The Water Shrew, *Sorex palustris* Richardson (Insectivora:Soricidae), and Its Habitat in Virginia

John F. Pagels, Leonard A. Smock, and Stephen H. Sklarew
Department of Biology, Virginia Commonwealth University
Richmond, Virginia 23284-2012

ABSTRACT - The water shrew, *Sorex palustris*, known from a single Virginia locality in Bath County as recently as 1991, has been found at four additional sites, all in Highland County. The five sites were above 900 m (mean = 1,000 m; range = 902-1,128 m) elevation. All sites were fully-canopied first or second order streams with habitat characteristics and a macroinvertebrate community typical of relatively pristine, high-altitude, headwater streams. All streams were high gradient (7-14% slope) and had a variety of flow and depth regimes and a predominately well-sorted cobble substrate with abundant woody debris. Channel banks were fully vegetated and had extensive undercut areas and many crevices. Riparian canopy trees at all sites were primarily northern hardwoods, including yellow birch (*Betula lutea*) and sugar maple (*Acer saccharum*). The macroinvertebrate community of the streams was dominated by stoneflies (Plecoptera), mayflies (Ephemeroptera), and midges (Diptera).

Although the water shrew, *Sorex palustris* Richardson, enjoys a broad distribution, including much of Canada, southwestern Alaska, and northern and high elevation regions of the United States (Hall 1981, Beneski and Stinson 1987), the Appalachian water shrew, *S. p. punctulatus* Hooper, is rare and found only in highly-localized boreal environments in the southern Appalachian Mountains. In an overview of distribution and diversity of Virginia mammals, Handley (1992:165) described *S. palustris* as a "high/medium boreal species" that occurs as a relict and is in danger of extirpation in Virginia. Laerm et al. (1995) summarized records of *S. p. punctulatus*, showing its known distribution as only 14 counties in a seven state area extending from southwestern Pennsylvania to northern Georgia.

The water shrew was first collected in Virginia in northwestern Bath County in 1974 (Pagels and Tate 1976) at the then proposed site of the upper reservoir for a pumped-storage electrical generating facility. Although feared lost from this site when the valley was flooded, the shrew was found in an undisturbed area just above the reservoir (Pagels 1987). Pagels and Handley (1991:564) subsequently observed, "The water shrew, extremely rare in Virginia, is known to occur in only one small watershed in the state." The Appalachian water shrew was declared a state endangered species in 1990, and a recovery plan was prepared (Pagels et al. 1991). The primary objective of that plan is to prevent extirpation of the water shrew in Virginia, with critical aspects being determination of its distribution, description of its habitat, and investigation of factors that might adversely impact the species.

Herein we report on records of the water shrew and examine biotic and abiotic features at all sites where it has been collected in Virginia. Our objective is to provide basic information on the water shrew that will be of interest to biologists and resource managers who might be concerned with the distribution, ecology, and protection of this species.

MATERIALS AND METHODS

SMALL MAMMAL SAMPLING

Efforts to locate the water shrew in Virginia were intensified in the late 1980s in conjunction with development of the recovery plan. Based on published information and knowledge obtained on *S. palustris* habitat during visits to sites where it had been collected in Maryland and West Virginia, a profile of apparently suitable habitat was developed for use in this study. Subsequently, numerous sites were sampled in northern hardwood or northern hardwood-conifer forests along mountain streams at or above about 900-m elevation in Virginia. Emphasis was placed on sampling in Bath, Highland, and Rockingham counties in western Virginia, and Grayson, Smyth, and Washington counties in southwestern Virginia. In addition to efforts by several individuals over many years, portions of approximately 45 first and second order streams were sampled for *S. palustris* by Pagels in the period 1989-1996.

Traps used included Museum Special snap-back traps and Sherman live traps, but most sampling in 1991 to present was completed with use of 2-L plastic pitfall traps. Traps were set as near the water as possible in "most likely" spots, for example, under overhanging banks or root masses of trees, but often a trap was placed in a given spot only because the substrate allowed placement of a pitfall. Number of traps, space between traps, and length of sampling period varied greatly among sites, but whenever trapping was completed in anticipation of perturbative activities, i.e. timbering, pitfalls were usually kept in place for a minimum of 30 days. Most sampling was between April to November as dictated by winter weather and road conditions. All specimens are deposited in the Virginia Commonwealth University Mammal Collection.

Table 1. Habitat parameters measured at streams where *S. palustris* was found in Virginia, 1974-1993. General methodology follows that of Platts et al. (1983).

