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EFFECTS OF ENVIRONMENTAL AND SPATIAL FEATURES ON MUSSEL POPULATIONS AND COMMUNITIES IN A NORTH AMERICAN RIVER

Barry P. Baldigo[1], Karen Riva-Murray[1] and George E. Schuler[2]

ABSTRACT

Decreases in mussel-species richness and their distributions in rivers worldwide may indicate these long-lived organisms are adversely affected by recent changes in suitability of habitat and (or) quality of surface waters. Unionid mussel communities and local physical-habitat and water-quality conditions were determined across the Neversink River in southeastern New York State to evaluate factors that affect the distribution and abundance of common and rare mussel species and the richness of mussel communities. Results from correlation and partial regression analyses indicate: (1) macrohabitat features such as percent open canopy, mean channel width, mean bank width, several water-quality factors (*e.g.*, conductivity and pH), and reach physiography (*e.g.*, elevation and drainage area) affected mussel-community richness and the distribution of *Alasmidonta heterodon* (Lea 1829) populations; and (2) the abandoned, low-head Cuddebackville Dam may have restricted *A. heterodon* populations to the lower reaches of the system. Potential positive affects of the main stem reservoir and negative effects of the abandoned dam on mussel populations indicate that the response of intended targets need to be well understood for effective management of impoundments, downstream flows, and biological resources in rivers of the world.

Keywords: Habitat, *Alasmidonta heterodon, A. varicosa, A. undulata, Anodonta implicata, Elliptio complanata, Pyganodon cataracta, Strophitus undulatus*, mussel, community, richness, reservoir, impoundment, dam, Neversink.

INTRODUCTION

Freshwater mussels (Unionidae) are some of the most imperiled fauna in North America – from 43 to 72% of the native species have been classified as extinct, endangered, threatened, or vulnerable (Bogan, 1993; Master, 1990; Williams & Neves, 1995). Decreases in mussel-species richness and their distributions worldwide indicate that these long-lived organisms have been adversely affected by alterations in habitat suitability, water quality, and the spread of non-indigenous species (Williams *et al.*, 1993). Although impoundments and associated changes in water quality, local fish populations, and temperature, flow, and sediment regimes contribute to these declines (Brim-Box & Mossa 1999; Vaughn & Taylor, 1999; Williams & Neves, 1995), specific factors and

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processes that affect abundance of mussel populations and the distribution of mussel species are poorly understood (Strayer, 1983; Strayer & Ralley, 1993). A number of studies have shown or proposed that certain microhabitat conditions can restrict mussel species to isolated patches in rivers. For example, Strayer & Ralley (1993) and others (Layzer & Madison, 1995; Strayer, 1993; Strayer & Ralley, 1991) determined that shear stress, water velocity, substrate particle sizes, and sediment stability might affect the presence or absence of certain species and richness of mussel species in riverine systems. The effects that large-scale, macrohabitat factors have on mussel-species populations, however, are poorly defined. In this report, "microhabitat" refers to environmental factors that potentially affect mussel species at the location of an individual specimen and are generally on a scale of one meter or less, and "macrohabitat" refers to physical and chemical factors that potentially affect species populations at the reach scale of 10's to 100's of meters. Macrohabitat also includes physiographic factors measured at the landscape or watershed scale, such as elevation, discharge, and drainage area, which may function as surrogates for overall habitat condition at the reach level. Macrohabitat features appear to determine suitability of a river reach for certain species; whereas, correlated or unrelated microhabitat factors limit where stable mussel beds (patches) may become established and sustained within suitable reaches. Many mussel species are also long-lived and propagate using various host-specific fish species (Strayer & Jirka, 1997). Patterns and variation in mussel-species distributions, abundance of species populations, and mussel communities, therefore, may be determined by a multitude of biotic, historical, and landscape-level constraints as well as local physical and chemical (environmental) conditions (Vaughn & Taylor, 2000).

Spatial autocorrelation and multi-correlation among predictor variables are issues particularly difficult to overcome when attempting to define relations in any observational study. Many environmental features and the distribution and abundance of aquatic species generally display strong spatial structure in a river system which can obscure, or more likely inflate, relations between ecological patterns and constraining/predictor variables. In addition, many predictor variables in rivers typically reflect various degrees of multi-correlation, and could be interdependent. Thus, the response gradient for selected aquatic community or population indices or measures might be misinterpreted simply due to the spatial structure of processes operating at different scales across sampled locations. Fortunately, the effects of different components on dependent variables can be partly isolated and separated into variation explained by pure spatial and environmental components and variation shared between and among components using partial regression analyses (Legendre & Legendre, 1998). It must be stressed that associations defined herein do not reflect cause and effect relations, but provide a foundation for further exploration of the factors that affect the health and distribution of mussel-species populations.

The Neversink River in southeastern New York State (Fig. 1) and extant mussel-species populations are unique in a number of respects and provide a good opportunity to assess factors that may affect the health and distribution of resident mussel species and communities. The basin supports two main stem dams, one large active reservoir for municipal supplies in the upper/ middle basin and one low-head abandoned structure in the lower basin (Fig. 1). Concentrations of dissolved minerals and salts in the basin are low and may approach lower limits for proper shell accretion in certain species (Strayer & Jirka, 1997). The system also possesses the richest diversity of freshwater mussels in the upper Delaware River Basin (Strayer & Ralley, 1991). One of the seven mussel species that occur in the Neversink is federally endangered, and another is on the draft New York State threatened-species list (The Nature Conservatory [TNC], 1949). Populations of the endangered dwarf wedgemussel (*Alasmidonta heterodon* Lea 1829) are restricted to a 18-km section in the lower third of the basin, whereas the threatened swollen wedgemussels (*Alasmidonta varicosa* Lamarck 1819) occupy the lower half of the basin (Strayer & Ralley, 1991; Strayer *et al.,* 1996). Dwarf wedgemussels have been collected only downstream from the abandoned, low-head Cuddebackville Dam (Fig. 1) (Strayer & Ralley, 1991; TNC, 1999). This population is one of the largest in the Northeast, but its limited distribution suggests it may be susceptible to local extinctions due to catastrophic floods, localized fuel or chemical spills, or epidemic diseases. Protecting and promoting *A. heterodon* populations in the Neversink Basin is problematic because: (1) they occur in beds that are patchily distributed which make distributions difficult to quantify, (2) the abandoned Cuddebackville Dam may restrict upstream movement of their host fish and, thus, the distribution of *A. heterodon* populations, and (3) the relationship of environmental factors to the distribution and abundance of their populations are poorly understood (Strayer, 1993; Strayer & Ralley, 1993; Strayer *et al.,* 1996; TNC, 1995).

The main objective of this paper is to identify the factors that potentially govern the distribution of mussel-species populations in the Neversink River Basin. This is achieved by assessing the importance of chemical and physical features on mussel-community richness and abundance and on the relative abundance of species populations in the basin. Related objectives are to: (1) characterize the range of endangered and threatened species in the basin, (2) evaluate the potential effects of the Cuddebackville Dam on rare-species populations, and (3) rank the influence of specific physical and chemical factors on mussel communities and the distribution of species populations across the basin.

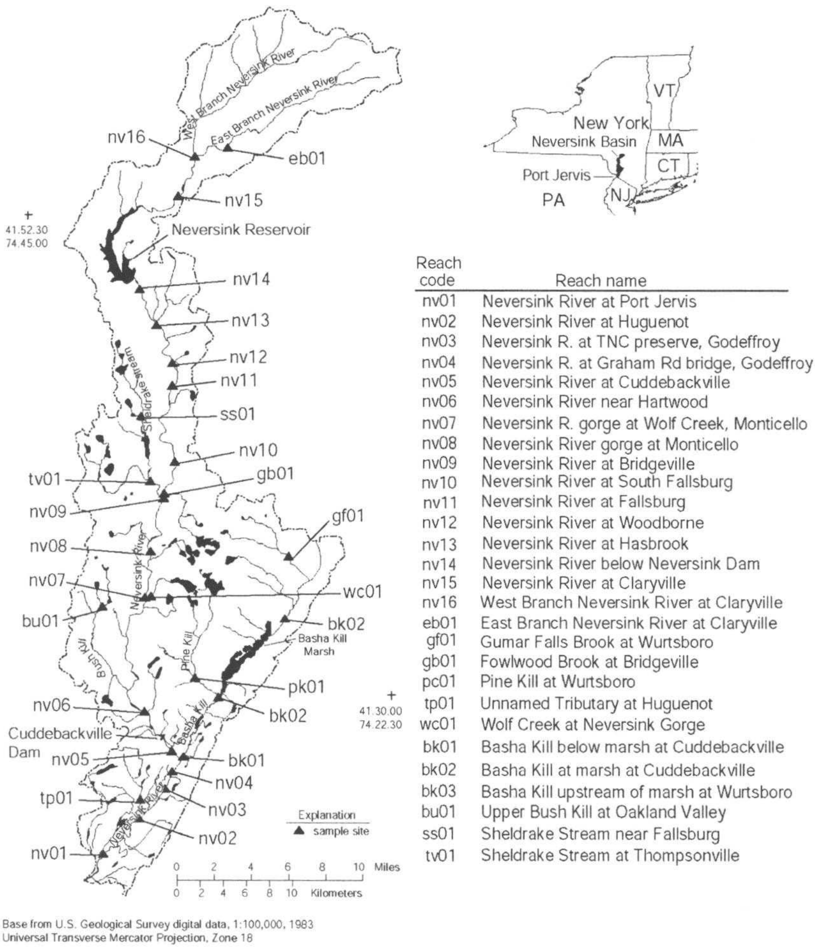
FIELD-SITE DESCRIPTION

The Neversink River drains about 1126 km^2 of land and forms headwaters for the Delaware River Basin. The river flows through four distinct physiographic regions. The 238-km^2 upper Neversink sub-basin is mountainous and terminates at the Neversink Reservoir and Dam. The 606 km^2 middle Neversink sub-basin, located between the reservoir and the confluence with the Basha Kill, starts as a broad floodplain but passes through a narrow gorge for most of its length. The 93-km^2 lower Neversink sub-basin is a broad river with an ancient, relatively narrow floodplain. The 189 km^2 Basha Kill sub-basin is the largest tributary to the lower Neversink and consists of a 12-km^2 stillwater marsh and several small tributaries. Its watershed is relatively undeveloped with only one city, Monticello, totally within the drainage basin.

The Neversink Reservoir and the Cuddebackville Dam potentially affect water quality, hydrology, habitat, and biological communities in the main-stem of the Neversink River. The reservoir is in the upper basin, covers 6.1 km^2 in surface area, and impounds 132,500,000 m^2 of water. During the 1997 water year, the reservoir released an average of 1.1 cubic meters of water per second (cms) into the Neversink (average daily flows varied from 0.7 to 2.0 cms depending on season) at a USGS gage immediately downstream of the dam, with an additional 6.2 cms diverted continuously to the New York City water-supply system (Butch *et al.,* 1998; Krejmas *et al.,* 1998). The annual mean discharge at the gage fell from 7.5 cms to just over 1.4 cms, the average length of low pulses increased from 6 to 44 days, and the average length of high pulses dropped from 5.3 to 2.7 after impoundment (TNC, 1999). The low-head Cuddebackville Dam is located on the main-stem Neversink River, about 2.5 km upstream from its confluence with the Basha Kill. It was first constructed in the early 1800s, rebuilt several times, and abandoned in the middle 1900s. The dam is currently in disrepair, has a 2-m high waterfall, confines a relatively small amount of sediment and standing water, and blocks upstream movement of several resident and anadromous fish species.

METHODS

Methods for mussel, water-quality, and habitat sampling and analysis and for statistical analyses are summarized below. Overall, 28 reaches on the main-stem and tributaries of the Neversink River were selected for study. Not all reaches were inventoried for mussels or for physical-habitat features because of resource limitations. Reach locations, names, and identifier codes are shown in Fig. 1.



Reach code	Reach name
nv01	Neversink River at Port Jervis
nv02	Neversink River at Huguenot
nv03	Neversink R. at TNC preserve, Godeffroy
nv04	Neversink R. at Graham Rd bridge, Godeffroy
nv05	Neversink River at Cuddebackville
nv06	Neversink River near Hartwood
nv07	Neversink R. gorge at Wolf Creek, Monticello
nv08	Neversink River gorge at Monticello
nv09	Neversink River at Bridgeville
nv10	Neversink River at South Fallsburg
nv11	Neversink River at Fallsburg
nv12	Neversink River at Woodborne
nv13	Neversink River at Hasbrook
nv14	Neversink River below Neversink Dam
nv15	Neversink River at Claryville
nv16	West Branch Neversink River at Claryville
eb01	East Branch Neversink River at Claryville
gf01	Gumar Falls Brook at Wurtsboro
gb01	Fowlwood Brook at Bridgeville
pc01	Pine Kill at Wurtsboro
tp01	Unnamed Tributary at Huguenot
wc01	Wolf Creek at Neversink Gorge
bk01	Basha Kill below marsh at Cuddebackville
bk02	Basha Kill at marsh at Cuddebackville
bk03	Basha Kill upstream of marsh at Wurtsboro
bu01	Upper Bush Kill at Oakland Valley
ss01	Sheldrake Stream near Fallsburg
tv01	Sheldrake Stream at Thompsonville

FIG. 1. Location and names for 28 reaches studied in the Neversink River Basin in southeastern New York State, 1997-2001.

Mussel-species surveys

Mussel searches were conducted during June 1997 at 25 reaches from which previous mussel data were not available. Mussel data for three reaches were obtained from semi-quantitative surveys done between 1994 and 1997 (written communication, D.L. Strayer, Feb., 1998). At each reach, two people searched for mussels along a 100- to 400-meter long reach for a total of 1 h using a combination of snorkeling and (or) wading with a view tube. Searches were extended to 2 hr if mussels were found during the first hour. Once a mussel bed was located, it was searched intensively, and all individuals found were identified, counted, and returned to the same area. A recent investigation of sampling efficiencies for timed mussel searches (Metcalfe-Smith *et al.*,

2000) showed that more rare species could be found if search times were at least 4.5 person hours per reach. Though longer searches were not feasible for the present study, a 2-hr search period produces catch rates that have been correlated with species density and proven to be reliable estimates of species richness (Strayer *et al.,* 1997). Relative abundance or density for: (1) the total number of mussels, and (2) number of each species for each reach were estimated as a catch rate (the number observed divided by the number of person hours searched). Most abundance data were rescaled to the number observed per 10-hours for statistical analyses to eliminate negative values when fractional data were $\log_{10}$-transformed.

Water quality

Water samples were collected from all 26 reaches, once in September 2000 and again in April 2001. Reaches nv08 and nv09 were sampled once in August 1997, but not during the later period due to access limitations. Monthly samples were collected between March 2000 and April 2001 at nv01, nv04, bk01, nv05, and nv12. Stream-water temperatures were measured when samples were collected. Samples were collected from a well-mixed section of the channel, placed on ice, and transported to the U.S. Geological Survey (USGS) laboratory in Troy, NY. Aliquots were filtered, preserved, shipped to the USGS National Water Quality Laboratory in Denver, CO, and analyzed for pH, conductivity, acid-neutralizing capacity (ANC), major cations and anions, and nutrients in accordance with standard USGS methods (Fishman & Friedman, 1989; Wolman, 1954). Dissolved organic carbon (DOC) concentrations were measured at the USGS Laboratory in Troy, NY, following standard methods (Lawrence *et al.,* 1995).

Habitat

Habitat and hydraulic characteristics were characterized at 20 reaches during June-July 1997, when discharge was at or near base flow. Habitat was not surveyed at reaches eb01, gf01, gb01, pc01, bk03, wc01, nv14, and tp01. Selected channel-morphology, substrate-particle size, bank stability, riparian vegetation, and hydraulic characters included those that describe physical stream habitat at reach and pool/riffle scales (Frissell *et al.,* 1986) and have been hypothesized to affect the abundance of mussels or community richness (Layzer & Madison, 1995; Michaelson & Neves, 1995; Strayer *et al.,* 1996; Strayer, 1993; Strayer & Ralley, 1993). Habitat-survey reaches bounded local mussel beds or search areas and were typically 20 mean-stream widths (MSW) in length (Meador *et al.,* 1993; Simonson *et al.,* 1993; Simonson *et al.,* 1994), but no longer than a predetermined 300-m maximum. The length of each geomorphic channel unit (pool, riffle, run) was measured according the methods summarized in Meador *et al.* (1993). In-stream channel features and bank conditions were measured or visually estimated at 5-7 transects spaced 1-2 MSW apart, depending on stream width. Transect spacing was one MSWs in streams greater than 10 m wide and two MSWs in streams less than 10 m wide.

Measurements of channel depth and substrate types, water velocity, and estimates of percent algal and macrophyte cover, were made at five or seven equally spaced points across each transect and at the thalweg. Measurements were generally made at five points in channels less than 20 m wide, and at seven points in channels greater than 20 m wide. Water depth was measured to the nearest cm, velocity was measured at six-tenths depth with a mechanical or electromagnetic water-velocity meter, and depth of fine sediments was measured according to methods described in Simonson *et al.,* (1994). Substrate sizes for the reach were quantified by modified Wolman-count methods (Wolman, 1954), in which five particles were randomly selected near each transect point, and the intermediate particle lengths recorded. Embeddedness was estimated to the nearest 5% (Platts *et al.,* 1983) for three gravel or larger-sized particles at each point.

Bank and riparian characteristics, unless otherwise noted, were measured or visually estimated at both ends of each transect according to methods described in Meador *et al.* (1993). Angle of open canopy was estimated with a climometer at the midpoint of each transect. Bankfull width and height, and total wetted width were measured for each transect according to methods of Simonson *et al.* (1994). Indicators of recurring high flows, such as debris dams, erosion lines, and vegetated extent, were used to estimate top or landward edge of the bank (generally bankfull). The streamward edge of the bank was defined as the edge of water. Bank shape was characterized as linear, concave, or convex. The percent of vegetated bank cover and type (trees, shrubs, grasses, or bare), angle of inclination, substrate types, and degree of erosion were estimated at both ends of each transect. Various land-use classes, and the percentage of each on both banks, were visually estimated from edge of water to 50 m away from the bank. Discharge at each reach was calculated as the average of flows at all transect; transect flows were determined from point velocities, depths, and widths of transect segments using modified USGS methods (Rantz, 1983). Elevation, stream-channel gradient, and watershed drainage area for each reach were determined from 1:24,000 scale USGS maps.

Statistical analyses

The effects of physical, chemical, and spatial factors and the Cuddebackville Dam on mussel-species assemblages were evaluated at 20 reaches where habitat was surveyed, using correlation and simple linear and partial multiple regression techniques (Legendre & Legendre, 1998). Mean, minimum, maximum, or total (cumulative) physical-habitat variables, elevation, and drainage area (treated as physical characters), and median estimates of each chemical parameter were used as predictor variables. Most physical-habitat and chemical data were $\log_{10}$ transformed to improve normality of their distributions. The number of mussel species, total abundance, and species abundance data were increased by 1 before being $\log_{10}$ transformed to avoid invalid data and omission from subsequent analyses. For all analyses, the numbers of physical and chemical variables were initially reduced using Principal Components Analyses (PCA) to isolate variables strongly correlated with major physical-habitat or chemical gradients. Important principal-component axes were used in regression analyses as pseudo-variables when they accounted for large amounts of variation in dependent mussel variables. Multi-correlated variables were identified and the total number of variables further reduced using both PCA and correlation analyses. The distance of each reach from the confluence of the Neversink and Delaware was used to define each reach's location and the spatial structure in this system because spatial orientation was nearly linear for the 20 main stem reaches. A binary-dummy variable described the spatial orientation of each reach either upstream (1) or downstream (0) from the Cuddebackville Dam and was used to assess its affect on dependent-mussel variables.

Partial regression analyses used mussel-species richness, total abundance of all mussels, and abundance of each mussel species as dependent variables, and partitioned variation into that explained by chemical, physical, or spatial components. For analysis of each dependent variable (*e.g.*, mussel richness), we first determined the variation explained by physical-habitat, chemical, and spatial components (sets of variables) alone, through a forward-selection process (Legendre & Legendre, 1998). Variables were retained that significantly ($p \leq 0.10$) explained the largest amount of variation remaining in dependent variables after earlier selections. The sets of physical, chemical, and spatial variables that were significantly related to each dependent variable alone were then used in various combinations (chemical and physical; chemical and spatial; physical and spatial; and chemical, physical, and spatial), regardless of statistical significance of slope coefficients, to determine the total variation explained/unexplained and the proportion of shared variation (overlap) between and among the three components. The proportion of variation in dependent variables explained by pure physical-habitat (P), pure chemical (C), and pure spatial (S) components; shared among physical and spatial (P+S), physical and chemical (P+C), chemical and

TABLE 1. Selected physical, chemical, and spatial characteristics for 20 study reaches in the Neversink River Basin, NY. [Physical data are from surveys conducted June-July 1997; chemical data are from 2 to 14 samples collected March 2000-April 2001; site names and locations are given in Fig. 1.]

Study reach name	Watershed area (km^2)	Elevation (m)	Mean annual flow (cms)	Mean channel slope (%)	Open canopy (%)	Mean channel width (m)	Mean channel depth (m)	Sand substrate (%)	Cobble substrate (%)	Mean particle size (mm)	Mean embeddedness (%)
bk01	178	159	6.00	0.10	24.2	15.7	44.7	32.7	28.7	45.3	43.5
bk02	156	155	5.23	0.10	15.1	7.7	16.8	8.4	55.5	79.0	31.9
bu01	14	464	0.46	0.30	20.7	6.9	28.0	45.0	27.8	45.7	56.8
nv01	844	109	12.93	0.09	44.4	42.9	79.6	88.6	0	3.6	na
nv02	826	143	12.59	0.11	34.4	45.3	52.7	16.0	31.4	48.4	41.7
nv03	798	146	12.08	0.36	35.8	42.3	73.2	17.1	62.3	86.5	29.2
nv04	794	151	11.99	0.39	46.3	54.3	46.0	11.5	71.5	130.2	31.4
nv05	614	149	8.60	0.33	43.1	34.1	36.1	10.3	61.1	142.9	41.3
nv06	591	187	8.18	0.70	53.8	39.2	26.4	2.4	54.1	194.4	19.1
nv07	480	298	6.08	0.74	44.4	29.1	52.8	11.2	15.9	2684.5	19.0
nv08	460	323	5.70	0.25	47.7	32.6	33.8	17.0	32.1	224.7	38.1
nv09	435	335	5.24	0.15	52.4	32.8	31.9	28.0	37.1	67.1	46.0
nv10	326	337	3.19	0.17	61.3	32.9	27.2	15.4	52.5	87.1	39.9
nv11	303	347	2.76	0.25	40.6	21.0	46.4	13.2	48.4	64.5	27.7
nv12	293	351	2.58	0.26	58.2	33.9	34.6	33.5	33.5	68.7	50.4
nv13	273	360	2.20	0.40	47.2	25.0	60.9	33.3	43.0	615	50.2
nv15	173	465	5.80	0.64	67.5	25.9	30.8	18.0	61.9	98.8	20.3
nv16	88	493	2.94	0.82	39.8	15.7	30.6	3.3	60.0	157.1	8.7
ss01	24	373	0.79	0.69	15.4	5.6	18.1	24.4	35.3	50.2	43.3
tv01	39	358	1.30	0.91	21.7	11.3	25.7	17.4	44.5	714.9	45.3

(continued on next page)

TABLE 1 (continued)

Study reach name	Watershed area (km^2)	Elevation (m)	Mean annual flow (cms)	Mean channel slope (%)	Open canopy (%)	Mean channel width (m)	Mean channel depth (m)	Sand substrate (%)	Cobble substrate (%)	Mean particle size (mm)	Mean embeddedness (%)
bk01	32.2	9.89	6.95	23.0	3.90	0.004	0.259	0.089	0.004	0.013	15.9
bk02	28.0	8.35	7.00	20.0	2.35	0.002	0.194	0.022	0.003	0.054	16.6
bu01	13.4	4.05	6.95	6.5	1.75	0.013	0.244	0.018	0.002	0.013	33.5
nv01	26.2	8.00	7.05	17.0	3.25	0.010	0.507	0.317	0.017	0.028	3.3
nv02	24.0	7.40	7.15	16.5	2.85	0.002	0.400	0.256	0.011	0.026	9.0
nv03	23.8	7.42	6.90	16.0	2.70	0.004	0.433	0.277	0.013	0.026	12.5
nv04	23.8	7.24	6.95	15.0	3.05	0.009	0.626	0.381	0.020	0.043	14.2
nv05	20.5	6.17	7.05	12.0	2.85	0.01	0.576	0.391	0.03	0.052	16.5
nv06	17.0	5.13	7.15	10.5	2.35	0.004	0.542	0.353	0.027	0.044	21.2
nv07	17.5	5.24	7.05	9.5	2.25	0.005	0.660	0.500	0.038	0.056	34.1
nv08	na	4.14	7.00	5.7	1.97	na	na	na	na	na	38.6
nv09	na	5.49	7.32	10.5	1.78	na	na	na	na	na	44.5
nv10	13.2	3.86	6.85	6.5	2.30	0.011	0.598	0.436	0.039	0.022	48.1
nv11	11.4	3.30	6.90	6.0	2.15	0.007	0.428	0.271	0.003	0.008	56.6
nv12	13.0	3.77	6.9	6.5	2.55	0.010	0.437	0.316	0.004	0.008	59.0
nv13	10.8	3.09	7.05	5.5	2.25	0.074	0.467	0.293	0.002	0.006	63.5
nv15	7.9	2.20	7.10	3.5	2.20	0.003	0.319	0.237	0.002	0.004	81.7
nv16	8.6	2.56	- 4.0	1.80	0.037	0.464	0.394	0.004	0.003	85.9	
ss01	28.1	8.63	7.15	18.5	2.00	0.010	1.196	0.831	0.053	0.084	53.5
tv01	33.3	10.28	6.95	17.0	2.20	0.010	1.126	0.737	0.028	0.056	46.9

[1] acid neutralizing capacity
[2] nitrogen
[3] phosphorus

spatial (C+S) components; shared among all three (P+C+S) components; and the total amounts of explained and unexplained variation were partitioned following addition and subtraction techniques described by Legendre & Legendre (1998), modified for three components. The variation attributed to spatial factors was further partitioned into that which could be explained by pure location (river kilometers), pure dam (binary), and variation shared by location and the dam using two-component partitioning techniques. The only deviation from the methods of Legendre & Legendre (1998) was the use of adjusted, rather than unadjusted regression coefficients, to more conservatively estimate amounts of variation in dependent variables explained when using multiple predictor variables.

Interpretations below may be contentious because our analyses were limited to a relatively small number of sites and interactions between predictor variables potentially confound true associations. Inferred relations, however, provide a basis for further exploration of the factors that affect the health and distribution of mussel-species populations.

RESULTS

Reach characteristics

Stream-reach elevation, drainage area, slope, and other selected characteristics at the 20 sites where habitat was assessed are provided in Table 1. With several exceptions, the sites reflected typical differences between low-order, high-elevation reaches with a small drainage area, steep slope, high water velocities, and cool temperatures, and high-order, low-elevation reaches with a large drainage area, low slope, low water velocities, and high temperatures. Several tributary reaches of low to middle order, such as bu01, bk01, and bk02 (Fig. 1) originated in marshes and were atypical stream reaches. Reaches nv13 and nv14, immediately below the Neversink Reservoir, and the lowest main-stem reach nv01 (Fig. 1), also exhibited many unique physical conditions related to their unusual flow, sediment, or thermal regimes. Three reaches (nv16, nv15, and eb01) in the upper basin, and reaches nv10, nv11, nv12, and nv14, below the Neversink Reservoir, showed some degree of acidification. High water temperatures (near 25°C) and low dissolved oxygen concentrations (4.5 mg/L) were observed at reaches nv01 and bk02. Low oxygen concentrations, stream slope, and water velocities and a deep layer of fine sediments indicate that nv01 was not a typical riverine reach.

Distribution of mussel species

Mussel-species richness, total number collected per hour, and the percent of each mussel species collected during one- to two-hour searches at 28 reaches are summarized in Fig. 2. Three to six mussel species were usually observed at reaches nv02 through nv10 located in the lower and middle reaches of the basin. *Elliptio complanata* (Lightfoot 1786) was observed at 16 of 28 reaches and were the most widely distributed mussel species. Except for *Pyganodon* *cataracta* (Say 1817), *Alasmidonta heterodon* and *Anodonta implicata* (Say 1829) were the most narrowly distributed species; they only were observed at reaches nv02 through nv05, downstream from the Cuddebackville Dam. One *P. cataracta* specimen was collected at reach ss01, immediately upstream of an abandoned beaver pond. *Alasmidonta varicosa*, *Strophitus undulatus* (Say 1817) and *Alasmidonta undulata* (Say 1817) were observed at 7-9 main-stem reaches in the low to middle reaches of the basin; *A. undulata* was also observed at two tributary reaches: tv01 and bk01 (Fig. 2).

Dense mussel beds of the main-stem Neversink River, were usually located outside the gorge and associated with several well-defined hydrologic and geomorphic settings. Mussel beds were often observed in shallow to moderately deep pools; however, they were most common in low to moderate-velocity glides at the downstream end (tail-out) of long pools which were controlled and stabilized by main-channel islands or bars. Beds of low-to-high mussel density were also found in moderate-velocity riffles and runs immediately downstream from these pool controls, but seldom where high-velocity rapids were evident. All mussel beds, regardless of geomorphic channel type, were generally denser along the channel margins than in the channel center. Small lateral pools located below gravel bars at the downstream end of short or long riffles and rapids sometimes contained high mussel densities. Substrate at reaches with dense mussel beds typically had low percent sand, fines, and embeddedness and high percent gravel and cobble. Large cobble and boulders were seldom evident in shallow runs and riffles where mussels were common. Individual mussels and sparse beds, however, were occasionally observed in moderately deep pools, riffles, or rapids where large cobble and (or) boulders created a matrix with fines, sand, and gravel-sized substrate and moderate-sized backwaters.

