FACTORS IN THE DISTRIBUTIONAL ECOLOGY OF UPPER NEW RIVER MOLLUSKS (VIRGINIA / NORTH CAROLINA)

by

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(ABSTRACT)

Mollusk macrodistribution in the upper New River is correlated with a large number of environmental variables in order to identify limiting factors. Twenty species of mollusks were collected at 87 stations throughout the drainage. Resultant range patterns were correlated to four years of water quality data from 11 stations. Further environmental data was inferred from basin geology and topography.

Four groups of parameters were found to influence mollusk macrodistributions. Hardness (expanded to include several chemical factors) was quite important to most unionid mussels and pulmonate snails. Goniobasis simplex and two species of Pisidium were found to be limited by hardness. Goniobasis proxima and Ferrissia rivularis may be calcifuge. Stream size was found important to the unionids, and some evidence suggests that stream size interacts with hardness to yield observed mussel distributions. Several pulmonate snails appeared to exhibit a similar interaction effect, but seemed not limited by stream size alone. Stream size was important in determining the range of all pleurocerids studied and that of the pulmonate Ferrissia rivularis. Enrichment (or trophic level) seemed quite important in the macrodistribution of Sphaerium striatinum, and may influence some pulmonate snails. Finally, perturbations such as sewage effluent excluded Mudalia

dilatata from certain tributaries. The possible negative effects of effluents and an upstream dam on some unionids were noted. The factors influencing mollusk macrodistribution were found to be numerous and interspecific tolerances diverse.

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GENERAL INTRODUCTION

In an introduction to freshwater ecology, Macan (1974) set out "to examine why species are present in some places and absent from others." The study of limiting factors has been widely recognized as vital to an understanding of freshwater ecosystems, Boycott (1936) authoring the classic work on mollusks. Boycott believed that the macrodistribution of mollusks in England was related to the hardness and cleanliness of the water, along with habitat size. Continuing Boycott's work, Macan (1950) restricted his area of study, made more detailed observations, and concurred with earlier findings. Hunter (1964), in a general summary of the ecology of freshwater mollusks, included trophic state as an important consideration. He noted in studies of Loch Lomond that mollusks favor eutrophic conditions. More recently, Dussart (1976) applied modern techniques to examine the importance of water hardness in determining the distributions of individual species. All species studied by him were effected by hardness, but he found some calcifuge species, those more common in soft waters. He thus found greater molluscan diversity in waters of medium hardness. These, then, are the four primary distributional determinants that will be investigated in this study: hardness, stream size, perturbation, and enrichment.

Several parameters are omitted from consideration in this study that have been considered important by previous workers in the field. Cummins (1975) stated generally that food, nature of sediments, and flow determine microdistribution, while general physical-chemical conditions determine macrodistribution. As this is an investigation of macrodistribution exclusively, food, flow, and substrate are excluded from discussion. Harrison and Farina (1965) found turbidity important in their studies of planorbid snails. But turbidity is quite low everywhere in this project area, measuring "less that 25 JTU" in 80% of the tests. Temperature was recorded continuously at five stations in the river for several years, but these data have been omitted from this report. It is felt that this parameter, so highly variable in lotic waters, indeed across any small creek and from one day to the next, may not be significantly different anywhere in the project area. Hunter (1964) noted the great temperature ranges mollusks can survive and thus discounted this as a factor in normal distributions. Finally, Hynes (1970) believed that oxygen is rarely a factor in invertebrate ecology in rivers, as the concentration rarely drops to low levels. Hynes' belief has been substantiated in many samplings of the New River (Benfield & Cairns 1974) so figures on oxygen concentrations are excluded. Researchers in the last two related factors might see van der Schalie and Berry (1973) or Berg and Ocklemann (1959).

Published studies on the ecology of mollusks in lotic systems are rare, perhaps because the wide fluctuations in physico-chemical parameters characteristic of rivers make such studies difficult. Rare also are studies of entire mollusk faunas employing more than a handfull of environmental variables. The purpose of this study is to describe the ranges of all the species of mollusks in the upper New River and to tender hypotheses explaining the origin of these ranges, on the basis of physico-chemical parameters.

DESCRIPTION OF STUDY AREA

The New River is the major tributary of the Kanawha River and flows northeasterly from its headwaters near Boone, NC, to "the horseshoe" near Radford, VA. At Radford, the river abruptly turns northeast and cuts perpendicularly across the ridges to its confluence with the Gauley River about 25 miles east of Charleston, WV. The river as therefore conviently divided into an upper and lower section at Radford (Kanawha River Basin Coord. Comm. 1971), and the upper New River drainage, a total of 2748 square miles, is the area of interest here. This drainage is particularly well-suited for a study of factors limiting the distribution of freshwater mollusks for several reasons, among these a diverse geology. Upstream areas are characterized by a gneiss and schist lithology, but near the Wythe/Carroll county line the river passes through a water gap into the Great Valley of Virginia, and limestone and dolomite become predominant (see map 1). Yet considered overall, the concentrations of most dissolved solids are low compared to national averages (Wright 1976). Further, the New River is one of the oldest rivers in North America (Janssen 1953) so species composition and distribution should be comparatively stable. The dispersal abilities of the individual mollusks, thought by Økland (1969) to be an important influence on distributions in Norway, should be a minor factor here. Finally, this is still a rather pristine area with much forest and farmland and few cities, dams, or industries (Wright, 1976).

METHODS

It is fortunate that a wealth of water quality data for this stretch of river was gathered as a part of the Blue Ridge Ecological Reconnaissance (table 1). The "Blue Ridge Project" was initiated in 1970 to gather ecological data in anticipation of Appalachian Power Company's multi-dam installation on the New River near Galax, VA. Benfield and Cairns (1974) give a complete background on the dams along with details of the water sampling and analysis method. The eleven water sampling stations may be located on map 2, along with the 78 other localities where extensive mollusk collections were made. Every attempt was made to cover a wide variety of stream sizes and geographic areas, and most stations were visited more than once at different times of the year. A team of two or more collectors scoured the predesignated site until all habitat types were covered thoroughly and made qualitative estimates of abundances. Many authors (e.g. Harman 1972 or Houp 1970) have investigated microdistribution and relative population densities by limiting the sample to a small area and quantifying abundances. Because such quantitative sampling often ignores scarce species, I deemed this technique unadvisable.

RESULTS AND DISCUSSION
Water Quality

Since the upper New River basin can be divided into two distinct lithologies, sedimentary rock downstream and crystalline rock upstream, tributaries fall into two fairly distinct classes, hard and soft. The term "hard" will be used as shorthand to describe water which, since it drains limestone or dolomite, has high calcium and magnesium concentrations, high conductivity, high alkalinity, and high pH. Likewise, "soft" will describe water draining any other, comparatively insoluble rock. These two terms will carry this extended meaning throughout the remaining text. Hynes (1970) pointed out that hard water not only has a higher calcium concentration, but also typically has a greater concentration of many other ions as well. He further noted that acid waters are almost by definition poor in calcium, and that it is often difficult to distinguish between the effects of low pH and low alkalinity on the biota. For these reasons, no attempt will be made in this work to separate the effects of any of these limestone-related parameters. See Golterman (1975) for a complete treatment of this aspect of river chemistry.

Macan (1950) stated that 20 ppm of calcium was the critical figure for calciphile mollusks, while Hunter (1964) considered 10 ppm calcium the minimum for "hard" waters. Williams (1970a) and McKillop and Harrison (1972) used three categories, soft water with less than 5 ppm calcium, hard water with greater than 40 ppm calcium, and medium water in between. According to this scheme, the upper New River contains almost no "hard" water at all. An intermediate system will therefore be employed for this study, designating as "hard" all water with greater than 7 ppm calcium. Hard tributaries include Little River (the northernmost of the two), Peak Creek, Pine Run, Reed Creek, and Cripple Creek, and all other tributaries of the drainage will be considered soft (Table 2). The main river has both hard and soft halves, the dividing line running between Stations 7 and 8, at the water gap (Table 1).

UNIONIDAE
Introduction

Table 3 lists the six species of mussels collected in this study, along with collection records. The four most common species, T. verrucosa, C. tuberculata, E. dilatata, and L. ovata are generally found throughout the Mississippi basin (Burch 1973). Burch lists A. marginata in the Mississippi drainage as restricted to the Ohio, Cumberland, and Tennessee systems. The most unusual element of the New River unionid fauna, L. subviridis, is believed to have evolved in the New River and spread from there to the Atlantic drainages by means of stream capture (Ortmann 1913, cited in Johnson 1970). It is now found in the New and Greenbriar rivers and in Atlantic drainages from South Carolina to New York (Burch 1973).

Distributions

The five most common mussels display three different distribution patterns. T. verrucosa and L. ovata are both found only in the main river and not further upstream than Station 106. Both are very common at Stations 8 and 103 well upstream from Claytor Lake, and Lampsilis is very common at Station 9 downstream from the dam. Cyclonaias tuberculata and L. subviridis are not as common in the New but are found over a slightly larger range, upstream to the Station 7 or 114 area. Elliptio dilatata is by far the most common and widespread mussel, found throughout the main river and in many tributaries: Little River N., Reed Creek, Cripple Creek, and the South Fork. I collected the sixth species, A. marginata only in two disjunct areas, one station on the main river and two stations in Reed Creek. Since this mussel is so uncommon and spottily distributed, it will be omitted from further discussion.