Parameter	Method
Stream order	method of Strahler (1964)
Elevation	U.S.G.S. 1:24,000 topographic maps
Channel gradient	altimeter
Channel width	bank-to-bank distance
Wetted width	width of the flowing stream
Water depth	determined from measurements at points along each transect across a stream
Water velocity	determined at points along each transect across a stream with a Marsh-McBirney impulse flow meter at six-tenths water depth
Substrate type	visual estimate of the proportion of each of six sediment particle sizes in the channel (bedrock; boulder = >256 mm; cobble = 64-256 mm; pebble = 16-64 mm; gravel = 2-16 mm; sand = 0.06-2 mm.
Riffle-pool prevalence	proportion of the stream channel in riffles, pools and glides
Bank undercutting	distance that the bank overhangs the channel
Bank water depth	depth of water at the bank
Wood abundance	volume of wood in the channel, calculated using the method of Wallace and Benke (1984)
Debris dams	number of large accumulations of woody debris per 100 m of stream
pH	field pH meter
Conductivity	conductivity meter
Riparian vegetation	percentage composition of canopy trees within 8 m of both banks

HABITAT CHARACTERIZATION

Two approaches were used to describe the in-stream and riparian habitat at each stream where *S. palustris* was found. The first approach described 16 general geomorphic and physico-chemical characteristics deemed as potentially significant habitat variables for the shrews (Table 1). Habitat characteristics were quantified over a 100-m stretch following the general methodology of Platts et al. (1983). Values for in-channel parameters are reported as the mean of measurements made at 5- or 10-m intervals along the entire 100-m stretch. Composition of the riparian vegetation was made from surveys of canopy trees along both banks. All habitat analyses were conducted in a three-day period in June 1995 when streams were at base flow.

The second approach to characterizing stream and riparian habitat was a formal assessment using the U.S. Environmental Protection Agency's (EPA) Rapid Habitat Assessment Protocol (Plafkin et al. 1989). Twelve metrics were used to score habitat condition at each stream (Table 2). All metrics were scored on a 20-point scale, 20 points indicting the best or preferred condition. A portion of the riparian zone and near-channel watershed of one of the sites at which *S. palustris* was collected was timbered between the time that the shrews were collected and the habitat analysis was conducted. Habitat data from this site were not included in our summary.

Table 2. Parameters measured for the habitat assessment of streams where *S. palustris* was found in Virgina. Methodology follows that of Plafkin et al. (1989).

Parameter	General Description
In-stream cover	abundance of submerged logs, undercut banks, and other forms of stable habitat
Epifaunal substrate	abundance of the "most productive benthic habitat," typically riffle areas and/or submerged snags
Embeddedness	degree to which the primary substrate was surrounded by fine sediment
Velocity/depth ranges	variety of water velocity and depth regimes in the stream
Channel alteration	evidence of stream channelization
Sediment deposition	evidence of recent sediment deposition
Frequency of riffles	prevalence and size of riffles
Channel flow status	percentage of the channel bed that was wetted
Condition of banks	evidence of bank stability versus erosion
Bank vegetative cover	percentage of bank that was covered with vegetation
Disturbance pressure	degree of disruption of riparian vegetation by grazing or other processes
Riparian vegetation	width of riparian zone that was vegetated and with minimal human disturbance

Fig. 1. General location of sites where *S. palustris* was found in Virginia, 1974-1993. B and H indicate Bath and Highland counties. Insert map (after Webster 1987:38) shows the range of the species in North America; its range in the southern Appalachian Mountains is solid dark.

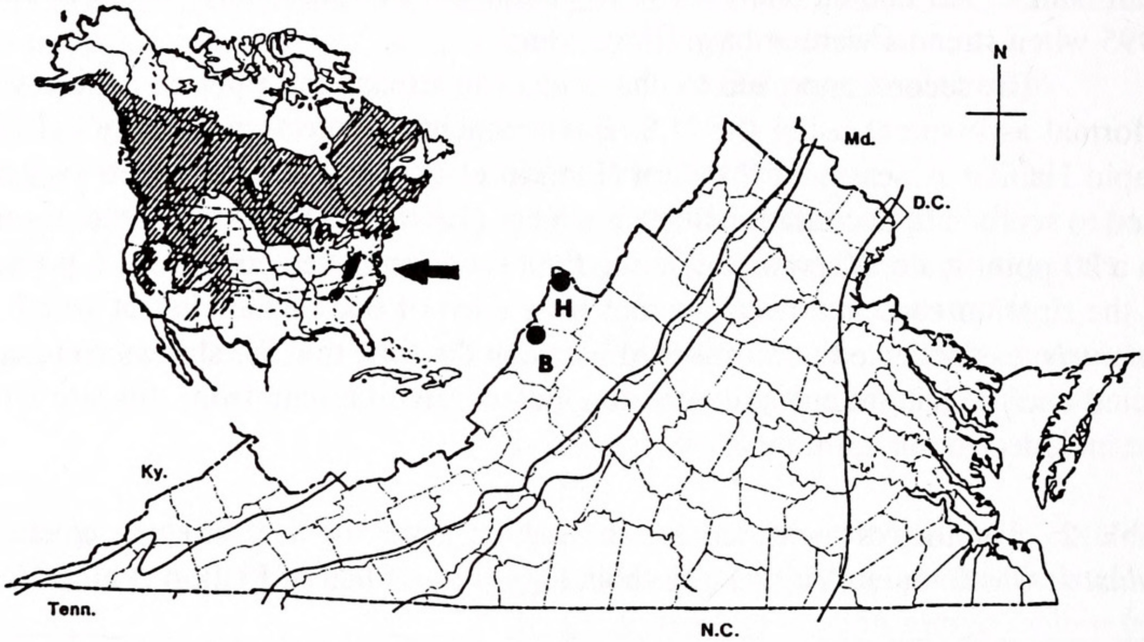


Table 3. Virginia Commonwealth University catalog number, sex, date of capture, and general location of captures of *S. palustris* in Virginia, 1974-1993. Bath County sites (B) include those of Pagels and Tate (1976) and Pagels (1987). Highland County sites are comprised of the private property location (HP) and three sites, H1, H2, and H3, in the Laurel Fork area of George Washington and Jefferson National Forests.