Mussel richness

Richness of mussel communities decreased significantly with increasing elevation and distance from confluence (location) and increased with channel size and concentration of nutrients, cations and anions, and ANC (Table 2). Regression results (Table 3) indicate that physical, chemical, and spatial variables together explained as much as 84.5% of the variation in mussel-species richness. Individually, four physical variables, elevation, maximum depth, maximum depth of fines, and pool-riffle ratio, significantly explained 76.2 % of the variation. Three chemical variables, total phosphorus, ammonia, and pH, significantly explained 69.5% of the variation in richness. Two spatial variables, distance (location) and dam (orientation of each reach upstream or downstream of the Cuddebackville Dam) significantly explained 60.2% of the

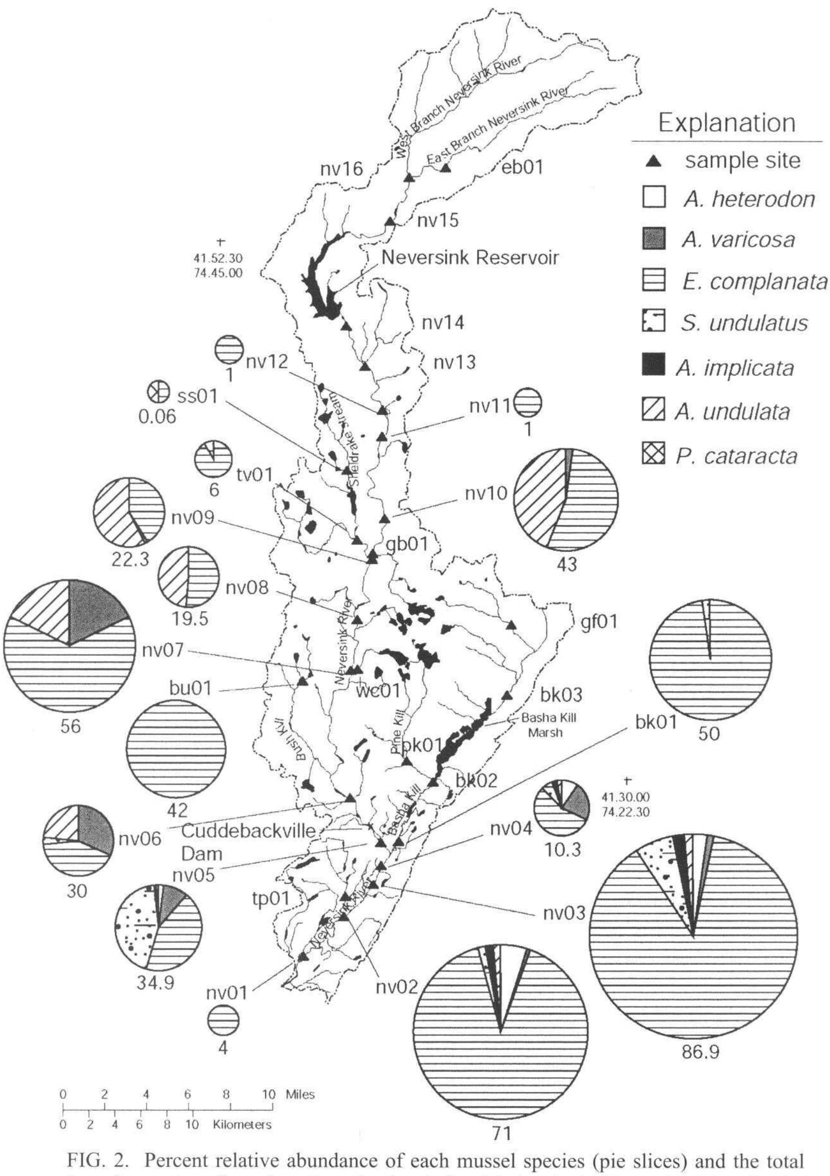


FIG. 2. Percent relative abundance of each mussel species (pie slices) and the total number of mussels collected per hour (under pies) at 28 sites in the Neversink River Basin, June - August, 1997; no mussels were observed at sites without pies.

variation. The variation explained by each of the three components add up to more than 100% due to shared variation (overlap) among variables that are spatially or multi-correlated.

Partial analyses indicate that pure physical habitat explained 11.1% of the variation, whereas, pure chemistry and space explained negative or small percentages of variation in mussel richness (Table 3). Pure environment (physical and chemical factors combined) explained 24.3 % of the variation. A large amount of the variation explained alone by either physical, chemical, or spatial components was actually overlap; *i.e.,* shared between (6.6 to 12.3%) and among 46.2% of the three components (Table 3, Fig. 3A). These findings show that there was spatial dependency among mussel, physical, and chemical variables. Though species richness was significantly related to both the location and the orientation of each reach upstream or downstream of the Cuddebackville Dam, pure location explained 29.6%, pure dam explained –3.6%, and 34.2% of the variation in species richness was shared between both factors (Table 4).

Mussel abundance

The total number of mussels at each site, like richness, decreased at reaches further upstream, but was significantly correlated only with distance from confluence and ammonia concentrations (Table 2). Physical, chemical, and spatial variables together explained 50.8% of the variation in abundance of mussels (Table 3) at all but three reaches upstream from the Neversink Reservoir. The third physical-habitat principal component axis, (PPCA3) significantly explained 42.7% of the variation in abundance of mussel communities and represented a gradient in substrate type as well as stream order and elevation; percent gravel was negatively correlated, and maximum substrate size, elevation, and slope were positively correlated with PPCA3. Alone, three chemical variables, ammonia, potassium, and dissolved phosphorus, significantly explained 59.1% of the variation in total abundance. Alone, the spatial variables, dam and location, significantly explained 30.4% of the variation in mussel abundance (Table 4).

Partial analyses indicated that pure chemistry explained 8.5% of the variation, whereas, pure physical habitat and pure space only explained negative amounts of variation in total mussel abundance (Fig. 3B). Pure environment (physical and chemical factors combined) explained 20.4% of the total variation. The moderate amounts of explained variation shared between physical, chemical, and spatial variables (2.9 to 16.3%) and among all variables (27.9%) (Fig. 3B) indicate that there was spatial dependency. Considering spatial factors, location significantly explained 30.4% and the dam explained 17.4% of the variation in

TABLE 2. Significant Pearson coefficients of correlation ($p \leq 0.10$) between richness of mussel communities, total abundance of all mussels, and relative abundance of each mussel species with physical, chemical, and spatial characters at 20 reaches in the Neversink River Basin, 1997-2001.

		Abundance						
Predictor variable	Mussel-species richness	All mussels	*Elliptio complanata*	*Strophitus undulatus*	*Alasmidonta undulata*	*Alasmidonta varicosa*	*Pyganodon heterodon*	*Anodonta implicata*
Open canopy	-	-	-	-	0.59	-	-0.76	-0.78
Mean channel width	0.54	-	-	-	-	-	0.62	0.56
Max. channel width	0.51	-	-	-	-	-	0.67	0.69
Embeddedness	-	-	-	-	-	-0.58	-	-
Percent boulder					0.56	0.59		
Percent cobble	-	-	-	0.64	-	-	-	-
Percent sand	-	-	-	-	-	-0.71	-	-
Mean substrate size	-	-	-	-	0.59	0.66	-	-
Depth of fines	-	-	-	-	-	-0.53	-	-
Percent algae	-0.45	-	-	-0.56	-	-	-	-
Vegetation index	-	-	-	-	-	0.71	-	-
Watershed area	0.51	-	-	-	-	-	0.67	0.65
Elevation	-0.70	-	-	-0.46	-	-	-0.60	-0.58
Mean annual flow	0.50	-	-	-	-	-	0.66	0.64
Channel slope	-	-	-	-	-	-0.76	-	-
Max. channel depth	-	-	-	-	-0.81	-	-	0.56
Depth-width ratio	-0.42	-	-	-	-	-	-	-
Bank stability index	-	-	-	0.49	0.45[6]	0.53[6]	-	-
Mean bank height	-	-	-	-0.51	-	-	-	-
Conductivity	0.69	-	-	-	-	-	-	-
Hardness	0.71	-	-	-	-	-	0.59	0.57
Calcium	0.71	-	-	-	-	-	0.65	0.64
Potassium	0.57	-	-	-	-	-	-	-
Sodium	0.72	-	-	-	-	-	-	-

(continued on next page)

TABLE 2 (continued)

Predictor variable	Abundance							
	Mussel-species richness	All mussels	*Elliptio complanata*	*Strophitus undulatus*	*Alasmidonta undulata*	*Alasmidonta varicosa*	*Pyganodon heterodon*	*Anodonta implicata*
ANC[1]	0.66	-	-	-	-	-	0.64	0.63
Chloride	0.70	-	-	-	-	-	-	-
Silica	0.46	-	-	-	-0.65	-	0.57	-
Sulfate	0.70	-	-	-	-	-	-	-
Ammonia	-	-0.69	-0.63	-	-	-	-	-
Total dissolved N[2]	-	-	-	-	-	0.63	-0.61	-0.68
Nitrate	-	-	-	-	0.57	0.66	-0.65	-0.69
Nitrite	0.52	-	-	-	0.88	-	-	-
Dissolved organic N	0.57	-	-	-	-	-	-	-
Total N	-	-	-	-	0.42	0.65	-0.64	-0.69
Ortho P[3]	0.71	-	-	-	0.67	0.72	-0.72	-0.74
Dissolved P	0.78	-	-	-	0.69	0.72	-0.65	-0.65
Total P	0.81	-	-	-	-	0.80	-	-
DOC[4]	0.42	-	-	-	-	-	-	-
Alim[5]	0.47	-	-	-	-	-	-	-
Dam	0.55	-	0.42	0.52	-0.63	-	0.79	0.76
Location	-0.80	-0.55	-0.68	-	-	-	-0.61	-0.60

[1] acid neutralizing capacity
[2] nitrogen
[3] phosphorus
[4] dissolved organic carbon
[5] Inorganic monomeric aluminum
[6] negatively correlated with erodability

mussel abundance (Table 4). Location predicted abundance better than both variables combined, pure location explained 4%, and about a quarter of the variation was shared between dam and location.

Elliptio complanata

Elliptio complanata was the most widely distributed and dominant mussel species at most reaches in the Neversink River Basin (Fig. 2). They comprised 74% of all mussels observed in the basin. Thus, it is unremarkable that the variables correlated to total abundance of all mussels were also correlated to abundance of *E. complanata* populations (Table 2). Abundance of *E. complanata* was significantly correlated with chemical-principal components axis 1 (CPCA1), physical-principal components axes 3 (PPCA3), the dam, and reach location. Physical, chemical, and spatial variables together could explain about 90% of the variation in the abundance of *E. complanata* populations (Table 3) at all except for three reaches above the Neversink Reservoir. Physical-PCA2 and PPCA3 significantly explained 60.0% of the variation in abundance of *E. complanata* populations. Physical-PCA3 represented a gradient in substrate as well as stream order/elevation as noted above for all mussels. Physical-PCA2 represented a gradient in channel size/depth; mean depth and width were positively correlated, and the bank stability index was negatively correlated, with PPCA2. Chemical-PCA1, potassium, dissolved phosphorus, and ammonia significantly explained 88.9% of the variation in *E. complanata* abundance. Conductivity, hardness, and concentration of cations and anions (Ca, Na, Cl, and SO_4) were positively correlated with CPCA1. The spatial variables, dam and location, significantly explained 49.1% of the variation (Table 4).

Partial analyses indicate that pure chemistry explained 24.7% of the variation in *Elliptio complanata* populations and that physical-habitat and space only explained negative amounts of variation (Table 3, Fig. 3C). Pure environment (physical and chemical factors combined) explained 34.6% of the total variation. The large amount of explained variation shared between physical, chemical, and spatial variables (4.8-17.4%) and among all variables (42.0%) (Fig. 3C) indicate that there was spatial dependency. Considering only spatial factors, pure location explained 31.7%, pure dam explained 2.6%, and overlap explained 14.8% of the variation in *E. complanata* abundance (Table 4).

Strophitus undulatus

Strophitus undulatus populations were most abundant just downstream from the Cuddebackville Dam and were the only species, other than *Elliptio*

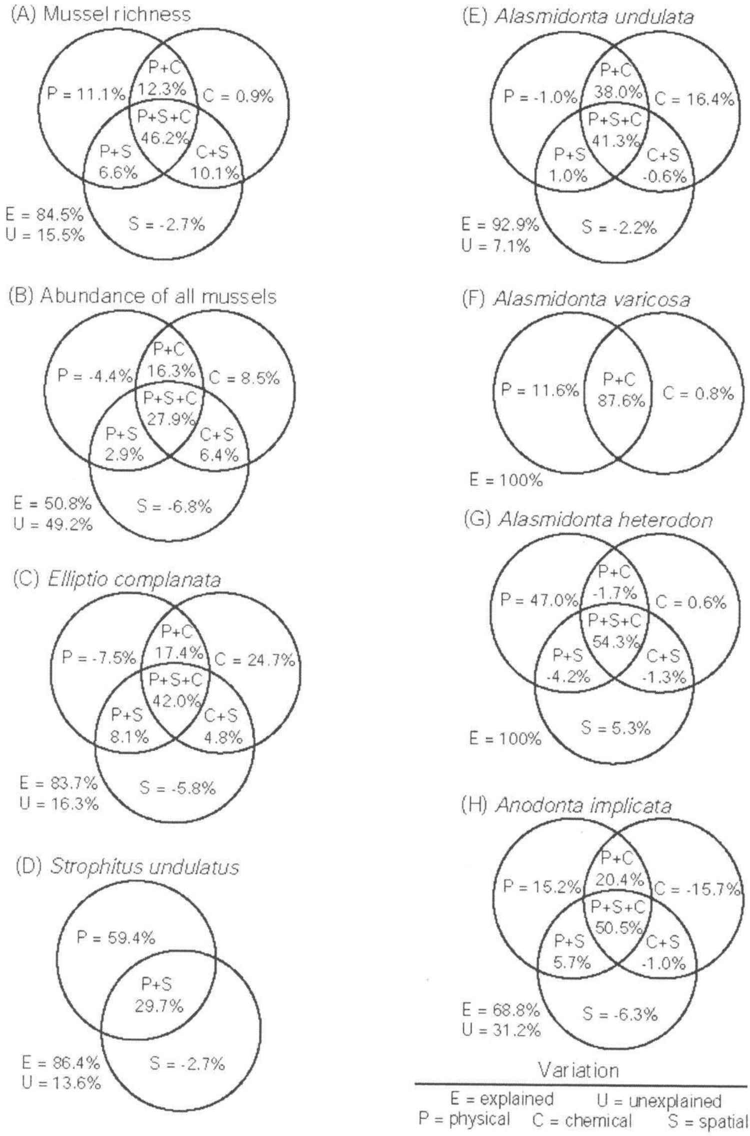


FIG. 3. Total amount of explained-E and unexplained-U variation in the (A) richness of mussel communities, abundance of (B) all mussels, and relative abundance of (C) *E. complanata,* (D) *S. undulatus,* (E) *A. undulata,* (F) *A. varicosa,* (G) *A. heterodon,* and (H) *A. implicata.* The percent of explained variation is partitioned into physical-P, chemical-C, and spatial-S components and into variation shared (overlap) between and among the three components. [Negative values are due to component calculations based on difference and are interpreted as approximately zero.]

TABLE 3. The cumulative variation in mussel species richness, abundance of all mussels, and relative abundance of each mussel species explained by physical, chemical, and spatial components; total variation explained (and unexplained) by combined variables; and pure variation attributed to each component and shared between and among the components. [Negative values are due to component calculations based on difference and are interpreted as approximately zero.]

	Cumulative variation explained by variables for each component			Cumulative variation associated with combined components		Variation in dependent variables explained by partitions						
Dependent variable	Physical	Chemical	Spatial	Explained (E)	Unexplained (U)	Physical (P)	Chemical (C)	Spatial (S)	Shared (P/C)	Shared (P/S)	Shared (C/S)	Shared (P/C/S)
Species richness:	76.2	69.5	60.2	84.5	15.5	11.1	0.9	-2.7	12.3	6.6	10.1	46.2
Abundance												
of all mussels	42.7	59.1	30.4	50.8	49.2	-4.4	8.5	-6.8	16.3	2.9	6.4	27.9
of *E. complanata*	60.0	88.9	49.1	83.7	16.3	-7.5	24.7	-5.8	17.4	8.1	4.8	42.0
of *S. undulatus*	89.1	ns[1]	27.0	86.4	13.6	59.4	0.0	-2.7	0.0	29.7	0.0	0.0
of *A. undulata*	79.3	95.1	39.5	92.9	7.1	-1.0	16.4	-2.2	38.0	1.0	-0.6	41.3
of *A. varicosa*	99.2	88.4	ns	100.0	0.0	11.6	0.8	0.0	87.6	0.0	0.0	0.0
of *A. heterodon*	95.4	51.9	54.1	100.0	0.0	47.0	0.6	5.3	-1.7	-4.2	-1.3	54.3
of *A. implicata*	91.8	54.2	48.9	68.8	31.2	15.2	-15.7	-6.3	20.4	5.7	-1.0	50.5

[1] not significant

TABLE 4. The cumulative variation in mussel species richness, abundance of all mussels, and relative abundance of each mussel species explained by either location/distance or a binary-dummy variable for orientation upstream or downstream from the Cuddebackville Dam; total variation explained (and unexplained) by combined spatial variables; and pure variation attributed to each, and shared among, both spatial variables. [Bold values identify significant, $p < 0.01$, correlations. Negative values are due to component calculations based on difference and are interpreted as approximately zero.]

Dependent variable	Cumulative variation explained by each spatial variable		Total variation explained by combined spatial variables		Variation in dependent variables explained by variable partitions		
	Dam	Location	Explained (E)	Unexplained (U)	Dam (D)	Location (L)	Shared (D/L)
Mussel richness:							
Abundance	**30.6**	**63.8**	60.2	39.8	-3.6	29.6	34.2
of all mussels	**17.4**	**30.4**	21.4	78.6	-9.0	4.0	26.4
of *E. complanata*	**17.4**	**46.5**	49.1	50.9	2.6	31.7	14.8
of *S. undulatus*	**27.0**	17.8	27.6	72.4	9.8	0.6	17.2
of *A. undulata*	**39.5**	15.5	34.1	65.9	18.6	-5.4	20.9
of *A. varicosa*	0.5	7.7	-2.3	102.3	-10.0	-2.8	10.5
of *A. heterodon*	**62.1**	**37.7**	54.1	45.9	16.4	-8.0	45.7
of *A. implicata*	**58.3**	**35.7**	48.9	51.1	13.2	-9.4	45.1

complanata and *Pyganodon cataracta,* observed in Neversink River tributaries (Fig. 2). Abundance of *S. undulatus* was positively correlated with percent cobble and the bank stability index and negatively correlated with elevation, bank height, and percent algae (Table 2). Physical-habitat and spatial variables together explained 86.4% of the variation in abundance of *S. undulatus* populations observed at eight reaches across the Neversink River Basin (Table 3). Chemical variables could not significantly explain any variation. Four physical-habitat variables, percent cobble substrate, elevation, percent algae, and percent gravel substrate, significantly explained 89.1% of the variation in abundance of *S. undulatus* populations. The Cuddebackville Dam significantly explained 27.0% of variation (Table 3).

Partial regression analyses indicate that pure physical habitat explained 59.4% and pure space explained no variation in abundance of *Strophitus undulatus* populations; 29.7% of the explained variation was shared between the two components (Table 3, Fig. 3D). Only the Cuddebackville Dam was significantly related to *S. undulatus* abundance; pure dam explained 9.8%, pure location explained 0.6%, and overlap explained 17.2% of the variation in abundance of their populations (Table 4).

Alasmidonta undulata

The trend in abundance of *Alasmidonta undulata* populations in the Neversink River was the reverse of that observed for most other species. Abundance increased between lower- and middle-basin reaches and was very low downstream from the Cuddebackville Dam (Fig. 2). Densities were low at reaches downstream from the Cuddebackville Dam and generally increased at main stem reaches located further upstream until nv11, where no *A. undulata* were collected. Abundance was positively correlated with substrate size, bank stability, percent open canopy, and concentrations of most nutrients and negatively correlated with maximum channel depth and concentration of silica (Table 2). Physical, chemical, and spatial variables together explained 92.9% of the variation in abundance of *A. undulata* populations (Table 3). Maximum depth and bank stability significantly explained 79.3% of the variation in abundance of *A. undulata*. Dissolved P, sulfate, and ammonia significantly explained 95.1% of the variation in *A. undulata* populations. Like *Strophitus undulatus*, the dam was the only spatial factor that significantly explained variation (39.5%) in abundance of *A. undulata*.

Partial analyses indicate that pure chemistry explained 16.4% and pure physical habitat and space explained no variation in abundance of *Alasmidonta undulata* populations; 79.7% of the explained variation was shared among the three components (Fig. 3E). Pure environment (physical and chemical factors combined) explained 53.4% of the total variation. Considering only spatial variables, pure dam explained 18.6% and overlap between the dam and location explained 20.9% of the variation in *A. undulata* abundance (Table 4). The large amount of variation shared between physical and chemical variables (38.0%) and among the three components (41.3%) indicate that there was spatial dependency among variables and that the Cuddebackville Dam affected abundance of *A. undulata* populations.

Alasmidonta varicosa

Alasmidonta varicosa were widely distributed across the Neversink River Basin and most abundant in mid-basin reaches near the Cuddebackville Dam; population abundance decreased at reaches located further upstream or downstream from the dam (Fig. 1). Abundance was positively correlated with the vegetation index, percent boulder, mean substrate size, bank stability, and nutrient concentrations and it was negatively correlated with the channel slope, embeddedness, depth of fines, and percent sand (Table 2). Physical-habitat and chemical variables together explained 100% of the variation in abundance of *A. varicosa* populations (Table 3). Spatial variables could not significantly explain any variation. Three physical variables, PPCA1, the vegetation index, and percent open canopy explained 99.2% of the variation in *A. varicosa* populations. Physical-PCA1 represented a gradient in stream size and substrate type; percent sand, embeddedness, pool-riffle ratio, and the depth-width ratio were negatively correlated, and drainage area and water velocity were positively correlated with PPCA1. Elevation, stream slope, and maximum depth also were good predictors of *A. varicosa* abundance in multiple regressions. Two chemical variables, total phosphorus and silica, significantly explained 88.4% of variation in their populations (Table 3).

Results of partial regression analyses indicate that pure physical-habitat explained 11.6% of the variation, and pure chemistry explained 0.8% of variation in abundance of *Alasmidonta varicosa* populations; 87.6% of the explained variation was shared between the two components (Table 3, Fig. 3F). The Cuddebackville Dam and location were not significantly related to abundance of *A. varicosa* populations (Table 4).

Alasmidonta heterodon

Alasmidonta heterodon (and *Anodonta implicata*) populations were only observed in main stem reaches downstream from the Cuddebackville Dam.

Abundance of *A. heterodon* populations in the basin were significantly and positively correlated with channel size (mean annual flow, channel width, drainage area), and to concentrations of hardness, Ca, silica, ANC and negatively correlated with elevation, percent open canopy, and concentrations of all nutrients (Table 2). Physical-habitat, chemical, and spatial variables together could explain 100% of the variation in abundance of *A. heterodon* populations (Table 3). Regression results based on variations in abundance of *A. heterodon* populations (and *A. implicata* below) at four reaches and on their absences at several nearby reaches are presented chiefly for empirical purposes. Physical-habitat variables, PPCA3, PPCA7, and mean bank height explained 95.4% of the variation in abundance of *A. heterodon* populations (Table 3). PPCA3 represented a gradient in substrate as well as stream order/elevation (percent gravel, maximum substrate size, elevation, and slope were highly correlated with PPCA3) as noted above for total number of mussels. PPCA7 represented a gradient in bank conditions and substrate size; mean bank width and percent open canopy were positively correlated, and the maximum particle size was negatively correlated with PPCA7. One chemical variable, orthophosphorus (ortho P) significantly explained as much as 51.9% of the variation (Table 3). The location and the Cuddebackville Dam significantly explained 54.1% of variation in their populations.

Partial regression analyses indicate that pure physical-habitat explained 47.0%, pure chemistry explained 0.6%, and pure space explained 5.3% of the variation in *Alasmidonta heterodon* populations (Table 3, Fig. 3G). Pure environment (physical and chemical factors combined) explained 45.9% of the total variation. Roughly, 47.1% of the explained variation was shared among all three components. Though the Cuddebackville Dam and location were both significantly related to *A. heterodon* abundance (Table 4), pure dam explained 16.4%, pure location explained 8%, and overlap explained 45.7% of the variation in abundance of their populations. Findings suggest there was spatial dependency among variables and that the Cuddebackville Dam affected abundance of *A. heterodon* populations.

Anodonta implicata

The distribution of *Anodonta implicata* in the Neversink River was similar to that of *Alasmidonta heterodon* (Fig. 2), thus, it was not surprising that abundance was significantly correlated with most of the same variables (Table 2). Combined physical-habitat, chemical, and spatial variables, however, only explained 68.8% of the variation in abundance of their populations (Table 3). Three physical variables, PPCA3, percent cobble substrate, and bank stability, significantly explained 91.8% of the variation in abundance. Physial-PCA3 represented a gradient in substrate type as well as stream order and elevation as noted above for abundance of all mussels. Ortho P significantly explained 54.2% of the variation. The location and the Cuddebackville Dam significantly explained 48.9% of variation in their populations.

Partial analyses (Fig. 3H) indicate that about 75% of the explained variation in *Anodonta implicata* populations was shared among physical, chemical, and spatial components. Pure physical-habitat explained 15.2% and pure chemistry and space explained negative amounts of variation. Pure environment (physical and chemical factors combined) explained 19.9% of the total variation. Like *Alasmidonta heterodon*, the Cuddebackville Dam and location were both significantly related to abundance of *A. implicata* (Table 4); however, pure dam explained 13.2%, pure location explained –9.4%, and overlap explained 45.1% of the variation in abundance. High levels of variation shared among all components (Fig. 3H) and the pure spatial variation attributed to the dam (Table 4) suggest that the Cuddebackville Dam affected the distribution and abundance of *A. implicata* populations.

DISCUSSION

Mussel communities

Abundance of mussel populations and, thus, species distributions and richness of mussel communities in the Neversink River Basin appear to be affected to different degrees by water-quality, habitat, spatial location (distance from mouth and proximity to other reaches), and the Cuddebackville Dam. Strong correlations among dependent and predictor variables imply that various factors may limit or regulate mussel populations or communities in the basin. Direct cause-and-effect relations, however, cannot be confirmed and mechanisms remain speculative because all findings are based on observations of natural ecosystems. Community richness, though moderately related to water quality, location, and the Cuddebackville Dam, was strongly related to several physical-habitat features. Total community abundance was related primarily to chemical factors and spatial location. Several investigations identified relations between the richness of mussel communities and microhabitat factors, landscape characteristics, and physiographic factors, but few noted strong relations between macrohabitat factors and the richness of mussel species or the distribution of individual species populations (Layzer & Madison, 1995; Strayer, 1993; Strayer, 1999; Strayer & Ralley, 1993; Vannote & Minshall, 1982). Stream size was the only macrohabitat variable significantly related to mussel species richness in non-tidal streams of the northern Atlantic Slope (Strayer, 1993). The distribution of mussel species in the Salmon River, Idaho, was partly regulated by sediment stability (Vannote & Minshall, 1982). Similarly, the patchy distribution of mussel beds under favorable or marginal environmental conditions in the Neversink River was hypothesized to result from the stability of stream sediments during high flows (Strayer & Ralley, 1991). A recent study in the lower Neversink Basin showed that mussel-sized stones remain in mussel beds after large storm-flows and over periods of several years, whereas those at adjacent reaches (within meters) containing no mussels were buried or transported downstream (Strayer, 1999). Others have found that seemingly important factors, such as calcium concentration and stream size, were not good predictors of unionid richness (Strayer & Ralley, 1991), and depth, organic content and granulometry of sediment, distance from shore, and concentration of particulate organic matter in freshwater tidal environments did not explain species distributions or variability in abundance of five mussel species (Strayer *et al.,* 1994). Related studies have shown that water depth and velocity were correlated with the distribution of mussel species at base flows, and that shear stresses at low and moderate flows during the period of juvenile settlement were significantly correlated with mussel abundances at reaches along a 4th-order stream in the Cumberland River Basin, KY (Layzer & Madison, 1995). Shear stress, water velocity, stream discharge, and certain substrate particle sizes also had been shown or hypothesized to restrict mussel species to stable patches (microhabitats) in suitable reaches (Strayer *et al.,* 1994; Strayer, 1993; Strayer & Ralley, 1993). The findings from the present study and others suggest that reach conditions at moderate to high flow might govern the distribution of mussel species and the richness of mussel communities in lotic systems.

The inability of many studies to identify strong relations between predictor variables and mussel populations and communities may be due to a number of factors. First, the micro- and macro-habitat or biological factors that truly affect mussel assemblages may not have been adequately characterized. This is understandable considering several potential predictors, such as water depth, velocity, and bed shear stress at effective discharge, occur under difficult-to-measure high flow conditions in large streams and rivers. Other critical factors, such as the distribution of host-fish species, are seldom evaluated. For example, more than 50% of the variation in the mussel species assemblages at 36 reaches across the Red River drainage basin of Texas was explained, in part, by the distribution and abundance of native fish species (Vaughn & Taylor, 2000). Fish assemblages, pure space, and pure environment explained 15.4, 16.1, and 7.8 percent of the variation in the mussel-species matrix, respectively; overlap among the three categories explained 40% of the variation (Vaughn & Taylor, 2000). More important, however, is the likelihood that individual mussel species are affected to different degrees by the same and different environmental factors. Various responses of different species across physical, chemical, and biological gradients in riverine systems can complicate community changes and confound or weaken evident relations. The effects that different environmental factors have on mussel communities can be refined after their effects on individual species populations are defined.