Effect of Fish Distributions

Because most unionids are parasitic on fish at the glochidial stage, Fuller (1974) believed the influence of fish on the distribution of mussels to be "enormous". Observed patterns of mussel distributions may reflect limits to a fish host's range rather than the true limits of the mussel, so the ranges of known fish hosts must be examined. A comprehensive table compiled by Fuller lists fish hosts known for only three of the six New River Mussels: Elliptio dilatata, Lampsilis ovata, and Alasmidonta marginata. The flathead catfish (Pylodictus olivaris) is the only known host of E. dilatata that has been collected from the upper New River. Virginia Tech teams collected this catfish from many stations on the main river in Virginia (Benfield and Cairns 1974) and Crowell (1974) recorded it from one station in North Carolina, but I find no record of Pylodictus outside the main river. Elliptio has here outstripped the range of its known hosts, for this mussel can be very common in smaller tributaries (e.g. Reed Creek). Conversely, A. marginata was found at only three stations while its host fishes, the white sucker (Catostomus commersoni), the northern hog sucker (Hypentelium nigricans) and the rock bass (Ambloplites rupestris) were found throughout the upper New River drainage (Benfield and Cairns 1974). Benfield and Cairns also found that the host fishes of L. ovata, the smallmouth bass (Micropterus dolomieui) and the bluegill (Lepomis machrochirus) are common well into North Carolina, while I found the mussel itself restricted to a small area of Virginia. Since no correlation between mussel ranges and host fish ranges is apparent in the upper New River, concerns that limiting factors of a fish are being considered rather than those of the mussel seem unfounded.

Effect of Hardness

The positive correlation between limestone and mussel diversity and abundance is well known (Clarke and Berg 1959). The range of E. dilatata, the mussel for which the most data are available, illustrates this dependence on hard water. Elliptio is noticably absent from Reed Island Creek, even though Map 2 shows this tributary near creeks where Elliptio was collected (Little River N and Reed Creek). Table 2 compares the calcium concentrations and hardnesses of these three tributaries. It is apparent that low hardness prohibits E. dilatata from entering Reed Island Creek, and this same factor probably excluded the species from other soft tributaries such as Little River (the southern tributary by that name) or Fox Creek.

The effect of water hardness is even more clearly demonstrated in the distributions of T. verrucosa and L. ovata. These two species range only up to the water gap, where the New River meets the Great Valley of Virginia limestone. A few miles upstream the basin geology has changed to shale and sandstone, almost all hardness parameters are halved (Table 1), and Tritogonia and Lampsilis have disappeared. Cyclonaias and Lasmigona, however, are able to live several miles upstream from the gap, where the water is quite soft. As evident in Table 1, water quality at Station 7 is nearly identical to that of Station 4, so there is no immediately evident explanation for the absence of Cyclonaias and Lasmigona further upstream. A reasonable hypothesis is that while these two species are more tolerant of soft water than either Lampsilis or Tritogonia, Cyclonaias and Lasmigona are unable to reproduce in this water quality. Perhaps the wall of soft water at the gap kills the glochidia of Lampsilis and Tritogonia while those of Cyclonaias and Lasmigona are uneffected.

In soft areas of the New River, C. tuberculata and L. subviridis apparently mature fairly normally but may themselves be sterile. This hypothesis would explain the extreme scarcity of these two species at Stations 7 and 114, for they can arrive only when their fish hosts run several miles upstream in a short period of time.

Effect of Stream Size

Another long-recognized limiting factor to the distributions of unionids is stream size. Van der Schalie (1938) surveyed the mussel fauna of the Huron River and characterized the species present by stream size preferred. He found both Alasmidonta marginata and Lampsilis ventricosa (the form of L. ovata found in the New River) most commonly in small rivers. Elliptio dilatata was very common in a wide variety of stream sizes but seemed to be a medium river species, and Cyclonaias tuberculata was restricted to rivers "fairly large" to "large".

Stream size is important as a limiting factor in the New River as well. Elliptio dilatata, as an example, was not found in the small, hard, Pine Run drainage at Station 175. Table 2 shows that the calcium concentration in this creek is quite high, but the area of the entire Pine Run drainage is only 15 square miles (Table 4). And even though Reed Creek is certainly hard enough to support Elliptio everywhere the water has been measured, I found this species only in the main body of that tributary (Stations 166 and 167), never in any branches (Stations 168 and 169). Clearly Elliptio is not established in Pine Run or the Reed Creek branches because these streams are too small.

The other species of mussel are restricted to the main river only, even though some tributaries approximate the main river's water quality, e.g. Little River N. Perhaps smaller streams do not dependably provide sufficient water for the mussel or its fish host, or perhaps physico-chemical parameters vary too radically for the mussel to become established. More probably, there is not sufficient organic material to serve as food, or the organic particle size is too great. Regardless of its mechanism, stream size dependence is an important factor in the distributional ecology of mussels in the upper New River drainage.

Interaction of Factors

Some details of mussel distribution in the upper New River do not agree with a model based entirely on hardness and stream size. Elliptio is moderately common in the South Fork, even though the hardness at Station 1 is comparable to that of Stations 10, 11, and 12 on tributaries where Elliptio was not found, i.e. Wilson and Fox Creeks and Little River South. However, Table 4 shows that the South Fork is much larger than any of these other three streams. Macan (1974) noted that the threshold value of any limiting factor can be influenced by the intensity of any other limiting factor. Perhaps hardness and stream size interact in some manner so that a large stream can support E. dilatata even though its hardness may be low, and a small stream can support mussels if it has high hardness. The presence of Elliptio at Station 183 on Meadow Creek (Table 2) would support this proposal, for the stream here is barely 3 meters wide. Outside the Great Valley of Virginia, I collected the species only in larger streams. Clearly some factor has stimulated this mussel to adapt to such a small stream, and hardness is a logical choice.

There must certainly be some absolute minimum stream size and minimum hardness to support Elliptio. The mussel was found nowhere in the upper New River's largest tributary, the very soft Big Reed Island Creek. It was also not found in Pine Run at Station 175, even though that creek has the highest calcium concentration recorded in this study. But within these broad, absolute tolerances there seems to be a balancing of one consideration with the other. There does not seem to be any interaction of hardness and stream size in the other four species I examined, but rather two strict criteria which must be met, a large river of a minimum size and hardness. It is possible, though, that an interaction mechanism controls the distributions of the other species of mussels in this study, but that since they have much lower tolerances to softness and stream size, this effect is not apparent in their distributions here.

Effect of Perturbation

The North Fork at Station 2 has higher calcium concentrations than the South Fork at Station 1, and the stream size at Station 187 on the

North Fork is much greater than that of the South Fork at Station 152. Yet Elliptio was collected throughout the South Fork and was not found in the North Fork. This may be attributed to the higher levels of heavy metals Benfield and Cairns (1974) tabulated at Station 3, on the North Fork downstream from a small electronics plant. Wright (1976) noted that levels of aluminum downstream from this plant may be 65 times higher than the upper limit established in the U.S. Environmental Protection Agency's Water Quality Criteria. Wright also noted a high concentration of zinc at Station 3. These findings are especially significant in light of the fact that mollusks are among the first animals to be eradicated by heavy metals (Wurtz 1962), and the fact that heavy metal toxicity can be greater in soft water than in hard (Cairns and Scheier 1958). Since the North Fork upstream form the plant is probably too small to support unionids at that hardness, Elliptio is excluded from the sub-drainage.

The absence of E. dilatata from Station 9, the most downstream station of this study, is also interesting. This species tends to become more abundant proceeding from the South Fork at Station 152 to Station 102 just upstream from Claytor Lake Dam. Cyclonaias and Tritogonia, also common above the impoundment, were present only as relics at Station 9. Since no chemical pollutants are indicated in the data of Benfield and Cairns (1974), these gaps in the distributions are probably an effect of the dam several miles upstream. The river here is still subject to pronounced fluctuations in flow according to the electrical generating schedule. See Fuller (1974) for an excellent discussion of both heavy metal toxicity and dam effects on freshwater mussels.

SPHAERIIDAE

Introduction

Four species of clams belonging to the family Sphaeriidae were collected in this study (see Table 5). By far the most widespread species was Sphaerium striatinum, and common though scattered were Pisidium compressum and Pisisium casertanum. Burch (1975) gives these three species as ranging throughout the United States. Herrington (1962) stated that P. compressum and P. casertanum are the most common species of Sphaeriidae in America. Pisidium dubium, on the other hand, is listed by Burch (1975) as restricted to the U.S. east of the Mississippi.