Catalog Number	sex	Date	Location
557	F	3 August 1974	B
558	F	5 October, 1974	B
559	F	4 October 1974	B
560	F	4 October 1974	B
4715	F	29 August 1986	B
4742	F	5 August 1986	B
10025	F	2 July 1992	HP
10491	F	11 September 1992	H1
10492	F	11 September 1992	H1
10940	F	15 June 1993	H2
11261	M	16 July 1993	H3
11262	F	16 July 1993	H3
11263	F	16 July 1993	H3

AQUATIC MACROINVERTEBRATES

Aquatic macroinvertebrate communities were sampled in June 1995 at each stream to provide information on the species composition and relative abundance of the shrew's primary food source. A D-frame dip net was used to collect organisms along a 100-m stretch. All primary habitats were sampled, including riffles, pools, bank areas, and woody debris; the material collected was composited into one sample per stream.

Invertebrates were removed from the samples in the laboratory under a stereo-microscope after addition of rose bengal to facilitate the sorting process. A minimum of 200 organisms was randomly picked from the samples; picking ending when no new taxa were observed. Organisms were identified with the taxonomic keys in Merritt and Cummins (1996) and Pennak (1989).

RESULTS

DISTRIBUTION

Sorex palustris was collected along four streams of the Potomac River drainage in Highland County. Along with the original Little Back Creek site (Pagels and Tate 1976, Pagels 1987) in the James River drainage in Bath County, it is now known from five Virginia localities, all on Allegheny Mountain. Three of the new sites are in the George Washington and Jefferson National Forests in the Laurel Fork area of northwestern Highland County. The other site is on private property just west of Hightown, Virginia, and is the site since timbered by the land owner. The continued existence of the water shrew at this site after timbering has not been confirmed. General locations of the sites where *S. palustris* has been captured in Virginia are given in Figure 1.

Four other species of shrews, the short-tailed shrew (*Blarina brevicauda*), masked shrew (*Sorex cinereus*), smoky shrew (*S. fumeus*), and rock shrew (*S. dispar*), were captured on traplines with *S. palustris* at all Highland County sites except the private property site where no *S. dispar* was taken. *Sorex fumeus* represented 66.5%, *S. cinereus* 17.9%, *S. dispar* 6.9%, *B. brevicauda* 4.6%, and *S. palustris* 4.0% of the 173 shrews taken at the four Highland County sites where *S. palustris* was captured. A summary of all *S. palustris* captured in Virginia, including records in Pagels and Tate (1976), and Pagels (1987), is given in Table 3.

HABITAT

Habitat characteristics of all streams were typical of relatively pristine headwater streams of the Virginia mountains (Table 4). Streamwater was cool, had a circum-neutral pH, and low to moderate conductivity. All streams were either first or second order and hence had a narrow channel and wetted width. Channel gradients were a relatively steep 7-14%. A variety of flow regimes

Table 4. Means, standard errors, and ranges of geomorphic, hydrologic, and

physico-chemical characteristics of the streams where *S. palustris* was found in Virginia, 1974-1993.

Parameter	Mean	SE	Range
Stream order	1	<0.1	1-2
Elevation (m)	1,000	37	902-1,128
Channel gradient (%)	10	1.4	7-14
Channel width (m)	4	0.7	2-10
Wetted width (m)	3	0.4	1-7
Water depth (cm)	8	1.3	1-1,510
Water velocity (m3/s)	0.15	0.01	0-0.80
Bank undercut (cm)	18	0.5	0-99
Wood volume (m3/m^2)	0.53	0.1	0.37-0.66
Debris dams (#/100m)	3	0.9	2-6
pH	7.0	0.1	6.7-7.2
Conductivity (uS/cm)	24	9	12-52