Mussel populations

Though spatial structure (location) and physical-habitat affected abundance of *Elliptio complanata*, water quality appeared to be mainly responsible for regulating their populations in the Neversink River Basin. The absence of strong relations with physical-habitat features and the Cuddebackville Dam is not notable given their broad tolerance to environmental conditions; the species occurs under lotic and lentic conditions ranging from small brooks to large rivers and lakes (Strayer & Ralley, 1991). It is also one of the most widespread unionid species in New York State and often dominates mussel communities where they occur (Strayer & Ralley, 1991). Combined with the wide distribution and high abundance of *E. complanata* throughout the Neversink Basin, our findings support relations (or lack of relations) identified in several other studies. The presence of *E. complanata* was only weakly correlated to stream size, and the species was categorized, along with *Alasmidonta undulata* and *Strophitus undulatus*, as a generalist, having no strong relations with a number of macrohabitat factors in streams of the northern Atlantic Slope (Strayer, 1993). Poor habitat relations are exemplified by the decreases in *E. complanata* abundance associated with increasing distance from the mouth and decreasing ionic strength of stream waters at main-stem and tributary reaches, regardless of stream or channel width or depth, substrate characteristics, mean annual flow, or elevation. Its distribution in the Neversink suggests it prefers sites with low concentrations of nitrate, ammonia, and ammonium, but moderate to high concentrations of phosphorus, conductivity, hardness, K, Ca, Na, Cl, and sulfate; and that the species may tolerate waters with relatively high temperatures and low dissolved oxygen concentrations.

Abundance of *Strophitus undulatus* populations in the Neversink River was primarily affected by physical-habitat factors and possibly by the Cuddebackville Dam; water quality and location had little or no effect. The species is sometimes common in small streams and rivers across parts of New York State (Strayer & Ralley, 1991). Though *S. undulatus* was categorized as having few strong preferences, its presence was weakly correlated with hydrologic stability and the lack of tidal influence in streams of the northern Atlantic Slope (Strayer, 1993). Its distribution in the middle and lower reaches of the Neversink support observations that stream size and hydrologic stability could regulate their populations. They were typically more abundant at sites downstream of nv06 (the first reach above the Cuddebackville Dam) than above, and abundance was positively related to percent cobble and gravel substrate and bank stability and negatively related to bank height and elevation. The presence of *S. undulatus* both upstream and downstream from the Cuddebackville Dam indicate the dam does not strongly affect population abundance, and that it is not a barrier to dispersion of the species.

Physical habitat, water quality, location, and the Cuddebackville Dam were all related to abundance of *Alasmidonta undulata* populations in the Neversink River; however, chemical factors appeared to be most important. Increasing densities at reaches further upstream was the reverse of trends for most other mussel species, but support the view that the species prefers large streams and small rivers (Strayer & Jirka, 1997; Strayer & Ralley, 1991). Though few other studies report preferences, the presence of *A. undulata* populations was weakly correlated with hydrologic stability, low Ca concentration, and the lack of tidal influence in streams of the northern Atlantic Slope (Strayer, 1993). Distribution of *A. undulata* and water quality data from the Neversink Basin suggest they prefer relatively high nutrient and productivity levels and low to intermediate concentrations of cations and anions, hardness, silica, sulfate, and ANC. These conditions occur at reaches with intermediate elevations, drainage areas, stream size, flows, temperatures, and hydrologic stability and may be the basis for large amounts of explained variation being shared among chemical, physical and spatial components. High levels of shared variation, coupled with pure variation, explained by the Cuddebackville Dam indicate that reach location and orientation to the Cuddebackville Dam affected abundance of *A. undulata* populations in the basin. Unlike populations of *Alasmidonta heterodon* and *Anodonta implicata* (see below), the dam appeared to separate larger populations in the middle reaches from smaller populations in the lower reaches. If not a result of unsuitable environmental conditions, low densities below the dam could be due to host fish species that are confined mainly to the middle basin or to heightened inter- and intra-specific competition with other mussel species, such as *A. heterodon* and *A. implicata*, which only occur downstream of the Cuddebackville Dam.

Abundance and distributions of *Alasmidonta varicosa* populations in the Neversink River were affected mainly by physical-habitat factors and to a lesser extent by water-quality conditions; they were not affected by spatial location or by the Cuddebackville Dam. *Alasmidonta varicosa* populations in the Neversink River were most abundant at mid-basin reaches where channel slope (0.70-0.75%) and percent boulder substrate (28-44%) were high and percent sand (19%) and embeddedness (20%) were at or near their minimums. At these reaches, median concentrations of Ca were about 5.0 mg/L, hardness was 17-18 mg$CaCO_3$/L, and total phosphorus (P) was about 0.050 mg/L. Species abundance was lower at reaches where concentrations of the three constituents were higher or lower. These results support findings from several other studies. Strayer & Jirka (1997) report that *A. varicosa* typically favor gravelly riffles in small rivers and streams that are nutrient poor and have low calcium concentrations. In a study of microhabitat preferences in the Neversink River, *A. varicosa* were found most frequently in quadrants with moderate velocities, with a high proportion of medium sands (0.25-1.0 mm), and intermediate depths (Strayer & Ralley, 1993). The presence of *A. varicosa* was strongly and negatively correlated only with Ca concentration in an evaluation of mussel-macrohabitat relations in streams of the northern Atlantic Slope (Strayer, 1993).

The presence of *Alasmidonta varicosa* at reaches above and below the Cuddebackville Dam and the absence of *Alasmidonta heterodon* above the dam are somewhat perplexing because both mussel species use closely related fish species as hosts (Strayer & Jirka, 1997). At least two resident fish species, the longnose dace, *Rhinichthys atratulus* (Hermann, 1804), and the slimy sculpin, *Cottus cognatus* (Richardson, 1836), are know hosts for *A. varicosa*, and the mottled sculpin, *Cottus bairdi* (Girard 1850), is a known host for *A. heterodon* (Strayer & Jirka, 1997). Presumably, either *A. varicosa* were present upstream of the Cuddebackville Dam before the early 1800s when the dam was first built, or one host fish species specific to *A. varicosa* can negotiate the dam's low head. In either case, the low head dam has little effect on the distribution of their populations.

Though physical-habitat variables alone could explain most of the variation in abundance of *Alasmidonta heterodon* populations in the Neversink River, the high amount of variation shared among physical, chemical, and spatial components suggests the species may be affected by many factors, including the Cuddebackville Dam and spatial location, elevation, percent open canopy, percent gravel, slope, maximum substrate size, concentration of nutrients. While few strong physical-habitat or chemical preferences are known for the species (Strayer & Ralley, 1993), findings from this study and those from several others suggest that the distribution and abundance of *A. heterodon* may be governed primarily by certain substrate matrices, channel sizes and depths, water velocities, and water-quality conditions. In laboratory experiments, individual *A. heterodon* specimens did not distinguish between moving or static waters but they always preferred finer *vs.* coarser substrates (Michaelson & Neves, 1995). In studies of microhabitat preferences in the Neversink River, *A. heterodon* were most frequently observed in quadrants with uniform and moderate velocities, intermediate depths, and with finer sediment patches that accumulate between cobbles (Strayer & Ralley, 1993). On a larger scale (1 to 10 km), *A. heterodon* abundance in streams of the northern Atlantic Slope were negatively correlated to calcium concentration and stream gradient (Strayer, 1993).

Negative relations with nutrients indicate that enrichment in middle and upper reaches of the Neversink could pose a threat to downstream populations of *Alasmidonta heterodon* and to the possible expansion of their populations into middle reaches of the basin. Limited water-quality preferences were indicated for *A. heterodon* as it was only found at reaches where median concentrations of nitrate were less than 0.4 mg N/L, ortho P was less than 0.030 mgP/L, and total phosphorus was less than 0.055 mgP/L. Residential septic systems across the basin, runoff of residential and agricultural fertilizers and municipal sewage-treatment effluents in the middle basin (TNC, 1999), and deposition of nitrous oxides in the poorly-buffered headwater reaches (Baldigo & Lawrence, 2000, Lawrence *et al.,* 1999; Lawrence *et al.,* 2000) are known or potential sources of eutrophication in the watershed.

The empirical relations defined above need to be qualified because any effects that the Cuddebackville Dam has on the distribution of *Alasmidonta heterodon* in the basin would partly nullify identified associations. Partial regression analyses indicate that distribution of *A. heterodon* in the Neversink River could have been affected by the Cuddebackville Dam. The low-head dam could physically limit expansion of *A. heterodon* populations because it blocks upstream movement of the tessellated darter, *Etheostoma olmstedi* (Storer 1842), which is a known host for the glochidea (larval) life stages of the dwarf wedgemussel (Michaelson & Neves, 1995). If part or all of the Cuddebackville Dam were removed to allow passage for this species and for anadromous fish that also are potential hosts (see *Anodonta implicata* below), then expansion of *A. heterodon* populations would be plausible. If the dam does restrict *A. heterodon* populations, identified relations might be biased and would need to be redefined if the species populated additional reaches.

The distribution of *Anodonta implicata* populations in the Neversink River match that of *Alasmidonta heterodon;* thus, it not surprising that their abundances were affected by most of the same factors. The presence of *A. implicata* in the Neversink River was a little unexpected as it is most commonly found in large rivers just upstream of the head of the tide (Strayer, 1993). In streams of the northern Atlantic Slope, *A. implicata* populations were strongly correlated with tidal influence, Ca concentration, hydrologic stability, and gradient (Strayer, 1993). Though environmental preferences for the species are not known, positive correlations of abundance with annual discharge, channel width, drainage area, Ca, and ANC and negative correlations with nutrient concentrations in the Neversink suggest the species can prosper in high order, low elevation, and deep rivers with relatively warm and moderate-velocity waters. Conditions suitable for *A. implicata* in the Neversink River were comparable to those in the Hudson and Connecticut River Basins where the species was also observed (Strayer & Jirka, 1997).

Like *Alasmidonta heterodon*, the Cuddebackville Dam appears to restrict *Anodonta implicata* populations to lower reaches of the Neversink River Basin. There is strong circumstantial evidence that obstacles to migration for a known host fish species could restrict *A. implicata* populations in the Neversink River. The upstream extent of *A. implicata* populations was increased in the Connecticut River following implementation of a shad-restoration program that included removal of at least one dam (Smith, 1985). The Cuddebackville Dam currently blocks upstream migration of anadromous American shad (*Alosa sapidissima* Wilson 1811) and hickory shad (*Alosa mediocris* Mitchell 1814) (TNC, 1999), at least one of which is a host for glochidea of *A. implicata* (Strayer & Jirka, 1997). Expansion of *A. implicata* (and *A. heterodon*) populations into middle reaches of the Neversink, like that observed in the Connecticut River, may be possible after the Cuddebackville Dam is removed.

Little can be inferred about the factors that might affect *Pyganodon cataracta* populations in the Neversink Basin because they were only found in one small tributary upstream from an abandoned beaver pond. Their absence from all riverine reaches in the Neversink could have been predicted because the species is usually encountered in quiet, well-protected ponds, and marshes (Strayer & Jirka, 1997).

Potential effects of the Neversink Reservoir on mussel communities

The present study determined that the Cuddebackville Dam could potentially affect the distribution of two or three mussel species in the lower Neversink River Basin. Effects of the Neversink Reservoir on mussel distributions could potentially be more significant due to impacts on downstream water quality and hydrologic regime. Possible effects of the reservoir, like that of the Cuddebackville Dam, are also speculative because no pre-construction mussel data are available to evaluate changes. Dams not only block fish migration and alter downstream riverine habitat, they significantly change water-temperature regimes, alter water quality, alter normal thermal and hydrologic regimes, and increase hydrologic and sediment stability (Anonymous, 1997; Richter *et al.*, 1997a). These alterations modify the distribution and availability of riverine habitat and disrupt native biodiversity and ecological integrity of affected reaches (Poff *et al.*, 1997; Richter *et al.*, 1996; Richter *et al.*, 1997b). Annual peak flows at a USGS continuous-discharge gage immediately downstream from the Neversink Reservoir (site nv14) decreased, on average, from 310 to 150 m^3/s after completion of the dam. These changes increased hydrologic and channel stability and decreased bed-sediment loads. The loss of seasonal flow peaks and changes to the timing of annual maximum and minimum flows in the Neversink River likely affected aquatic species that use flow cues for spawning, migration, and egg hatching; the distribution of native fish and macroinvertebrate species; and the composition of affected communities. Dampened discharge peaks and increased substrate stability could have been favorable to the establishment and long-term maintenance of mussel beds. The possibility that both main stem impoundments in the basin could have beneficial as well as adverse affects on populations of common, threatened, and endangered mussels has broad implications for watershed and reservoir management and for ecosystem restoration. Some semblance of original biodiversity and ecosystem integrity might be reconstituted in the Neversink and in similar regulated rivers if water releases from reservoirs were managed to approximate certain components of natural flow regimes. In an era of stream and ecosystem restoration, both the negative effects and the positive management potential of impoundments need to be evaluated before plans to restore natural biodiversity and hydrogeomorphology in riverine systems are implemented.

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CURRENT STATUS OF FRESHWATER MUSSELS (BIVALVIA: UNIONIDAE) IN THE BIG SOUTH FORK NATIONAL RIVER AND RECREATION AREA OF THE CUMBERLAND RIVER AND RECREATION AREA OF THE CUMBERLAND RIVER, TENNESSEE AND KENTUCKY (1999-2002). EVIDENCE OF FAUNAL RECOVERY

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ABSTRACT

In 1974, the Big South Fork Cumberland River was designated a National River and Recreation Area and managed by the National Park Service. The drainage basin suffered extensively from coal mining, forestry and agricultural practices, domestic runoff, and oil and gas exploration and extraction. Information concerning the mussel fauna in the drainage is based upon a few sites sampled in Kentucky (1910-1911, 1947-1949) and Tennessee (1938-1939). At least 55 species are reported from the Big South Fork but the river at its confluence had access to the rich mussel fauna of the Cumberland River prior to impoundment. The Big South Fork River has been affected by extensive pollution in the drainage basin. Past pollution problems were recently thought severe enough that the fauna was destroyed. However, in the mid-1970s and 1980s, 23 mussel species were found live in the river and larger tributaries. The 23 mussel species were the first indication that some mussels had survived. Recent surveys from 1999-2002 have identified 26 species including five that are federally listed endangered (*Alasmidonta atropurpurea, Epioblasma brevidens, E. florentina walkeri, Pegias fabula*, and *Villosa trabalis*) and three thought extirpated (*Alasmidonta marginata, A. viridis,* and *Elliptio crassidens*). The National River and Recreation Area of the Big South Fork contains some of the best mussel populations that remain in the Cumberland River system and the fauna appears to be recovering for some species. Restoration of extirpated mussels is feasible via culture, propagation, and translocation of adults. The Big South Fork could serve as a mussel refuge and seed source for other streams in the Cumberland River system following pollution abatement.

Key Words: Big South Fork Cumberland River, National River and Recreation Area, National Park Service, Unionidae, endangered mussels, recruitment.

INTRODUCTION

The freshwater mussel fauna in the Southeastern United States is globally

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[5]US Fish and Wildlife Service, 160 Zillicoa Road, Asheville, North Carolina 28801.

unparalleled. Regional differences in physiography, geology, water chemistry, and stream habitat characteristics have resulted in distinct faunal assemblages and considerable endemism within river basins (Neves *et al.*, 1997). A recent status review of approximately 300 mussel species in the United States and Canada revealed significant declines and an imperilment rate of over 70% (Williams *et al.*, 1993). A profound increase in federal listings of threatened and endangered species has occurred in recent years and no other group of animals approaches this level of imperilment. When species richness is assessed from a regional perspective, it becomes readily apparent that the "rain forest" of mussel diversity is in the Southeastern United States and that over 90% of North America's native mussel species occur in the Southeast (Neves *et al.*, 1997). Mussel species in the Cumberland, Tennessee, and Mobil River Basins, which includes portions of seven states in the Southeast, are in the most severe decline. Many of the extinct mussel species reported by Neves (1993) occurred in the Cumberland, Tennessee, and Mobil Rivers and their major tributaries in Tennessee, Kentucky, Virginia, and Alabama.

Historically, 94 mussel species were reported from the Cumberland River system and the faunal composition and distribution of mussels in the drainage has changed substantially over the last 75 years (Starnes & Bogan, 1988; Gordon & Layzer, 1989; Parmalee & Bogan, 1998). At least 55 species are reported from the Big South Fork (BSF) Cumberland River (Wilson & Clark, 1914; Shoup & Peyton, 1940; Neel & Allen, 1964; Harker *et al.*, 1979, 1980, 1981; Schuster, 1988; Bakaletz, 1991; Cicerello & Laudermilk, 2001), but an additional 20 species may have had direct access into the BSF and some tributary streams from populations occurring in the historically rich mussel beds of the upper Cumberland River. The inclusion of 20 additional species is based upon mussels confirmed in museum collections at the University of Michigan, Museum of Zoology (UMMZ), The Ohio State University, Museum of Zoology (OSUMZ), Carnegie Museum of Natural History (CMNH), Harvard University, Museum of Comparative Zoology (MCZ), literature sources, and/or best professional judgment (Paul Parmalee, McClung Museum, pers. comm., 2002) (Johnson, 1978; Schuster, 1988; Cicerello *et al.*, 1991; Biggins *et al.*, 2001). Since many mussels are found in association or assemblages with each other (Gordon & Layzer, 1989; Parmalee & Bogan, 1998; Garner & McGregor, 2001), it is reasonable to assume that the mussel fauna in the BSF was probably larger than what had been reported.

The National River and Recreation Area (NRRA) was established by Congress in 1974 "to conserv[e] and interpret[e] an area containing unique cultural, historical, geological, biological, archeological, scenic, and recreational resources, [and] preserving the Big South Fork of the Cumberland River as a natural free-flowing stream ..." (National Park Service, 1997). Initially, the U.S. Army Corps of Engineers proposed the construction of an impoundment for flood control and power production at Devil's Jump near Blue Heron in McCreary County, Kentucky. Alternative uses of the area were also explored and as a result of these studies, the outstanding resources of the river and gorge were recognized, as well as, the lack of economic justification for impounding the river (National Park Service, 1993). The NRRA is a unit of the National Park Service (NPS) and all lands and facilities within the boundaries of the park are operated and maintained for the benefit and use of the public. Like all federal agencies, the NPS is required by the Endangered Species Act (ESA) to protect endangered and threatened species, and to avoid any actions that might jeopardize their survival or adversely modify designated critical habitats. In addition, the NPS recognizes that the ESA requires federal agencies to actively promote the conservation of listed species and extends these responsibilities to protecting state-listed as well as candidate species for federal listing (Mehrhoff & Dratch, 2002). The NRRA is unique and significant because the BSF is one of the few remaining free-flowing rivers in the region that contains a diversity of rare, endangered, and threatened species in a limited area (National Park Service, 2003).

Purpose and Scope

The US Geological Survey (USGS) entered into a three-year contract with the NPS to provide the most recent information on the mussel resources of the NRRA. This report describes an investigation to determine what federally listed and other mussel species currently exist in the NRRA. This information is needed to help managers plan and assess restoration activities outlined in recovery plans prepared by the US Fish and Wildlife Service (USFWS); to assist with road and trail planning efforts in the NRRA; to evaluate the existence of federally listed and other imperiled mussels and fishes that occur at horse crossings in the BSF and tributary streams throughout the NRRA; and to evaluate whether or not the fauna is recovering from past perturbations. A combination of qualitative and quantitative sampling techniques were used to determine if mussels were present, and to use their relative abundance and size-class distributions as evidence that the fauna is recovering and recruiting. Permanent fixed sites are needed so that the NPS can establish baseline information for long-term monitoring of the health and recovery of mussel populations. Mussels are excellent surrogate species to indicate water-quality conditions because many are relatively long-lived and relegated to the shoals where they live out their existence.

STUDY AREA

The BSF is a large tributary of the upper Cumberland River and is located entirely within the Cumberland Plateau subsection of the Appalachian Plateaus Physiographic Province. The river is formed in north-central Tennessee by the confluence of the New River and Clear Fork and flows in a northeasterly direction 124 kilometers (km) through Morgan, Scott, and Fentress counties and joins the Cumberland River (now Lake Cumberland) at Burnside, in southeastern Kentucky (Fig. 1). Approximately, 17 km of the BSF north from the Tennessee and Kentucky state line is designated Kentucky Wild River, and 72 km of the lower BSF are affected by the impounded backwaters from Wolf Creek Dam located on the Cumberland River.

The NRRA encompasses an area of approximately 506 km^2 and is situated in a narrow deep gorge that is inaccessible and sparsely populated in some of the most rugged terrain on the plateau. All totaled, the BSF drains an area of 3,545 km^2.

Historically, the drainage suffered extensively from coal mining, forestry, and agricultural practices, domestic runoff, and oil and gas exploration and extraction (Evaldi & Garcia, 1991). Coal mining effects are extensive with numerous concentrations of coal fines washed up along stream-banks, islands, and concentrated in pools and riffles. A ferrous precipitate known as "yellow boy" may be found in smaller tributaries. Most of the coal originates from the heavily mined New River drainage but coalmines are evident in the BSF gorge downstream into Kentucky (Fig. 2).

Throughout the river's length, the BSF has eroded through parallel layers of Pennsylvanian sandstone, shale, siltstone, conglomerate, and coal and Mississippian limestone and shale. The river has eroded into a shale and limestone formation known as the Pennington Formation (Beatty, 1982). Water quality data reported by Parker & Carey (1980) indicate that dissolved calcium carbonate from limestone exposed within the streambed strongly influences water chemistry by increasing the streams buffering capacity and thus producing an environment suitable for mussels. The Pennington Formation becomes exposed in the Big South Fork in the vicinity of Station Camp Creek. Stream flows can be unpredictable and extreme with low flows during the summer and fall of less than 100 cubic-foot-per-second (cfs) and flooding during prolonged rainfall resulting in flows exceeding 50,000 cfs. The drainage is prone to flash floods but water clarity is exceptionally good during low flows and may exceed three meters. The NRRA is considered to be outstanding in the spring for whitewater kayaking and rafting because of high stream flows and is one of the

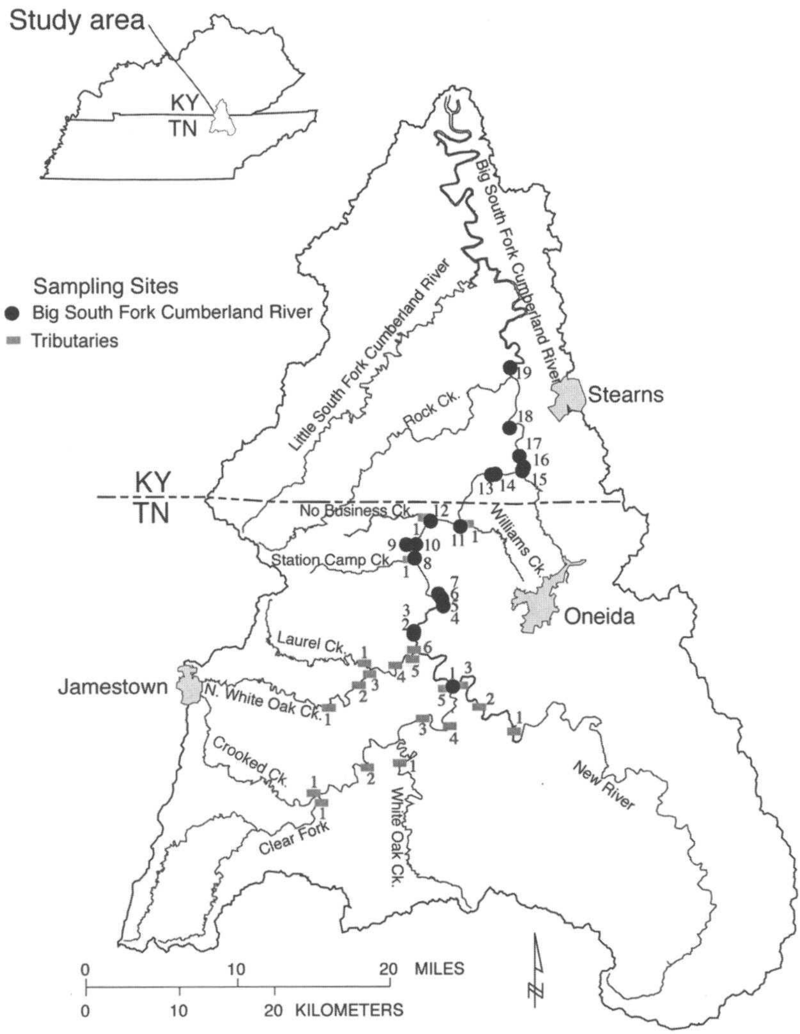

FIG. 1. Big South Fork Cumberland River Basin mussel survey.

premier National Parks in the country for horseback riding. The drainage also features numerous visible rock shelters that were used by Native Americans and early pioneers throughout the area.

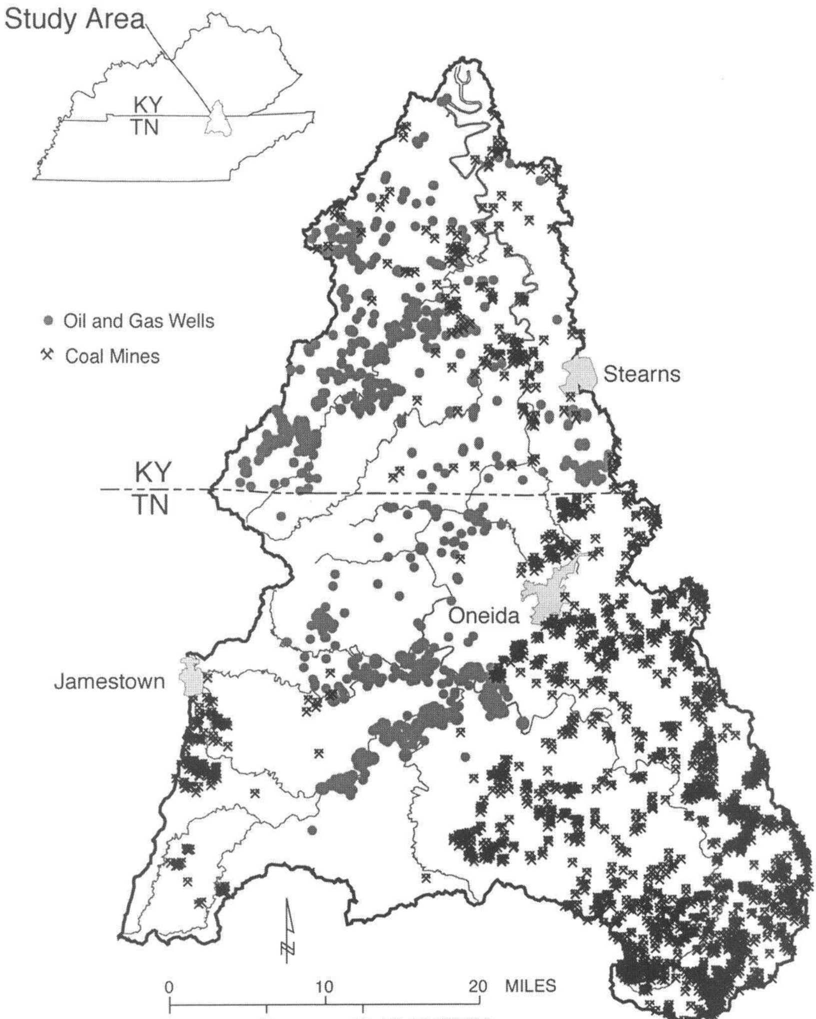

FIG. 2. Big South Fork Cumberland River Basin oil and gas wells and coal mines.

PREVIOUS SURVEYS

Historical Fauna (pre-1975)

Information concerning the historical occurrence of mussels in the BSF is limited to collections made from 1910-1911 by Wilson & Clark (1914), Shoup

& Peyton (1940) in 1938-1939, and Neel & Allen (1964) from 1947-1949 (Table 1). Wilson & Clark (1914) were primarily interested in the commercial value of mussels in the Cumberland River system for the shell-button industry. In their report, 41 species were found at two collecting sites in the BSF and one in the Cumberland River near the confluence of the BSF in Kentucky.

Shoup & Peyton (1940) studied the biological and chemical characteristics of the BSF drainage in Tennessee at 86 sampling sites. They reported 11 mussel species: two in the BSF at Leatherwood Ford, one in the Clear Fork at Peter's Bridge, and eight species from two sites in the New River at Cordell and New River Station (Table 1).

Neel & Allen (1964) studied the mussel fauna of the upper Cumberland basin before its impoundment by closure of Wolf Creek Dam in 1950. Their collections are limited to two sites sampled in the lower BSF in Kentucky: Yamacraw and an area identified as upstream from Burnside. No mussels were found at Yamacraw and noted that acid coal mine waters had destroyed all mussels in the river from the region of Yamacraw. However, 16 species were reported downstream above Burnside (Table 1).

Recent Fauna (post-1975)

The mussel fauna in the BSF was largely neglected after 1950 and thought destroyed by extensive mining wastes originating primarily from the New River drainage and other areas along the BSF gorge. Oil and gas exploration and extraction, drilling, road construction, and logging throughout the watershed contributed untold amounts of pollution to the river system.