Distribution

Sphaerium striatinum was found commonly throughout the main river and in many of the larger tributaries: Little River N, Reed and Cripple Creeks and the North and South Forks. A single dead specimen was found in Little River S at Station 12, and several dead specimens were collected in Pine Run. It seems to be a riffle-dweller primarily, scattered in sand and gravel pockets. Pisidium dubium lives in the same situations as S. striatinum, but occurs much more rarely. I collected it at six stations, usually only a few individuals each place, including three localities on the main river and one station each on the South Fork, Reed Creek, and Pine Run. The tiny Pisidium compressum and P. casertanum were collected only in quiet backwaters where silt and mud accumulate. Their relative scarcity is probably due to the difficulty I experienced locating and sampling these areas. These Pisidium were collected at a wide variety of localities: four places in the lower reaches of the main river and in the Reed Creek and Little River N sub-drainages.

Effect of Enrichment

Much of the ecological research involving sphaeriids has centered around their response to organic enrichment. Sphaeriids have been documented to increase in abundance after artificial fertilizations (Smith 1970) or the introduction of a new pollution source (Armitage 1976). Fuller (1974) discussed the tolerance of sphaeriids to enrichment and noted that in his experience Pisidium compressum and P. casertanum were particularly tolerant. The tolerance of Sphaerium striatinum (as S. solidulum Prime) has also been reported (Ingram et al 1953). My results suggest that S. striatinum, at least, is not merely "tolerant", but that it requires such concentrations of organic enrichers that its macro-distribution can be influenced by them.

Cripple Creek and Reed Creek are very similar tributaries in many respects. They occupy adjoining sub-basins and both are hardwater streams. Reed Creek is somewhat larger than Cripple Creek (Table 4). Yet S. striatinum was found almost throughout Reed Creek, from the main tributary to the tiniest branches, while it was almost absent from Cripple Creek. The most striking difference between the two creeks is basin topography. Reed Creek drains a broad valley with much agriculture and several large towns, and Cripple Creek runs through a very mountainous area with a high percentage of forest land. In a study of non-point source nutrient runoff, Uttormark (1974) calculated that farmland exports 1.5 times the total phosphorus and twice the total nitrogen as does forest. There are also three point sources of enrichment in the Reed Creek sub-drainage but none in Cripple Creek (Table 6). It is thus quite probable that Reed Creek is more organically enriched than Cripple

Creek, certainly a significant difference in light of previous research on sphaeriid ecology. Station 166 is located on Reed Creek a few miles downstream from the Wytheville sewage treatment facility, where the major component of the macrobenthos is Sphaerium. Dozens of S. striatinum can be collected in a single handful of substrate, and they grow to tremendous size for the species. These observations suggest that S. striatinum is prevented from colonizing the upper reaches of Cripple Creek by a critical lack of nitrogen and phosphorus.

Effect of Hardness

Hardness appears to play a role in the distributional ecology of Sphaerium striatinum, though the effect is not as pronounced as in the unionids. I collected specimens of S. striatinum in the very soft Little River S and upper Little River N drainages. Yet the absence of this species from many of the other soft drainages (e.g. Reed Island Creek, Elk Creek, Fox Creek) may be due in part to the soft water. Sphaerium striatinum was not found in Chestnut Creek at Station 181 downstream from the basin's fourth largest city, Galax. The species was also absent from collections made at Station 165, on Little Reed Island Creek below Hillsville (the sixth largest city, Table 6). When added to the observation that S. striatinum reaches greatest population densities in hard water, it seems certain that hardness effects the distribution of this species.

Pisidium dubium seems to share with S. striatinum an ability to survive in soft waters. By contrast, the two smaller species of Pisidium, P. compressum and P. casertanum were not collected any further upstream than Station 7. These two species appear to be much more sensitive than either P. dubium or S. striatinum to the change in basin geology. In studies of the diverse Pisidium fauna of England, Bishop and Hewitt (1975) suggested that members of this genus are limited by the availability of food micro-organisms, which themselves feed on detritus. They felt that **Pisidium** is limited by water hardness because calcium deficiency reduces microbiological activity. This is a possible mechanism for the enrichment effect as well. At any rate, hardness can potentially be quite important in sphaeriid macrodistribution.

Effect of Stream Size

To my knowledge no evidence is available indicating that sphaeriids are limited by stream size, perhaps because of their own smallness. Unlike unionids, sphaeriids can live in very tiny amounts of water, and need only tiny amounts of organic matter for food. As an example, Mill Creek at Station 169 in the Reed Creek drainage is never wider than 2 meters, and very nearly dries completely in the summer. Given all other necessary physical and chemical requirements, some sphaeriids may be capable of surviving in any permanently flowing stream, regardless of size.

PROSOBRANCH GASTROPODS

Introduction

The three species of the family Pleuroceridae and one species of the family Viviparidae collected in the upper New River are listed in Table 7. The pleurocerids are particularly interesting because of their more restricted geographical range. Goodrich (1940) lists Goniobasis simplex from only one locality in the Kanawha River drainage, in the Bluestone River of West Virginia. It is generally a species of the Tennessee River system. *Goniobasis proxima* is given by Goodrich (1940, 1942) as a trans-Appalachian inhabitant of the highlands of North Carolina, South Carolina, and Tennessee. *Mudalia*[1] *dilatata* is listed as endemic to the Kanawaha River and its head streams and branches (Goodrich 1940). By contrast, the viviparid *Campeloma crassulum* is quite widespread, occuring in the Ohio River and many other drainages in the east and northeast (Clench 1962).

Distributions

Mudalia dilatata is one of the most common mollusks in the upper New River, and certainly the most visible. It was found throughout the main river and in all its major tributaries (those listed in Table 4). *Gonibbasis proxima* is most common in small creeks but is also quite widespread throughout most of the upper New River. It is prevalent in the headwaters of Little River (North), Reed Island, Cripple, and Chestnut Creeks, Little River (South), Wilson and Fox Creeks, and in many of the small tributaries of the North and South Forks. *Goniobasis simplex* is restricted to small creeks with very hard water, including the lower creeks of the Cripple and Little River N. drainages, plus the Reed Creek and Pine Run drainages. *Campeloma crassulum* was found spottily distributed in the main river and the South Fork, but was quite difficult to collect anywhere. It seems to diffuse widely throughout river bottoms and was always inconspicuous if not buried in the substrate. For this reason it was felt that my collections underestimated

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[1]Generic taxonomy controversial. See Parodiz (1956).

the true range of C. crassulum, so no further comment will be made on this species.

Effect of Stream Size

Stream size has rarely been investigated as an aspect of pleurocerid macrodistribution, but to the pleurocerids of this study it is of primary importance. Regardless of water quality, both species of Goniobasis studied are generally restricted to smaller creeks. As an example, G. proxima is very common in the tiny streams of the homogeneously soft upper Reed Island Creek drainage at Stations 135 (2.79 ppm calcium)and 137 (2.96 ppm calcium). It is even very common at Station 131, which is listed as "intermittent" on USGS topographic maps. It is uncommon at Station 127 (2.20 ppm calcium) which is located on upper Reed Island Creek proper, but was not found at Station 125 (2.08 ppm calcium) or at any collecting site downstream, where the river is quite large. As a basin-wide trend, Goniobasis is common in small creeks, rarely found in the larger tributaries, and never found in the main river.

The mechanism by which a species such as G. proxima might be limited from downstream areas in the New River poses an interesting question. I have observed that Mudalia begins to reach its upstream limit where Goniobasis begins to be limited downstream. Though Lassen (1975) felt that competitive exclusion is more important in microdistribution, competition with Mudalia may limit Goniobasis macrodistributionally. It is also possible that Goniobasis proxima is a calcifuge species, and is limited by increasing calcium concentrations (see "Effect of Hardness"). Harman (1972) considered substrates of primary importance in mollusk distribution, and I have observed that G. proxima seems to prefer the coarse sand characteristic of calm places in small creeks. Perhaps Goniobasis is substrate specific. A final possibility is that organic particle size is the important factor in the downstream limit of Goniobasis. Given the importance of detritus in the energy flow of smaller creeks, and the observation that Goniobasis is often very common under bridges, it is probable that these snails are primarily detritivorus or microbivorus. Eggleshaw (1964) demonstrated the importance of detritus in microdistribution, but decreasing average particle size downstream might be important in macrodistribution.

The distribution of Mudalia dilatata also shows the effects of stream size, independent of water hardness. Once again the homogeneous waters of the Reed Island Creek drainage will serve as an example. Mudalia is very common from Station 123 (2.39 ppm calcium) at the mouth of the creek to Station 127 (2.20 ppm calcium) where the creek is much smaller. It is moderately common several miles upstream at Station 134 (2.96 ppm calcium) or 135 (2.79 ppm calcium). This same pattern is evident in Reed Creek where the water is very hard, and throughout the upper New River. I therefore conclude that stream size is important in determining the macrodistribution of all pleurcerids in this study.

Effect of Hardness

Both pH and total alkalinity were found important in the ecology of Pleurocea acuta and Goniobasis livescens by Dazo (1965), and McKillop and Harrison (1972) also correlated the distribution of G. livescens to hard water. Shoup (1943) noted that alkalinity was important in pleurocerid productivity, but found a wide range of tolerances when looking at a large number of species. In this study, Goniobasis simplex manifested in its distribution an absolute requirement of very high hardnesses. It was found only in creeks draining limestone areas, where total hardness is sometimes 199 ppm (Station 183). Goniobasis proxima, on the other hand, seems nearly uneffected by water hardness, being found in almost all small creeks in the upper New River except where it seems replaced or out-competed by G. simplex. Goniobasis proxima apparently requires a minimum concentration of calcium to survive. I did not collect it at Station 130, in the headwaters of Reed Island Creek, where the calcium concentration was only 1.01 ppm on August 22, 1976. But given a minimum amount of calcium, G. proxima can thrive even in "intermittent" creeks draining solid crystalline rock. The possibility that G. proxima is a calcifuge species cannot be ascertained, for G. simplex is so dominant in hard creeks.