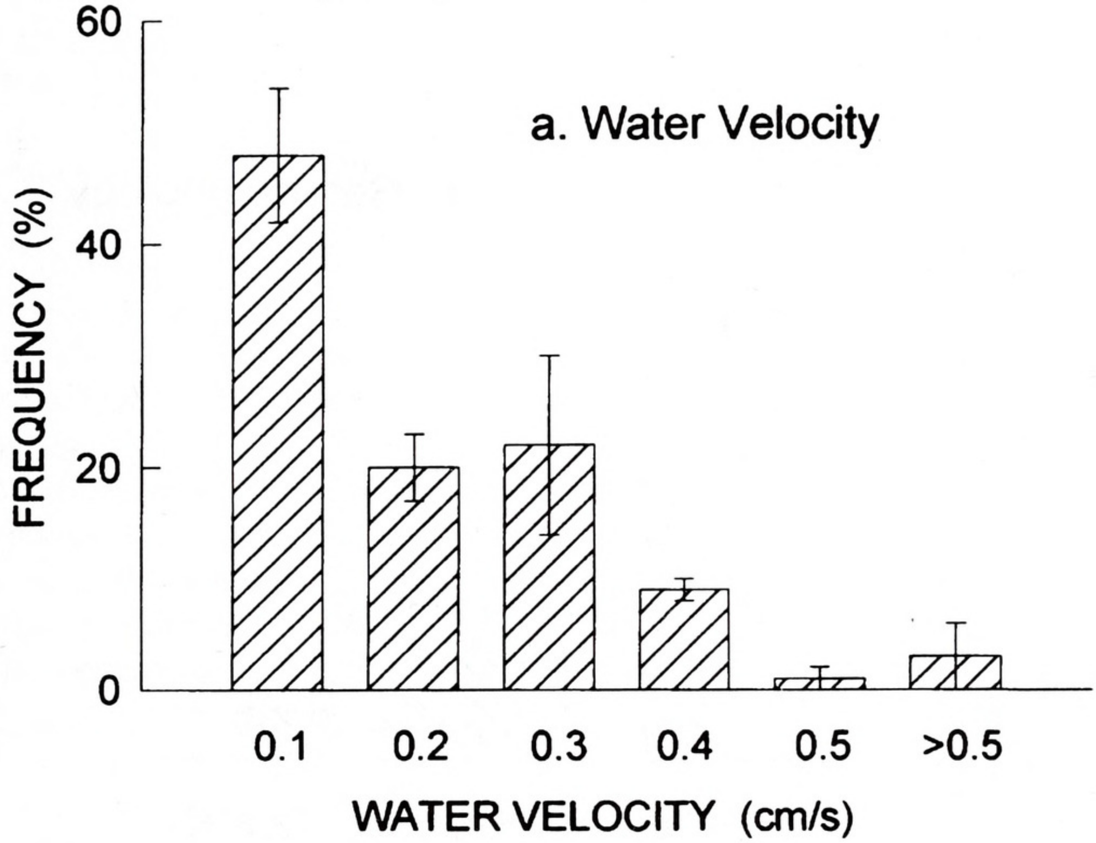
existed in the streams, as reflected by the ranges in water velocity and depths (Fig. 2). Also, although riffles were the predominant habitat (Fig. 3), a distinct riffle-pool geomorphology occurred in all of the streams.

In-stream cover was abundant in all streams. Cobble was the predominant substrate, with boulder, pebble and gravel also being relatively common (Fig. 3). The sediment was well sorted, with little embeddedness by fine-grained particles (Table 5). Woody debris and resulting debris dams were common in the channels of all streams, and growth of moss in the channel was evident at most sites.

The riparian areas of the streams were undisturbed, vegetated, and stable (Table 5). All channel banks had extensive undercut areas (Fig. 4) and areas that were rocky with many crevices and downed wood. Most of the undercuts were not in contact with the flowing stream but rather with dry channel sediment. One site had a broad floodplain and many side channels where water flowed freely through interstitial areas in the rocky floodplain floor.

Yellow birch (*Betula lutea*) was the most abundant canopy tree along the riparian areas of all streams (Table 6). Other common canopy species along the streams were black birch (*B. lenta*), sugar maple (*Acer saccharum*), basswood (*Tilea americana*), black cherry (*Prunus serotina*), red maple (*A. rubrum*), American beech (*Fagus grandifolia*), and Eastern hemlock (*Tsuga canadensis*). The understory was generally undeveloped, typical of mature forests.

Fig. 2. Frequency distribution (mean ± SE) of water velocity and depth in four streams at which *S. palustris* was found in Virginia.



