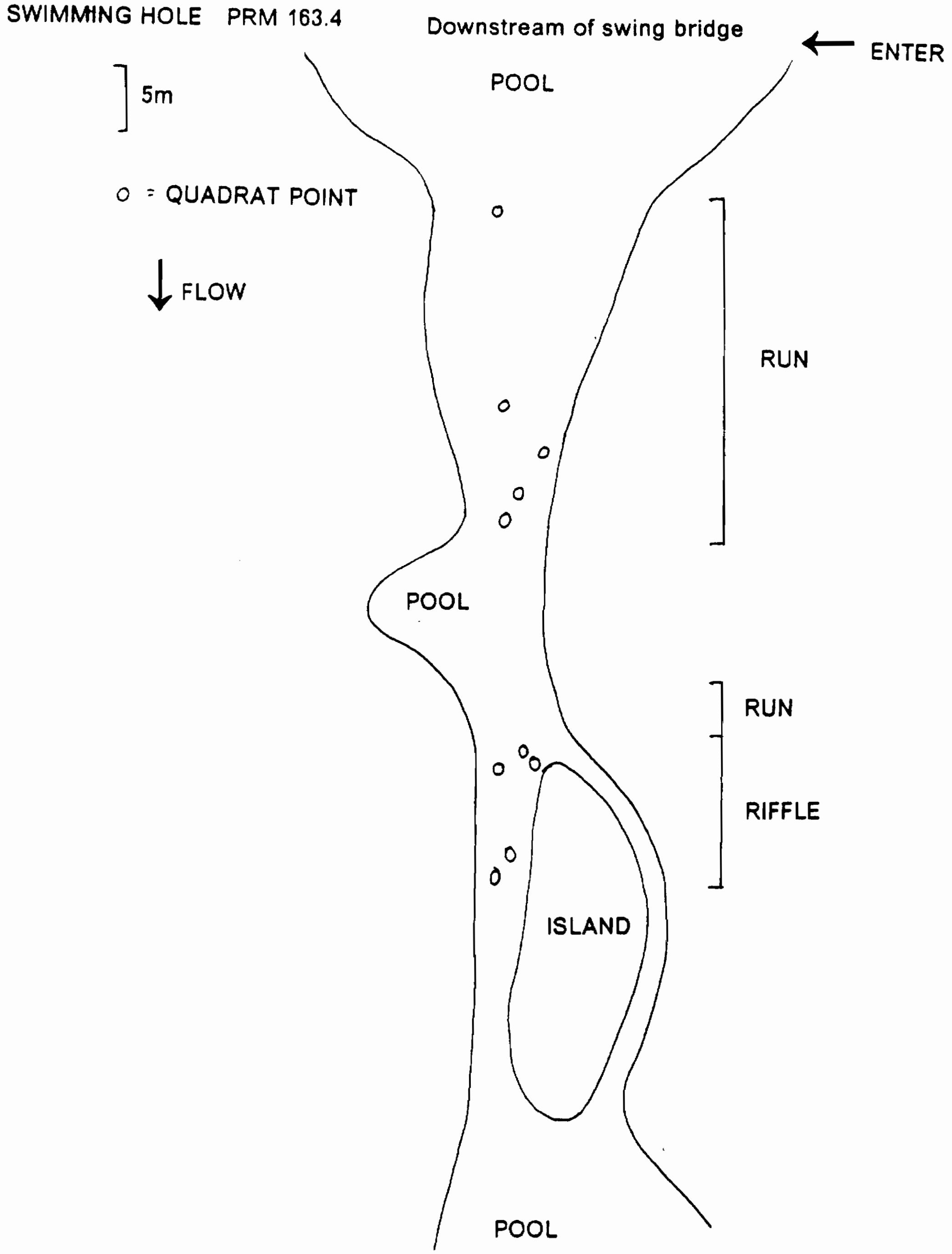

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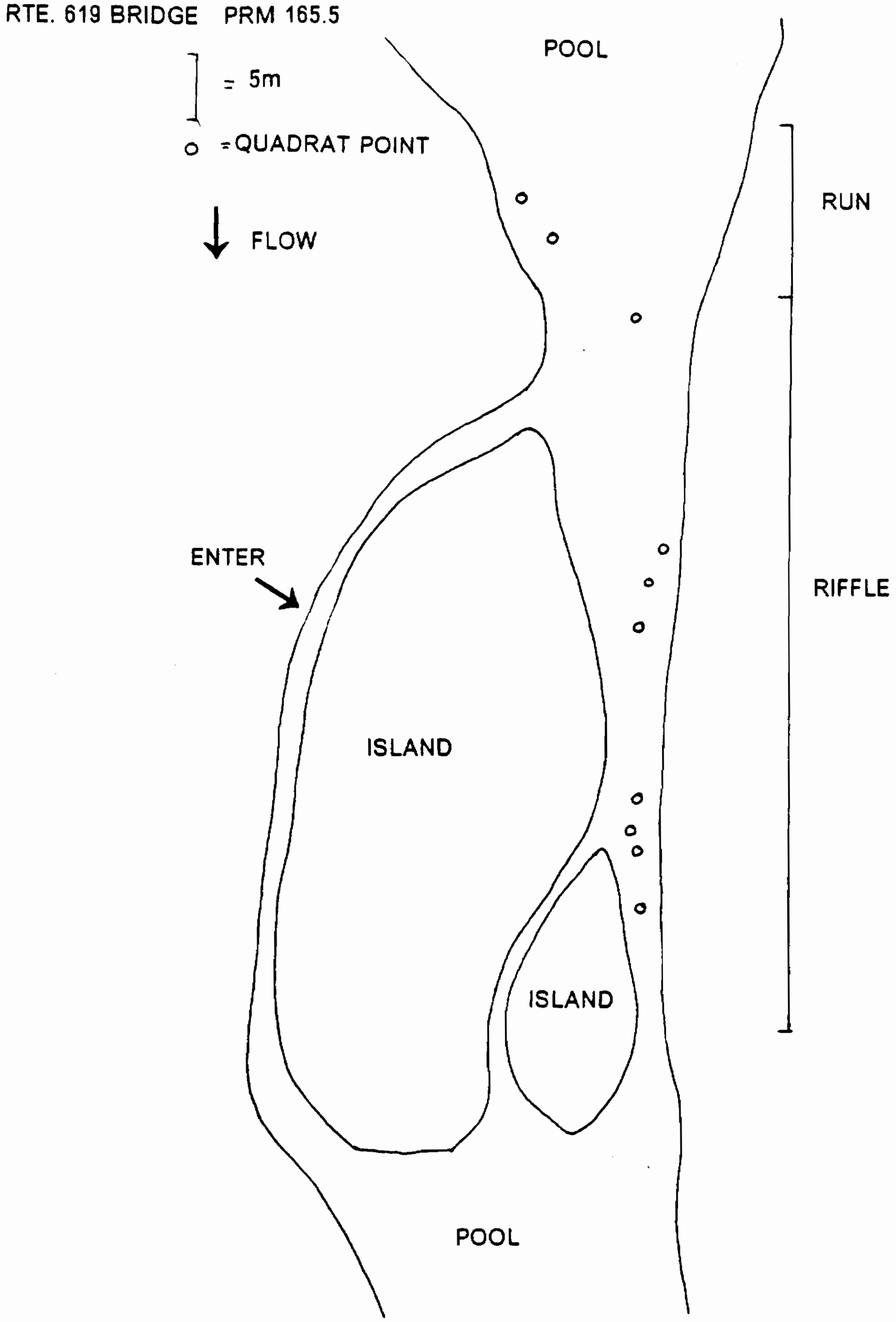

Appendix A. Maps of sites sampled by quadrats on the Powell River, Virginia.

Appendix B. Mean monthly water quality parameters from EPA's STORET database for the Powell River, Virginia, 1988-1989.

APPENDIX B. Mean monthly water quality parameters from EPA's STORET database for the Powell River, Virginia, 1988-1989.