Mudalia dilatata seems to share with G. proxima an ability to extract calcium from very low concentrations in a river. As an example, Mudalia is moderately common as far upstream as Station 118 in the Little River S drainage, and very common at Station 163 upstream in the soft Helton Creek (North Fork) drainage. An important observation is that this species seems to climb about the same distance into all tributaries, regardless of hardness. Mudalia was not found, as an example, in Cripple Creek at Station 171 or Reed Creek at Station 169, both stations a good distance upstream but having hard water. So while M. dilatata doubtlessly also requires some minimum calcium concentration, it seems limited by stream size before this concentration is reached. In conclusion, hardness seems to be important in the distributional ecology of

G. simplex, but apparently plays only a minor roll in the macrodistribution of G. proxima and M. dilatata.

Effect of Perturbation

Pleurocerids have long been regarded a fauna of clean water (Dazo, 1965). But since both species of Goniobasis are most common in creeks characteristic of more remote areas, the effect of pollution in them would be speculation. The effects of pollution, particularly city sewage, on populations of Mudalia are quite marked, however. Mudalia is common upstream from the larger towns of Pulaski, Wytheville, and Galax (Stations 185, 167, 120), but is significantly absent from downstream stations (Stations 184, 166, 181). Mudalia was also expected in the South Fork downstream from Boone (Station 155) but was not collected. Given this species' wide distribution in the upper New River, along with its ease of collection and identification, Mudalia would be of great value as a water quality indicator organism. So there is no evidence that organic enrichment benefits pleurocerid populations, but in fact it seems that high enrichment is deleterious to at least one species.

The Environment and Shell Morphology

One interesting aspect of pleurocerid ecology that deserves special note is the variability the shell displays in response to diverse physico-chemical conditions. Dazo (1965) gives an excellent review of the ample literature on the subject. He lists several authors who have correlated various aspects of pleurocerid shells to chemical factors, and many more who investigated physical effects on shell character. Cheatum and Houzon (1934, cited in Dazo 1965) showed that the shells of river *Goniobasis* were more obese than shells of *Goniobasis* collected from the lakes, and Goodrich (1937) observed that *Pleurocera* shells become proportionately wider downstream. In the upper New River, the shells of *Mudalia* also tend to reflect stream size, but here the trend is to larger and heavier shells in smaller rivers (Figure 1). I have not observed any correlation between large shells and water hardness or *Mudalia* population densities. There also seems to be a correlation between hardness and *Mudalia*'s shell shape, though there is much interpopulation variability. Soft water forms generally have a lower spire than hard water forms, the eroded condition of the apex notwithstanding (Figure 2).

In a discussion of variability in freshwater gastropods, Hunter (1964) noted the difficulty in separating genotypic and phenotypic characters. For example, some selection may exist for the smallest *Mudalia* in large streams, tending to favor a small shell genotype. On the other hand, if *Mudalia* has the potential at birth to build as high a spire as calcium is available, a phenotypic character results. Certainly breeding experiments or transfer studies would cast more light on the nature of pleurocerid variability.

Regardless of the nature of the variability, correlations between water quality and *Mudalia* shell morphology are easily observable. It would certainly not be unreasonable to hypothesize that shell characters of *Goniobasis* may similarly be related to the environment. Goodrich (1942) recognized the close affinities between *Goniobasis simplex* and *G. proxima*, but left these species in different "groups". Indeed, there are differences in shell shape, *G. simplex* having a more convex whorl, and the last whorl of G. proxima being a greater portion of its total length. Yet here we see a phenomenon similar to the one noted in Mudalia, two different shell morphologies isolated in creeks of different water quality. When one examines the atypical forms collected from waters of intermediate hardness (Figure 3), questions regarding the systematics of these two species emerge. Variability in the Pleuroceridae would certainly be a productive subject for research.

PULMONATE GASTROPODS
Introduction

Table 8 lists the distributions and abundances of the six species of pulmonate snails, representing four families, collected in this survey. Physa pomilia ranges from Florida to Maryland, but little is known about the range of Physa hendersoni beyond its type locality in South Carolina (George Te, pers. comm.). Baker (1911) describes Lymnaea obrussa as widespread throughout most of North America, including all the Mississippi drainage, and records L. columella from most of the United States east of the Mississippi. Baker (1945) found Helisoma anceps similarly widespread throughout most of North America. Ferrissia rivularis was given by Basch (1963) as extending from the east coast to the Rocky Mountains. Thus most of the pulmonate species found in the upper New River are quite common nationally.

Distributions

The distributions of Physa hendersoni, Helisoma anceps, and Lymnaea obrussa are all similar. These species were collected throughout the main river, in both forks, and in the Reed and Cripple Creek drainages. They were also found in the lower, hardwater section of the Little

River (N) drainage and rarely in some of the smaller tributaries, i.e. Fox, Wilson, and Helton Creeks, and Pine Run. Physa pomilia and Lymnaea columella were of limited or spotty distribution, generally the same as the above species but encountered too infrequently to draw any significant conclusions. Ferrissia rivularis, the most common and widespread species of mollusk found in the upper New River, was collected almost everywhere from the main river near Radford to the tips of the highest tributaries.

Effect of Hardness

Much of the literature on the distributional ecology of mollusks has dealt with the effect of hardness on pulmonate snails. Boycott (1936), Macan (1950), McKillop and Harrison (1972), and Dussart (1976) have all correlated high hardnesses with presence and abundance of lymnaeids, physids, and planorbids. The transplant studies of Malone (1965) also implicated hardness as a limiting factor. The most intensive research on the ecology of any mollusks has been conducted on the planorbid intermediate hosts of schistosomiasis, Biomphalaria and Bulinus, and is summarized by Liang (1974). Some workers (e.g. de Meillon et al. 1958, Schutte and Frank 1974) found no correlation between distributions of Biomphalaria and water quality. But in a definitive work, Williams (1970 a and b) found that two species of Bulinus are in fact effected by hardness. One species reflected hardness ranges only by its population densities, and the other required a certain hardness but was limited by an excess of about 40 ppm calcium. Since there is almost no water in the upper New River with a calcium concentration that high, we should expect only positive hardness effects in pulmonate macrodistribution.

Positive hardness effects are in fact evident in the distribution of P. hendersoni, L. obrussa, and H. anceps. All three species were found throughout the hard Reed Creek drainage from the mouth (Station 166) to the headwaters (Station 169). They were also found in hard Cripple Creek, where two species were collected as far upstream as Station 171 (see Map 2). However, no Physa, Helisoma, or Lymnaea were collected at any locality in the soft Reed Island Creek sub-drainage, which is only a few miles from Reed and Cripple Creeks. All three pulmonates were also found in the hard downstream reaches of Little River (N), but none were found in its softer headwaters. Hardness clearly limits the range of these three species of pulmonate snails in the upper New River.

By contrast, the distribution of Ferrissia rivularis indicates very little calcium dependence. As in the case of Mudalia dilatata, Ferrissia seems to climb a certain distance up the tributaries regardless of water quality. This limpet displays a much greater range up the tributaries than did Mudalia, however, and was found as far upstream as Station 132 in the Reed Island Creek drainage, and Station 142 in the Fox Creek drainage (see Map 2). This remarkable range may be explained by the findings of Hunter et al. (1967) that populations of F. rivularis vary in their ability to take up calcium. The species clearly needs some minimum calcium concentration, as it was not found at Station 130 on Reed Island Creek (1.01 ppm calcium) or in any of the other tiny feeder streams like those at Station 122 (Chestnut Creek) and 119 (Little River S). Maitland (1964) believed that another ancylid, Ancylus fluviatilis, requires a minimum of 2 ppm calcium. Dussart (1976) found that *A. fluviatilis* is more abundant in soft (0-10 ppm calcium) than in medium or hard water in British streams. Bussart believed *A. fluviatilis* to be a true calcifuge, and there is some indication that this is the case for *F. rivularis*. *Ferrissia* is remarkably absent from such otherwise productive Stations as 183 on the lower Little River N and 167 on Reed Creek. So in conclusion, hardness seems to play only a minor role in the distribution of *F. rivularis* in the upper New River. Higher hardness may in fact be detrimental to the species.

Effect of Stream Size

Physa hendersoni, *Helisoma anceps*, and *Lymnaea obrussa* are not as strictly limited by stream size as the unionids or pleurocerids. In hard waters these species can live in very small creeks, e.g. Mill Creek at Station 169, Little Pine Run at Station 175, and Meadow Creek at Station 183. However, in soft water stream size seems to influence pulmonate macrodistribution to a greater degree. The calcium concentrations in the North and South Forks, Wilson and Fox Creeks, Little River (S) and the main river above the water gap were all identical (2.40 - 3.85 ppm, Table 1). *Physa*, *Helisoma*, and *Lymnaea* are common throughout the main river and in both forks, but are almost absent from the smaller Fox, Wilson, and Little Rivers. It appears that stream size can effect the critical hardness limiting these pulmonates.