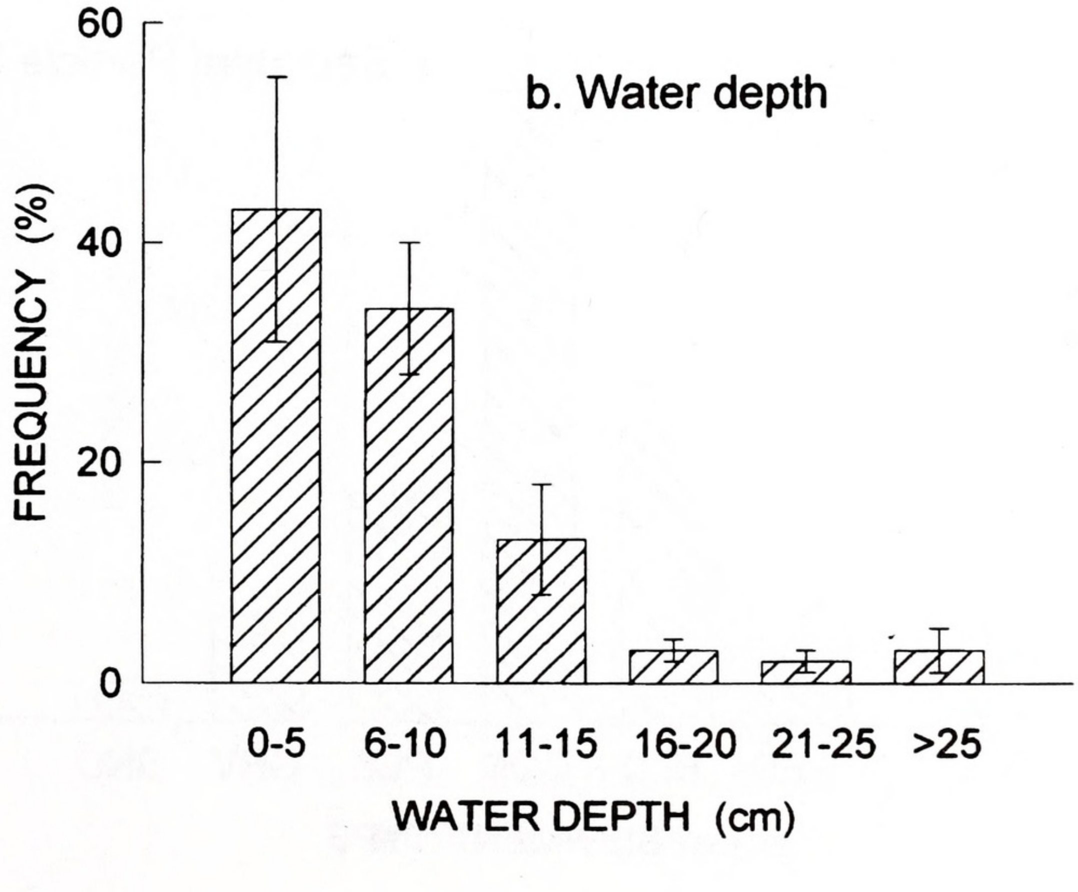


Fig. 3. Frequency distribution (mean ± SE) of riffle, pool, and glide areas and sediment particle sizes in four streams at which *S. palustris* was found in Virginia. BED = bedrock, BLD = boulder, COB = cobble, PEB = pebble, GRV = gravel, SND = sand.

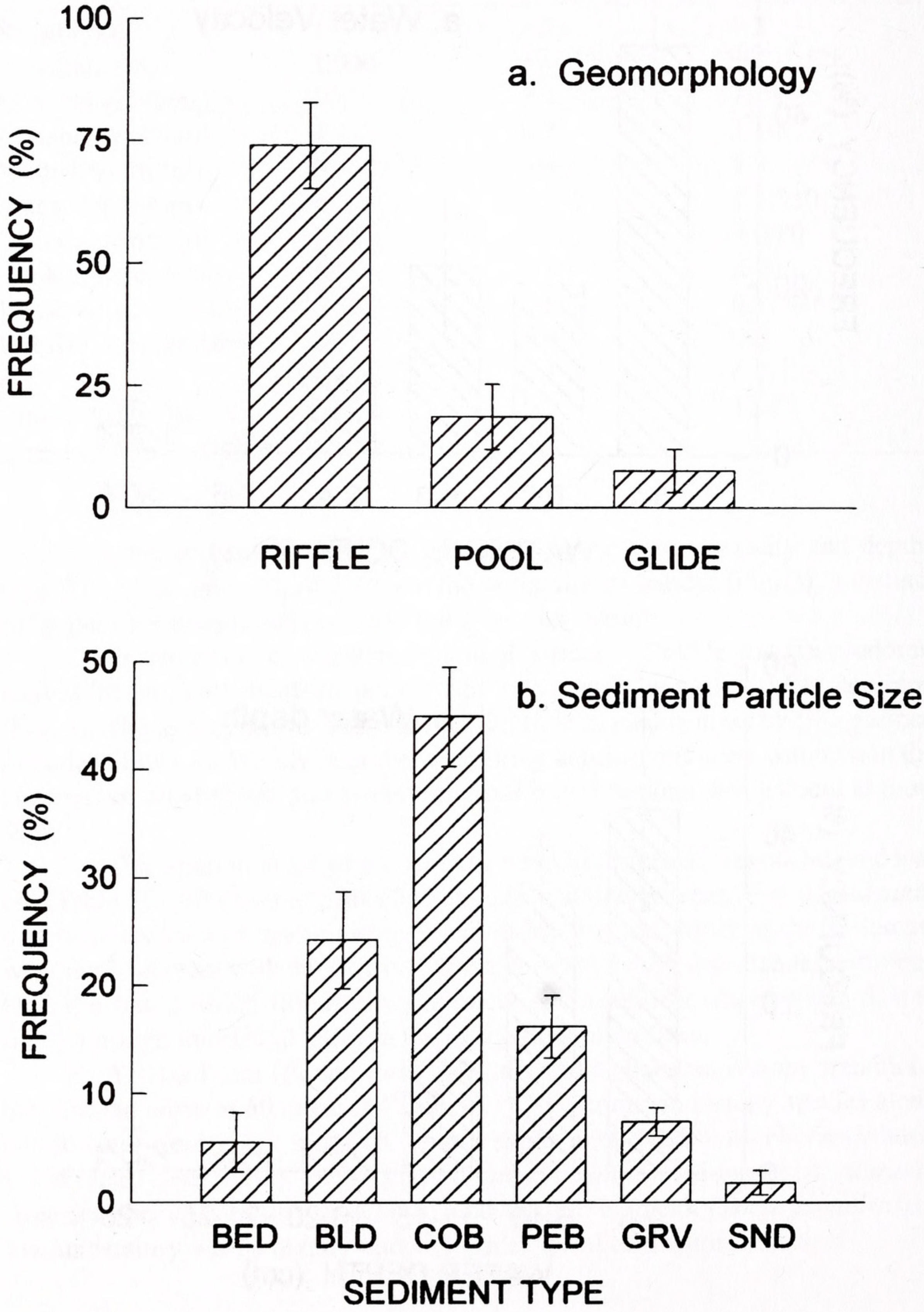


Table 5. Means, habitat assessment metric scores (after Plafkin et al. 1989), standard errors and ranges for five streams in Virginia where *S. palustris* was found, 1974-1993. Values range from 0-20, with 20 indicating the highest quality.