	January - July 1988 Mean (Range)		January-September 1989 Mean (Range)	
	PRM 142.5	PRM 180.0	PRM 143.5	PRM 180.0
Temperature	14.2	11.2	10.5	9.7
	(2.8-24.9)	(0.7-22.0)	(2.2-19.8)	(0.7-17.9)
D.O. (mg/l)	10.15	10.8	10.68	11.7
	(7.0-12.3)	(8.1-13.8)	(7.9-13.2)	(9.3-15.6)
BOD(mg/l)	1.0	1.0	1.2	1.3
	(1.0)	(1.0)	(1.0-2.0)	(1.0-2.0)
pH	8.24	8.22	7.96	8.12
	(7.89-8.88)	(7.80-8.43)	(7.05-8.29)	(7.81-8.39)
Total P ((mg/l)	0.100	0.120	0.114	0.100
	(0.100)	(0.100-0.200)	(0-0.100)	().100)
Total Solids (mg/l)	234	403	247	366
	(177-287)	(238-752)	(154-329)	(243-506)
Turbidity (JTU)	-	-	22.6	8.3
	-	-	(0.8-115.0)	(0.9-50.0)
Nitrates (mg/l)	0.440	0.508	0.682	0.655
	(0.270-0.640)	(0.430-0.690)	(0.430-1.010)	(0.510-1.140)
Sulfate (mg/l)	-	-	76	203
	-	-	(42-113)	(64-460)

Appendix C. Mean water velocity measurements in riffles and runs at sites sampled quantitatively in the Powell River, Virginia, 1988.

APPENDIX C. Mean water velocity measurements in riffles and runs at sites sampled quantitatively in the Powell River, Virginia, 1988

		RIFFLES			RUNS	
SITE	Mean (cm/sec)	Range	Std. Error	Mean (cm/sec)	Range	Std. Error
FLET	45.67	24-60	11.02	36.18	14-50	1.95
833B	47.33	26-70	6.77	31.86	19-55	2.72
SNOD	52.20	46-61	2.46	38.47	19-60	3.41
HALL	40.50	35-46	5.50	31.50	22-52.0	3.48
POTE	50.70	16-90	8.26	19.50	16-30	1.25
CHEE	64.60	43-90	7.85	35.8	25-50	4.21
SHAF	68.33	60.85	8.33	50.29	40-65	3.90
SWIM	75.80	58-93	6.32	36.00	20-48	5.97
619B	66.12	55-78	2.78	26.00	26	-

Appendix C. Mean water velocity measurements in riffles and runs at sites sampled quantitatively in the Powell River, Virginia, 1988.

Appendix D. Median size class distribution of mussel species as determined by quantitative and qualitative surveys, 1988.

APPENDIX D. Median size class distribution of mussel species as determined by quantitative and qualitative surveys, 1988.

Amblema plicata

Median size class (mm)

SITE	5	15	25	35	45	55	65	75	85	95	105	115
QUALITATIVE												
833B	-	-	-	-	-	-	-	1	-	-	1	1
SNOD	-	-	-	-	1	-	-	-	-	2	-	-
HALL	-	-	-	-	-	-	1	1	-	-	-	-
FLAN	-	-	-	-	-	-	-	1	-	-	-	1
SEWE	-	-	-	-	-	-	1	-	1	-	-	-
POTE	-	-	-	-	-	-	-	-	-	1	-	-

Cyclonaias tuberculata

Median size class (mm)

SITE	5	15	25	35	45	55	65	75	85	95
QUADRATS										
FLET	-	-	-	-	-	-	-	1	-	-
QUALITATIVE										
FLET	-	-	-	-	-	2	-	-	1	1
YELL	-	-	-	-	-	1	-	-	-	-
833B	-	-	-	-	-	-	-	-	1	-
SNOD	-	-	-	-	-	-	1	1	-	2
HALL	-	-	-	-	-	-	-	1	-	-
SEWE	-	-	-	-	-	-	-	-	1	-
POTE	-	-	-	-	-	-	-	-	1	-

Dromus dromas

	Median size class (mm)							
SITE	5	15	25	35	45	55	65	75
QUADRATS								
SNOD	-	-	-	-	-	-	-	1
QUALITATIVE								
FLET	-	-	-	-	-	-	-	3
YELL	-	-	-	-	-	-	1	1
SNOD	-	-	-	-	-	-	-	2

Epioblasma brevidens

	Median size class (mm)					
SITE	5	15	25	35	45	55
QUADRATS						
FLET	-	-	-	-	1	2
833B	-	-	-	-	1	-
QUALITATIVE						
FLET	-	-	-	-	2	-
833B	-	-	-	-	-	1
SNOD	-	-	-	-	-	1
SEWE	-	-	-	-	1	-

Epioblasma capsaeformis

	Median size class (mm)				
SITE	5	15	25	35	45
QUALITATIVE					
833B	-	-	-	-	1

Appendix D. Median size class distribution of mussel species as determined by quantitative and qualitative surveys, 1988.