From 1978-1981, water quality and aquatic biology studies in the BSF by the Kentucky Nature Preserves Commission near the confluence with Troublesome Creek in Kentucky provided the first evidence that at least 20 mussel species had survived in the river (Harker *et al.,* 1979, 1980, 1981; Schuster, 1988). A more detailed mussel float-survey of the BSF in Tennessee and Kentucky followed in 1985 and 1986 and included tributary streams (Bakaletz, 1991). Bakaletz (1991) reported 22 species extant in the drainage and spatially his survey represents the most comprehensive mussel study completed in the NRRA of the BSF (Table 1).

In 1998, Conservation Fisheries, Inc. (CFI) was contracted by the NPS to survey and report on the distribution and abundance of federally endangered duskytail darter, *Etheostoma percnurum*, and mussels in the BSF at Station Camp Creek horse crossing and Parch Corn Creek (Shute *et al.,* 1999). A total of 16 mussel species were found including a new distribution record in Tennessee for *Pegias fabula* (Table 1).

TABLE 1. Freshwater mussel species reported from the Big South Fork Cumberland River Basin, Tennessee and Kentucky. [**WC**, Wilson & Clark, 1914; **SP**, Shoup & Peyton, 1940; **NA**, Neel & Allen, 1964; **S**, Schuster, 1988; **B**, Bakaletz, 1991; **SSRH**, Shute *et al.*, 1999; **D**, Dunn, 2000; **ABFHTB**, Ahlstedt, Bakaletz, Fagg, Hubbs, Treece & Butler, 2003, unpublished; **X**, specimens reported; –, no specimens reported; E, endangered; ?, unconfirmed identification.]

Species	WC	SP	NA	S	B	SSRH	D	ABFHTB
Actinonaias ligamentina	X	X	X	X	-	-	-	-
Actinonaias pectorosa	X	-	X	X	X	-	X	X
Alasmidonta atropurpurea **E**	-	-	-	-	X	X	X	X
Alasmidonta marginata	X	X	-	X	-	-	-	X
Alasmidonta viridis	-	X	-	X	-	-	-	X
Cumberlandia monodonta	-	-	-	X	-	-	-	-
Cyclonaias tuberculata	X	-	X	X	-	-	-	-
Dromus dromas **E**	X	-	-	X	-	-	-	-
Ellipsaria lineolata	X	-	-	X	-	-	-	-
Elliptio crassidens	X	-	X	X	-	-	-	X
Elliptio dilatata	X	X	X	X	X	X	X	X
Epioblasma arcaeformis	X	-	-	X	-	-	-	-
Epioblasma biemarginata	-	-	-	X	-	-	-	-
Epioblasma brevidens **E**	X	-	-	X	X	X	X	X
Epioblasma capsaeformis **E**	X	-	X	X	-	-	-	-
Epioblasma flexuosa	-	-	-	X	-	-	-	-
Epioblasma f. florentina **E**		-	-	X	-	-	-	-
Epioblasma f. walkeri **E**	X	-	X	X	X	X	X	X
Epioblasma haysiana	X	-	X	X	-	-	-	-
Epioblasma lewisii	-	-	-	X	-	-	-	-
Epioblasma o. obliquata **E**	-	-	-	X	-	-	-	-
Epioblasma stewardsonii	-	-	-	X	-	-	-	-
Epioblasma triquetra	-	-	-	-	-	-	-	X*
Fusconaia barnesiana	X	-	-	-	-	-	-	-
Fusconaia subrotunda	X	-	-	X	-	X	-	-
Hemistena lata **E**	X	-	-	X	-	-	-	-
Lampsilis cardium	X	X	X	X	X	X	X	X
Lampsilis fasciola	X	-	X	X	X	X	X	X
Lasmigona costata	X	X	-	X	X	X	X	X
Leptodea fragilis	X	-	-	-	-	-	-	X
Ligumia recta	X	X	X	X	X	X	X	X
Medionidus conradicus	X	-	-	X	X	-	-	X
Obliquaria reflexa	X	-	-	X	-	-	-	-
Obovaria subrotunda	X	-	-	X	-	-	-	-
Pegias fabula **E**	-	-	-	X	X	X	X	X

Table 1 (continued)

Species	WC	SP	NA	S	B	SSRH	D	ABFHTB
Pleurobema clava **E**	X	-	-	X	-	-	-	X?
Pleurobema cordatum	X	-	-	-	-	-	-	-
Pleurobema oviforme	X	-	-	X	X	-	-	X
Pleurobema rubrum	X	-	-	X	-	-	-	-
Pleurobema sintoxia	X	-	-	X	X	X	X	X
Potamilus alatus	X	-	X	X	X	X	X	X
Ptychobranchus fasciolaris	X	-	X	X	X	X	X	X
Ptychobranchus subtentum	X	-	-	X	X	-	-	-
Pyganodon grandis	-	-	-	-	-	-	-	X*
Quadrula c. cylindrica	X	-	-	X	-	-	-	-
Quadrula metanevra	-	-	-	X	-	-	-	-
Quadrula p. pustulosa	X	X	X	X	X	X	X	X
Quadrula sparsa **E**	-	-	-	X	-	-	-	-
Quadrula tuberosa	X	-	-	-	-	-	-	-
Strophitus undulatus	X	-	-	X	X	-	X	X
Toxolasma lividus	-	-	-	X	-	-	-	-
Toxolasma parvus	-	-	-	X	-	-	-	-
Tritogonia verrucosa	X	X	-	X	X	X	X	X
Truncilla donaciformis	-	-	X	X	-	-	-	-
Truncilla truncata	X	-	-	X	-	-	-	-
Utterbackia imbecillis	-	-	-	X	-	-	-	X*
Villosa iris	X	X	-	X	X	-	-	X
Villosa lienosa	-	-	-	X	-	-	-	-
Villosa taeniata	X	X	-	X	X	-	X	X
Villosa trabalis **E**	X	-	-	X	X	X	X	X
Villosa v. vanuxemensis	-	-	X	-	-	-	-	-
Total number of species	41	11	16	53	22	16	18	26
* Ronald Cicerello, pers. comm., 2003 (not included in the total)								

Ecological Specialists, Inc. (ESI) was contracted by the NPS in 1999 to assess the impacts of horses on mussel populations at two horse crossings in the BSF: Station Camp Creek and Big Island (Dunn, 2000). A total of 18 mussel species were found including five of the currently extant federally listed mussels (Table 1).

STUDY METHODS

Mussel sampling consisted of snorkeling at sites accessible by road, foot and horse trail, and canoeing. SCUBA equipped divers searched the deeper pools. Mussels were located in the substrate by visual searching, moving slab boulders, and digging. The finding of juvenile mussels was an important component of the survey for documenting recent recruitment. Many live mussels were found under large slab boulders that are not imbedded in the substrate. This appears to be the most stable habitat and was where many of the juvenile mussels were located. It is assumed that juvenile mussels are deposited there by host fish and/or wash in during periods of high surface flows. Winter sampling using dry suits was effective for finding mussels that vertically migrate to the surface of the substrate for winter and spring spawning and attraction of host fish.

Stream banks were searched for shell feeding stations (middens) left by muskrats, *Ondatra zibethica*. No shell middens were found in the BSF and seldom were collected from tributary streams. Evidence of river otter predation on mussels was noted since otters break the shell to extract mussel flesh. River otters were reintroduced into the BSF in the mid-1980s and may have severely reduced muskrat populations. All live, fresh dead (shiny nacre and/or evidence of tissue left inside of shell), and relict (weathered nacre no longer lustrous) mussels were identified to species and recorded. Individual specimens of live and fresh dead mussels were measured for total length (in millimeters) for size-class distribution using a digital dial caliper. The total person hours spent sampling mussels (timed search) was recorded by site for determining the Catch Per Unit of Effort (CPUE).

All sites sampled were identified by latitude and longitude using a hand-held Global Positioning System (GPS) unit. Sampling sites also were identified by river mile location, natural landmarks, creeks, and towns using USGS, 7.5-minute topographic maps (Tables 2 and 3). Individual specimens of federally listed and non-listed mussel species were collected under USFWS Federal Permit SA 00-14 and sent to the University of Alabama for genetic sequencing and phylogenetic studies. Federally listed and non-listed mussels taken for this purpose included the following: *Alasmidonta atropurpurea, Epioblasma brevidens, E. florentina walkeri, P. fabula*, and *Villosa trabalis*. Non-listed: *Actinonaias pectorosa, Alasmidonta viridis, Lampsilis fasciola, Pleurobema sintoxia, Quadrula pustulosa, Villosa iris*, and *V. taeniata*.

RESULTS

In the combined 1999-2002 surveys, a total of 7,885 live mussels representing 26 species were collected at 19 BSF sampling sites and 20 sites in nine tributary streams (Tables 1-5). Mussel data from a few sites sampled in 1998 were included with the 1999-2002, study. Five species found are federally listed under the Endangered Species Act: *Alasmidonta atropurpurea, Epioblasma brevidens, E. florentina walkeri, Pegias fabula*, and *Villosa trabalis*. A single live specimen of another federally listed species, *Pleurobema clava*, was considered

TABLE 2. Sampling sites in the Big South Fork Cumberland River Basin.

[**d m s**, degrees, minutes, seconds; **mi**, mile; **km**, kilometer; **BSF**, Big South Fork Cumberland River.]

Site number	Stream name	Site location description	County	State	Latitude (d m s)	Longitude (d m s)	River mi/km	Topo Quad
BSF1	Big South Fork Cumberland River	confluence of Clear Fork and New River	Morgan	Tenn.	362528	843725	77/124	Oneida South
BSF2	Big South Fork Cumberland River	upstream of Leatherwood Ford	Scott	Tenn.	362832	844007	70.5/113	Honey Creek
BSF3	Big South Fork Cumberland River	Leatherwood Ford	Scott	Tenn.	362841	844005	70/113	Honey Creek
BSF4	Big South Fork Cumberland River	upstream of Rough Shoals Branch	Scott	Tenn.	363004	843756	67.5/109	Barthell SW
BSF5	Big South Fork Cumberland River	mouth of Rough Shoals Branch	Scott	Tenn.	363027	843801	67/108	Barthell SW
BSF6	Big South Fork Cumberland River	downstream of Rough Shoals Branch	Scott	Tenn.	363033	843805	66.5/107	Barthell SW
BSF7	Big South Fork Cumberland River	mouth of Stevens Branch	Scott	Tenn.	363045	843816	66/106	Barthell SW
BSF8	Big South Fork Cumberland River	shoal downstream of Station Camp Creek	Scott	Tenn.	363251	843953	62.5/101	Barthell SW
BSF9	Big South Fork Cumberland River	Parch Corn Creek	Scott	Tenn.	363332	844018	61.5/99	Barthell SW
BSF10	Big South Fork Cumberland River	island downstream of Parch Corn Creek	Scott	Tenn.	363339	844017	61.3/99	Barthell SW
BSF11	Big South Fork Cumberland River	Big Island	Scott	Tenn.	363457	843840	59/95	Barthell SW
BSF12	Big South Fork Cumberland River	mouth of Williams Creek	Scott	Tenn.	363446	843633	57/92	Oneida North
BSF13	Big South Fork Cumberland River	shoal downstream of Oil Well Branch	McCreary	Ky.	363726	843413	52.3/84	Oneida North
BSF14	Big South Fork Cumberland River	mouth of Hueling Branch	McCreary	Ky.	363728	843356	52/84	Oneida North
BSF15	Big South Fork Cumberland River	shoal upstream of Bear Creek	McCreary	Ky.	363737	843160	50.3/81	Barthell
BSF16	Big South Fork Cumberland River	below gage above Salt Branch	McCreary	Ky.	363749	843154	50/80	Barthell
BSF17	Big South Fork Cumberland River	Big Shoal	McCreary	Ky.	363827	843211	49.2/79	Barthell
BSF18	Big South Fork Cumberland River	Blue Heron	McCreary	Ky.	364006	843249	45.5/73	Barthell
BSF19	Big South Fork Cumberland River	Yamacraw	McCreary	Ky.	364331	843238	40.5/65	Barthell

TABLE 3. Sampling sites on tributaries to the Big South Fork Cumberland River.

[**d m s**, degrees, minutes, seconds; **mi**, mile; **km**, kilometer; **CF**, Clear Fork; **NR**, New River; **CC**, Crooked Creek; **NWO**, North White Oak Creek; **WOC**, White Oak Creek; **LF**, Laurel Fork; **SCC**, Station Camp Creek; **NBC**, No Business Creek; **WC**, Williams Creek; –, missing data.]

Site number	Stream name	Site location description	County	State	Latitude (d m s)	Longitude (d m s)	River mi/km	Topo Quad
CF1	Clear Fork	upstream of Peters Bridge	Fentress/Morgan	Tenn.	361928	844712	20/32	Burrville
CF2	Clear Fork	Brewster Bridge	Fentress/Morgan	Tenn.	362106	844341	14/23	Rugby
CF3	Clear Fork	Sheep Ranch (gas drilling site)	Fentress/Morgan	Tenn.	362342	843939	7/11	Honey Creek
CF4	Clear Fork	upstream of Burnt Mill Bridge	Scott	Tenn.	362312	843744	3.7/6	Honey Creek
CF5	Clear Fork	500 yards upstream from mouth	Scott	Tenn.	362523	843724	.3/.5	Oneida South
CC1	Crooked Creek	300 yards upstream from mouth	Fentress	Tenn.	361928	844717	.2/.3	Burrville
NR1	New River	Highway 27 bridge (no mussels)	Scott	Tenn.	362250	843310	9/14	Oneida South
NR2	New River	Silcox Ford	Scott	Tenn.	362416	843533	4.7/7.6	Oneida South
NR3	New River	500 yards upstream from mouth (no mussels)	Scott	Tenn.	362526	843717	.3/.5	Oneida South
NWO1	North White Oak Creek	mouth of Mill Creek (no mussels)	Fentress	Tenn.	362425	844619	.3/.5	Stockton
NWO2	North White Oak Creek	Zenith	Fentress	Tenn.	362542	844409	--	Honey Creek
NWO3	North White Oak Creek	upstream from confluence with Laurel Fork	Fentress	Tenn.	362630	844319	--	Honey Creek
NWO4	North White Oak Creek	upstream from confluence with Coyle Branch	Scott	Tenn.	362647	844130	--	Honey Creek
NWO5	North White Oak Creek	ATV crossing -- O and W ATV crossing	Scott	Tenn.	362718	844020	1/1.6	Honey Creek
NWO6	North White Oak Creek	500 yards upstream of mouth	Scott	Tenn.	362729	843958	.3/.5	Honey Creek
WOC1	White Oak Creek	below Hwy. 52 (Whiteoak) Bridge near Rugby	Morgan	Tenn.	362114	844124	5.5/8.8	Rugby
LF1	Laurel Fork	upstream from ATV crossing (no mussels)	Fentress	Tenn.	362638	844319	.3/.5	Honey Creek
SCC1	Station Camp Creek	500 yards upstream from mouth (no mussels)	Scott	Tenn.	363251	843953	.3/.5	Barthell SW
NBC1	No Business Creek	500 yards upstream from mouth (no mussels)	Scott	Tenn.	363501	843849	.3/.5	Barthell SW
WC1	Williams Creek	100 yards upstream from mouth (no mussels)	Scott	Tenn.	363442	843627	.1/.16	Oneida North

TABLE 4. Freshwater mussels collected in the Big South Fork Cumberland River, 1999-2002.

[**BSF**, Big South Fork Cumberland River; –, no specimens collected; **E**, federally listed endangered; **CPUE**, catch per unit effort.]

	Site Number																		
	BSF 1	BSF 2	BSF 3	BSF 4	BSF 5	BSF 6	BSF 7	BSF 8	BSF 9	BSF 10	BSF 11	BSF 12	BSF 13	BSF 14	BSF 15	BSF 16	BSF 17	BSF 18	BSF 19
Actinonaias pectorosa	--	--	--	3	4	1	2	58	50	5	14	6	20	5	44	7	10	--	--
Alasmidonta atropurpurea **E**	--	--	--	2	3	--	--	2	2	--	5	--	--	--	2	--	--	--	--
Alasmidonta marginata	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--
Alasmidonta viridis	--	--	--	1	3	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Elliptio crassidens	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--
Elliptio dilatata	--	2	1	6	9	--	1	101	403	63	235	37	78	24	136	4	20	3	--
Epioblasma brevidens **E**	--	--	--	--	7	--	--	161	54	1	16	6	5	4	6	1R	1	1R	--
Epioblasma f. walkeri **E**	--	--	--	--	--	--	--	2	87	1	7	--	15	--	1	--	--	--	--
Lampsilis cardium	--	7	4	7	45	14	20	150	59	1	60	4	26	11	27	2	1	--	--
Lampsilis fasciola	--	2	2	6	17	11	4	91	56	3	41	6	8	5	8	--	2	--	--
Lasmigona costata	--	2	1	13	34	--	7	62	58	5	31	1	3	1	18	1	5	1	--
Leptodea fragilis	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--
Ligumia recta	--	--	--	1	2	--	2	17	12	--	6	1R	1	--	4	--	2	--	--
Medionidus conradicus	--	--	--	--	--	--	--	--	--	2	1	--	11	1	1	--	--	--	--
Pegias fabula **E**	--	--	--	--	--	--	--	1	55	15	10	--	23	--	2	--	1	--	--
Pleurobema clava **E**	--	--	--	--	--	--	--	--	--	--	1?	--	--	--	--	--	--	--	--
Pleurobema oviforme	--	--	--	--	--	1	--	--	--	--	1R	--	--	--	--	--	--	--	--
Pleurobema sintoxia	--	--	--	4	24	12	8	661	263	2	452	102	55	50	266	4	4	--	--

Table 4 (continued)

	Site Number																		
	BSF 1	BSF 2	BSF 3	BSF 4	BSF 5	BSF 6	BSF 7	BSF 8	BSF 9	BSF 10	BSF 11	BSF 12	BSF 13	BSF 14	BSF 15	BSF 16	BSF 17	BSF 18	BSF 19
Potamilus alatus	--	1	2	23	117	--	39	140	187	5	94	59	14	15	26	3	28	19	--
Ptychobranchus fasciolaris	--	--	--	1	6	1	1	11	33	1	21	5	7	10	27	2	3	2	--
Quadrula p. pustulosa	--	12	6	9	114	38	25	338	127	--	88	9	8	18	79	5	2	--	1R
Strophitus undulatus	--	--	--	1	11	1	--	67	23	1	15	2	--	--	5	--	--	3	--
Tritogonia verrucosa	--	--	12	--	2	18	18	95	4	1	6	--	1	--	5	--	1R	--	--
Villosa iris	--	--	--	7	--	--	--	--	12	4	8	--	4	3	11	--	1	--	--
Villosa taeniata	--	--	--	2	--	--	--	2	37	4	15	1	1	2	9	1	2	1	--
Villosa trabalis **E**	--	--	--	3	4	--	--	8	23	--	6	--	--	--	1	--	1	--	--
Total number of specimens	0	26	28	89	402	97	127	1969	1545	114	1134	239	280	149	678	30	84	30	1
Total number of species	0	6	7	16	16	8	11	20	19	16	23	13	17	13	20	10	15	7	1
Total sampling hours	1.5	3	12	3	13	3	6	69	52	5.5	58.5	5	11	16	35.5	3	6.5	17.5	7
CPUE by site	0	8.7	2.3	29.7	30.9	32.3	21.2	28.5	29.7	20.7	19.4	47.8	25.4	9.3	19.1	10	12.9	1.7	0.14

TABLE 5. Freshwater mussels collected in tributaries of the Big South Fork Cumberland River 1999-2002.

[**CF**, Clear Fork; **CC**, Crooked Creek; **WOC**, White Oak Creek; **NR**, New River; **NWO**, North White Oak Creek; **LF**, Laurel Fork; **SCC**, Station Camp Creek; **NBC**, No Business Creek; **WC**, Williams Creek; –, no specimens collected; **E**, Federally listed endangered; **CPUE**, catch per unit effort.]

	Site Number																			
Mussel species	CF 1	CF 2	CF 3	CF 4	CF 5	CC 1	WOC 1	NR 1	NR 2	NR 3	NWO 1	NWO 2	NWO 3	NWO 4	NWO 5	NWO 6	LF 1	SCC 1	NBC 1	WC 1
Alasmidonta atropurpurea **E**	74	14	8	9	1	32	61	--	2	--	--	14	42	66	17	3	--	--	--	--
Elliptio dilatata	34	2	2	13	1	22	2	--	1R	--	--	--	--	--	--	--	--	--	--	--
Lampsilis cardium	10	6	3	12	1	1	1	--	1	--	--	--	--	--	--	--	--	--	--	--
Lampsilis fasciola	6	5	15	6	3	4	5	--	1	--	--	--	--	1	--	--	--	--	--	--
Lasmigona costata	24	96	68	64	--	--	40	--	12	--	--	--	--	--	--	--	--	--	--	--
Potamilus alatus	--	--	--	--	--	--	--	--	1R	--	--	--	--	--	--	--	--	--	--	--
Quadrula p. pustulosa	--	--	1	--	1R	--	--	--	2R	--	--	--	--	--	--	--	--	--	--	--
Strophitus undulatus	--	--	2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Villosa iris	18	4	5	12	--	--	11	--	1	--	--	--	--	--	--	--	--	--	--	--
Total number of specimens	166	127	104	116	7	59	120	0	21	0	0	14	42	67	17	3	0	0	0	0
Total number of species	6	6	8	6	5	4	6	0	8	0	0	1	1	2	1	1	0	0	0	0
Total sampling hours	9.5	6	5	6	2	5	6.5	3.5	10.5	1.5	3	3	1	2	4.5	4	1	3	2	1
CPUE by site	17.5	21.2	20.8	19.3	3.5	11.8	18.5	0	2	0	0	4.7	42	33.5	3.8	0.75	0	0	0	0

a questionable record because its identification was not confirmed. The 53 mussel species reported in Table 1 by Schuster (1988) represents a compilation of mussel species reported in the literature and verification of museum records. Of the 29 mussel species reported during the present survey, three species (*Epioblasma triquetra*, *Pyganodon grandis*, and *Utterbackia imbecillis*) are included with this report as records for the BSF (Ronald Cicerello, personal communication, 2003). The recent survey was limited to the free-flowing reaches of the BSF.

Table 6 is a summary of statistics related to the presence of mussels in the BSF basin. A total of 328 person hours were spent sampling mussels in the BSF and 80 person hours in tributary streams. Based on percent composition, the three most abundant species found in the mainstem BSF were *Pleurobema sintoxia* (27%), *Elliptio dilatata* (16%) and *Quadrula pustulosa* (12%). The three most abundant species found in tributary streams were *Alasmidonta atropurpurea* (40%), *Lasmigona costata* (35%) and *E. dilatata* (9%). Three species are extremely rare in the BSF and were represented as single live individuals: *Alasmidonta marginata, Elliptio crassidens* and *Leptodea fragilis*. Two additional species are also rare in the BSF: *Pleurobema oviforme*, two specimens and *Alasmidonta viridis*, four specimens.

The middle reach of the BSF between the mouth of Rough Shoals Branch, Tennessee (site BSF 5) and the shoal upstream from the confluence of Bear Creek, Kentucky (site BSF 15) is the most productive for mussels. Sampling sites containing the greatest number of mussel species were found at Big Island (23 species, site BSF 11), followed by 20 each at Station Camp Creek (site BSF 8) and Bear Creek (site BSF 15), and 19 at the confluence with Parch Corn Creek (site BSF 9). These four sites in addition to Oil Well Branch (site BSF 13) are considered the best nursery areas in the river based on the number of smaller size-class individuals measured and interpreted as evidence of recent reproduction and recruitment. All five federally listed species are reproducing and recruiting in the BSF based on measured individuals in the 4-40 mm size-class. Individual size-class measurement data for all mussels are presented in Fig. 3(a-e).

Results of mussel sampling in the tributaries of the BSF are presented in Tables 5 and 6. Eight species were found in Clear Fork and New River, six in White Oak Creek, four in Crooked Creek, and two in North White Oak Creek. A large population of *A. atropurpurea* exists in Clear Fork. Both *Quadrula pustulosa* and *Strophitus undulatus* are present in Clear Fork but are rare. In New River, a population of *Alasmidonta atropurpurea* was identified along with live specimens of *Lampsilis cardium, L. fasciola* and *Villosa iris*. Relic individuals of three species *Elliptio dilatata, Potamilus alatus, and Q. pustulosa*

TABLE 6. Summary statistics related to the presence of freshwater mussels in the Big South Fork Cumberland River Basin, 1999-2002.

[**CPUE**, catch per unit effort; –, no specimens collected; **E**, federally listed endangered; **na**, not applicable.]

	Big South Fork Cumberland River (total sampling hours = 328)			Tributaries to Big South Fork (total sampling hours = 80)		
Mussel species	Total specimens	Percent composition	CPUE	Total specimens	Percent composition	CPUE
Actinonaias pectorosa	229	3	0.70	--	--	--
Alasmidonta atropurpurea **E**	16	<1	.05	343	40	4.3
Alasmidonta marginata	1	<.1	.003	--	--	--
Alasmidonta viridis	4	<.1	.01	--	--	--
Elliptio crassidens	1	<.1	.003	--	--	--
Elliptio dilatata	1,123	16	3.4	77	9	0.96
Epioblasma brevidens **E**	263	4	.80	--	--	--
Epioblasma f. walkeri **E**	113	2	.34	--	--	--
Lampsilis cardium	438	6	1.3	35	4	.43
Lampsilis fasciola	262	4	.80	46	5	.57
Lasmigona costata	243	3	.74	304	35	3.8
Leptodea fragilis	1	<.1	.003	--	--	--
Ligumia recta	48	1	.15	--	--	--
Medionidus conradicus	16	<1	.05	--	--	--
Pegias fabula **E**	107	1	.33	--	--	--
Pleurobema clava **E**	1	<.1	.003	--	--	--
Pleurobema oviforme	2	<.1	.006	--	--	--
Pleurobema sintoxia	1,907	27	5.8	--	--	--
Potamilus alatus	772	11	2.3	1	<1	.01
Ptychobranchus fasciolaris	131	2	.40	--	--	--
Quadrula p. pustulosa	879	12	2.7	4	<1	.05
Strophitus undulatus	129	2	.40	2	<1	.02
Tritogonia verrucosa	163	2	.50	--	--	--
Villosa iris	50	1	.15	51	6	.64
Villosa taeniata	77	1	.23	--	--	--
Villosa trabalis **E**	46	1	.14	--	--	--
Total	7,022	na	na	863	na	na

were also reported. A new population of *A. atropurpurea* was discovered in Crooked Creek, a tributary of Clear Fork. Both White Oak and North White Oak Creeks contained large numbers of *A. atropurpurea.* No live mussels or relict shell were found in Laurel Fork, Station Camp Creek, No Business Creek, or Williams Creek.

SPECIES ACCOUNTS

Species accounts of all mussels reported from the BSF or near the confluence of the BSF with the Cumberland River are based on literature sources, museum records, field surveys, and best professional judgment.

Actinonaias ligamentina (Lamarck 1819) (Mucket)

Wilson & Clark (1914) reported the mucket from the BSF at Parkers Lake Station (UMMZ 107789) and above Burnside, Kentucky. In 1924, Ortmann identified the mucket from the BSF at Burnside (CMNH 12060) (Schuster,

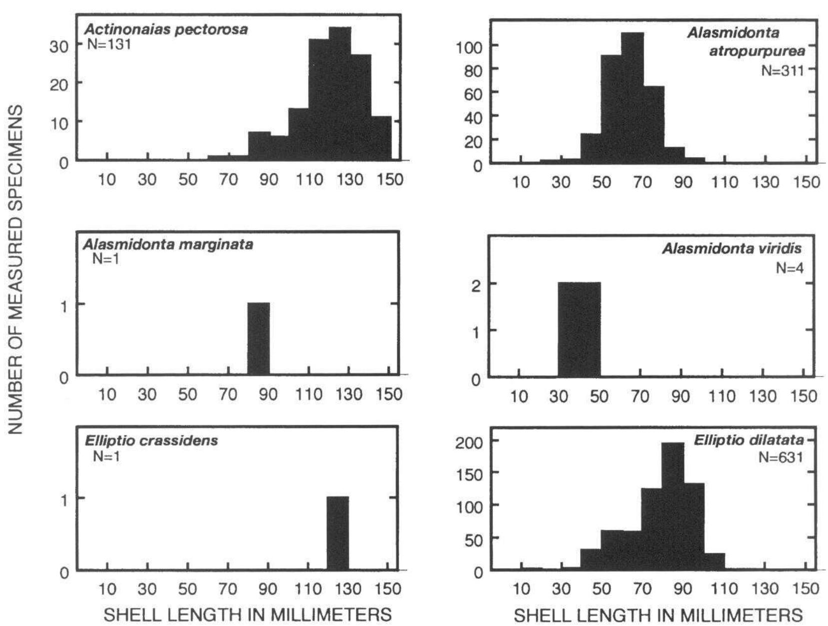

FIG. 3a. Size class distribution of measured mussels from the Big South Fork Cumberland River Basin, 1999-2002. N = Tolal number of specimens measured.