Parameter	Mean	SE	Range
In-stream cover	20	0.0	20-20
Epifaunal substrate	20	0.0	20-20
Embeddedness	18	0.2	18-19
Velocity/depth ranges	15	0.2	15-16
Channel alteration	20	0.0	20-20
Sediment deposition	18	1.2	15-20
Frequency of riffles	20	0.0	20-20
Channel flow status	16	1.0	13-18
Bank condition	19	0.2	19-20
Bank vegetative protection	19	0.2	18-19
Disturbance pressure	20	0.0	20-20
Riparian vegetation	19	1.0	16-20

Fig. 4. Frequency distribution (mean ± SE) of the extent of bank undercutting in four streams at which *S. palustris* was found in Virginia.

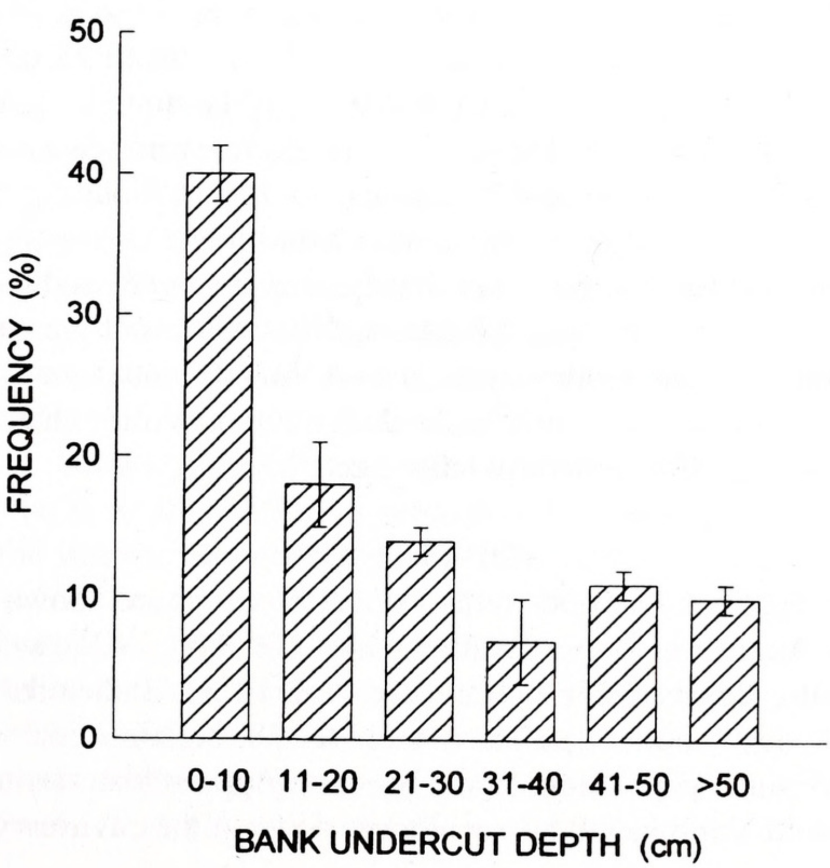


Table 6. Mean percent abundance, standard error, and range of riparian canopy trees at the streams where *S. palustris* was found in Virginia, 1974-1993.

Species	Mean	SE	Range
Betula lutea	29	3	22-35
Betula lenta	13	4	0-24
Acer saccharum	10	2	4-17
Tilia americana	9	4	0-22
Prunus serotina	7	3	0-14
Acer rubrum	6	4	0-18
Fagus grandifolia	6	3	0-14
Tsuga canadensis	6	2	0-9
Fraxinus sp.	3	2	0-8
Quercus rubra	3	1	0-7
Robinia pseudo-acacia	2	1	0-6
Carya sp.	<1	<1	0-2
Picea rubens	<1	<1	0-2
Standing dead trees	6	2	0-9

MACROINVERTEBRATE COMMUNITY

Taxonomic composition and richness were very similar among all streams (Table 7). Taxonomic richness ranged from 26 to 28 taxa, but would have been considerably higher had individuals in the dipteran family Chironomidae (midges) been identified to genus. The macroinvertebrate communities of all of the streams were dominated by species of midges (Diptera), stoneflies (Plecoptera) and mayflies (Ephemeroptera). Non-midge taxa common at most streams included stoneflies in the families Leuctridae and Perlodidae; the mayfly families Heptageniidae, Ephemerellidae, and Baetidae; and the caddisfly families Philopotamidae and Hydropsychidae. Although biomass of macroinvertebrates was not measured, these taxa no doubt dominated the macroinvertebrate biomass because of their generally large size.

