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DISTRIBUTION OF *SOREX CINEREUS* AND *S. FUMEUS* ON NORTH- AND SOUTH-FACING SLOPES IN THE SOUTHERN APPALACHIAN MOUNTAINS

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ABSTRACT – The distributions of masked shrews (*Sorex cinereus* Kerr) and smoky shrews (*S. fumeus* Miller) were examined in relation to environmental conditions on opposing slopes in the southern Appalachian Mountains. Arrays of drift fences and pitfall traps were established on 3 north-facing plots, 3 south-facing plots, and 6 streamside plots in the Gingercake Creek drainage of Burke County, North Carolina. Shrews and invertebrates were collected on several consecutive nights each month in the autumn of 1996 and in the spring and summer of 1997 (TN = 2544). Leaf litter moisture content, daily high temperatures, and volume of downed logs were measured. South-facing plots were significantly warmer and drier than north-facing and streamside plots ($p < 0.001$) and had the lowest percentage volume of heavily decomposed logs ($p = 0.02$). Capture rates of *S. cinereus* and *S. fumeus* were significantly greater on mesic north-facing slopes and at streamside sites than on xeric south-facing slopes ($p = 0.05$ and 0.04), but biomass of invertebrate prey was similar between habitats. Smoky shrews were significantly positively correlated with percentage litter moisture and heavily decomposed logs but negatively correlated with invertebrate biomass. Masked shrews were not significantly correlated with any habitat variable. Results suggest that the distributions of these shrews are strongly influenced by habitat heterogeneity at high-resolution scales.

INTRODUCTION

Distributions of shrews are greatly influenced by environmental moisture (Kirkland 1991, Pagels et al. 1994, Parmley and Harley 1995, Spencer and Pettus 1966, Wrigley et al. 1979). Because of their high metabolic rates, shrews experience relatively high respiratory water losses and may be unable to regulate such losses in xeric environments (Getz 1961). Moisture is also important in supporting diverse and abundant litter invertebrate fauna (Gist and Crossley 1975) that serve as the food resource base for soricids (Kirkland 1991).

Masked shrews (*Sorex cinereus* Kerr) and smoky shrews (*S. fumeus* Miller) are common soricids in the southern Appalachian mountains that occur primarily in moist forests with considerable structural microhabitat such as logs and rocks (Brannon 2000, McCay et al. 1998, Mitchell et al. 1997). They are most abundant in mesic northern hard-

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wood and cove hardwood communities but are relatively rare in xeric oak-pine communities (Laerm et al. 1999). Components of the forest-floor microhabitat may help to mediate humidity levels (Getz 1961, Laerm et al. 1999, McCay et al. 1998, Pagels et al. 1994).

However, species may respond to components of their environment on a scale of resolution finer than gross habitat differences (Dueser and Shugart 1978). Habitat patches that seem homogenous at low resolutions may be extremely heterogeneous at high resolutions (Orrock et al. 2000). For example, moisture, temperature, and associated vegetation can differ greatly even between neighboring slopes (Matlack 1993, Whittaker 1956). In the northern hemisphere, north-facing slopes are typically cooler and wetter than south-facing slopes because duration and intensity of sunlight exposure are reduced (Wales 1972). Consequently, small mammal species with high moisture requirements may not be distributed equally between opposing slopes (McComb and Rumsey 1982). My objective was to determine if distributions of *S. cinereus* and *S. fumeus* in the southern Appalachian Mountains are affected by variation in environmental moisture between north- and south-facing slopes.

METHODS

Twelve 50- by 50-m plots were established in an approximately 1.5 km^2 area of the Gingercake Creek drainage of the Pisgah National Forest, Burke County, western North Carolina (35°55'30", 81°52'0"). This area consisted of steep (20-38°) north- and south-facing slopes separated by a relatively narrow riparian corridor that flowed roughly west to east. Stand ages were about 55 years and elevations averaged 787 m.

Plots were spaced a minimum distance of 100 m apart. Three plots were located on north-facing slopes, and another 3 were located directly opposite from them on neighboring south-facing slopes. Woody vegetation on north-facing slopes consisted primarily of white pine (*Pinus strobus*), chestnut oak (*Quercus prinus*), and red maple (*Acer rubrum*) with an understory of rhododendron (*Rhododendron maximum*). South-facing slopes were dominated by white pine, red maple, chestnut oak, and red oak (*Q. rubra*) with a sparse understory of mountain laurel (*Kalmia latifolia*). The remaining six plots were located within the riparian corridor and served as controls due to the presence of a permanent water source. Vegetation in streamside areas consisted mainly of tulip poplar (*Liriodendron tulipifera*), black birch (*Betula lenta*), and eastern hemlock (*Tsuga canadensis*) with a dense understory of rhododendron.

Drift fences with associated pitfalls were used to collect shrews. A single Y-shaped array was installed in the middle of each plot, consisting of a central pitfall surrounded by three other pitfalls spaced 3 m from

the center. Each 20-L pitfall (5-gal plastic bucket) was connected to the central pitfall by a 61 cm tall section of aluminum flashing. Pitfalls were partially filled with water to drown shrews quickly and prevent predation within traps (Kirkland and Sheppard 1994). Pitfalls were open concurrently for 5 to 7 consecutive nights each month from August to November 1996 and from March to August 1997, for a total of 2544 trap nights (TN). Trappability was assumed to be equal in all habitats. Shrews were removed daily during each trapping period and deposited in the Appalachian State University mammal collection.

Pitfalls also collected large numbers of epigeal invertebrates which represented available prey. Invertebrates were removed during each trapping period, and collectively weighed to obtain total biomass for each plot. Invertebrate taxa that are not regularly eaten by shrews, such as millipedes, were excluded.