Epioblasma triquetra

	Median size class (mm)					
SITE	5	15	25	35	45	55
QUALITATIVE						
FLAN	-	-	-	-	-	1

Lampsilis fasciola

	Median size class (mm)									
SITE	5	15	25	35	45	55	65	75	85	95
QUADRATS										
FLET	-	-	-	-	-	-	-	1	-	-
SHAF	-	-	-	-	-	-	-	1	-	-
QUALITATIVE										
FLET	-	-	-	-	-	2	2	-	-	-
YELL	-	-	-	-	-	1	-	1	3	-
833B	-	-	-	-	-	1	1	1	-	-
SNOD	-	-	-	-	-	-	1	1	-	2
HALL	-	-	-	-	-	1	-	-	-	-
HURR	-	-	-	-	-	-	2	-	1	-
SEWE	-	-	-	-	-	-	2	-	1	-
POTE	-	-	-	-	-	1	2	2	-	-
CHEE	-	-	-	-	-	-	-	1	-	-
ROCK	-	-	-	-	-	-	1	1	-	-
SWIM	-	-	-	-	-	-	-	1	-	1

Lampsilis ovata

	Median size class (mm)												
SITE	5	15	25	35	45	55	65	75	85	95	105	115	>125
QUADRATS													
SNOD	-	-	-	-	-	-	-	-	-	-	1	-	-
QUALITATIVE													
833B	-	-	-	-	-	-	-	-	-	-	1	-	-
FLAN	-	-	-	-	-	-	-	-	1	-	-	-	-
HURR	-	-	-	-	-	-	-	-	-	1	2	1	-
SEWE	-	-	-	-	-	-	-	-	-	1	-	2	2
POTE	-	-	-	-	-	-	-	-	-	-	2	2	-

Lasmigona costata

	Median size class (mm)												
SITE	5	15	25	35	45	55	65	75	85	95	105	115	125
QUALITATIVE													
FLET	-	-	-	-	-	-	2	2	3	-	-	-	-
833B	-	-	-	-	-	-	-	-	1	1	-	-	-
SNOD	-	-	-	-	-	-	-	1	2	-	-	-	-
HALL	-	-	-	-	-	1	1	1	1	1	-	-	-
FLAN	-	-	-	-	-	-	-	-	-	-	1	1	-
HURR	-	-	-	-	-	-	-	-	2	-	-	-	1
SEWE	-	-	-	-	-	-	-	-	1	2	2	1	-
POTE	-	-	-	-	-	-	-	-	1	1	-	-	-
CHEE	-	-	-	-	-	-	-	-	-	1	-	-	-

Appendix D. Median size class distribution of mussel species as determined by quantitative and qualitative surveys, 1988.

Lemiox rimosus

	Median size class (mm)					
SITE	5	15	25	35	45	55
QUADRATS						
POTE	-	-	-	1	-	-
QUALITATIVE						
FLET	-	-	-	-	-	1

Ligumia recta

	Median size class (mm)											
SITE	5	15	25	35	45	55	65	75	85	95	105	115
QUADRATS												
SNOD	-	-	-	-	-	-	1	-	-	-	-	-
QUALITATIVE												
CHEE	-	-	-	-	-	-	-	-	-	-	-	1

Medionidus conradicus

	Median size class (mm)						
SITE	5	15	25	35	45	55	65
QUADRATS							
FLET	-	1	-	2	2	-	-
833B	-	-	1	1	4	-	-
SNOD	-	-	-	3	8	3	-
QUALITATIVE							
FLET	-	-	-	1	4	3	-
YELL	-	-	-	2	2	4	-
833B	-	-	-	6	7	10	-
SNOD	-	-	-	9	5	-	-
SEWE	-	-	-	-	-	-	1
619B	-	-	-	-	-	1	-

Appendix D. Median size class distribution of mussel species as determined by quantitative and qualitative surveys, 1988.