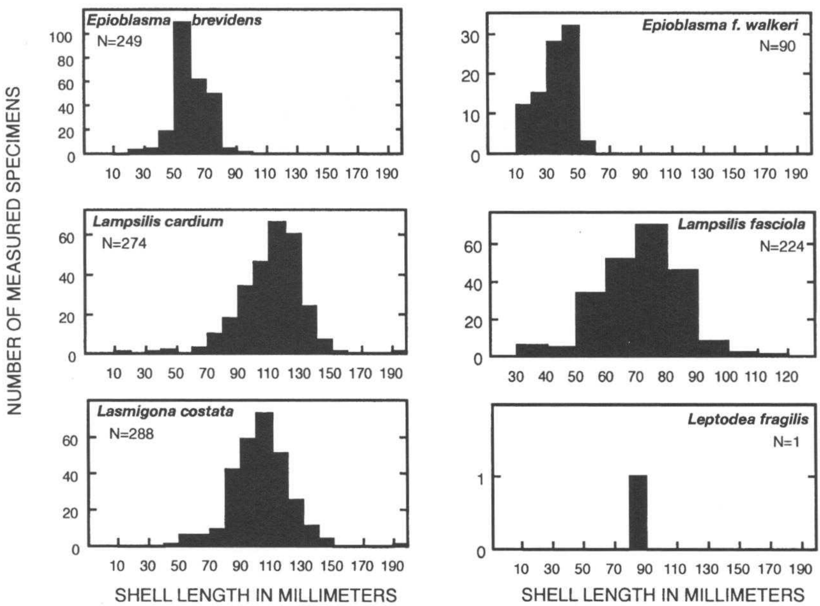

FIG. 3b. Size class distribution of measured mussels from the Big South Fork Cumberland River Basin, 1999-2002 (continued). N = Tolal number of specimens measured.

1988), but Neel & Allen (1964) considered it rare in the BSF two miles above Burnside (UMMZ 172820). Shoup & Peyton (1940) reported eroded individuals in the New River at Cordell, Scott County, Tennessee. No individuals were found during the present survey and the mussel is believed extirpated from the BSF. The mucket should be considered a candidate for restoration in the BSF, New River, and possibly Clear Fork. Williams *et al.* (1993) considered this species to be currently stable.

Actinonaias pectorosa (Conrad 1834) (Pheasantshell)

The pheasantshell was considered fairly common in the BSF (Wilson & Clark, 1914) but Neel & Allen (1964) considered it rare. The mussel was rediscovered in the BSF in 1979 near the confluence with Troublesome Creek, Kentucky (Harker *et al.,* 1979, 1981; Schuster 1988). Bakaletz (1991) found pheasantshells in the BSF in Tennessee in the mid-1980s and recently by Dunn (2000). The mussel was found live at 14 sites in the BSF but apparently does not occur in any of the tributaries streams sampled. The pheasantshell is a Cumberlandian species that should be considered a candidate for restoration in

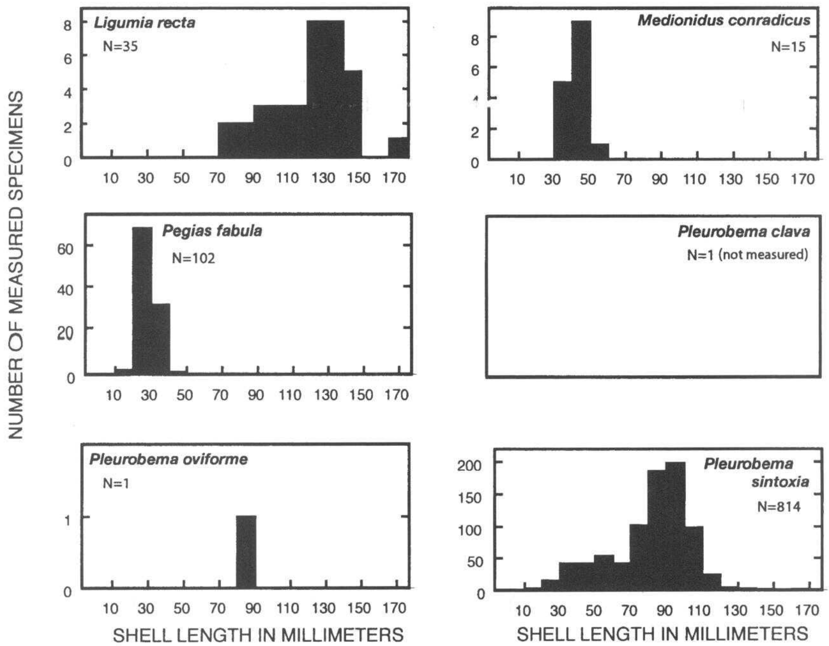

FIG. 3c. Size class distribution of measured mussels from the Big South Fork Cumberland River Basin, 1999-2002 (continued). N = Tolal number of specimens measured.

the New River and possibly Clear Fork. Williams *et al.* (1993) considered this species to be of special concern.

Alasmidonta atropurpurea (Rafinesque 1831) (Cumberland elktoe)

The Cumberland elktoe was not known to occur in the mainstem BSF. Bakaletz (1991) discovered the mussel in the BSF in the mid-1980s. In 1924, Ortmann collected the mussel from the New River at New River, Scott County, Tennessee (UMMZ 62174). Shoup & Peyton (1940) reported it in 1939 from the Clear Fork at Peter's Bridge, Morgan County, Tennessee (UMMZ 134860) but were misidentified as *Alasmidonta marginata*. The mussel is relatively rare in the BSF but more common in tributary streams throughout the drainage (Call & Parmalee, 1981; Gordon & Layzer, 1993; Cicerello & Laudermilk, 2001; Shute *et al.*, 1999; and Dunn, 2000). The Cumberland elktoe was found live at 6 sites in the BSF and 13 sites in tributary streams. A new population was discovered in Crooked Creek (tributary to Clear Fork) and was rediscovered in the New River. The largest populations occurring in the NRRA are found in

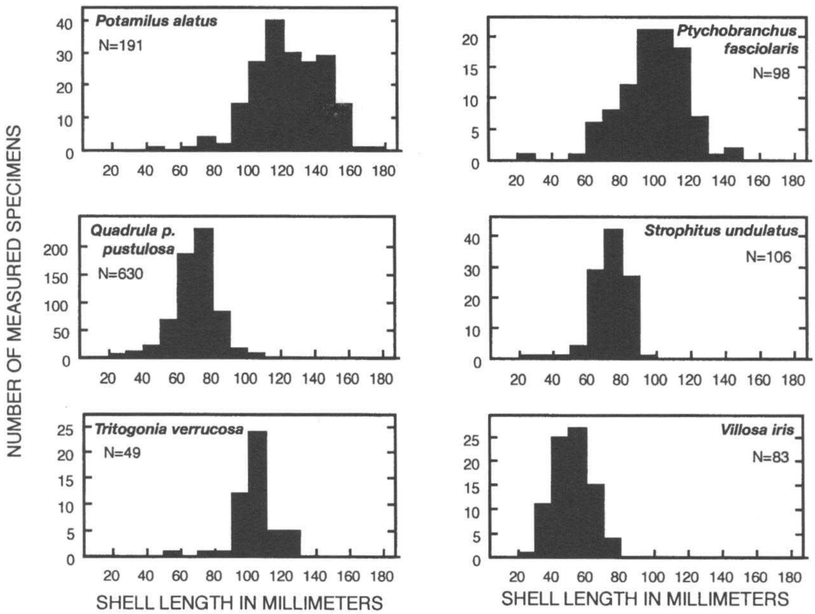

FIG. 3d. Size class distribution of measured mussels from the Big South Fork Cumberland River Basin, 1999-2002 (continued). N = Tolal number of specimens measured.

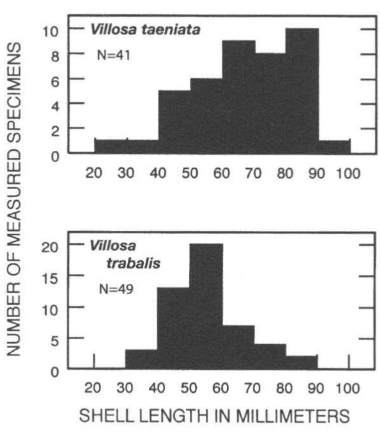

FIG. 3e. Size class distribution of measured mussels from the Big South Fork Cumberland River Basin, 1999-2002 (continued). N = Tolal number of specimens measured.

tributary streams including Clear Fork, Crooked Creek, White Oak Creek, and North White Oak Creek. Undiscovered populations of Cumberland elktoe may occur in isolated streams of the Cumberland Plateau. This Cumberland River endemic is currently listed endangered under the federal Endangered Species Act.

Alasmidonta marginata Say 1818 (Elktoe)

The elktoe was reported historically from the BSF above Burnside and the Cumberland River at Burnside, Kentucky (UMMZ101091) (Wilson & Clark, 1914; Schuster, 1988). Shoup & Peyton (1940) misidentified the mussel from Clear Fork. During the present survey one large adult was found at Big Island (site BSF 11). It is uncertain whether or not this species is reproducing and recruiting in the river. Additional monitoring of mussel populations in the BSF may identify more individuals. The elktoe is uncommon in the BSF and should be considered a candidate for restoration in other reaches of the BSF and New River. Williams *et al.*, (1993) considered this species to be of special concern.

Alasmidonta viridis (Rafinesque 1820) (Slippershell Mussel)

The slippershell was reported in 1939 from the BSF at Leatherwood Ford, Scott County, Tennessee (UMMZ 134865) (Shoup & Peyton, 1940). The mussel is also reported from the Little South Fork Cumberland River (Schuster, 1988). Four live individuals were found in the BSF at two upper sites near Rough Shoals Branch (sites BSF 4 and 5). Additional monitoring of mussel populations in the river and tributary streams may identify more individuals. The slippershell mussel is often associated with smaller headwater streams and uncommon in the BSF. This mussel should be considered a candidate for restoration in other reaches of the BSF including the New River, Clear Fork, Crooked Creek, White Oak Creek, and North White Oak Creek. Williams *et al.* (1993) considered this species to be of special concern.

Cumberlandia monodonta (Say 1829) (Spectaclecase)

The spectaclecase was collected from the BSF at Burnside, Pulaski County (UMMZ 107643) and Fords Island, McCreary County, Kentucky (Walker, 1911; Schuster, 1988). The mussel was not reported in surveys done by Wilson & Clark (1914) or Neel & Allen (1964). The river near Burnside is now impounded from the backwaters of Wolf Creek Dam. The spectaclecase is probably extirpated from the BSF and the Caney Fork, Tennessee, may harbor the last population in the Cumberland River system. This species should be considered a candidate for restoration in the BSF. Williams *et al.* (1993) considered it to be threatened.

Cyclonaias tuberculata (Rafinesque 1820) (Purple Wartyback)

The purple wartyback was collected in the BSF by Wilson & Clark (1914). In 1924, Ortmann reported the mussel in the Cumberland River at Burnside, Kentucky (UMMZ 98629) (Schuster, 1988), but Neel & Allen (1964) considered it rare. No individuals were found during the recent survey indicating this species is either extremely rare or possibly extirpated from the BSF. The purple wartyback is a candidate for restoration in the BSF and New River. Williams *et al.* (1993) considered it to be of special concern.

Dromus dromas (Lea 1834) (Dromedary Pearly Mussel)

The dromedary pearly mussel was reported from the Cumberland River in Kentucky at Burnside (MCZ 99936), the BSF opposite Parkers Lake Station (UMMZ 98569), and mouth of Fishing Creek (Wilson & Clark, 1914; Schuster, 1988). In 1924, Ortmann collected it in the Cumberland River at Burnside (UMMZ 62153) (Schuster 1988). This mussel is apparently extirpated from the BSF and possibly the Cumberland River system. The largest extant populations occur in the Clinch and Powell Rivers of the Tennessee River system. Therefore, Tennessee River populations can be used to recover the dromedary in the BSF. This Cumberlandian species is currently listed endangered under the Endangered Species Act.

Ellipsaria lineolata (Rafinesque 1820) (Butterfly)

The butterfly was collected in 1910 from the Cumberland River at Burnside, Pulaski County, Kentucky (UMMZ 71077) (Wilson & Clark, 1914). In 1924, Ortmann reported the mussel from the same locality (CMNH 12066) (Schuster, 1988). No individuals were found during the recent survey and it is apparently extirpated from the BSF. This mussel should be considered a candidate for restoration in the BSF. Williams *et al.* (1993) considered this Ohioan species to be of special concern.

Elliptio crassidens (Lamarck 1819) (Elephantear)

The elephantear was identified from the BSF by Wilson & Clark (1914) and reported by Neel & Allen (1964) as rare. One live individual was found in the BSF upstream from the confluence with Station Camp Creek (site BSF 8). It is uncertain whether or not this species is reproducing and recruiting in the river based upon one individual. Additional monitoring of mussel populations in the BSF may locate more individuals. The elephantear should be a candidate for restoration in the BSF and possibly the New River. Williams *et al.* (1993) considered this species to be currently stable.

Elliptio dilatata (Rafinesque 1820) (Spike)

The spike was collected from the BSF by Wilson & Clark (1914) and reported by Neel & Allen (1964) as common. It formerly occurred in the New River (Shoup & Peyton, 1940). The spike is the second most abundant mussel in the NRRA and occurs at 16 sites in the BSF and 7 sites in three tributary streams (Clear Fork, Crooked Creek, and White Oak Creek). A relict individual was found in the New River. This mussel should be considered a candidate for restoration in the New River and possibly North White Oak Creek. Williams *et al.* (1993) considered this species to be currently stable.

Epioblasma arcaeformis (Lea 1831) (Sugarspoon)

The sugarspoon was considered rare in the BSF based on one individual found two miles above Burnside, Pulaski County, Kentucky (Wilson & Clark, 1914; Schuster, 1988). No other information exists confirming its continued presence in the river and it apparently was extirpated at the time of Neel & Allen (1964) surveys (1947-1949). The sugarspoon is a Cumberlandian species that is listed as possibly extinct by Williams *et al.* (1993) and Turgeon *et al.* (1998).

Epioblasma biemarginata (Lea 1857) (Angled Riffleshell)

Based on one record, the angled riffleshell was reported from the BSF at Burnside, Pulaski County, Kentucky (UMMZ 90654) (Johnson, 1978; Schuster, 1988, Parmalee & Bogan, 1998). No information is available concerning the distribution of this mussel in the upper Cumberland River or BSF. Williams *et al.* (1993) considered the angled riffleshell as possibly extinct.

Epioblasma brevidens (Lea 1831) (Cumberlandian Combshell)

Wilson & Clark (1914) reported the Cumberlandian combshell as abundant in the BSF opposite Parkers Lake Station and above Burnside, Kentucky (UMMZ

91369) (Schuster, 1988). The mussel was collected in 1902 by Daniels from the Cumberland River at Burnside (MCZ 236704) (Johnson, 1978) and was not found by Shoup & Peyton (1940) or Neel & Allen (1964). The mussel was rediscovered in the BSF in 1979 and 1986 near the confluence of Troublesome and Bear Creeks, Kentucky (Harker *et al.* 1979, 1981; Schuster, 1988). Bakaletz (1991) collected the mussel in Tennessee in the mid-1980s and in recent surveys (Shute *et al.* 1999; Dunn, 2000). The Cumberlandian combshell was found live in the BSF at 10 sites, relict at two sites. The NRRA of the BSF contains the largest remaining population in the Cumberland River system and those populations can be used for restoration in the New River and other locations within its known historical range. At least one site in the BSF was noted as a major nursery area containing both adults and juveniles. This Cumberlandian species is currently listed endangered under the federal Endangered Species Act.

Epioblasma capsaeformis (Lea 1834) (Oyster Mussel)

Wilson and Clark (1914) reported the oyster mussel as fairly abundant in the BSF (UMMZ 90702, 90703), but Neel & Allen (1964) considered it rare (UMMZ 172823). The oyster mussel was collected in 1979 and 1986 in the BSF near the confluence of Troublesome (OSUM 45468) and Bear Creeks, Kentucky (Harker *et al.* 1979, 1981; Schuster, 1988). No oyster mussels were found during the present survey and the mussel is believed extirpated from the BSF and the Cumberland River system. The individuals previously identified in 1979 and 1986 may actually represent *Epioblasma florentina walkeri*. Known extant populations of oyster mussel occur in the Clinch River of the Tennessee River system and those populations can be used for recovery in the BSF, New River, and other streams within its known historical range. This Cumberlandian species is currently listed endangered under the federal Endangered Species Act.

Epioblasma flexuosa (Rafinesque 1820) (Leafshell)

Based on one record, the leafshell was reported from the Cumberland River, at Port Burnside, Pulaski County, Kentucky (Johnson, 1978; Schuster, 1988). The specimen is reportedly in the mollusk collections at UMMZ. No information is available concerning the distribution of this mussel in the upper Cumberland River or BSF. Williams *et al.* (1993) considered the leafshell as possibly extinct.

Epioblasma florentina florentina (Lea 1857) (Yellow Blossom)

The yellow blossom was reported from the BSF at Burnside, Pulaski County, Kentucky (UMMZ 90740) (Johnson, 1978; Schuster, 1988). Parmalee & Bogan (1998) noted that *Epioblasma florentina florentina* inhabited the larger rivers and graded into the headwaters form, *E. f. walkeri*. No information is available concerning the distribution of this species in the upper Cumberland River or BSF. The yellow blossom is a Cumberlandian species listed as endangered under the federal Endangered Species Act, but considered possibly extinct by Williams *et al.* (1993) and Turgeon *et al.* (1998).

Epioblasma florentina walkeri (Wilson & Clark 1914) (Tan Riffleshell)

Wilson & Clark (1914) reported the tan riffleshell as formerly occurring in the BSF with no reference as to the validity of their statement. In 1924, Ortmann collected the mussel from the Cumberland River at Burnside, Pulaski County, Kentucky (CMNH 12132) (Schuster, 1988). Neel & Allen (1964) identified it as questionable from the BSF above Burnside. However, examination of one *Epioblasma florentina walkeri* specimen from the BSF (no date or specific locality information) was confirmed that had been misidentified as *E. capsaeformis* (UMMZ 90717). Bakaletz (1991) rediscovered the tan riffleshell in the mid-1980s and has recently been found by Shute *et al.* (1999) and Dunn (2000). Recent surveys found tan riffleshells live in the BSF at six sites including two sites identified as nurseries containing both adults and juveniles. The mussel is rare in the BSF and the NRRA contains the only extant population remaining in the Cumberland River system. This Cumberlandian species is a candidate for restoration in the BSF, and possibly the New River and Clear Fork since its more of a headwater species. The tan riffleshell is currently listed as endangered under the federal Endangered Species Act.

Epioblasma haysiana (Lea 1833) (Acornshell)

Wilson & Clark (1914) noted the acornshell as rare in the BSF at Burnside and Parkers Lake Station, Kentucky (UMMZ 91436, 91428, 62136). The mussel was also collected in the BSF in 1924 by Ortmann (CMNH 12130)(Schuster, 1988). Neel & Allen (1964) considered it rare but formerly abundant in the river (UMMZ 172284). No individuals were found during the present survey. The acornshell is a Cumberlandian species listed as possibly extinct by Williams *et. al.* (1993) and Turgeon *et al.* (1998).

Epioblasma lewisii (Walker 1910) (Forkshell)

Walker (1910) reported the forkshell from the BSF at Burnside, Kentucky (UMMZ 91458) (Schuster, 1988). Johnson (1978) synonomized *Epioblasma lewisii* under *E. flexuosa*, claiming that *E. lewisii* is only the small stream form of *E. flexuosa*, a big river species. Little is known of this formerly rare mussel (Parmalee & Bogan, 1998) and Williams *et al.* (1993) considered this species as possibly extinct.

Epioblasma obliquata obliquata (Rafinesque 1820) (Catspaw)

Johnson (1978) confirmed specimens of catspaw at UMMZ collected from the Cumberland River at Burnside, Pulaski County, Kentucky (Schuster, 1988). The mussel would have had access into the BSF from populations in the Cumberland River (Parmalee & Bogan, 1998). The BSF joins the Cumberland River at Burnside. The catspaw is currently listed as endangered under the federal Endangered Species Act.

Epioblasma stewardsonii (Lea 1852) (Cumberland Leafshell)

Johnson (1978) confirmed specimens of Cumberland leafshell collected from the Cumberland River, Pulaski County, Kentucky (UMMZ 90561) (Schuster, 1988). The mussel would have had access into the BSF from populations in the Cumberland River. Williams *et al.* (1993) considered this species as possibly extinct.

Epioblasma triquetra (Rafinesque 1820) (Snuffbox)

No records exist for this species occurrence in the BSF. However, the snuffbox was identified from the Little South Fork Cumberland River, a major tributary in the lower BSF (Ronald Cicerello, pers. comm., 2003). The snuffbox had access into the BSF from populations occurring in the Cumberland River. This mussel should be a candidate for restoration in the BSF and possibly the New River. Williams *et al.* (1993) considered this species to be threatened.

Fusconaia barnesiana (Lea 1838) (Tennessee Pigtoe)

The Tennessee pigtoe was identified in the BSF as *Pleurobema crudum* (Wilson & Clark, 1914). Parmalee & Bogan (1998) considered *P. crudum* a synonym of *F. barnesiana*. However, *Fusconaia barnesiana* does not occur in the upper Cumberland River system. No specimens were found during the present study and the Wilson & Clark (1914) record is considered spurious.

Fusconaia subrotunda (Lea 1831) (Longsolid)

The longsolid was reported from the BSF at Parkers Lake Station (UMMZ 92614) (Wilson & Clark, 1914). In 1924, Ortmann collected it at Burnside, Kentucky (UMMZ 92350) (Schuster, 1988). Shute *et al.* (1999) considered it rare in the BSF at Station Camp Creek horse crossing in Tennessee. No individuals were found during the present survey and the recent record for its occurrence in the BSF is questionable. The longsolid is believed extirpated from the BSF but should be considered a candidate for restoration in the BSF and possibly the New River. Williams *et al.* (1993) considered this species to be of special concern.

Hemistena lata (Rafinesque 1820) (Cracking Pearlymussel)

Wilson & Clark (1914) were the last to report the cracking pearlymussel from the BSF (UMMZ 107878) (Schuster, 1988). This mussel was not found during the present survey and is believed extirpated from the BSF and the Cumberland River system. The largest population remaining for this species occurs in the Clinch River of the Tennessee River system. Therefore, the Clinch River population can be used to recover the mussel in the BSF. The cracking pearlymussel is currently listed endangered under the federal Endangered Species Act.

Lampsilis cardium (Rafinesque 1820) (Plain pocketbook)

The plain pocketbook was reported in the BSF by Wilson & Clark (1914), but Neel & Allen (1964) considered it rare. Shoup & Peyton (1940) collected it in the BSF at Leatherwood Ford and New River at New River Station, Scott County, Tennessee. The mussel is documented in all recent surveys (Schuster, 1988; Bakaletz, 1991; Shute *et al.,* 1999; Dunn, 2000). The plain pocketbook is relatively common in the BSF and found live at 16 sites and 8 sites in Clear Fork, Crooked Creek, White Oak Creek, and New River. Williams *et al.* (1993) considered this species to be of special concern.

Lampsilis fasciola Rafinesque 1820 (Wavy-rayed Lampmussel)

Wilson & Clark (1914) collected the wavy-rayed lampmussel from the BSF, but Neel & Allen (1964) considered it rare. The mussel was not found by Shoup & Peyton (1940), but is reported in all recent surveys (Schuster, 1988; Bakaletz, 1991; Shute *et al.,* 1999; Dunn, 2000). This mussel is relatively common in the BSF, but rare in tributary streams. The wavy-rayed lampmussel was found live at 15 sites in the BSF and nine sites in Clear Fork, Crooked Creek, White Oak Creek, North White Oak Creek, and New River. Williams *et al.* (1993) considered this species to be currently stable.

Lasmigona costata (Rafinesque 1820) (Flutedshell)

Wilson & Clark (1914) reported the fluted shell from the BSF, and Shoup & Peyton (1940) discovered the species in New River at New River Station, Scott County, Tennessee. The mussel was rediscovered in the BSF in 1979 near the confluence with Troublesome Creek, Kentucky (Harker *et al.,* 1979, 1981; Schuster, 1988). The fluted shell is reported in all recent studies and occurs at 16 sites in the BSF and six sites in Clear Fork, White Oak Creek, and New River. Williams *et al.* (1993) considered this species to be currently stable.

Leptodea fragilis (Rafinesque 1820) (Fragile Papershell)

Wilson & Clark (1914) were the last to collect fragile papershells in the BSF. The mussel was rediscovered in 1996 in the lower impounded BSF in Kentucky (Ronald Cicerello, pers. comm., 2003). During the present survey one live individual was found in the BSF in a pool just upstream from the horse crossing at Station Camp Creek (site BSF 8). The fragile papershell is a common mussel but rare in the BSF and additional monitoring of mussel populations in the BSF may identify more individuals. The fragile papershell should be considered a candidate for restoration into the BSF and tributary streams. Williams *et al.* (1993) considered this species to be currently stable.

Ligumia recta (Lamarck 1819) (Black Sandshell)

The black sandshell was reported from the BSF at Parkers Lake Station and above Burnside, Kentucky (Wilson & Clark, 1914), but Neel & Allen (1964) reported it rare. Shoup & Peyton (1940) collected it from the New River at New River Station, Scott County, Tennessee. The mussel was rediscovered in 1979 in the BSF near the confluence with Troublesome Creek, Kentucky (Harker *et al.,* 1979, 1981; Schuster, 1988). Black sandshells were found live in the BSF at nine sites and relict at one site. The black sandshell is relatively uncommon in the river and occurs in both pool and riffle habitats. This mussel should be considered a candidate for restoration in the New River. Williams *et al.* (1993) considered this species to be of special concern.

Medionidus conradicus (Lea 1834) (Cumberland Moccasinshell)

The Cumberland moccasinshell was collected from the BSF opposite Parkers Lake Station and two miles above Burnside, Kentucky (Wilson & Clark, 1914). In 1924, Ortmann reported it from the Cumberland River at Burnside, Kentucky (UMMZ 98446) (Schuster, 1988). The mussel was rediscovered in 1979 in the BSF near the confluence with Troublesome Creek, Kentucky (OSUM45461) (Harker *et al.*, 1979, 1981; Schuster, 1988) and reported in the mid-1980s (Bakaletz, 1991). The Cumberland moccasinshell is uncommon in the BSF occurring at five sites. This Cumberlandian species may have occurred historically in some of the tributary streams and should be considered a candidate for restoration at other locations in the BSF and Clear Fork, Crooked Creek, White Oak Creek, North White Oak Creek, and New River. Williams *et al.* (1993) considered this species to be of special concern.

Obliquaria reflexa (Rafinesque 1820) (Threehorn Wartyback)

Wilson & Clark (1914) were the last to report this species from the BSF (UMMZ 98798) (Schuster, 1988). No specimens were found during the present survey and the mussel is believed extirpated from the river. The threehorn wartyback should be considered a candidate for restoration in the BSF. Williams *et al.* (1993) considered this species to be currently stable.

Obovaria subrotunda (Rafinesque 1820) (Round Hickorynut)

The round hickorynut was reported as common in the BSF at Burnside, Kentucky (Wilson & Clark, 1914). The mussel was collected in 1924 by Ortmann from the Cumberland River at Burnside (UMMZ 105718) and in 1948 by Neel two miles upstream from Burnside (UMMZ 172832) (Schuster, 1988). No individuals were found during the present survey and the mussel is believed extirpated from the BSF. The round hickorynut should be considered a candidate for restoration in the BSF. Williams *et al.* (1993) considered this species to be of special concern.

Pegias fabula (Lea 1838) (Littlewing Pearlymussel)

The littlewing pearlymussel was collected live in the BSF in the mid-1980s and is the first record of its occurrence in the river (Bakaletz, 1991). It has since been reported by Shute *et al.* (1999) and Dunn (2000). The mussel was previously known to occur in the BSF drainage in the Little South Fork Cumberland River (Starnes & Starnes, 1980; Starnes & Bogan, 1982; Schuster, 1988). The littlewing pearlymussel was collected live at seven sites in the BSF and two sites were noted as a nursery for the species containing both adults and juveniles: Parch Corn Creek (site BSF 9) and Oil Well Branch (site BSF 13). The mussel has been extirpated from much of the Cumberland and Tennessee River systems and the BSF contains the largest extant population range-wide. The mussel should be considered a candidate for restoration in other parts of the BSF and potentially tributary streams of the Tennessee River system. This Cumberlandian species is currently listed endangered under the federal Endangered Species Act.

Pleurobema clava (Lamarck 1819) (Clubshell)

Wilson and Clark (1914) considered the clubshell relatively rare in the BSF. They reported the mussel from Parkers Lake Station, Whitley County, Kentucky (UMMZ81487) and above Burnside, Pulaski County, Kentucky (UMMZ81486) (Schuster 1988). One live individual was found in the BSF at Big Island (site BSF 11) and tentatively identified as *P. clava*. The mussel was not photographed and permit constraints did not allow for the taking of what may have been this federally listed mussel for verification purposes. Additional monitoring of the mussel populations may verify its presence in the BSF. Options for restoring this species in the river are limited since the clubshell is probably extirpated from both the Cumberland and Tennessee River systems. Parent stock would either have to come from the Green River (Kentucky) or Allegheny River (Pennsylvania), both tributaries in the Ohio River system. The clubshell is currently federally listed endangered under the federal Endangered Species Act.

Pleurobema cordatum (Rafinesque 1820) (Ohio Pigtoe)

The identification of the Ohio pigtoe in the BSF above Burnside was questionable (Wilson & Clark, 1914). The Ohio pigtoe is a big river species that had access into the BSF from populations in the Cumberland River. No evidence could be found that this mussel occurred in the BSF however, two closely related species, *Pleurobema rubrum* and *P. sintoxia*, are both reported from the BSF (Wilson & Clark 1914). This adds credibility for the occurrence of the mussel in the river since all three species co-exist in other river systems.

The Ohio pigtoe should be considered a candidate for restoration in the BSF. Williams *et al.* (1993) considered it to be of special concern.