Effect of Enrichment

The effects of organic enrichment on pulmonates have also received attention in literature. Hunter (1964) noted the important positive effects of enrichment on the mollusks, including pulmonate snails, and Lassen (1975) found more species of pulmonates in eutrophic than oligotrophic lakes. Ingram et al. (1958) reported that quantities of the "sewage plant snail", *Physa gyrina*, can clog trickling filters at waste treatment facilities. Ingram also cited records of *Physa cubensis*, a species closely related to *P. hendersoni* (Te, pers. comm.), and *Lymnaea humilis modicella*, a species related to *L. obrussa* (Baker, 1911), associated with sewage plants. The excellent compilation of macrobenthos inhabiting areas of sewage outfall made by Kolkwitz & Marsson (1909) includes many pulmonates. Basch (1963) noted that *Ferrissia rivularis* is tolerant of organic pollution.

High levels of enrichment were observed to effect pulmonate microdistribution at several stations. *Ferrissia rivularis* was more common in the South Fork at Station 155 just downstream from Boone than at any other station on the main tributary, despite the elimination of almost all other macrobenthos by sewage. *Lymnaea obrussa* was more common at the polluted Station 166 downstream from the city of Wytheville than at any other station in this survey. Often the best place to collect pulmonate snails was found to be a watering or fording area for cattle. The largest *Lymnaea columella* population by size and number was in a stagnant pool that cattle ford daily (Station 7), an interesting observation in light of the fact that this species is a known vector for cattle liver flukes like *Fasciola hepatica*. But I have found no evidence that enrichment effects pulmonate macrodistribution in this study.

SUMMARY AND CONCLUSIONS

The range of known fish hosts was not found to correlate with the range of the mussels that parisitize them. Therefore, these mussels seem to be limited by factors other than those that limit fish. Both water hardness and stream size were found to have profound effects on unionid distributions, though interspecific tolerances differ. *Elliptio dilatata* manifested the greatest tolerance for the small stream habitat, while the other four species were restricted to the main river. *Elliptio* could also survive in much softer water than *C. tuberculata* or *L. compressa*, which could in turn live in softer water than *L. ovata* or *T. verrucosa*. Displayed in the distribution of *Elliptio* was an interaction between these two limiting parameters, such that hard waters extended *E. dilatata*'s range up smaller creeks, and large rivers could support *Elliptio* even if the water was soft. Other mussels did not have range sufficiently extended in the upper New River to allow observation of any interaction effects.

Numerous authors have documented the "tolerance" of sphaeriids to organic enrichment, but in the upper New River concentrations of nitrogen and phophorus seem to be of primary importance in limiting *Sphaerium striatinum* macrodistribution. Hardness plays a large part in the distribution of *S. striatinum*, but it appears to be much more critical for *Pisidium compressum* and *P. casertanum*. Stream size is probably unimportant as a limiting factor for all sphaeriids studied.

The pleurocerids of the upper New River are distributed primarily according to stream size, *Goniobasis* in the creeks and *Mudalia* in the rivers. Hardness is very important in limiting *G. simplex*, but is only of minor importance to G. proxima and M. dilatata. I find no evidence that any of these species is limited by enrichment, and in fact M. dilatata is drastically inhibited by municipal sewage effluents. The shell morphology of all three species seems influenced by environmental variables, to a degree that species determination by shell character may be difficult.

The most important limiting parameter for some pulmonates studied is hardness. Physa hendersoni, Lymnaea obrussa, and Helisoma anceps all need fairly high concentrations of calcium to survive, such that they are restricted from several sub-basins of the New River by the lack of it. But stream size is important in determining the exact tolerance to softness, more calcium being needed in smaller streams. No absolute minimum size stream was noted for Physa, Helisoma, or Lymnaea, however. Hardness does not seem to be an important limiting factor for Ferrissia rivularis, and its range is probably determined by stream size entirely. Calcium may, in fact, be toxic to Ferrissia in high concentrations. Several microdistributional effects of enrichment were noted, but this was not seen as an important factor in the macrodistribution patterns of the upper New River pulmonates.

The most important conclusion to be made is that any one environmental parameter can have a broad spectrum of effects on a freshwater molluscan fauna. The great differences in the distributions of various freshwater species, so commonly observed by collectors, indicates that each species often radically differs in tolerances and requirements of at least four important factors. Any generalization regarding the factors effecting freshwater mollusk macrodistributions must therefore be made with care.

Table 1. Blue Ridge Project water quality data means, 1970-1974 (60 samples). Compiled from Benfield and Cairns (1974), Benfield (unpub.) and Wright (1976).

Parameter	Station Number				
	1	2	3	4	6
alkalinity (ppm)	15.96	18.85	7.38	16.41	18.48
pH	6.81	6.82	5.43	6.76	6.78
hardness (ppm)	12.99	14.95	20.95	14.06	14.85
specific conductivity (micromhos)	39.03	41.44	116.44	45.54	45.86
total solids (ppm)	69.45	75.75	120.92	72.55	79.18
calcium (ppm)	3.35	3.85	5.22	3.63	3.79
magnesium (ppm)	1.18	1.30	1.73	1.21	1.31
sodium (ppm)	2.41	2.07	12.45	2.96	3.01
potassium (ppm)	.97	1.01	1.08	1.23	1.22
manganese (ppm)	.006	.005	.106	.005	.005
iron (ppm)	.13	.11	.06	.13	.19
sulfate (ppm)	1.59	1.65	8.69	2.29	2.30
chloride (ppm)	2.69	1.50	16.21	2.84	2.77
nitrate (ppm N)	.262	.331	2.044	.347	.317
total phosphate (ppm P)	.096*	.081*	.144*	.092*	.106*

* Sampled only three years, total 36 samples.

Table 1, continued.

Parameter	Station Number					
	7	8	9	10**	11**	12**
alkalinity (ppm)	18.50	35.58	38.52	16.65	16.51	11.51
pH	6.85	7.06	7.14	6.72	6.72	6.54
hardness (ppm)	14.75	31.51	42.75	13.30	12.45	9.11
specific conductivity (micromhos)	47.77	78.33	103.61	40.27	38.68	26.01
calcium (ppm)	3.77	7.19	10.18	3.79	3.39	2.40
magnesium (ppm)	1.30	3.27	4.21	.93	.97	.76
sodium (ppm)	2.97	2.81	2.97	3.25	3.47	2.19
potassium (ppm)	1.21	1.27	1.49	.89	1.02	.93
manganese (ppm)	.006	.008	.007	.007	.007	.007
iron (ppm)	.15	.16	.11	.07	.07	.13
sulfate (ppm)	2.55	3.55	6.16	2.33	2.41	1.96
chloride (ppm)	2.89	3.13	3.27	1.86	1.64	2.03
nitrate (ppm N)	.340	.351	.331	.240	.250	.205
total phosphate (ppm P)	.090*	.070*	.091*	.028	.035	.053
total solids (ppm)	79.78	83.50	91.66	47.90	46.51	46.03

*Sampled only three years, total 36 samples.
**Sampled for 1 year, total 12 samples (Stations 10, 11, and 12.)

Table 2. Hardness of selected tributaries[1]

Category	Tributary	Station	Hardness (ppm)	Calcium (ppm)
Hard	Little River (North)	109	92.12	15.43
"	"	183	198.93	40.00
Soft	"	110	10.47	1.84
Hard	Pine Run	175	153.63	43.20
"	Reed Creek	166	158.25	34.41
"	"	167	158.19	39.40
"	"	168	120.19	28.01
"	"	169	175.50	43.02
"	Cripple Creek	105	130.24	26.50
Soft	Reed Island Creek	123	13.83	2.39
"	"	125	12.66	2.08
"	"	134	17.18	2.96
"	"	130	4.86	1.01
"	Little River (South)	12*	9.11	2.40
"	Fox Creek	11*	12.45	3.39
"	Wilson Creek	10*	13.30	3.79
"	North Fork	2*	14.95	3.85
"	South Fork	1*	12.99	3.35
"	"	155	15.17	3.30

[1]Based on single measurements taken August 22, 1976, excepting those values taken from Table 1, marked with an asterisk.

Table 3. Distribution and abundance of the Unionidae

Species	Relative Abundance	Station
Tritogonia verrucosa (Raf.)	uncommon	9, 106.
	moderately common	102.
	very common	8, 103.
Cyclonaias tuberculata (Raf.)	uncommon	7, 8, 9.
	moderately common	102, 103.
Elliptio dilatata Raf.	uncommon	1, 4, 8, 105, 109, 179, 183.
	moderately common	7, 106, 114, 144, 152, 166, 167.
	very common	102.
Alasmidonta marginata Say	uncommon	7, 166, 167.
Lasmigona subviridis (Con.)	uncommon	8, 9, 103, 106, 114.
Lampsilis ovata (Say)	moderately common	102, 106.
	very common	8, 9, 103.

uncommon - dead shells present, usually in moderate abundance. If living specimens were collected, it was with great diligence.
moderately common - several live specimens found with some difficulty.
very common - live specimens present in large numbers and many collected.