DISCUSSION

In Virginia, Pleistocene remains of *S. palustris* are known from Natural Chimneys in Augusta County, elevation 414 m (Guilday 1962), and Clarks Cave in Bath County, elevation 456 m (Guilday et al. 1977). Indicative of the boreal nature of the sites where *S. palustris* now occurs, certain other boreal species with highly disjunct populations in the southern Appalachians remain associates of *S. palustris* in Virginia, but also no longer occur in the environs of the Natural

Table 7. Taxonomic richness and mean percent contribution (1 SE and range) of macroinvertebrate taxa occuring in four streams at which S. palustris was found in Virgina, 1974-1993.

Taxon	Number of Genera	Mean Percent Abundance	SE	Range (%)
Hydracarina	1	<1	<1	0-1
Decapoda	1	1	<1	0-2
Ephemeroptera	6	26	10	6-54
Odonata	1	1	<1	1-2
Plecoptera	6	26	2	20-31
Trichoptera	8	22	4	14-31
Coleoptera	3	3	2	1-8
Diptera	8	22	4	11-32
Pelecypoda	1	<1	<1	0-1

Chimneys or Clarks Cave sites. These include the rock vole (*Microtus chrotorrhinus*), in the Little Back Creek area of Bath County (Pagels 1990), and the northern flying squirrel (*Glaucomys sabrinus*), at the Highland County sites (Pagels et al. 1990). Handley (1992:159) suggested that these species, along with a few others, probably "...represent the last stages of the recoil of high boreal species from southern latitudes into higher latitudes in the United States and Canada---north and west of Virginia."

Sorex palustris was found only at sites where cool, mesic conditions occurred along with considerable cover on the banks of swift-flowing streams. Beneski and Stinson (1987) observed that although it is found in a variety of habitats, rocky crevices, logs, and abundant overhanging areas along stream banks are typical of *S. palustris* habitat throughout much of its range, and likely are critical in warmer, southern areas to provide cool, mesic microhabitats for the shrews. Also, the full canopy of mature forests, as occurred at the sites where the shrews were found, probably is essential for maintaining the cool conditions.

Habitat conditions also are important in affecting the food resources available to the shrews. Both terrestrial and aquatic invertebrates are consumed by water shrews (Beneski and Stinson 1987). Wrigley et al. (1969) suggested that a mesic microhabitat along stream banks was important for supporting terrestrial invertebrates that at times can compose a significant portion of the diets of the shrews (Hamilton 1930, Whitaker and Schmeltz 1973). The primary aquatic organisms consumed by shrews, including stoneflies, mayflies, and caddisflies (Conoway 1952, Conoway and Pfitzer 1952, Sorenson 1962, Linzey and

Linzey 1973) are most abundant in streams with fast current and cobble substrate. Those conditions were prevalent at the five sites at which *S. palustris* was found and these aquatic insect orders were common.

All streams where shrews were found had habitat characteristics indicative of relatively pristine conditions. The Envrionmental Protection Agency habitat assessment metric scores (Table 4) show the high quality of in-stream, bank, and riparian habitat at all sites. All metrics were scored at 15 or higher, and many scores were at or near the maximum score of 20. Total metric scores of 220-229 points where shrews were found reflect high habitat quality at the streams. The taxonomic composition of macroinvertebrates also is indicative of relatively undisturbed streams. Most taxa we collected are generally intolerant of low habitat or water quality.

We cannot state assuredly that *S. palustris* does not occur along streams that we sampled unsuccessfully, or on streams that possess the habitat conditions reported herein. Laerm et al. (1995:49) observed that despite the great increase in knowledge of shrew species that were formerly thought to be very rare, including both *Sorex hoyi* and *S. dispar* that are now known to be more common than was earlier thought, "...the water shrew appears to be the rarest and most localized shrew in the southeastern United States." New records such as those reported herein, and a low altitude site (808 m) in northern Georgia (Laerm et al. 1995), provide hope that *S. palustris* will be found at additional locations. Baseline data on suitable habitat will make searching for new sites more efficient, and will aid in the development of management programs for protection of known and potential sites.

ACKNOWLEDGEMENTS. - Individuals who assisted in field work included J. Baker, J. Blevins, T. Blevins, B. Glasgow, D. Kirk, S. Klinger, J. McGovern, J. E. Pagels, J. Pound, R. Reynolds, S. Rinehart, C. Thomas, and S. Whitcomb. K. Terwilliger (formerly of the Virginia Department of Game and Inland Fisheries), M. Fies and R. Reynolds of the Virginia Department of Game and Inland Fisheries, R. Glasgow (formerly of the U.S. Forest Service, George Washington and Jefferson National Forests) and J. Bellemore, S. Croy, and S. Klinger of the U. S. Forest Service were supportive in numerous aspects of the study. E. Thomson and D. Feller, Maryland Natural Heritage Program, and C. Stihler, West Virginia Department of Natural Resources, graciously led visits to sites in their states, and D. Webster provided unpublished observations on habitat in North Carolina. C. Handley, Jr. and the late J. Guilday were inspirational leaders. Throughout most of the study funding to JFP was received from the Nongame and Endangered Species Program of the Virginia Department of Game and Inland Fisheries, and more recently also from matching funds from the U. S. Forest Service, George Washington and Jefferson National Forests.