Pleurobema oviforme (Conrad 1834) (Tennessee Clubshell)

One record exists for the Tennessee clubshell from the Cumberland River, Burnside, Kentucky (OSUM 112833) (Wilson & Clark, 1914; Schuster, 1988). Bakaletz (1991) rediscovered the mussel in the mid-1980s from the BSF. The Tennessee clubshell is rare in the BSF and one live specimen was found downstream from Rough Shoals Branch (site BSF 6) and fresh dead at Big Island (site BSF 11). Additional monitoring of the mussel populations in the river may identify more individuals. The Tennessee clubshell should be considered a candidate for restoration in the BSF and possibly the New River and Clear Fork, since it also occurs in smaller tributary streams including the Little South Fork Cumberland River (Starnes & Bogan 1982). Williams *et al.* (1993) considered this Cumberlandian species to be of special concern.

Pleurobema rubrum (Rafinesque 1820) (Pyramid Pigtoe)

Wilson & Clark (1914) reported the pyramid pigtoe in the BSF above Burnside, Kentucky (UMMZ 80943, 81000). In 1924, Ortmann collected the mussel from the same location (CMNH 12010) (Schuster, 1988). The pyramid pigtoe was not found during the present survey and is believed extirpated from the river. The mussel should be considered a candidate for restoration in the BSF. Williams *et al.* (1993) considered this species to be threatened.

Pleurobema sintoxia (Rafinesque 1820) (Round Pigtoe)

The round pigtoe was reported as occurring rather frequently in the BSF (UMMZ 81582, 80989) (Wilson & Clark, 1914). In 1924, Ortmann collected the mussel from the Cumberland River at Burnside (CMNH 12009) but not found by Neel & Allen (1964). The mussel was rediscovered in the river in 1978, 1979, and 1986 near the confluence of Difficulty (OSUM 43012), Troublesome (OSUM 45472), and Bear Creeks, Kentucky (Harker *et al.*, 1979, 1981; Schuster 1988). The round pigtoe was reported in the mid-1980s by Bakaletz (1991) and collected in all recent surveys. It was found live at 14 sites and is the most common mussel in the BSF. It may have occurred historically in the New River. The BSF contains one of the largest extant populations in the Cumberland or Tennessee River systems and should be considered a candidate for restoration in the New River. Williams *et al.* (1993) considered this species to be currently stable.

Potamilus alatus (Rafinesque 1820) (Pink Heelsplitter)

Wilson & Clark (1914) were the first to report pink heelsplitters from the BSF but Neel and Allen (1964) considered it rare. The mussel was rediscovered in the BSF in 1979 near the confluence with Troublesome Creek, Kentucky (Harker *et al.,* 1979, 1981; Schuster, 1988). The pink heelsplitter is reported in all recent surveys and considered relatively common at 16 sites in the BSF and relict in the New River. Additional monitoring of mussel populations in the New River and Clear Fork may identify more individuals. This mussel should be a candidate for restoration in the New River and Clear Fork. Williams *et al.* (1993) considered this species to be currently stable.

Ptychobranchus fasciolaris (Rafinesque 1820) (Kidneyshell)

Wilson & Clark (1914) found kidneyshells in the lower BSF at Burnside and Parkers Lake Station, Kentucky, but Neel & Allen (1964) considered it rare. The kidneyshell was rediscovered in 1979 in the BSF near the confluence of Troublesome Creek, Kentucky (Harker *et al.,* 1979, 1981; Schuster, 1988). Bakaletz (1991) reported the mussel in the mid-1980s and it has been found in all recent surveys. The kidneyshell is not uncommon in the BSF and reported live at 15 sites. Additional monitoring of the mussel populations in the New River, Clear Fork, White Oak Creek, and North White Oak Creek may produce live individuals. The kidneyshell is a candidate for restoration in the New River and Clear Fork. Williams *et al.* (1993) considered this species to be currently stable.

Ptychobranchus subtentum (Say 1825) (Fluted Kidneyshell)

The fluted kidneyshell was first reported from the BSF above Burnside and Parkers Lake Station, Kentucky (UMMZ 74147) (Wilson & Clark, 1914). Bakaletz (1991) rediscovered the mussel in the BSF in the mid-1980s. No individuals were found during the present survey but the mussel appears limited in distribution to Kentucky near Oil Well Branch (BSF 13) (Bakaletz, 1991). The area near Oil Well Branch, Anne Branch and Troublesome Creek, may be the only location in the BSF where the species occurs. The fluted kidneyshell should be considered a candidate for restoration at other locations in the BSF including the New River and possibly Clear Fork. This Cumberlandian species is a candidate for federal listing under the Endangered Species Act.

Pyganodon grandis (Say 1829) (Giant Floater)

One weathered dead specimen was identified in 1994 from the lower impounded BSF near Burnside, Kentucky (Ronald Cicerello, pers. comm., 2003). The giant floater was not found during the present survey. Giant floaters probably invaded the lower BSF post-impoundment. The present study of the BSF only included the free-flowing reaches of the river downstream to Yamacraw, Kentucky (site BSF 19).

Quadrula cylindrica cylindrica (Say 1817) (Rabbitsfoot)

Wilson & Clark (1914) and Ortmann in 1924 were the last to collect the rabbitsfoot from the BSF (UMMZ 11757, CMNH 11993) (Schuster, 1988). No specimens were found during the present survey and the mussel is believed extirpated from the river. The rabbitsfoot should be considered a candidate for restoration in the BSF, New River, and possibly Clear Fork. Williams *et al.* (1993) considered this species to be threatened.

Quadrula metanevra (Rafinesque 1820) (Monkeyface)

In 1923, Calvin Goodrich collected the monkeyface in the BSF at Burnside, Pulaski County, Kentucky. This is the first record of its occurrence in the river (CMNH 11676) (Schuster, 1988). No individuals were found during the present survey but the mussel had access into the BSF from populations occurring in the Cumberland River. The monkeyface should be considered a candidate for restoration in the BSF. Williams *et al.* (1993) considered this species to be currently stable.

Quadrula pustulosa pustulosa (Lea 1831) (Pimpleback)

The pimpleback was reported from the BSF at Burnside, Kentucky (Wilson & Clark, 1914), but Neel & Allen (1964) considered it rare. Shoup & Peyton (1940) found it in the New River in Tennessee. The mussel was later rediscovered in the BSF in 1979 near the confluence with Troublesome Creek, Kentucky (Harker *et al.*, 1979, 1981; Schuster, 1988) and collected in Tennessee in the mid-1980s (Bakaletz, 1991). The mussel was found live at 16 sites in the BSF, one site in Clear Fork, and relict in the New River. The pimpleback is the third most abundant mussel in the BSF but rare in Clear Fork. This mussel should be considered a candidate for restoration in the New River and possibly other locations in Clear Fork. Williams *et al.* (1993) considered this species to be currently stable.

Quadrula sparsa (Lea 1841) (Appalachian Monkeyface)

In 1900, the Appalachian monkeyface was collected from the Cumberland River at Burnside, Pulaski County, Kentucky by Daniels and is the first record of its occurrence near the confluence of the BSF (UMMZ 76822) (Schuster, 1988). No individuals were found during the present survey. Parmalee & Bogan (1998) report its occurrence from the Cumberland River on their distribution map for the Appalachian monkeyface. They state that if *Quadrula tuberosa* and *Q sparsa* are synonymous, then the form Ortmann (1912) called *Q. sparsa* was also present in the headwaters of the Cumberland River. The possible occurrence of this mussel historically in the BSF remains questionable. The Appalachian monkeyface is a Cumberlandian species currently listed endangered under the federal Endangered Species Act.

Quadrula tuberosa (Lea 1840) (Rough Rockshell)

In 1910, Boepple collected this rare mussel from the BSF at Sloan Shoals near Burnside, Kentucky (Wilson & Clark 1914). A specimen was examined and labeled as collected from the BSF at Burnside, Pulaski County, Kentucky (UMMZ 76856). The exterior of the shell was eroded and positive identification could not be determined. However, the interior of the shell was noted to have lateral and pseudocardinal teeth more closely associated with *Q. metanevra*. Parmalee & Bogan (1998) considered *Quadrula tuberosa* a synonym of *Q. metanevra*. The taxonomic status and the record of its occurrence in the BSF are uncertain.

Strophitus undulatus (Say 1817) (Creeper)

Wilson & Clark (1914) were the first to report the creeper from the BSF. The mussel was rediscovered in the BSF in 1979 and 1986 near the confluence of Troublesome and Bear Creeks, Kentucky (Harker *et al.,* 1979, 1981; Schuster, 1988) and in Tennessee in the mid-1980s (Bakaletz, 1991). This mussel is fairly widespread in the BSF and found live at 10 sites where it is locally common, but rare in Clear Fork. The creeper should be considered a candidate for restoration in the New River, Clear Fork, Crooked Creek, White Oak Creek, and North White Oak Creek. Williams *et al.* (1993) considered this species to be currently stable.

Toxolasma lividus (Rafinesque 1831) (Purple Lilliput)

No record exists for this species occurrence in the BSF. The purple lilliput is reported from the Little South Fork Cumberland River, a major tributary to the lower BSF (Harker *et al.,* 1979, 1981; Starnes & Bogan, 1982; Schuster, 1988). It is reasonable to assume that this mussel was historically part of the BSF fauna and may have been overlooked during sampling due to its small size. The purple lilliput is a Cumberlandian species that should be a candidate for restoration in the BSF and New River. Williams *et al.* (1993) considered this species to be of special concern.

Toxolasma parvus (Barnes 1823) (Lilliput)

No record exists for the lilliput in the BSF but one individual was collected from the Little South Fork Cumberland River in 1977 by Lynn Starnes (OSUMZ 48534) (Schuster 1988, Cicerello and Laudermilk 2001). It is reasonable to assume that this mussel was historically part of the BSF fauna and may have been overlooked during sampling because of its small size. Williams and others (1993) considered this species to be currently stable.

Tritogonia verrucosa (Rafinesque 1820) (Pistolgrip)

The pistolgrip was reported from the BSF (Wilson & Clark, 1914) but not found by Neel & Allen (1964). Historically it occurred in the New River (Shoup & Peyton, 1940). The mussel was rediscovered in 1979 in the BSF near the confluence of Troublesome Creek, Kentucky (Harker *et al.,* 1979, 1981; Schuster, 1988) and in Tennessee in the mid-1980s (Bakaletz, 1991). The pistolgrip was found live at 10 sites in the BSF. The mussel should be a candidate for restoration in the New River. Williams *et al.* (1993) considered this species to be currently stable.

Truncilla donaciformis (Lea 1828) (Fawnsfoot)

Neel & Allen (1964) were the last to report the fawnsfoot from the BSF above Burnside, Kentucky (Schuster, 1988). The mussel was not found during the present survey and is now believed extirpated from the river. The fawnsfoot should be a candidate for restoration in the BSF. Williams *et al.* (1993) considered this species to be currently stable.

Truncilla truncata Rafinesque 1820 (Deertoe)

Wilson and Clark (1914) were the last to report the deertoe from the BSF (UMMZ 70964, 70965) (Schuster, 1988). This mussel was not found during the present survey and is now believed extirpated from the river. The deertoe should be a candidate for restoration in the BSF and New River. Williams *et al.* (1993) considered this species to be currently stable.

Utterbackia imbecillis (Say 1829) (Paper Pondshell)

Paper pondshells were collected in 1994 from the lower impounded BSF near Burnside, Kentucky (Ronald Cicerello, pers. comm., 2003). The mussel is reported from the Little South Fork Cumberland River (Starnes & Bogan, 1982; Schuster, 1988). Paper pondshells probably invaded the BSF post-impoundment of the river. The present survey of the BSF only included the free-flowing reaches of the river downstream to Yamacraw, Kentucky (site BSF 19).

Villosa iris (Conrad 1834) (Rainbow)

Wilson & Clark (1914) reported *Lampsilis picta* and *L. punctata* from the BSF. Both are synonyms under the present nomenclature for *Villosa taeniata* (Parmalee & Bogan, 1998). However, Wilson and Clarks description for *L. picta* fits the description for *V. iris,* and *L. punctata* fits the description for *V. taeniata*. The rainbow mussel occurs in the BSF and was reported in 1939 from Leatherwood Ford, Tennessee (Shoup & Peyton, 1940). The mussel was later rediscovered in the BSF in 1979 near the confluence of Troublesome Creek, Kentucky (Harker *et al.,* 1979, 1981; Schuster, 1988) and reported in Tennessee in the mid-1980s (Bakaletz, 1991). Rainbow mussels were found live at eight sites in the BSF and six sites in Clear Fork, White Oak Creek, and New River. The mussel should be a candidate for restoration in Crooked Creek, New River, North White Oak Creek, and Station Camp Creek. Williams *et al.* (1993) considered this species to be currently stable.

Villosa lienosa (Conrad 1834) (Little Spectaclecase)

One record exists for this species in the BSF from museum collections at UMMZ (172830). Specimen was collected in 1948 two miles above Burnside, Kentucky, and identification confirmed by Schuster (1988) and Cicerello & Laudermilk (2001). No individuals were found during the present survey and it is now believed extirpated from the BSF. The little spectaclecase should be a candidate for restoration in the BSF. Williams *et al.* (1993) considered this species to be currently stable.

Villosa taeniata (Conrad 1834) (Painted Creekshell)

Wilson & Clark (1914) reported the painted creekshell as *L. punctata* that fits the description for this species. The mussel was not found by Neel & Allen (1964) but was reported in 1939 from the New River in Tennessee (Shoup & Peyton, 1940). The painted creekshell was rediscovered in the BSF in 1979 near the confluence of Troublesome Creek, Kentucky (Harker *et al.*, 1979, 1981; Schuster 1988). The mussel has since been reported in the BSF in Tennessee (Bakaletz, 1991; Dunn, 2000). The painted creekshell was found live at 12 sites in the BSF and not found in any tributaries. Additional monitoring of mussel populations in Clear Fork, Crooked Creek, New River, White Oak Creek, and North White Oak Creek may identify live individuals. The painted creekshell should be a candidate for restoration at other locations in the BSF and tributary streams. Williams *et al.* (1993) considered this Cumberlandian species to be currently stable.

Villosa trabalis (Conrad 1834) (Cumberland Bean)

The Cumberland bean was collected in the BSF above Burnside (UMMZ 89248) and Parkers Lake Station, Kentucky (Wilson & Clark, 1914). The mussel was rediscovered in the BSF in 1979 near the confluence of Troublesome Creek, Kentucky (OSUM 45463) (Harker *et al.*, 1979, 1981; Schuster, 1988). Bakaletz (1991) reported the Cumberland bean in Tennessee in the mid-1980s and is reported in recent studies (Shute *et al.*, 1999; Dunn, 2000). The mussel is rare in the BSF and live individuals were found at seven sites. Historically it may have occurred in the New River and possibly Clear Fork. The Cumberland bean should be a candidate for restoration at other locations in the BSF including New River and Clear Fork. This Cumberlandian species is currently listed endangered under the Endangered Species Act.

Villosa vanuxemensis vanuxemensis (Lea 1838) (Mountain Creekshell)

The mountain creekshell was reported rare in the BSF (Neel & Allen, 1964). However, the mussel may have actually been misidentified *Toxolasma lividus* that occurs in the Little South Fork Cumberland River (Harker *et al.*, 1979, 1981; Starnes & Bogan, 1982; Schuster, 1988). The mountain creekshell does not occur in the upper Cumberland River system and the record is spurious.

DISCUSSION AND CONCLUSION

Several federally listed and candidate aquatic species are extant in the BSF drainage. This includes one fish (duskytail darter, *Etheostoma percnurum*) and six mussel species: Cumberland elktoe, *Alasmidonta atropurpurea*; cumberlandian combshell, *Epioblasma brevidens*; tan riffleshell, *E. florentina walkeri*; little-wing pearlymussel, *Pegias fabula*; Cumberland bean, *Villosa trabalis,* and fluted kidneyshell, *Ptychobranchus subtentum*, a candidate for federal listing. All are currently found within the boundaries of the NRRA. Another potential federally listed mussel was found live and tentatively identified as the clubshell, *Pleurobema clava*. The identification of this species was not confirmed and permit constraints did not allow for the taking for verification purposes because of the possibility it could be federally listed. The clubshell was reported historically from the BSF (Wilson & Clark, 1914) and its confirmed identification would be of significant importance for the BSF since it is now believed extirpated from the Cumberland and Tennessee River systems. Four listed mussels are documented historically from the BSF, but are probably extirpated from the BSF and the Cumberland River system: dromedary pearlymussel, *Dromus dromas*; oyster mussel, *E. capsaeformis*; catspaw, *E. obliquata obliquata*; and cracking pearlymussel, *Hemistena lata*. Seven species are possibly extinct according to Williams *et al.* (1993) and Turgeon *et al.* (1998): sugarspoon, *E. arcaeformis*; angled riffleshell, *E. biemarginata*; leafshell, *E. flexuosa*; yellow blossom, *E. florentina florentina* (federally listed); acornshell, *E. haysiana*; forkshell, *E. lewisii*; and Cumberland leafshell, *E. stewardsonii*.

The best documentation as to the historical occurrence of mussels in the BSF is based on Wilson & Clark (1914), Shoup & Peyton (1940), and Neel & Allen (1964) surveys of the drainage and verification of museum records (Schuster, 1988). All three studies were for different purposes and limited by access into the drainage. The purpose of the Wilson & Clark (1914) study of the Cumberland River and its tributaries was the appraisal of the mussel resources from a commercial standpoint for the button industry. They were more interested in the larger, thicker shelled, white nacre species used in the manufacturing of buttons. The probability exists that some small, thin-shelled, or rare species considered of no commercial value were either not found, reported, or of interest.

Shoup & Peyton (1940) studied the biological and chemical characteristics of the upper BSF drainage in Tennessee (1938-1939). They reported widespread pollution occurring in the upper Tennessee portion of the drainage and add credibility to Neel & Allen (1964) observations that the river was severely affected in Kentucky by coalmine wastes. Shoup and Peyton reported crude oil on the surface of White Oak Creek that extended the length of the creek, and pollution from acid mine wastes in the New River. The acid mine drainage in New River was considered severe enough to affect the BSF throughout its entire length. In 1974, 56 percent (4.9 million tons) of Tennessee's coal production originated from the New River basin. Suspended sediments discharged from the New River basin into the BSF amounted to approximately 590,000 tons in 1977 (Parker & Carey, 1980).

Neel and Allen's (1964) survey was initiated to document changes in the mussel fauna as a result of impoundment of the Cumberland River (Lake Cumberland). Their sampling was limited to two sites accessible in the lower BSF in Kentucky. Unfortunately, at the time of their survey (1947-1949) the mussel fauna in the BSF was already in the process of being destroyed from coalmine acids. One of two sites sampled at Yamacraw, Kentucky was noted to contain eroded shell fragments. However, Neel and Allen did find 16 species from above Burnside, Kentucky and all but one species *Elliptio dilatata* was considered rare.

Major changes occurred in the BSF drainage in 1974 with the creation of the NRRA. The status of the mussel fauna in the BSF remained largely unknown until the mid-to-late 1970s when the Kentucky Nature Preserves Commission while conducting water quality and aquatic biology investigations sampled mussels in the BSF near the confluence with Troublesome Creek. This was the first evidence in Kentucky that approximately 20 mussel species had survived in the BSF (Harker *et al.*, 1979, 1980, 1981). From 1985-1986, Bakaletz (1991) float-surveyed the free-flowing sections of the river (approximately 72 km) and sampled tributary streams throughout the drainage under contract to the U.S. Corps of Engineers, Nashville District, Tennessee. Bakaletz (1991) reported 22 species in the BSF and tributary streams including the first report of *Alasmidonta atropurpurea, Epioblasma florentina walkeri,* and *Pegias fabula* (excluding tributaries). His study was the first indication that some mussels had survived in Tennessee.

Approximately 55 mussel species are reported from the BSF drainage and 26 were found live during the recent survey including a specimen tentatively identified as *Pleurobema clava*. Four species were reported as single individuals and are considered extremely rare in the BSF: *Alasmidonta marginata, Elliptio crassidens*, *Leptodea fragilis* and *P. oviforme*. The BSF may have contained as many as 70 species historically based on published reports, museum records, and field surveys. All 70 would have had direct access into the BSF and some of the tributary streams from populations occurring in the historically rich mussel beds of the Cumberland River. Since many mussels are found in association or assemblages with each other, it is reasonable to assume that the fauna in the BSF was probably larger than what had been reported.

Size-class information for measured mussels indicates all five federally listed species are reproducing and recruiting based on specimens measured in the 4-40 mm size range. Seven mussels are questionable as to whether or not they are reproducing and recruiting in the river since only larger or single individuals were found: *Actinonaias pectorosa, Alasmidonta marginata, Elliptio crassidens, Leptodea fragilis, Ligumia recta, Pleurobema oviforme* and *Tritogonia verrucosa.* All other mussels collected during the study are considered to be reproducing and recruiting in the river however the problem with the seven previously mentioned mussels may be our inability and/or difficulty in finding small individuals or, they are indeed extremely rare.

The BSF drainage has suffered from severe pollution from extensive coal mining in the watershed and oil and gas exploration/extraction. The survival of 26 species in the river system is probably attributed to the river's protection as a NRRA and the Surface Mining Control and Reclamation Act (SMCRA) of 1977. The Act contains several provisions related to protecting the environment from surface coal mining operations and federal protection as a national park (National Park Service 1998). Obviously, the mussel fauna was still surviving at a low level for some species in the drainage however the protection of the area as a national park has allowed for some mussels to recover and re-colonize previously degraded areas of the river system.

The mussel fauna in the BSF is one of the healthiest faunas remaining in the Cumberland River system and is crucial for the survival of many imperiled species because of their rarity and extirpation from other rivers. The BSF contains the largest extant reproducing populations of *Pegias fabula* range-wide, the largest reproducing populations of *Epioblasma brevidens* and *E. florentina walkeri* in the Cumberland River system, and some of the largest populations of *Alasmidonta atropurpurea* in Clear Fork, White Oak Creek, and North White Oak Creek. For some mussels, the fauna could be restored and expanded via culture and propagation and/or translocation of adults. Four of the five (*A. atropurpurea* not propagated) federally listed mussels present in the BSF have successfully been cultured, propagated, and released back into the river as two month old juveniles as an experiment for expanding those populations into other suitable habitats away from horse crossings (Jess Jones, Virginia Cooperative Fish and Wildlife Research Unit, pers. comm., 2003). Expanding mussels at other locations in the river reduces the risk of seriously damaging populations that are confined to a localized area. The BSF could serve as a refuge and seed stock for mussels in the upper Cumberland system until recovery occurs in other damaged streams.

The BSF has more extant federally endangered fish and imperiled mussel species than any other NPS unit in the country and represents one of the richest remaining mussel faunas in the Cumberland River system. The NRRA is unique in that most mussels occur within the boundaries of the park and these lands and the fauna that occurs within them are protected federally as a national park. One major problem identified in this study is the continued deposition of silt and coal fines washing out of the New River drainage into the BSF from outside the boundaries of the NRRA. A large coal-washing facility and spoil pond exists in the New River that has currently been reactivated. Increased demands for coal and oil and gas exploration/extraction could reverse positive gains observed for mussels and other imperiled species in the BSF.

Long-term fixed station monitoring sites are needed at 10 locations in the NRRA: Leatherwood Ford (site BSF 2); Rough Shoals (site BSF 5); Station Camp Creek (site BSF 8); Big Island (site BSF 11); Bear Creek (site BSF 15); Blue Heron (site BSF 18); Clear Fork, Burnt Mill Bridge (site CF 4); Crooked Creek (site CC 1); New River, Silcox Ford (site NR 2); and North White Oak Creek, ATV crossing (site NWO 2). Long-term sites, monitored every three years, are needed to document whether the mussel fauna is continuing to recover or decline. Additional long-term monitoring may find other species believed extirpated from the drainage. Other biological and chemical information are needed including fish and benthic macro-invertebrates, and water quality data. Studies related to sediment toxicity from coal-fines on juvenile mussels are needed for determining whether high sediment concentrations of polycyclic aromatic hydrocarbons (PAH's), may be a limiting factor affecting mussel recruitment and survival in the BSF. Researchers need to continue culturing and propagating mussels found within the NRRA and disseminate federally listed and non-listed species to other suitable sites away from horse-crossings. Where practical, all mussels documented historically in the BSF could be restored via culture and propagation and/or the translocation of adults from the Cumberland and Tennessee River systems.

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FISH HOSTS FOR GLOCHIDIA OF THE PHEASANTSHELL, *ACTINONAIAS PECTOROSA*

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ABSTRACT

In the laboratory, we artificially infested 19 species of fish with glochidia of *Actinonaias pectorosa;* metamorphosis occurred on seven species *(Ambloplites rupestris, Cottus carolinae, Micropterus dolomieu, Micropterus punctulatus, Micropterus salmoides* and *Sander canadense).* The percentage of glochidia that metamorphosed on six species ranged from 15 % on sauger (*S. canadense)* to 43 % on largemouth bass *(M. salmoides).* Rock bass *(A. rupestris)* are considered to be a marginal host because less than 0.1 % of the glochidia transformed, and metamorphosis occurred on only two of 11 individuals tested. Since banded sculpin (*C. carolinae*) and *Micropterus* spp. are common in streams of the Cumberlandian region, it is unlikely that the lack of host fishes has been responsible for the loss of pheasantshell populations.

Key words: *Actinonaias pectorosa,* pheasantshell, glochidia, fish hosts, Clinch River, Tennessee.

INTRODUCTION

Freshwater mussels are one of the most endangered faunal groups in North America; 61 of the nearly 300 recognized taxa are federally listed as endangered. Moreover, populations of many non-listed species have declined or have been extirpated. Despite this degree of imperilment, basic life history information is lacking for many species. The larvae (glochidia) of most freshwater mussel species are parasitic, and require a suitable fish host to complete metamorphosis into juveniles. Although glochidia of some species can complete metamorphosis on the gills or fins of a wide range of fish species, others are very host-specific and can metamorphose only on a single fish species (see Watters, 1994). Hosts have been identified for only about one-third of the species occurring in North American (O'Dee & Watters, 2000). Many populations of mussels are functionally extinct, in that they consist entirely of old individuals with no evidence of recent recruitment. Altered thermal and flow regimes of regulated streams have been implicated as the causative factors for the lack of recruitment in some populations (Layzer *et al.*, 1993; Heinricher & Layzer, 1999; Hardison & Layzer, 2001); however, the lack of recruitment in some populations seems

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related to a decrease or absence of host fish populations (Smith, 1985; Watters, 1996; Khym & Layzer, 2000).

The pheasantshell, *Actinonaias pectorosa* (Conrad 1834), is a Cumberlandian species endemic to the Cumberland and Tennessee river systems (Ortmann, 1924). It once occurred in most of the major tributaries of these rivers (Cicerello *et al.*, 1991; Parmalee & Bogan, 1998); however, many of these populations have either disappeared or exist only as remnants (Ahlstedt, 1991; Anderson *et al.*, 1991; Fraley & Ahlstedt, 2000; Layzer *et al.*, 1993; Schmidt *et al.*, 1989). Little is known about the life history of the pheasantshell other than it is considered a riffle-inhabiting species (Gordon & Layzer, 1989), and is gravid from September through May (Ortmann, 1921), but the glochidial host is unknown. Our ongoing efforts to reestablish populations of listed and non-listed species in the upper Tennessee River system requires either identifying a source population of sufficient size to allow translocating a large number of individuals, or artificially propagating and culturing the mussels needed. The objective of the present study was to identify host species of the pheasantshell to facilitate propagation of this species and to determine if potential recipient streams contained hosts.

METHODS

Because previous exposure to glochidia may induce immunological resistance to subsequent infestations (Reuling, 1919; Arey, 1923), all fish used were collected by electro fishing in streams or reservoirs that contained few or no mussels. Fish were acclimated to laboratory conditions for about 1 week before being infested with glochidia. In September 1997, pheasantshells were collected from the Clinch River, Tennessee, and examined in the field; gravid individuals were transported in insulated coolers to the laboratory, and placed into a living stream maintained at 10°C. To obtain glochidia, we anaesthetized mussels in 250 mg/l of MS-222; when the mussels relaxed and gaped, we removed them from the solution, and used a hypodermic syringe (Waller *et al.*, 1985) to flush glochidia from the marsupia. Fish in water-filled coolers were exposed to glochidia for 10-15 minutes to allow for attachment. During our initial screening tests to identify hosts, infested fish were separated by species and, depending upon size, were placed into either 38 l or 95 l aquaria. At 2-3 day intervals, the bottoms of the aquaria were siphoned, and the siphonate was collected on a 100 μm mesh screen. Filtered material was then washed into a gridded petri dish and examined with cross-polarized microscopy. We considered individuals to be fully developed juveniles if they possessed two adductor muscles, and exhibited movement within 24 h.

In a subsequent test designed to compare the percent transformation among identified host species, we isolated individual fish following infestation in January 1998. Methods used for siphoning of aquaria and examination of the siphonate were the same as described above; however, for this test, we also counted the number of glochidia sloughed by individual fish. The sum of the glochidia and transformed juveniles collected from an individual tank was considered to be the initial infestation intensity (Khym & Layzer, 2000).

RESULTS

In all, 19 fish species were artificially infested with glochidia. Cyprinids and the northern hog sucker sloughed all glochidia within two days; most other non-host species sloughed all glochidia within 15 days of infestation (Table 1). Glochidia metamorphosed on seven species belonging to three families; however, metamorphosis occurred on only one of six rock bass infested. In contrast, metamorphosis occurred on all individuals of the other six species. The period of juvenile excystment was prolonged; the first juveniles were collected 21 days post-infestation, and the last juvenile excysted 70 days later. The mean number of juveniles recovered per fish ranged from 0.5 to 238. To determine if the variation in the number of juveniles recovered from each species was a function of initial infestation intensity or was a reflection of host suitability, we infested six of the seven identified host species (walleye were unavailable for this trial). Juveniles began excysting from all species, except rock bass, within 18 days of infestation. Juveniles metamorphosed on only one of five rock bass infested. The mean percent of glochidia that metamorphosed on other species varied from 15 to 43 and did not seem to be related to infestation intensity (Table 2).