Table 4. Areas drained major tributaries of the upper New River (Kanawha R. Basin Coord. Comm. 1971).

Tributary	Area ($mi.^2$)
Big Reed Island Creek	356.0
Little River (North)	349.1
South Fork New River	328.0
North Fork New River	282.0
Reed Creek	259.0
Cripple Creek	166.0
Little River (South)	139.5
Peak Creek	100.0
Elk Creek	96.5
Chestnut Creek	61.7
Fox Creek	61.1
Wilson Creek	35.8

Table 5. Distribution and abundance of the Sphaeriidae

Species	Relative Abundance	Station
Sphaerium striatinum (Lam.)	uncommon	2, 12, 105, 169, 175, 186.
	moderately common	168.
	very common	1, 4, 7, 8, 9, 102, 103, 114, 144, 166, 167, 183.
Pisidium casertanum (Poli)	uncommon	9, 169.
	moderately common	7, 8, 102, 166.
Pisidium compressum Prime	uncommon	166, 169, 183.
	moderately common	7, 8, 9.
Pisidium dubium (Say)	uncommon	1, 4, 7, 114, 167, 175.

uncommon - Only dead shells and occasional single individuals found.
moderately common - Live specimens found with some difficulty.
very common - Many live specimens readily collected.

Table 6. Known sources of municipal and industrial waste effluents in the upper New River (Kanawha R. Basin Coord. Comm. 1971).

Sub-drainage	Tributary	Source (population, 1970)
South Fork New R.	Middle Fork	Blowing Rock, NC (801)
"	Boone Ck.	Boone, NC (8,754)
"	direct	"
"	Naked Ck.	Jefferson, NC (943)
North Fork New R.	direct	Sprague Electric
"	Buffalo Ck.	Smethport, NC (60)
"	"	West Jefferson, NC (889)
Little River (S)	Bledsoe Ck.	Sparta, NC (1,304)
main river	Peach Bottom Ck.	Independence, VA (673)
"	direct	Fries, VA (885)
Chestnut Creek	direct	Galax, VA (6,278)
Reed Island Ck.	Beaverdam Ck.	Hillsville, VA (1,149)
"	Greasy Ck.	Willis, VA (70)
Reed Creek	direct	Wytheville, VA (6,069)
"	S. Fork Reed Ck.	Rural Retreat, VA (872)
"	Miller Ck.	Max Meadows, VA (400)
Peak Creek	direct	Pulaski, VA (10,279)
Little River (N)	Dodd Ck.	Floyd, VA (474)
main river	direct	Radford, VA (11,100)

Table 7. Distribution and abundance of the prosobranch gastropods.

Species	Relative Abundance	Station
Mudalia dilatata (Con.)	uncommon	165.
	moderately common	118, 128, 174.
	very common	1, 2, 4, 7, 8, 9, 10, 11, 12, 102, 103, 105, 109, 114, 120, 123, 125, 127, 133, 141, 144, 152, 157-159, 163, 164, 167, 168, 174, 179, 180, 185-187.
Goniobasis proxima (Say)	uncommon	2, 4, 118, 127, 128, 132, 133, 150, 151, 158.
	moderately common	1, 10, 116, 117, 119, 126, 136, 146, 149, 157, 178.
	very common	113, 131, 134, 135, 137, 141, 143, 148, 154, 156, 162-164, 170, 177, 182.
Goniobasis simplex (Say)	uncommon	171, 172.
	very common	107, 169, 175, 183.

uncommon - One to several live specimens found with some difficulty.
moderately common - More than 5 specimens collected, estimated density of one individual per square meter of suitable habitat or less.
very common - Many specimens collected, estimated density greater than one individual per square meter suitable habitat.

Species	Relative Abundance	Station
Campeloma crassulum Raf.	uncommon	11, 144, 179.
	moderately common	1, 4, 7, 9, 114.

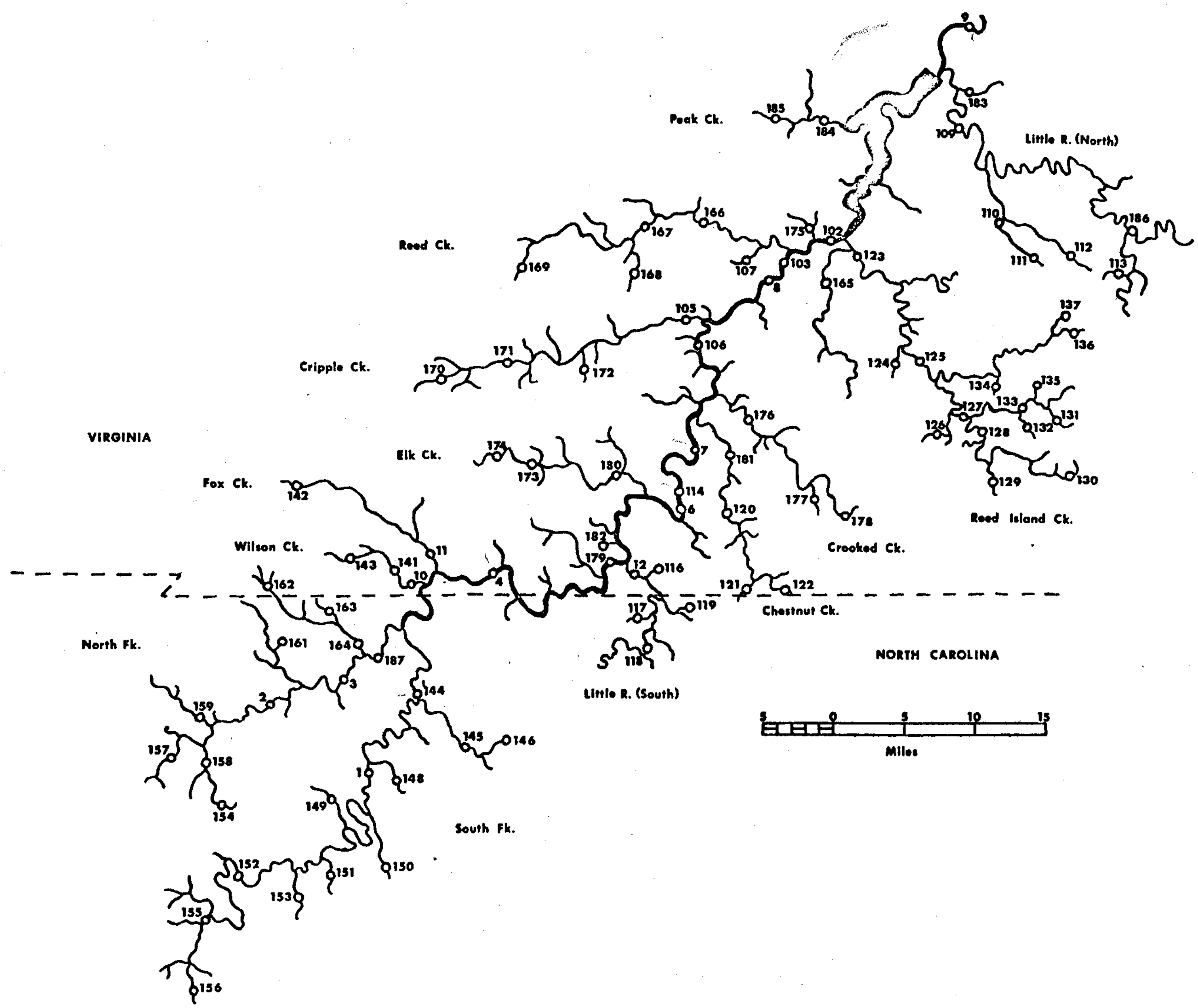
uncommon - Dead shells, or only one living specimen collected.
moderately common - Several specimens collected with some difficulty.

Table 8. Distribution and abundance of pulmonate gastropods.

Species	Relative Abundance	Station
Physa hendersoni Clench	uncommon	1, 164.
	moderately common	2, 102, 103, 114, 152, 175, 179.
	very common	4, 7, 8, 105, 106, 166-169, 171, 187.
Physa pomilia (Con.)	very common	9, 109, 183.
Lymnaea obrussa (Say)	uncommon	2, 102, 103, 105, 152, 168, 169, 171.
	moderately common	4, 9, 109, 187.
	very common	8, 166, 183.
Lymnaea columella Say	uncommon	4, 109, 114, 160, 166.
	moderately common	7.
Helisoma anceps Menke	uncommon	1, 2, 10, 11.
	moderately common	4, 9, 166, 167, 183.
	very common	105, 169, 187.
Ferrissia rivularis (Say)	uncommon	2, 4, 123, 145, 148, 152, 158, 159, 172, 179, 186.
	moderately common	7, 8, 102, 109, 112, 114, 120, 126-128, 133, 136, 142, 143, 146, 166, 171, 174, 175, 180, 187.
	very common	9, 10, 11, 12, 105, 106, 110, 132, 137, 141, 149, 155, 157, 162-165, 177, 178, 182.