Plethobasus cyphyus

	Median size class (mm)					
SITE	5	15	25	35	45	55
QUADRATS						
FLET	-	-	-	-	-	1
QUALITATIVE						
FLET	-	-	-	-	-	1

Potamilus alatus

	Median size class (mm)												
SITE	5	15	25	35	45	55	65	75	85	95	105	115	>125
QUALITATIVE													
FLET	-	-	-	-	-	-	-	1	-	-	-	-	-
FLAN	-	-	-	-	-	-	-	-	-	-	-	-	1
HURR	-	-	-	-	-	-	-	-	-	1	3	1	3
SEWE	-	-	-	-	-	-	-	-	-	-	2	-	-
POTE	-	-	-	-	-	-	-	-	-	1	-	-	-
CHEE	-	-	-	-	-	-	-	-	-	-	1	-	-

Ptychobranchus fasciolaris

	Median size class (mm)												
SITE	5	15	25	35	45	55	65	75	85	95	105	115	125
QUALITATIVE													
FLET	-	-	-	-	-	-	-	1	-	-	-	-	-
YELL	-	-	-	-	-	-	-	-	-	-	1	-	-
833B	-	-	-	-	-	-	-	1	2	1	-	-	-
SNOD	-	-	-	-	-	-	-	-	1	-	3	-	1
SEWE	-	-	-	-	-	-	-	-	-	-	1	-	-
POTE	-	-	-	-	-	-	-	-	-	-	2	1	-
CHEE	-	-	-	-	-	-	-	-	1	-	-	-	-
ROCK	-	-	-	-	-	-	-	-	-	1	-	-	-

Quadrula cylindrica strigillata

SITE	Median size class (mm) 5	15	25	35	45	55	65	75	85	95	105	115
QUALITATIVE												
833B	-	-	-	-	-	-	-	-	1	-	-	-
FLAN	-	-	-	-	-	-	-	-	-	1	-	-
SEWE	-	-	-	-	-	-	-	-	1	-	-	-
POTE	-	-	-	-	-	-	-	-	-	2	-	1
ROCK	-	-	-	-	-	-	-	-	-	-	1	-

Quadrula intermedia

SITE	Median size class (mm) 5	15	25	35	45	55	65	75
QUADRATS								
SNOD	-	-	-	-	-	1	1	-
QUALITATIVE								
FLET	-	-	-	-	-	1	1	-
YELL	-	-	-	-	-	1	-	-
SNOD	-	-	-	-	-	-	-	2
SEWE	-	-	-	-	-	-	1	-
POTE	-	-	-	-	-	-	1	2

Quadrula sparsa

SITE	Median size class (mm) 5	15	25	35	45	55	65	75
QUALITATIVE								
FLET	-	-	-	-	-	-	1	-
YELL	-	-	-	-	-	-	-	1

Appendix D. Median size class distribution of mussel species as determined by quantitative and qualitative surveys, 1988.

Villosa iris

Median size class (mm)

SITE	5	15	25	35	45	55	65
QUALITATIVE							
SNOD	-	-	-	-	-	-	1
HALL	-	-	-	-	-	-	1

Villosa v. vanuxemensis

Median size class (mm)

SITE	5	15	25	35	45	55	65
QUADRATS							
SWIM	-	-	-	-	1	-	-
QUALITATIVE							
CHEE	-	-	-	-	-	-	1
ROCK	-	-	-	-	-	1	-
619B	-	-	-	-	-	1	-

Appendix E. Mean water velocity measurements in riffles at sites sampled for substrata in the Powell River, Virginia, 1988.

APPENDIX E. Mean water velocity measurements in riffles at sites sampled for substrata in the Powell River, Virginia, 1988.

SITE	Mean (cm/sec)	Range	Std. Error
FLET	70.00	67-74	2.03
833B	65.67	50-85	10.27
SNOD	60.33	57-64	2.03
HALL	41.67	35-53	5.70
POTE	64.00	60-70	3.05
CHEE	52.33	40-70	9.06
SHAF	58.33	50-70	6.01
SWIM	98.33	80-130	15.90
619B	58.00	40-72	9.45
DRYD	60.00	50-70	5.77

Vita

Lisa Terwilliger Wolcott was born March 18, 1959, in Rutland, Vermont. She graduated from Otter Valley Union High School in Brandon, Vermont in 1977 and received a B.S. Degree in Wildlife Sciences at the University of Vermont, Burlington in 1982. She worked in temporary positions for the Vermont Department of Fish and Wildlife and the Vermont Department of Water Resources. In January 1988, she became a candidate for the Master of Science degree in Fisheries and Wildlife Sciences (Fisheries Science) at Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

Lisa Wolcott