DISCUSSION

Pheasantshell glochidia metamorphosed on seven species during our initial screening test; however, only one juvenile was recovered from six rock bass infested with glochidia. In contrast, the average number of glochidia completing metamorphosis on the other six species ranged from 121 to 238 per fish. Infestation intensity was not measured during the initial screening test; consequently, variation in the average number of juveniles obtained from individual fish may not reflect the suitability of a species as a host. Khym & Layzer (2000) found that infestation rates of black sandshell *Ligumia recta* (Lamarck 1819) glochidia varied greatly among individuals and species of fish that were simultaneously exposed to glochidia. They recommended determining

TABLE 1. Fish species artificially-infested with glochidia of *Actinonaias pectorosa* in the laboratory, maximum periods of attachment, and periods of metamorphosis at a mean (± SD) water temperature of 18.4 ± 1.3°C.

Scientific name	Common name	N	Period of Attachment (days)	Period of metamorphosis (days)
Ambloplites rupestris (Rafinesque 1817)	rock bass	6	–	23-24
Campostoma anomalum (Rafinesque 1820)	central stoneroller	5	2	–
Cottus carolinae (Gill 1861)	banded sculpin	6	–	21-46
Etheostoma blenniodes Rafinesque 1819	greenside darter	5	7	–
Etheostama caeruleum Storer 1845	rainbow darter	8	13	–
Etheostoma flabellare Rafinesque 1819	fantail darter	9	11	–
Etheostoma rufilineatum (Cope 1870)	redline darter	4	25	–
Etheostoma simoterum (Cope 1868)	snubnose darter	2	7	–
Hypentelium nigricans (Lesueur 1817)	northern hog sucker	1	2	–
Lepomis macrachirus Rafinesque 1819	bluegill	2	15	–
Lepomis megalotis (Rafinesque 1820)	longear sunfish	2	11	–
Lythrurus ardens (Cope 1868)	rosefin shiner	3	2	–
Micropterus dolomieu (Lacepede 1802)	smallmouth bass	2	–	21-55
Micropterus punctulatus (Rafinesque 1819)	spotted bass	3	–	23-55
Micropterus salmoides (Lacepede 1802)	largemouth bass	3	–	27-91
Percina caprodes (Rafinesque 1818)	logperch	1	7	–
Pimephales notatus (Rafinesque 1820)	bluntnose minnow	4	2	–
Sander canadense (Smith 1834)	sauger	2	–	21-40
Sander vitreum (Mitchill 1818)	walleye	1	–	21-56

TABLE 2. Comparison of infestation intensities and % juvenile transformation among host fish species infested with glochidia of *Actinonaias pectorosa* at a mean (± SD) water temperature of 19 ± 1.7°C.

Species	N	Mean infestation intensity	Juvenile excystment period (days)	Mean number of juveniles/fish	% Juvenile transformation	
					mean	range
Ambloplites rupestris	5	1345	28	0.8	<0.1	0-0.25
Cottus carolinae	25	578	18-39	122	21	NA
Micropterus dolomieu	1	1017	18-63	351	35	–
Micropterus punctulatus	3	1529	18-65	651	38	23-65
Micropterus salmoides	5	1975	18-72	878	43	18-65
Sander canadense	2	2939	18-44	409	15	9-21

NA = not determined because multiple individuals held in each aquarium.

infestation intensities and percent transformation to evaluate host suitability. The results of our suitability test clearly indicate that rock bass are a marginal host for pheasantshell glochidia; only four of 6,725 glochidia metamorphosed on rock bass. In contrast, 10,558 of 35,876 glochidia metamorphosed on the other five species tested. We could not determine if suitability as hosts varied significantly among these five species because of small sample sizes; however, mean transformation percentages on *Micropterus* spp. were similar (35-43 %) and tended to be higher than for other species. Although the pheasantshell is restricted to the upper Cumberland and Tennessee river systems, host fishes identified in our study have much larger geographic distributions. Most identified hosts of other Cumberlandian species are also widely distributed (Zale & Neves, 1982; Bruenderman & Neves, 1993; Gordon & Layzer, 1993; Gordon *et al.*, 1994; Yeager & Saylor, 1995). In addition to their wide distribution, banded sculpin and *Micropterus* spp. tend to be common or abundant throughout the Cumberlandian region. Thus, it is unlikely that the decline in most pheasantshell populations is related to the absence of host fishes.

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A SURVEY OF TERRESTRIAL GASTROPODS IN 1800+ HECTARES OF RECLAIMED STRIP MINE LAND AT THE WILDS, OHIO, U.S.A.: IMPLICATIONS FOR FUTURE SURVEYS

G. Thomas Watters[1] and Scott H. O'Dee[2]

ABSTRACT

A GIS-based land snail survey was conducted at The Wilds in Muskingum County, Ohio, USA, in conjunction with a study of the parasitic nematode *Parelaphostrongylus* sp. The Wilds is the largest contiguous area of reclaimed strip-mine land in North America. This area was put into reclamation between 1949 and 1972 and is now a free-range zoo. Sixty species of terrestrial gastropods were encountered in 436 0.25m^2 quadrats over 1,863 hectares. These were classified as strictly woodland species, strictly field species, or species common to both. Most field species, although never found in woods, nevertheless occurred within 200m of the nearest woods. Three species are recorded from Ohio for the first time: *Discus catskillensis*, *Euconulus polygyratus*, and *Vitrina angelicae*. The very small ranges of many species indicate that only fine-scale surveys will adequately document the existing diversity.

Key words: gastropods, surveys, reclamation, Ohio, parasites.

INTRODUCTION

The meningeal worm *Parelaphostrongylus* sp. is a parasite of white-tail deer in Ohio. Several intermediate hosts have been identified as terrestrial snails. These include members of the genera *Zonitoides, Triodopsis, Succinea, Fossaria, Discus, Cochlicopa* and *Derocera.* It is likely that additional intermediate hosts will be identified. Adult worms pass their larvae in the feces of the deer. The larvae burrow into snails. The life cycle is completed when ungulates ingest these parasitized snails. At The Wilds in Muskingum County, Ohio, a free-range zoo, exotic ungulates have become infected with this parasite, which have lead to debility or death in these unnatural definitive hosts.

Several options were available for the control of this disease: manage the white-tailed deer, manage the snails, locate exotics in areas that do not harbor the deer, or locate exotics in areas that do not harbor the snails. The first option, removal of the deer either by capture or hunting, is costly, because most of The Wilds is not fenced, and so deer removal would need to be continuously

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applied. The second option, removal of the snails, is neither feasible nor desirable. Estimates from this study place the number of snails contained within The Wilds at perhaps one billion individuals. Snails are an important part of the ecosystem, functioning as biodegradors and a source of food for other wildlife. The third option, placing exotics in areas devoid of deer, may be difficult to attain because of the highly mobile deer population. The fourth option, placing exotics in areas devoid of snail vectors, was the most feasible but required a knowledge of the distribution of the host snails within The Wilds. Many species of snails are habitat-specific and few species were expected to occur throughout all of The Wilds. The purpose of this study therefore was to map the distributions of snail species at The Wilds on a fine scale for eventual use in managing the exotic wildlife. This paper reports on those distributions and the implications of this study for future surveys.

Study area

The Wilds resulted from the donation of reclaimed strip-mined land from the American Electric Power Service Corporation; it is one of the largest contiguous areas of reclaimed strip-mine land in North America. The area was intensively mined for coal, including the use of the largest drag-line back hoe ever built, *Big Muskie*. Reclamation between 1949 and 1972 consisted of leaving quarries intact and reforesting the area, leaving a rugged landscape where the sides of otherwise rolling hills have been removed. Seeps may emerge from these excavations, creating small fens and streams. Areas mined after 1972 were smoothed and planted with fast-growing Autumn Olive or left to become fields. Therefore, the wooded areas are the oldest parts of the study area and the fields are the youngest.

Fields consisted of grasses, thistles, Queen Anne's Lace, White Wood Aster, and Bush Clover. Wetter areas had Waterpenny Wort and cat-tails. Extensive groves of the exotic Autumn Olive occurred between the fields and woodlands, planted as part of the original reclamation.

Newer deciduous woodlands were nearly impenetrable. These areas were characterized by Ailanthus, Amur Honeysuckle, Black Locust, Blackberry, hawthorns, Multiflora Rose, nettles, Poison Ivy, and Sycamore. Older deciduous woodland had open understories consisting of American and Slippery Elms, Black Cherry, Black Willow, Red, Silver and Sugar Maples, Red and Swamp Oaks, Sassafras, Shagbark Hickory, Sycamore, Sweetgum and Tuliptree.

Coniferous stands, comprised of White Pine and Norway Spruce, were largely limited to a narrow band along the north edge of the study area. Acreage for each type of land cover is given in Table 1. The study area is shown in Fig. 1.

MATERIALS AND METHODS

Quarter-meter quadrats were placed at random throughout the study area. Leaf-litter and humus were collected down to bare earth and placed in zip-loc bags. Sampling was done from May through September 1998, April through October 1999, and June through October 2000. Samples were air-dried and sorted with a dissecting microscope.

Land cover maps were downloaded from Microsoft Terraserver (http://terraserver.microsoft.com) based on 8 April 1994 flyover photography. In most cases, coniferous stands could be discerned from deciduous ones. These were ground-truthed for verification. Other maps showing buildings, roads, wetlands, reclamation areas, and pastures were obtained from The Wilds. Overlays of streams and contours were downloaded into ArcInfo. All maps and overlays were then transferred to ArcView3.1.

Each site was associated with coordinates derived from a Magellan Global Positioning System (GPS) ColorTRAK/tracker receiver. Prior to the elimination of Selective Acquisition by the U.S. Government in early 2000, the estimated error of any reading was as great as 30m. Coordinate accuracy was increased with ground-truthing and averaging of repetitive readings by the GPS unit. After Selective Acquisition was eliminated, the estimated errors declined to ~1m. Collecting sites are shown in Fig. 2.

A Shannon-Weiner Diversity Index (H) was calculated using log10 for each sample. Comparisons of species number, diversity (H), and density were made using a t-test assuming unequal variances.

RESULTS AND DISCUSSION

A total of 436 samples was taken over the 1,863 hectare study area, for an average sampling density of 0.23 samples per hectare. Sampling density by land cover and reclamation date are given in Table 2. Forest samples averaged 231g wet weight whereas field samples averaged 117g.

Sixty species of terrestrial or semi-terrestrial snails were recorded from 3,106 specimens. This is over half of all snail species recorded from the state by Taft (1961) and Hubricht (1985). Forty-one are Muskingum County records, and three are new records for Ohio *(Discus catskillensis, Euconulus polygyratus, Vitrina angelicae*). A list of species and their relative abundance is given in Table 3.

The average densities of snails in the various land cover types are given in Table 4. Using these numbers and the percentage of each land cover at the study area yields an estimated 445,935,858 snails in total. Again using an average, the total numbers of snails on all Wilds property approaches one billion snails. On average, snails were more diverse within the woods than in the fields ($P<0.0000$; Table 5). Maximum species richness for woods was 17 species/$0.25m^2$, compared with ten species for fields. Maximum density/$0.25m^2$ was 53 snails for woods and 58 for fields. The average density for fields is biased toward a lower number by the presence of zero density sites beyond the 200m buffer (described below). Olive groves often formed between woods and fields

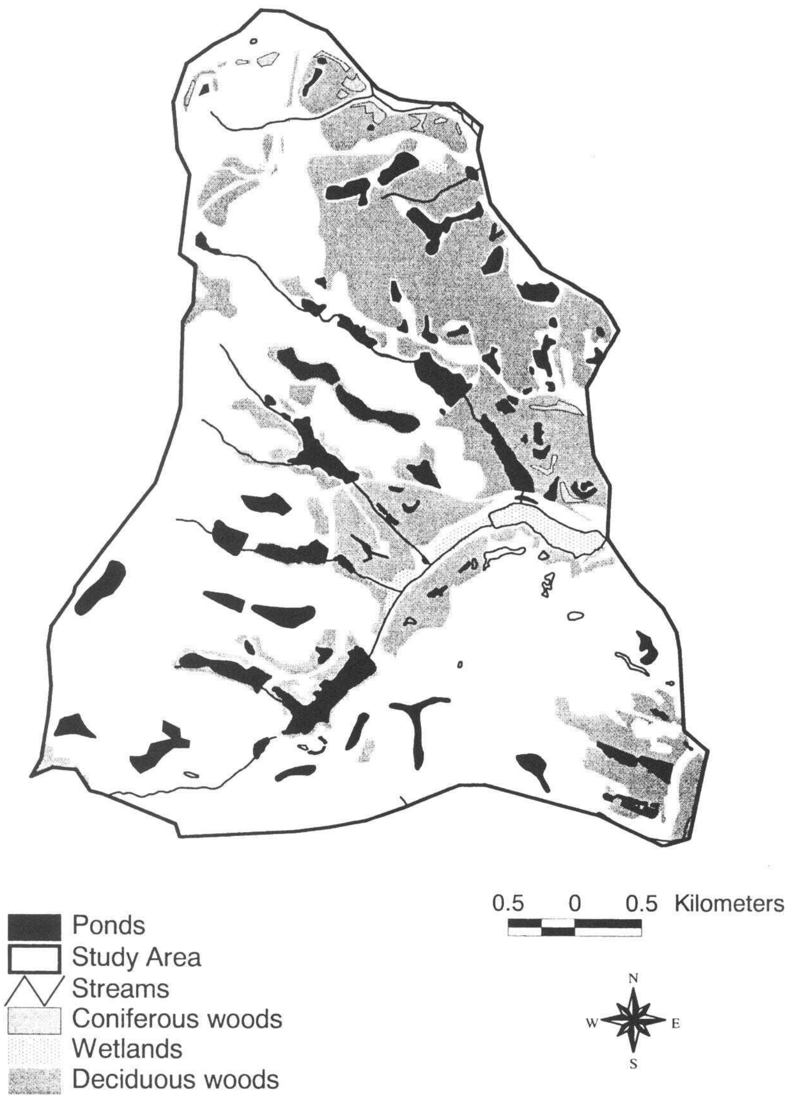

FIG. 1. The study area.

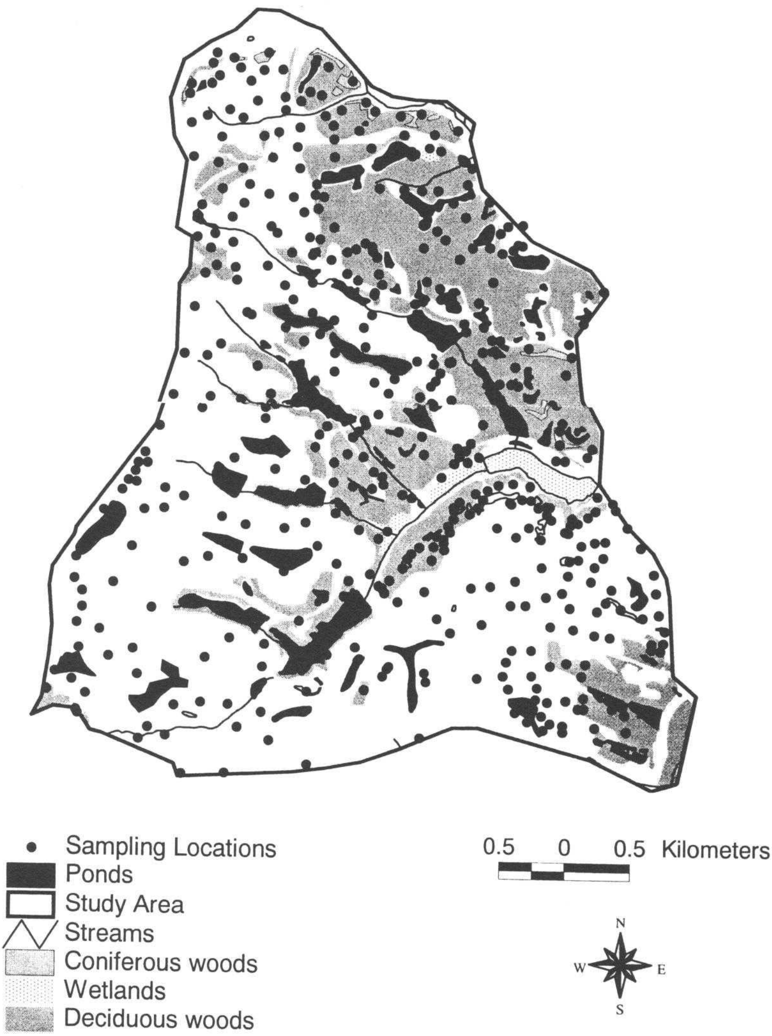

FIG. 2. Collecting sites.

TABLE 1. Acreage for land cover and reclamation.

	Hectacres	Acres	% of Total
Study Area	1863	4602	100
Land Cover			
Fields Out of Pasture	745	1840	39.97
Deciduous Woods	518	1280	27.81
Coniferous Woods	10	26	0.56
Ponds	145	358	7.78
Wetlands	25	62	1.35
Pastures	420	1037	22.52
Year Reclaimed			
1949	232	573	12.45
1966	298	737	16.01
1972	1333	3298	17.54

TABLE 2. Sampling intensity for land cover and reclamation.

	# Samples	% of Total Samples	Samples per Hectare of Land Cover
Study Area	436	100	0.23
Land Cover			
Fields Out of Pasture	234	53.67	0.31
Deciduous Woods	169	38.76	0.33
Coniferous	9	2.06	0.86
Pastures	24	5.50	0.06
Year Reclaimed			
1949	90	20.55	0.39
1966	75	17.12	0.25
1972	273	61.87	0.21

and had an intermediate number of species and individuals; olive grove sites were not statistically different for diversity (H) and density from either woods or fields. Similarly there was no difference between deciduous and coniferous snail diversity (H) or density.

Of the 60 species encountered, 23 were woodland species. These rarely, if ever, were found beyond the forest margin. Twenty-four species were exclusively field species. However, one of the most interesting results of this study was the observation that although these species never occurred in woodland and only occurred in fields, 20 of the 24 species nevertheless were only found within

TABLE 3. Relative abundance or species encountered. MCR Muskingun County record; OH - Ohio record.

Species	Found at # sites	% of all sites	# individuals	% of all individuals	New record
Glyphyalinia indentata	160	36.70	484	15.58	MCR
Vallonia excentrica	102	23.39	350	11.27	MCR
Ventridens demissus	99	22.71	236	7.60	MCR
Striatura milium	63	14.45	157	5.05	MCR
Glyphyalinia rhoadsi	48	11.01	103	3.32	MCR
Punctum minutissimum	45	10.32	116	3.73	MCR
Gastrocopta pentodon	42	9.63	87	2.80	MCR
Haplotrema concavum	41	9.40	60	1.93	
Gastrocopta armifera	41	9.40	94	3.03	MCR
Catinella avara	40	9.17	96	3.09	
Neohelix albolabris	36	8.26	81	2.61	
Nesovitrea electrina	33	7.57	122	3.93	MCR
Anguispira alternata	33	7.57	102	3.28	
Euconulus fulvus	25	5.73	42	1.35	MCR
Vertigo gouldi	22	5.05	208	6.70	MCR
Ventridens ligera	20	4.59	48	1.55	
Gastrocopta contracta	20	4.59	37	1.19	MCR
Vertigo milium	19	4.36	49	1.58	MCR
Vitrina angelicae	17	3.90	46	1.48	MCR, OH
Deroceras laeve	16	3.67	20	0.64	
Philomycus carolinianus	14	3.21	14	0.45	MCR
Pupoides albilabris	13	2.98	31	1.00	MCR
Mesodon thyroides	13	2.98	19	0.61	
Zonitoides arboreus	12	2.75	19	0.61	
Succinea ovalis	12	2.75	14	0.45	MCR
Pallifera dorsalis	12	2.75	15	0.48	MCR
Vallonia costata	11	2.52	46	1.48	MCR
Carychium exile	11	2.52	42	1.35	MCR
Striatura ferrea	10	2.29	3	0.10	MCR
Euchemotrema fraternum	10	2.29	15	0.48	MCR
Fossaria exigua	10	2.29	18	0.58	
Cochlicopa lubrica	10	2.29	29	0.93	
Mesomphix inonatus	9	2.06	21	0.68	MCR
Glyphyalinia wheatleyi	9	2.06	14	0.45	MCR
Discus catskillensis	9	2.06	27	0.87	MCR, OH
Vertigo tridentata	8	1.83	45	1.45	MCR

Table 3 (continued)

Species	Found at # sites	% of all sites	# individuals	% of all individuals	New record
Ventridens intertextus	7	1.61	23	0.74	MCR
Stenotrema hirsutun	7	1.61	12	0.39	
Vertigo ventricosa	6	1.38	28	0.90	MCR
Helicodiscus parallelus	6	1.38	13	0.42	
Guppya sterkii	5	1.15	9	0.29	MCR
Vertigo ovata	4	0.92	6	0.19	
Triodapsis tridentata	4	0.92	4	0.13	
Mesodon zaletus	4	0.92	4	0.13	MCR
Discus patulus	4	0.92	37	1.19	
Arion subfuscus	4	0.92	16	0.52	
Zonitoides limatulus	3	0.69	4	0.13	MCR
Euconulus polygyratus	3	0.69	4	0.13	MCR, OH
Deroceras reticulatum	3	0.69	8	0.26	
Vertigo parula	2	0.46	2	0.06	MCR
Vertigo elatior	2	0.46	9	0.29	MCR
Nesovitrea binneyana	2	0.46	4	0.13	MCR
Hawaiia minuscula	2	0.46	3	0.10	MCR
Vertigo pygmaea	1	0.23	1	0.03	MCR
Strobilops affinis	1	0.23	1	0.03	MCR
Pupilla muscorum	1	0.23	1	0.03	MCR
Philomycus flexuolaris	1	0.23	1	0.03	MCR
Pallifera fosteri	1	0.23	1	0.03	MCR

TABLE 4. Diversity, density, and estimated population numbers for land cover.

Land Cover	# Species / 0.25 m^2	Density / 0.25 m^2	Estimated # Snails for land Cover
Deciduous Forest	3.98	9.78	202,659,282
Coniferous Forest	3.67	10.56	4,408,673
Olive Groves	3.30	8.00	
Fields	1.68	5.13	238,867,902*
Debris	2.60	6.20	
Total Study Area	2.66	7.12	445,935,858

200m of woodland (Figs. 3, 4). Beyond this buffer was essentially a dead zone, although there was no noticeable difference in vegetation. Clearly the snails could not exist in the woods, but yet derived some necessary component from the woods that ended at ~200m into the fields. The identity of this component has not been identified and has not been reported in similar surveys. Possible explanations include nutrients leaching out from the woods, cool or moist air extending from the woods, and wind-blown debris. Further studies are necessary to identify this puzzling phenomenon.

No species may be said to be truly ubiquitous at The Wilds. *Glyphyalinia indentata* dominated the woods and nearby fields, and *Vallonia excentrica* was abundant in fields, but no one species occurred in all habitats. Only four field species regularly occurred outside of the 200m buffer: *Catinella avara*, *Succinea ovalis*, *Vallonia excentrica* and *Vitrina angelicae*. However, even these were more common within the buffer zone than without.

The oldest areas of reclamation were reforested whereas the newest areas of reclamation were put into fields. This complicates any comparison between diversity and elapsed time since reclamation, because the old and new areas have obviously different habitats. Reforestation was accomplished in two stages, one from 1949 to 1966, and the second from 1966 to 1972. Woodland species were generally distributed across both areas of reforestation. However, a few taxa were found only in the oldest areas. These were generally rare species. This suggests that some species may be less dispersive and do not recolonize as readily as others and require longer times to return. Other species may require habitats that are only attained in older forests. These old forest species were *Discus catskillensis, D. patulus, Glyphyalinia binneyana, Hawaiia minuscula, Mesodon zaletus, Philomycus carolinianus, P. flexuolaris, Stenotrema hirsutum* and *Striatura ferrea.*

The great snail diversity encountered at The Wilds was surprising given the history of the landscape. The study area, only 0.016% of the state, had over 50% of the entire state's known diversity. Although only 0.23 samples per hectare were taken, this was sufficient to demonstrate that many species exist only as small, localized populations. Seven species were found in only a single site of the 436 total sites. Both of the two snails recorded as new from Ohio were locally abundant, but only occurred in specialized, aerially small habitats. This indicates that most snail surveys, which may consist of a few scattered samples within a county, will grossly underestimate the overall diversity.

SPECIES ACCOUNTS

MCR – Muskingum County record based on data published in Taft (1961)

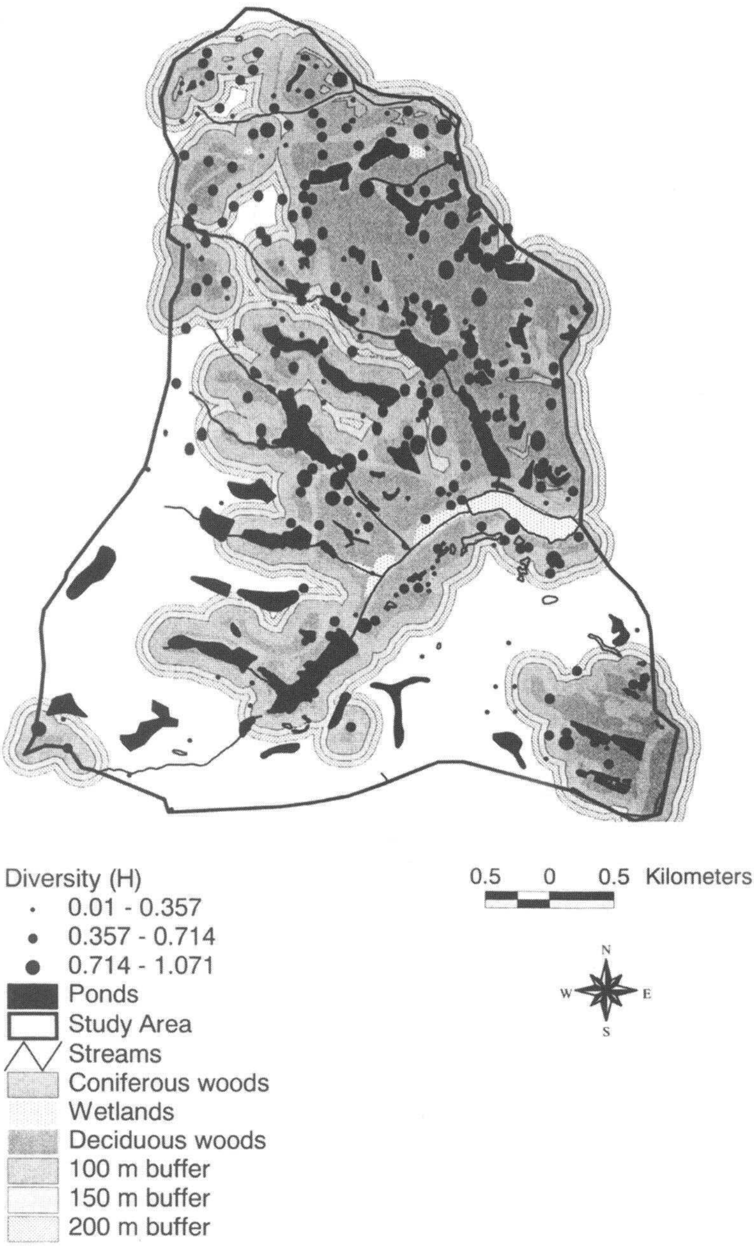

FIG. 3. Diversity (H) in relation to 100, 150, and 200 m buffers from the nearest woods.

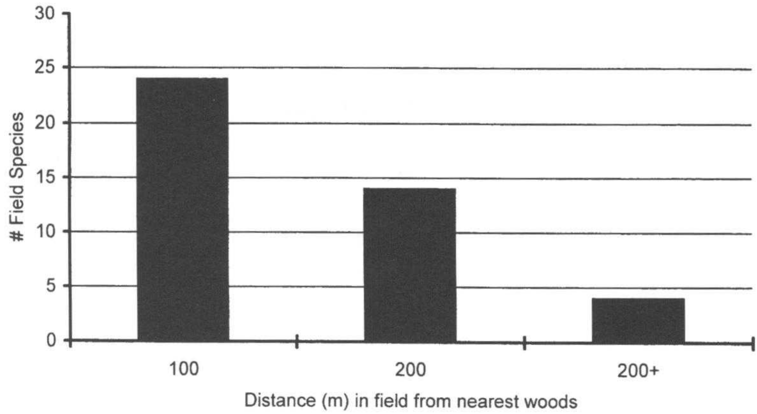

FIG. 4. Numbers of strictly field species found within 100 and 200 m buffer zone of nearest woods.

and Hubricht (1985). Species are listed alphabetically by family, genus, and species.

Shelled species

Carychiidae

Carychium exile (Lea 1842) – Ice Thorn. The Ice Thorn was sporadic in The Wilds and apparently confined to disjunct borders of woodland. It is distributed over most of the eastern United States except for Florida. MCR.

Cochlicopidae

Cochlicopa lubrica (Müller 1774) – Glossy Pillar. Six or seven small, widely separated populations appear to exist in The Wilds. Most specimens were found in dry fields. This species is found throughout most of the United States and northern Europe. MCR.