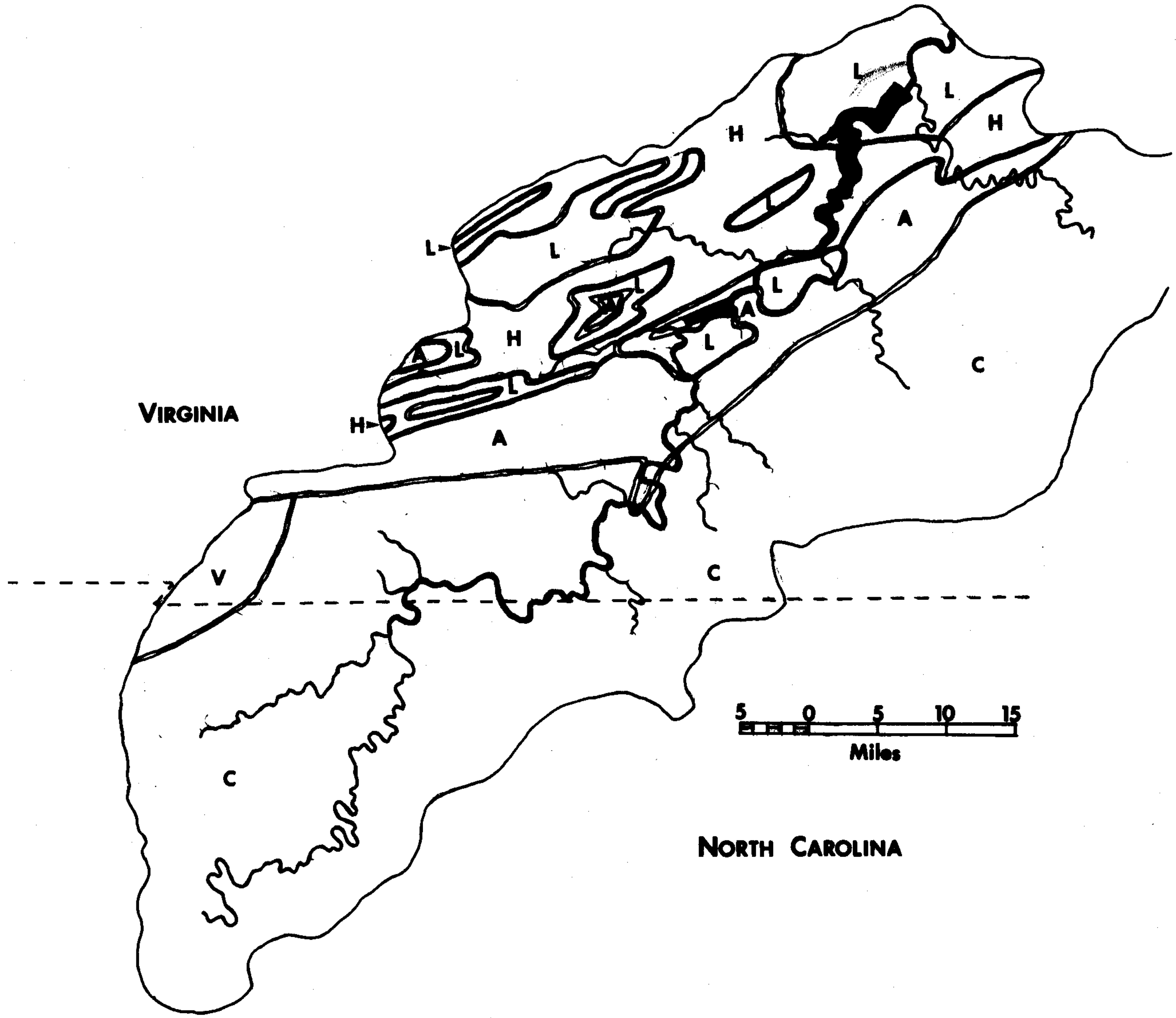
uncommon - One to several living specimens found with diligence.
moderately common - Estimated density not more than five specimens per square meter of suitable habitat.
very common - Estimated density greater than five specimens per square meter of suitable habitat.

Map 1. Generalized surface geology of the upper New River Basin, adapted from Kanawha R. Basin Coord. Comm. (1971). A - Sandstone, shale, and quartzite. C - Crystalline rock (gneiss, schist). H - Shale and sandstone. L - Limestone and dolomite. V - Volcanic rock (rhyolite, arkose, tuff).



Peak Ck.
Little R. (North)
Reed Ck.
Cripple Ck.
VIRGINIA
Elk Ck.
Fox Ck.
Wilson Ck.
Crooked Ck.
Reed Island Ck.
Chestnut Ck.
North Fk.
NORTH CAROLINA
Little R. (South)
South Fk.
Miles
5 0 5 10 15

Map 2. Collection Stations, and major tributaries of the upper New River.



VIRGINIA
NORTH CAROLINA
L
H
A
C
V
5 0 5 10 15
Miles

Figure 1. The relationship between stream size and average shell size in _Mudalia dilatata_. From left, Station 163 on Little Helton Creek (North Fork drainage), Station 164 on Helton Creek, Station 187 on the North Fork, and Station 179 on the main river. (X3).

Figure 2. Comparison of typical spire height in *Mudalia dilatata* from streams of differing hardness. Left, Station 167 from hard Reed Creek. Right, Station 120 from soft Chestnut Creek. (X5.3).

Figure 3. Variability in the shell morphology of *Goniobasis*. Far left, typical *G. proxima* from soft Spurlock Creek at Station 113. Far right, typical *G. simplex* from hard Meadow Creek at Station 183. Central, two atypical *Goniobasis simplex* representative of populations from moderately hard water. Left center, Station 169 at Mill Creek and right center, station 171 at Cripple Creek. (X4).

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APPENDIX

Collection station locality data. Note that "Quad" is an apprevi-ation for United States Geological Survey topographic map, 7.5 minute series.

1 - South Fork New River at NC 16 bridge, near Index, Ashe Co. Jefferson Quad.

2 - North Fork New River off NC 88 at Lou Jones Road bridge (Co. 1343), 1.6 mi. W of Warrensville, Ashe Co., NC Warrensville Quad.

3 - North Fork New River above Co.1642 bridge, .08 miles below Sprague Electric Co. near Lansing, Ashe Co., NC. Warrensville Quad. (No mollusk collections at this site.)

4 - New River at Va. 601 low water bridge, 1.2 mi. N of Cox Chapel, Grayson Co. Sparta West Quad.

6 - New River, 1.0 mi. downstream from U. S. 58 bridge near Galax, VA. Grayson Co., Galax Quad. (No mollusk collections at this site.)

7 - New River at low water bridge near Fries, Carroll Co., VA. Galax Quad.

8 - New River, .5 mi. upstream from U. S. 52 bridge near Austinville, Wythe Co., VA. Max Meadows Quad.

9 - New River at Va. 114 bridge, 2 miles downstream from Radford, Montgomery Co., VA. Radford North Quad.

10 - Wilson Creek at Va. 767 bridge, .5 mi. NE of Mouth of Wilson, Grayson Co. Mouth of Wilson Quad.

11 - Fox Creek at U. S. 58 bridge, .1 mi. upstream from mouth in Grayson Co., VA. Mouth of Wilson Quad.

12 - Little River at Va. 629 low water bridge, 2.5 mi. SW of Baywood, Grayson Co. Sparta East Quad.

102 - New River .08 mi. downstream from Allisonia guaging station near Allisonia, Pulaski Co., VA. Hiwassee Quad.

103 - New River at end of Va 619, 4.5 mi. downstream from Fosters Falls, Wythe Co. Fosters Falls Quad.

105 - Cripple Creek at Va 94 bridge, 2 mi. N of Ivanhoe, Wythe Co. Austinville Quad.

106 - New River at the mouth of Powder Mill Branch at Ivanhoe, Wythe Co., VA. Austinville Quad.

107 - Cedar Run at Va. 619 and Va. 626, near Major Grahams, Wythe Co. Foster Falls Quad.

109 - Little River at Va. 613 bridge below Graysontown, Montgomery Co. Radford South Quad.

110 - Little Indian Creek, .2 mi. upstream from mouth, .5 mi. S of Copper Valley Church, Floyd Co., VA. Indian Valley Quad.

111 - Little Indian Creek at jct. of Va. 753 and Va. 812, 1.5 mi. NW of Indian Valley, Floyd Co. Indian Valley Quad.

112 - Big Indian Creek along Va. 766, .2 mi. upstream from Duncan, Floyd Co. Alum Ridge Quad.

113 - Spurlock Creek at Va. 740 bridge, 1.7 mi. NE of Greasy Creek Church, Floyd Co. Alum Ridge Quad.

114 - New River, .9 mi. downstream from Va. 641, 1.8 mi. SW of Fries, Grayson Co. Galax Quad.

117 - Moccasin Creek at County 1411 bridge, .5 mi. S of Pleasant Home Church, Alleghany Co., NC Sparta East Quad.

118 - Little River at Hooker Road (Co. 1433) bridge, 1 mi. upstream from confluence with Brush Creek, 1.3 mi. E. of Edwards Crossroads, Alleghany Co., NC. Sparta East Quad.