LITERATURE CITED

Beneski, J. T., Jr., and D. W. Stinson. 1987. *Sorex palustris*. Mammalian Species 296:1-6.

Conoway, C. H. 1952. Life history of the water shrew (*Sorex palustris navigator*). American Midland Naturalist 48:219-248.

Conoway, C. H., and D. W. Pfitzer. 1952. *Sorex palustris* and *Sorex dispar* from The Great Smoky Mountains National Park. Journal of Mammalogy 33:106-108.

Guilday, J. E. 1962. The Pleistocene local fauna of the Natural Chimneys, Augusta County, Virginia. Annals of Carnegie Museum 36:87-122.

Guilday, J. E, P. W. Parmalee, and H. W. Hamilton. 1977. The Clark's Cave bone deposit and the Late Pleistocen paleoecology of the central Appalachian Mountains of Virginia. Bulletin of Carnegie Museum of Natural History 2:1-86.

Hall, E. R. 1981. The mammals of North America. Second edition. John Wiley and Sons, Inc., New York, New York.

Hamilton, W. J., Jr. 1930. The food of the Soricidae. Journal of Mammalogy 11:26-39.

Handley, C. O., Jr. 1992. Terrestrial mammals of Virginia: Trends in distribution and diversity. Virginia Journal of Science 43:157-169.

Laerm, J. L., C. H. Wharton, and W. M. Ford. 1995. First record of the water shrew, *Sorex palustris* Richardson (Insectivora: Soricidae), in Georgia with comments on its distribution and status in the southern Appalachians. Brimleyana 22:47-51.

Linzey, D. W., and A. V. Linzey. 1973. Notes on food of small mammals from Great Smoky Mountains National Park, Tennessee-North Carolina. Journal of the Elisha Mitchell Scientific Society 89:6-14.

Merritt, R. W., and K. W. Cummins. 1996. An introduction to the aquatic insects of North America. Kendall/Hunt, Dubuque, Iowa.

Pagels, J. F. 1987. The pygmy shrew, rock shrew and water shrew: Virginia's rarest shrews (Mammalia: Soricidae). Virginia Journal of Science 38:364-368.

Pagels, J. F. 1990. First record of the rock vole, *Microtus chrotorrhinus* (Miller) (Rodentia: Cricetidae), in Virginia. Brimleyana 16:1-3.

Pagels, J. F., R. P. Eckerlin, J. R. Baker, and M. L. Fies. 1990. New records of the distribution and internal parasites of the endangered northern flying squirrel, *Glaucomys sabrinus*, in Virginia. Brimleyana 16:73-78.

Pagels, J. F., M. L. Fies, and R. Glasgow. 1991. Recovery plan: Appalachian water shrew, *Sorex palustris punctulatus* Hooper. Virginia Department of Game and Inland Fisheries. Unpublished manuscript.

Pagels, J. F., and C. O. Handley, Jr. 1991. Water shrew: *Sorex palustris punctulatus* Hooper. Pages 564-565 *in* Virginia's endangered species (K. Terwilliger, coordinator). McDonald and Woodward Publishing Company, Blacksburg, Virginia.

Pagels, J. F., and C. M. Tate. 1976. The shrews (Insectivora: Soricidae) of the Paddy Knob-Little Back Creek area of western Virginia. Virginia Journal of Science 27:202-203.

Pennak, R. W. 1989. Fresh-water invertebrates of the United States. Third Edition. John Wiley, New York, New York.

Plafkin, J. L., M. T. Barbour, K. D. Porter, S. K. Gross, and R. M. Hughes. 1989. Rapid bioassessment protocols for use in streams and rivers: benthic macroinvertebrates and fish. U.S. Environmental Protection Agency, PA/444/4-89-011. Washington, D.C.

Platts, W. S., W. F. Megahan, and G. W. Minshall. 1983. Methods for evaluating stream, riparian and biotic conditions. U.S. Forest Service, General Technical Report INT-138, Ogden, Utah.

Strahler, A. N. 1964. Quantitative geomorphology of drainage basins and channel networks. Section 4-2 in (V. T. Chow, editor). Handbook of Applied Hydrology, McGraw-Hill, New York, New York.

Sorenson, M. W. 1962. Some aspects of water shrew behavior. American Midland Naturalist 68:445-462.

Wallace, J. B., and A. C. Benke. 1984. Quantification of wood habitat in subtropical Coastal Plain streams. Canadian Journal of Fisheries and Aquatic Science 41:1643-1652.

Webster, W. D. 1987. *Sorex palustris punctulatus* Hooper. Pages 36-38 *in* Endangered, threatened, and rare fauna of North Carolina (M. K. Clark, Editor) Part I. A re-evaluation of the mammals. Occasional papers of the North Carolina Biological Survey, 1987-3, North Carolina State Museum of Natural Sciences, Raleigh.

Whitaker, J. O., Jr., and L. L. Schmeltz. 1973. Food and external parasites of *Sorex palustris* and food of *Sorex cinereus* from St. Louis Co., Minnesota. Journal of Mammalogy 54:283-285.

Wrigley, R. E. 1969. Ecological notes on the mammals of southern Quebec. Canadian Field Naturalist 83:201-211.

Received 13 September 1996
Accepted 3 December 1996