Discidae

Anguispira alternata (Say 1817) – Flamed Disc. This is a large, showy species not to be confused with any other snail at The Wilds. It is strictly a woodland species, usually in moist leaf litter and under logs. It may be locally common. Newly hatched juveniles were common in early September. Generally distributed north of the Mason-Dixon Line east of the Rocky Mountains.

Discus catskillensis (Pilsbry 1896) – Angular Disc. Four small, isolated populations of this snail were encountered at The Wilds, all but one on moist rotting logs in deep deciduous woods. Hubricht (1985) gave the Recent distribution of this species in the United States as northernmost Wisconsin, Minnesota, and Michigan, and from Maine through New England into Pennsylvania and West Virginia. Pleistocene records indicate a once wider range along the Ohio and Mississippi River valleys to Arkansas. This is the first record of this species for Ohio. It is apparent that isolated pockets of this species were left behind in the Allegheny foothills of southwestern Ohio as the species's range contracted. The Angular Disc co-occurred with *Discus patulus* (the Domed Disc, which is common throughout Ohio) at one of the three sites. Both species of *Discus* were often found actively crawling on logs during daylight hours. They are locally abundant in this specific habitat.

Discus patulus (Deshayes 1830) – Domed Disc. Two populations were found in the deep woods around the central wetland. This probably was a single population skirting a small stream before damming formed the wetland. Like the Angular Disc, individuals were only found crawling on rotting logs, and were often locally abundant. Distributed east of the Mississippi River except for peninsular Florida.

Haplotrematidae

Haplotrema concavum (Say 1821) – Gray-Foot Lancetooth. The Gray-Foot Lancetooth was a widespread woodland species usually found in moist leaf litter and under logs. It generally occurs east of the Mississippi River.

Helicarionidae

Euconulus fulvus (Müller 1774) – Brown Hive. Several scattered populations of this uncommon snail were found in woodlands at The Wilds. The Brown Hive is a Holarctic species. MCR.

Euconulus polygyriscus (Pilsbry, 1899) – Fat Hive. Like the Brown Hive, this was an uncommon species in woodlands. This is an Ohio record for this more northern snail.

Guppya sterkii (Dall 1888) – No common name. This minute species was found at only five sites, all in rich leaf litter. It is widely scattered in North America, most commonly in the Appalachians. MCR.

TABLE 5. Comparisons of diversity (H) and density between land cover.

T-test assuming unequal variances		# Sites	Mean	P
Deciduous *vs*. Olive – Density				
	Deciduous	169	9.78	0.2848
	Olive	10	8	
Deciduous *vs*. Olive – Diversity (H)				
	Deciduous	169	0.4	0.0827
	Olive	10	0.31	
Deciduous *vs*. Coniferous – Density				
	Deciduous	169	9.8	0.4302
	Coniferous	9	10.55	
Deciduous *vs*. Coniferous – Diversity (H)				
	Deciduous	169	0.45	0.2622
	Coniferous	9	0.38	
Deciduous Forest *vs*. Field – Density				
	Forest	169	9.78	<0.0000
	Field	243	5.13	
Deciduous Forest *vs*. Field – Diversity (H)				
	Forest	69	0.4	<0.0000
	Field	243	0.18	

Helicodiscidae

Helicodiscus parallelus (Say 1821) – Compound Coil. The Compound Coil was an uncommon snail at The Wilds, occurring at only six sites. Most specimens were found along pond edges. The Compound Coil occurs east of the Rocky Mountains. MCR.

Lymnaeidae

Most lymnaeids are aquatic but the genus *Fossaria* has members that are better characterized as amphibious.

Fossaria exigua (Lea 1841) – No common name. This species was sporadic in its distribution, usually occurring around temporary ponds, ditches, potholes, or watering holes. It was never found submerged, but always occurred adjacent to water, usually on mud. Generally distributed east of the Mississippi River.

Fossaria parva (Lea 1841) – Pygmy Fossaria. A single population was encountered in a wet field. Generally distributed east of the Mississippi River.

Polygyridae

Euchemotrema fraternum (Say 1824) – Upland Pillsnail. This uncommon species was sporadically encountered along the margins of woodlands, often associated with fallen logs. It occurs east of the Mississippi River except for the Gulf States. MCR. Listed in older literature as *Stenotrema fraternum*.

Mesodon inflectus (Say 1821) – Shagreen. A single specimen was found in old growth woods. Widely distributed between the Rockies and the Appalachians.

Mesodon thyroides (Say 1816) – White-Lip Globe. Rarer than the similar and largely sympatric Whitelip (see below), this species occurred only in or adjacent to the oldest woods within The Wilds. It is one of three large polygyrids found at The Wilds: *M. thyroides*, *M. zaletus*, and *Neohelix albolabris*. Widely distributed east of the Rocky Mountains.

Mesodon zaletus (Binney 1837) – Toothed Globe. This is the rarest of the three large polygyrids encountered at The Wilds. Like the White-Lip Globe, it occurred only in or adjacent to the oldest woods. Generally distributed in the Midwest. MCR.

Neohelix albolabris (Say 1817) – Whitelip. The Whitelip, the largest shelled snail at The Wilds, is strictly a woodland species, usually living among fallen timber, firewood piles, or other woody debris. It is locally common. Many populations at The Wilds have a distinct reddish colored shell that fades after death. Generally distributed east of the Mississippi River except for the Gulf states. This is listed in most literature as *Triodopsis albolabris*.

Stenotrema hirsutum (Say 1817) – Hairy Slitmouth. An uncommon species at The Wilds in woodland borders. This is a species of the Appalachians and its foothills.

Triodopsis tridentata (Say 1817) – Northern Threetooth. Only a few widely scattered individuals of this woodland species were found at The Wilds. It is common in woodlands from the Appalachians to Indiana.

Pupillidae

Gastrocopta armifera (Say 1821) – Armed Snaggletooth. This was the largest pupillid species at The Wilds, reaching nearly 5 mm in length. It occurred in fields adjacent to woodlands and along the margins of ponds in wooded areas. The Armed Snaggletooth was often caked with dirt and mud. Generally distributed east of the Rocky Mountains. MCR.

Gastrocopta contracta (Say 1822) – Bottleneck Snaggletooth. This species is slightly smaller than the Armed Snaggletooth and occurs in the same habitat, but was not as widespread in The Wilds. MCR.

Gastrocopta pentodon (Say 1821) – Comb Snaggletooth. Widespread at The Wilds, but more likely to be encountered in woodland than either of the other *Gastrocopta* found in the study area. Generally occurring east of the Rocky Mountains. MCR.

Pupilla muscorum (Linne 1758) – Widespread Column. As its name suggests, this pupillid has a wide distribution from Kansas to New England and holarctic Europe. However, only a single specimen was found at The Wilds in deep woods. MCR.

Pupoides albilabris (Adams 1841) – White-Lip Dagger. This species was associated with the most xeric habitats. It was most common in dry, dusty grass along roads. Widely distributed east of the Rocky Mountains except for the extreme north. MCR.

Vertigo elatior (Sterki 1894) – Tapered Vertigo. One of the rarest pupillids encountered at The Wilds, found in only two samples. One was from an open field, the other from a woods. Distributed in northeast Ohio and Michigan. MCR.

Vertigo gouldi (Binney 1843) – Variable Vertigo. There was a large, dense population of this species in the fields in the northernmost portion of the study area and an isolated small population in the south. The northern population may reach over 160 individuals per square meter. It appears to be sporadic in its general range in the northern Midwest. MCR.

Vertigo milium (Gould 1840) – Blade Vertigo. A population of this tiny species occurred throughout a field in the northern portion of the study area, and smaller populations are widely scattered along woodland and pond margins. Very widely distributed east of the Rocky Mountains. MCR.

Vertigo ovata (Say 1822) – Ovate Vertigo. A rare species found along the woodland and pond margins in the northern part of study area. Widely distributed east of the Rocky Mountains.

Vertigo parvula (Sterki 1890) – Smallmouth Vertigo. Single individuals were found at two sites in fields in the central portion of the study area. This species has a narrow range, with most records from the Appalachians in Virginia. However, Hubricht (1985) gives a single Ohio record for Summit County. MCR.

Vertigo pygmaea (Draparnaud 1801) – Crested Vertigo. A single specimen of this species was found along a strip of grass between woods and a road. Generally distributed in northeast North America and into Europe. MCR.

Vertigo tridentata (Wolf 1870) – Honey Vertigo. Sporadic at The Wilds in fields bordering woods or along roads through woodlands. Distributed throughout the eastern United States north of Tennessee. MCR.

Vertigo ventricosa (Morse 1865) – Five-Tooth Vertigo. This species was found at only five widely separated sites. All were in open fields. It has the same general distribution as the Tapered Vertigo (above). MCR.

Punctidae

Punctum minutissimum (Lea 1841) – Small Spot. Common and widespread, it was found in both fields and woods, in dry or moist habitats, but was most common in woods. Adults are less than 1.5 mm in diameter. The Latin name of this species means "the smallest spot" in reference to its size. It resembles the zonitid *Striatura milium*, and often occurs with it, but the Small Spot is smaller, more tightly coiled, and brownish. Generally distributed east of the Rocky Mountains. MCR.

Strobilopsidae

Strobilops affinis (Pilsbry 1893) – Eightfold Pinecone. This was one of the rarest species found at The Wilds, represented by a single specimen. It was collected in a dry, open field. Sporadic in the northern Midwest. MCR.

Succineidae

Catinella avara (Say 1824) – Suboval Ambersnail. Most individuals are found in open fields beneath compacted grass where it remains cool and wet. It was not a woodland species, but may occur along pond margins in woods. Found east of the Rocky Mountains.

Succinea ovalis (Say 1817) – Oval Ambersnail. The Oval Ambersnail was found in fields, rarely in woodlands. It occurs in the northern United States east of the Rocky Mountains. MCR.

Valloniidae

Vallonia costata (Müller 1774) – Costate Vallonia. The Costate Vallonia is much less common than the next species, the Iroquois Vallonia. Although associated with fields, it was seldom encountered far from ponds or woodland margins. It ranges throughout New England to the Midwest, and northern Europe. MCR.

Vallonia excentrica (Sterki 1893) – Iroquois Vallonia. The Iroquois Vallonia is the most widespread and common species in fields at The Wilds, often occurring in large numbers along with pupillids. In woodlands it occurred only along edges or roads. Found in New England and the Midwest. MCR.

Vitrinidae

Vitrina angelicae (Beck 1837) – Eastern Glass-snail. In the study area the Eastern Glass-snail occurs in a northern population, a southern population, and a few scattered individuals between the two. Most individuals occur in open fields. This is the first record of this species from Ohio. In every respect this is a curious snail. The shell is extremely fragile and small compared to the animal and the early whorls contain microscopic pits. Unlike other snails at The Wilds, the Eastern Glass-snail hatches in late summer and is most active in the fall and winter. Pilsbry (1946: 503), quoting the collector George Clapp, noted that "In October they appear suddenly in large numbers. From October to January is their active season, and during these months they may be found active on any pleasant day. Have found them very active when the temperature was below 40°." Other collectors report finding specimens actively crawling over the snow. As might be expected of this winter-loving species, it occurs mainly in the northern States. In The Wilds it typically was found on the north-facing slopes near the summit of hills and was often abundant (>80 per square meter at one site); it often occurred at sites having no other snail species.

Zonitidae

Glyphyalinia indentata (Say 1823) – Carved Glyph. The Carved Glyph is the most abundant and widespread snail at The Wilds. It seems to have little preference for habitat although the largest densities were found in woodland areas. Nevertheless this is a Muskingum County record. This "species" actually may represent a suite of sibling species. Hubricht (1985) noted that "What has been called *Glyphyalinia indentata* (Say 1823) is a series of anatomical species, with little or no shell differences." Whatever its status, the Carved Glyph has been reported from most of the United States east of the Rocky Mountains except for peninsular Florida. Newly hatched juveniles were found throughout the summer and autumn.

Glyphyalinia rhoadsi (Pilsbry 1899) – Sculpted Glyph. Another common and widespread zonitid, but unlike its congener the Carved Glyph, this species is almost exclusively a woodland species. Distributed throughout much of eastern North America, particularly along the Appalachian Mountains. MCR.

Glyphyalinia wheatleyi (Bland 1883) – Bright Glyph. The rarest of the three Glyphs found at The Wilds, it is a woodland species. Largely found in the

Appalachian Mountains and their foothills, with other populations in northern Michigan and Canada. MCR.

Hawaiia minuscula (Binney 1840) – Minute Gem. Like *Zonitoides arboreus* (see below), this is an otherwise very widely distributed species in North America that was quite rare at The Wilds. It was found in xeric habitats at only two sites. MCR.

Mesomphix inornata (Say 1821) – Plain Button. This is a rare woodland species at The Wilds found in decaying wood. There are a few widely scattered populations, the largest occurring in the extreme southeast woods in the study area. However, when found there are usually several individuals together. A species of the northern Appalachians and their foothills. MCR.

Nesovitrea binneyana (Morse 1864) – Blue Glass. This is a more northern species, rare in Ohio and at The Wilds. Strictly woodland in distribution. MCR.

Nesovitrea electrina (Gould 1841) – Amber Glass. The Amber Glass is a woodland species associated with newer stands along the forest margins. It was not found in the older woods. MCR.

Striatura ferrea (Morse 1864) – Black Striate. This was a rare woodland species at The Wilds, encountered at only two sites. It occurs in eastern North America along the Appalachians and Great Lakes. MCR.

Striatura milium (Morse 1859) – Fine-ribbed Striate. A minute, finely-sculptured species closely resembling the Small Spot (see above). At The Wilds this species occurred in both fields and woods, in dry and wet habitats, and was often quite common. The Fine-ribbed Striate occurs in the United States east from Kansas and north of the Mason-Dixon Line. MCR.

Ventridens demissus (Binney 1843) – Perforate Dome. The most widespread and common of the *Ventridens* found at The Wilds. It occurred in nearly all habitats, from fields to deep woods. Found from the Gulf states north into the Appalachians. It is curious that Hubricht (1985) gave no Ohio records for this common species whereas Taft (1961) gave numerous localities. MCR.

Ventridens intertextus (Binney 1841) – Pyramid Dome. The rarest of the *Ventridens* found at The Wilds, it occurred only in the oldest woodlands. It has the same overall distribution as the Perforate Dome. MCR.

Ventridens ligera (Say 1821) – Globose Dome. More common than the Pyramid Dome, but rarer than the Perforate Dome. It is strictly a woodland species, occurring from the forest margins to the deep woods. Common throughout the Ohio and Mississippi River valleys.

Zonitoides arboreus (Say 1826) – Quick Gloss. Although one of the most widespread snails in the world, it was uncommon at The Wilds, where it occurred sporadically in woods.

Zonitoides limatulus (Binney 1840) – Dull Gloss. This rare species was encountered at three widely separated sites in the study area, all in rich woodland leaf litter. It has a sporadic distribution in the eastern United States north of Tennessee. MCR.

Slugs

Philomycidae

Pallifera dorsalis (Binney 1842) – Pale Mantleslug. This is a rather small, bluish slug found sporadically in woodland at The Wilds, usually beneath logs. The Pale Mantleslug prefers cooler habitats and ranges across the northern United States east of Kansas and down the Appalachian Mountains. MCR.

Pallifera fosteri (Baker 1939) – Foster Mantleslug. This small slug is boldly marked with black spots on a white background. It was very rare at The Wilds and was found at only one site—a wooded ravine with flowing water, abundant moss, and seeps. It is rare in Ohio, and this is a Muskingum County record. It is distributed primarily in the southern half of the United States east of the Rocky Mountains.

Philomycus carolinianus (Bosc 1802) – Carolina Mantleslug. This was the largest slug species encountered at The Wilds, reaching 10 cm when fully extended. It was a woodland species and one of the few slugs that occurred in coniferous stands. Typically it was found under logs, but in wet cool weather was commonly seen climbing trees to a height of 2m. Like the Foster Mantleslug, the Carolina Mantleslug is distributed primarily in the southern half of the United States east of the Rocky Mountains. MCR.

Philomycus flexuolaris (Rafinesque 1820) – Winding Mantleslug. A single specimen was found in association with the Carolina Mantleslug. This slug is more common in the Appalachians. Hubricht (1985) does not record it from Ohio, but Pilsbry (1948) gives two records, although there is some question as to whether his specimens might have been *P. carolinianus* or *P. togatus* (Gould 1841). MCR.

Limacidae

Deroceras laeve (Müller 1774) – Meadow Slug. Because this slug also occurs in Europe, it was originally thought that its presence in North America was due to introductions. But it has been found in Pleistocene deposits, indicating that it undoubtedly was native to North America as well. However, it is likely that its current distribution across eastern North America has been mediated by man—possibly including subsequent introductions from Europe. It was uncommon but widespread at The Wilds. More than the philomycid slugs, this species was likely to be found among piles of debris, rocks, and trash, even in open fields.

Deroceras reticulatum (Müller 1774) – Gray Fieldslug. This is an exotic slug that was only encountered at two sites, where it was however common. One site was a woodpile at a campground, the other along an access road near buildings. It undoubtedly has been introduced on construction machinery or by visitors.

Arionidae

Arion subfuscus (Draparnaud 1805) – Dusky Arion. This is an exotic. Not unexpectedly it was found adjacent to the newly constructed Visitor Center, where it was very common. It also was abundant at the storage yard and had spread several hundred meters into neighboring woods. Undoubtedly this slug was introduced on construction equipment and building material. This slug exudes a yellow-orange mucus when handled that will stain fabric and skin. Originally from Europe, it occurs in many US cities, particularly in the South.

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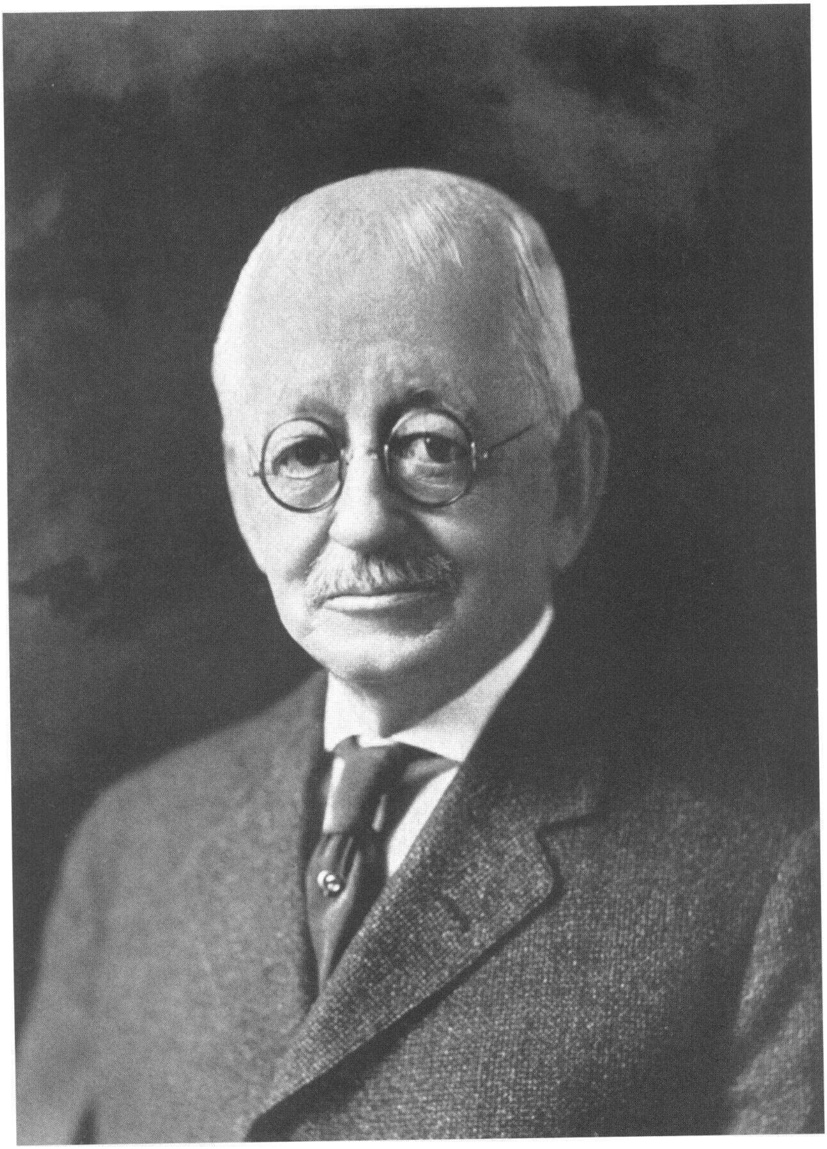
BRY ANT WALKER 1856-1936

Running through the first volume of the *American Naturalist*, March, 1867, to February, 1868, was a series of articles by E. S. Morse on "The Land Snails of New England." One of the numbers of this first volume came to the hands of Edward Carey Walker, a lawyer of Detroit. He mailed it to his eleven-year old son, Bryant, who had been sent to a farm near Ypsilanti, twenty miles away, for his summer vacation. Young Bryant Walker had collected butterflies. He had climbed for birds' eggs as many boys of that time did. It was a belief of his that he was the first to observe the advent of the English sparrow in eastern Michigan. He saw the bird 'feeding among chickens in a yard of the suburban Springwells and collected it by means of a topheavy, muzzle-loading shotgun, with maybe some of the chickens. The Morse paper on snails fixed with sharp definiteness an interest in natural history that hitherto had been without direction. With some slight waning during the early struggles for a livelihood and in the period of courtship, the interest flamed high until well along in Bryant Walker's last illness when eyesight and attentiveness both weakened. The span of years between Morse's chance begetting of a student of mollusks and the final sick bed was very nearly seventy.

Edward Walker was among the emigrants of the great folkwandering out of the eastern states to Michigan, then virtually the inhabitable frontier. Like the mass of those emigrants he was from rural New York, and that meant that he, together with the others, was only a generation out of New England. Through his mother, Bryant Walker was related to William Cullen Bryant. The family in Detroit was Presbyterian in religious affiliation. But either on one side or the other, there was some former connection with the Society of Friends. In this, Mr. Walker appeared to take rather more than the usual pride in such history or tradition. The fact is curious. For although he had the full measure of the Quaker's virtue of modesty, he had—the same as the Quaker-born Isaac Lea—no whit of that meekness which is the Quaker's rule of life. In a folder that was found on his desk was copy of correspondence with a person who, he thought, was retaining borrowed specimens unduly. "I insist," he wrote, "upon the immediate return of the shells (all of them), whether you are through with them or not. This is peremptory and final."

Mr. Walker was graduated from the University of Michigan in 1876 with the degree of B.A. It was the year of his first conchological paper. It was written in collaboration with C. E. Beecher who was to become a professor of paleontology at Yale University and pre-decease his friend by 32 years. The slim little paper



Bryant Walker

listed the shells in the vicinity of Ann Arbor. Not until 1879 did Mr. Walker venture upon a second effort. This was the year of his graduation from the law school of his university and twelve months after he had been licensed to practise law. Yet conchological work was still going on if this is to be interpreted from the secretaryship and then the presidency of the Detroit Scientific Association, lasting from 1877 to some time after 1884. In my hearing, the organization was never mentioned. Word of it came from same casual reading of local history. All that was said of it was that it had bought one of the Ward collections of rocks and was having exceeding trouble in maintaining a home for the possession.

Actual law practise began in partnership with the father, but it was not made easy by that. The country was passing out of the financial blight of the 1870s. Detroit was poor, and competition at the bar intensive. There were hard and discouraging days. A friend recalled at the time of Mr. Walker's death that one of the latter's tasks had been to serve papers on passing schoonermen who, to escape levy for debt, would sail as close to the Canadian shore of the Detroit River as they could. It fell to the young lawyer to learn the precise line of the international border, to row a boat with daring, to dodge the missiles of sailors and be deaf to their descriptive comment. The period of probation appears, however, to have been short. Fair living came as the economic situation bettered. There was a marriage that was to end tragically in scarcely a year by the death of the wife. Two effects followed, an intensification of natural reserve as to matters relating to himself and a concentration upon the interest in shells.

The home that Mr. Walker occupied for the greater part of his life was a three-storied, high-ceilinged, mansard-roofed house of a type that flourished in Detroit in its simpler days and which now is nearly a symbol of the slums. The attic was used as a study during the early years. At best, it could hardly have been comfortable. Then a small, two-floored museum was built at the back of the house, its windows looking out on a garden that strangely remained a halting place for migrating birds long after the district had ceased to be suburban even remotely. Toward the close of the World War, the museum was doubled in size. The ground floor was devoted to gastropods, the upper to bivalves. When the collection was moved in June to the University of Michigan at Ann Arbor, a great pile of boxed shells was discovered in the attic rooms, others on shelves in the basement where some were partly buried under coal. Shells were in closets, on the tops of the forty-two cases and in an entry-way which the household still spoke of as the wood-shed.

The great allowance of space largely accounts for Mr. Walker's readiness to accumulate specimens. How many collections he bought in entirety there is no precise way of learning. The catalogues merely list the sources of the material and say nothing as to the ways by which it was acquired. Of the purchases, the proprietor was inclined to speak vaguely or to depreciate, and he once told the writer that the collection, kept to land and freshwater shells, was in fact built up mostly by exchanges and the small percentages that were taken as remuneration for identifications.

Examination of the catalogues has proven to be highly interesting. The first was made in the back part of a university notebook on physics, the date of which, 1874, can just barely be made out. Therein are 6635 entries. The beginning is with "*Z. nitida*, Great Britain," and the Ypsilanti shells, which actually were obtained first, follow scatteringly. There were experiments thereafter with a number of forms of catalogues until, finally, all the items were laboriously copied into specially printed blank books and cross-indexed with cards. These cards were small, and must have supplied insufficient data. Yet Mr. Walker clung to them. Experiment was over so far as they were concerned. Conservatism of the same kind involved microscopes. Five handsome and costly instruments turned up here and there among his effects. Yet the microscope he most frequently used was a feeble, awkward, and imperfect mechanism that the college student of today would think unworthy of his mishandling. It was with the crazy Viennese apparatus that, for one thing, he studied the surface sculpture of *Somatogyrus*. A little apologetically he said that he knew its bad habits whereas the newer instruments raised in his mind the suspicion that they were doing better than they should. The conservatism had its limitations. It did not extend to the ever-changing scientific nomenclature or cause him to accept the International Code as inspired of heaven.

In all, Mr. Walker published 155 papers on mollusks. Counting new names that he substituted for preoccupied names, he is, to be credited with 143 species. A paper of his on *Ancylus* was issued by the NAUTILUS in 1902. Before the studies of the Ancylidae were halted, he had prepared twenty-five papers on this subject alone, brought together an extraordinary collection of the family and obtained virtually all of its literature. Besides being a remarkable record for painstaking, this will probably stand as his best work. A second interest had a patriotic slant. It consisted of compiling catalogues of the shells of Michigan. Five such catalogues were made, and at his urging the Museum of Zoology of his university put out a semi-popular handbook on the Mollusca of the state.

It seems likely that the work Mr. Walker did in his "free" hours could not have been performed if it were not that he had acquired speed in his labors and a singularly retentive memory for minutiae. Where many of us rewrite and revise and irresolutely set down our statements, he commonly wrote his papers only once. Facts, references, footnotes and everything needed marshalled themselves for him like proud, regimented soldiery, and the end of the paper actually meant the end and not irksome reincubation. Only four pieces of incomplete or unpublished work have come to light.

Older students will remember the serrate handwriting that was likely to lapse unconsciously, as Sterki's did, into a self-devised shorthand and sometimes bring bewilderment rather than enlightment. For illustration, "Salm T R. Marq Co. Mich." revealed itself, after translation, to be Salmon Trout River, Mar quette County, Michigan. Type-writing, when he adopted it at last, was difficult for him. He felt that it was forced on him, and it vexed his sense of freedom.

A habitual formality in Mr. Walker's letters was likely to give a correspondent who never had met him an impression of overseriousness. The truth is that in speech he was more often humorous than earnest or grave. He took an enjoyment particularly in jests upon himself. One such jest concerned the lost species *Planorbis multivolvis* Case. He thought at one time that he had found it and announced its rediscovery. Then, one summer, Professor C. A. Davis, whose pursuing problem had to do with the formation of marl and peat in the glaciated area, visited him at his cottage on Lake Superior. He came in one day with a pocketful of the true *multivolvis*, having taken the specimens from a small lake in which Mr. Walker had partial ownership. That, in Mr. Walker's own words, was putting him in his rightful place as a shell collector.

The first section of the Walker will directed that the scientific library and the collection of shells were to go to the University of Michigan. This, clearly, was foremost in his mind, and, indeed, it was the most explicitly set forth provision of the document. Edward Carey Walker had been a regent of the university. He himself was twice a student of the institution. It was in one of its halls that he was chosen to be the second president of the Michigan Academy of Science, and there also that he was given the honorary degree of Doctor of Science. While Dr. A. G. Ruthven was restoring the healthy breath of life to the moribund Museum of Zoology, his warmest encourager and counselor was Mr. Walker. For several years, funds of his sent annual expeditions from the museum into the field and there were numbers of other contributions, lost today to record, that supported educational enterprises. All these bound him sentimentally to the university, and it was as a matter of course that his collections should receive their final housing there.

The public offices that Mr. Walker held were of the unremunerative, "good citizenship" order. He was trustee of Harper's Hospital and trustee of the Detroit Medical College. He was a member of the Wayne County Library Commission for ten years, for three years, president of the Detroit Museum of Art. He acted as director of the Detroit Zoological Society, the organization which promoted the public zoological park, and for a time its president. Until its absorption into the state conservation department, he served on the Michigan Non-game

Licensing Commission. The last of these offices was as a member of the Detroit City Planning Commission.

CALVIN GOODRICH