119 - Crab Creek at NC 18 bridge, .5 mi. N of Ennice, Alleghany Co. Cumberland Knob Quad.

120 - Chestnut Creek at jct. of Va. 97 and Va. 608, 1 mi. S of Galax, Grayson Co. Galax Quad.

121 - West Fork of Chestnut Creek, first time Blue Ridge Parkway crosses heading North, 1.1 mi. S of Fairview School, Grayson Co., VA. Cumberland Knob Quad.

122 - Chestnut Creek at confluence of E and W Forks, 1 mi. E of Fairview School, Grayson Co., VA. Cumberland Knob Quad.

123 - Big Reed Island Creek, at Va. 607 low water bridge, .5 mi. above mouth, Pulaski Co. Hiwassee Quad.

124 - small creek at Va. 750 bridge, .7 mi. NW of Allison Chapel, Carroll Co. Hillsville Quad.

125 - Big Reed Island Creek at U. S. 221 bridge, 5 mi. NE of Hillsville, Carroll Co., VA. Hillsville Quad.

126 - Cherry Creek, by Va. 664, .3 mi. from mouth, 6 mi. E of Hillsville, Carroll Co. Hillsville Quad.

127 - Big Reed Island Creek at Va. 664 bridge, 2.3 mi. SW of Meadowview Church, Carroll Co. Dugspur Quad.

128 - Big Reed Island Creek at U. S. 58 bridge. 1.5 mi. E of Crooked Oak, Carroll Co., VA. Laurel Fork Quad.

129 - Sulfur Spring Branch at Va. 648 bridge, 2.5 mi. E of Gladesboro, Carroll Co. Laurel Fork Quad.

130 - Pine Creek at Va. 631 bridge, .3 mi. N of Bell Spur, Carroll Co. Laurel Fork Quad.

131 - "Intermittant" branch of Tory Creek at U. S. 58 bridge, .2 mi. S of Tory Creek Church, Floyd Co., VA. Meadows of Dan Quad.

132 - Roads Creek, 200 ft. upstream from mouth, 1.9 mi N of town of Laurel Fork, Carroll Co., VA. Laurel Fork Quad.

133 - Laurel Fork at Va. 638 bridge, 1.9 mi. N of town of Laurel Fork, Carroll Co. Laurel Fork Quad.

134 - Branch of Burks Fork at Va. 638 bridge, 300 ft. from intersection with Va. 628, 1 mi. N of Pine View Church, Carroll Co. Dugspur Quad.

135 - Chisholm Creek at Va. 629 bridge, .5 mi. SE of Buffalo Mt. Church, Floyd Co. Dugspur Quad.

136 - Burks Fork at Va. 799 bridge, .5 mi. NW of Burks Fork Church, Floyd Co. Willis Quad.

137 - Branch of Burks Fork, .4 mi. upstream from Union Church at Va. 799 bridge, Floyd Co. Willis Quad.

141 - Wilson Creek at Va. 16 bridge, .6 mi. W of Mouth of Wilson, Grayson Co. Mouth of Wilson Quad.

142 - Fox Creek at Va. 16 bridge, 1 mi. S. of Trout Dale, Grayson Co. Trout Dale Quad.

143 - Wilson Creek by Va. 16, .5 mi. upstream from Volney, Grayson Co. Trout Dale Quad.

144 - South Fork New River by Chestnut Hill Rd. (Co. 1567), .5 mi. upstream from U. S. 221 bridge, Ashe Co., NC. Laurel Springs Quad.

145 - Cranberry Creek at NC 88 bridge, 1.4 mi. W of Laurel Springs School, Ashe Co. Laurel Springs Quad.

146 - Piney Fork at Jones Tilley Road (Co. 1177) bridge, 2.4 mi. NE of Laurel Springs, Alleghany Co., NC. Whitehead Quad.

148 - Roan Creek at NC 88 bridge, .2 mi. W of Wagoner, Ashe Co. Jefferson Quad.

149 - Beaver Creek by NC 163, at Othello, Ashe Co. Glendale Springs Quad.

150 - Obids Creek by NC 163, at Obids, Ashe Co. Glendale Springs Quad.

151 - Pine Swamp Creek, .6 mi. upstream from mouth, 1.5 mi. N of Idlewild, Ashe Co., NC. Glendale Springs Quad.

152 - South Fork New River at Co. Rd. 1351 bridge near Grassy Island, 1.4 mi. upstream from Brownwood, Watauga Co., NC. Todd Quad.

153 - Cranberry Creek at Co. Rd. 1100 bridge, 1.2 mi. E of Brownwood, Ashe Co., NC. Todd Quad.

154 - Three Top Creek by Co. R. 1100, .7 mi. S of Toliver, Ashe Co., NC. Todd Quad.

155 - South Fork New River, .2 mi. upstream from U. S. 221 bridge, 1.8 mi. E of Boone, Watauga Co., NC. Boone Quad.

156 - Middle Fork by U. S. 221, .1 mi. S of Tweetsie Railroad, Watauga Co, NC. Boone Quad.

157 - North Fork New River, at Co. 1119 bridge off NC 88, 1.2 mi. E of Green Valley, Ashe Co. Baldwin Gap Quad.

158 - North Fork New River at Three Top Creek near Creston, Ashe Co., NC. Warrensville Quad.

159 - Big Laurel Creek, at Co. 1310 bridge .2 mi. downstream from mouth of Little Laurel Creek, .1 mi N of Oliver Cemetary, Ashe Co., NC. Baldwin Gap Quad.

161 - Old Field Branch, just downstream from fork near Bethel Church, 1.8 mi. N of Lansing, Ashe Co., NC. Park Quad.

162 - Helton Creek at Co. 1370 bridge off U. S. 58, .3 mi. E of Mt. Rogers School, Grayson Co., VA. Park Quad.

163 - Little Helton Creek at E. C. Frances Road (Co. 1379) bridge, .9 mi. S of state line, Ashe Co., NC. Grassy Creek Quad.

164 - Helton Creek at NC 16 bridge, 2.6 mi. NW of Crumpler, Ashe Co. Grassy Creek Quad.

165 - Little Reed Island Creek at Va. 100 bridge, near High Rocks Mill, Wythe Co. Fosters Falls Quad.

166 - Reed Creek at U. S. 11 bridge, 1.9 mi. E of Ft. Chiswell, Wythe Co., VA. Max Meadows Quad.

167 - Reed Creek at Va. 667 bridge, .8 mi. S of Petunia, Wythe Co. Crockett Quad.

168 - South Fork at Va. 667 bridge, .3 mi. E of Groseclose, Wythe Co. Crockett Quad.

169 - Mill Creek, just downstream from confluence with Huddle Branch, by Va. 680, 2.9 mi. N of Rural Retreat, Wythe Co. Rural Retreat Quad.

170 - Cripple Creek at Va. 749 bridge, .5 mi. S of Cedar Springs, Wythe Co. Cedar Springs Quad.

171 - Cripple Creek at Va. 749 bridge, 1.3 mi. W of Speedwell, Wythe Co. Speedwell Quad.

172 - Francis Mill Creek by Va. 602, just upstream from town of Cripple Creek, Wythe Co. Cripple Creek Quad.

173 - Elk Creek at U. S. 21 bridge, 1 mi. SE of town of Elk Creek, Grayson Co., VA. Elk Creek Quad.

174 - Elk Creek at Va. 663 bridge, 1 mi. E of Bennington Mill, Grayson Co. Elk Creek Quad.

175 - Little Pine Run at Va. 100 bridge, by Pine Run Church, Pulaski Co. Fosters Falls Quad

176 - Crooked Creek at Va. 635 bridge, 1.9 mi. SE of Byllesby, Carroll Co. Austinville Quad.

177 - Crooked Creek at Va. 630 bridge, 2 mi. E of Pipers Gap, Carroll Co. Woodlawn Quad.

178 - East Fork at Va. 775 bridge, 1.3 mi. S of New Hope Church, Carroll Co. Woodlawn Quad.

179 - New River, .2 mi. upstream from Va. 624 ford, 1.4 mi. downstream from mouth of Little River, Grayson Co. Sparta East Quad.

180 - Elk Creek at Va. 660 bridge, .8 mi. N of Carsonville, Grayson Co. Briarpatch Mountain Quad.

181 - Chestnut Creek at Va. 607 bridge, 3.2 mi. N of Galax, Carroll Co. Galax Quad.

182 - Johns Creek at Va 624 bridge, .2 mi. upstream from mouth, 1.6 mi. NE of Pleasant Grove Church, Grayson Co. Sparta East Quad.

183 - Meadow Creek at Va. 787 bridge, 2 mi. N of Graysontown, Montgomery Co. Radford South Quad.

184 - Peak Creek at Va. 99 bridge, 1 mi. downstream from Pulaski, Pulaski Co. Dublin Quad.

185 - Peak Creek, .1 mi. upstream from confluence with Rocky Branch, 1.5 mi. W of Pulaski, Pulaski Co., VA. Pulaski Quad.

186 - Little River at Va. 705 bridge, 4 mi. N of Floyd, Floyd Co. Floyd Quad.

187 - North Fork New River at Co. 1573 bridge near Crumpler, Ashe Co., NC. Grassy Creek Quad.