Environmental conditions of the forest floor at each plot were measured for each trapping period. Max-min thermometers were oriented with slope and placed 5 cm off the forest floor near the center of each plot to record daily high temperatures. These values were used to calculate average maximum temperature per plot for each trapping period.

A 0.25-m^2 sample of leaf litter was collected from a randomly selected point within each plot on the first and last day of each trapping period. Samples were weighed immediately upon return to the lab (wet mass), dried at 100°C for 24 h, and reweighed (dry mass). Litter moisture content of each sample was calculated as wet mass minus dry mass and expressed as a percentage of wet mass (Brannon 2000).

Because of their spongy texture, logs in the advanced stages of decomposition may also serve as a source of environmental moisture for shrews (Brannon 2000). For each plot the diameter and length of every downed log ≥10 cm in diameter was measured to determine its volume. Any branches ≥10 cm in diameter were treated as separate logs. Stage of decomposition was classified for each log from class 1 for recently fallen logs with little evidence of decay to class 5 for extremely decomposed logs (Maser et al. 1979).

Differences in capture rates (number of captures per 100 TN) of *S. cinereus* and *S. fumeus* between plots in each of the three habitat types were examined using one-way analysis of variance (Zar 1984). One-way ANOVA was also used to examine differences in invertebrate biomass, average maximum temperatures, percentage litter moisture, and percentage volume of heavily decomposed (decay classes 4 and 5) logs between sites. All percent values were arcsine-transformed prior to analysis (Zar 1984). To assess their influence on shrew species' relative abundance, habitat variables were correlated with shrew capture data for each plot using Pearson's product moment correlation analysis (Ford et al. 1997, Zar 1984).

RESULTS

Sites differed significantly in both maximum temperatures ($F_{2,117}$ = 22.09, p < 0.001) and percentage litter moisture content ($F_{2,237}$ = 79.34, p < 0.001). South-facing slopes had the highest mean ($\pm$ 1 SE) maximum temperatures (26.6 $\pm$ 0.6 EC), whereas north-facing slopes had the lowest (20.9 $\pm$ 0.5 EC) and those at streamsides were intermediate (22.8 $\pm$ 0.6 EC). Mean percentage litter moisture was lowest on south-facing slopes (47.27 $\pm$ 1.53%), but similar between north-facing slopes (56.71 $\pm$ 1.80%) and streamside habitats (59.97 $\pm$ 1.09%).

Percentage volume of heavily decomposed logs also differed significantly between sites ($F_{2,9}$ = 5.11, p = 0.02). Mean percentage volume was high on north-facing slopes (96.92 $\pm$ 0.62%) and at streamside sites (88.78 $\pm$ 4.99%), but low on south-facing slopes (30.37 $\pm$ 21.48%). Two of the three south-facing plots had no logs that were classified as heavily decomposed.

No significant differences in invertebrate biomass were observed between sites ($F_{2,9}$ = 0.64, p = 0.54). Mean biomass was 207.79 $\pm$ 34.58 g at streamside sites, 237.41 $\pm$ 16.97 g on north-facing slopes, and 313.68 $\pm$ 29.87 g on south-facing slopes.

A total of 17 *S. cinereus* and 32 *S. fumeus* were collected on north-facing slopes, whereas only 4 *S. cinereus* and 10 *S. fumeus* were captured on south-facing slopes (Table 1). Capture rates (captures per 100 TN) were significantly different between sites for both masked shrews ($F_{2,9}$ = 3.54, p = 0.05) and smoky shrews ($F_{2,9}$ = 4.10, p = 0.04). Mean capture rates of masked shrews were highest at north-facing plots (2.67 $\pm$ 0.03), intermediate at streamside plots (1.57 $\pm$ 0.04), and lowest at south-facing plots (0.63 $\pm$ 0.03; Table 1). Only 3.3% of masked shrew captures occurred at each south-facing plot compared to 13.8% at each north-facing plot and 8.1% at each streamside plot. Mean capture rates of smoky shrews were similar at mesic north-facing (5.03 $\pm$ 0.59) and streamside plots (4.95 $\pm$ 1.24) but over 3 times less at xeric south-facing plots (1.57 $\pm$ 0.59; Table 1). Each south-facing plot yielded 3.2% of captures of smoky shrews compared to 10.2% at each north-facing plot and 10.0% at each streamside plot.

Smoky shrews (n = 105) were strongly positively correlated with percentage litter moisture and heavily decomposed logs, and significantly negatively correlated with invertebrate biomass (Table 2). There

Table 1. Summary of shrew captures in each habitat type in the study area in Autumn 1996 and spring and summer 1997.

Habitat	Plots	TN	*Sorex cinereus*			*S. fumeus*			Combined		
			n	capture rate	% relative abundance	n	capture rate	% relative abundance	n	capture rate	% relative abundance
Streamside	6	1272	20	1.57	8.1	63	4.95	10.0	83	6.53	9.47
North-facing slope	3	636	17	2.67	13.8	32	5.03	10.2	49	7.70	11.19
South-facing slope	3	636	4	0.63	3.3	10	1.57	3.2	14	2.20	3.20

was no significant correlation between smoky shrews and maximum temperatures. Masked shrews (n = 41) showed no significant correlation with any habitat variable (Table 2), although correlations with litter moisture and percentage of rotten logs were positive.

DISCUSSION

Although many factors may influence distributions of soricids (Pagels et al. 1994, Parmley and Harley 1995), environmental moisture may be of the greatest importance to shrews because of their extremely high water turnover rates (Getz 1961, Wrigley et al. 1979). Masked shrews and smoky shrews are most abundant in mesic forests and near standing water but are uncommon, if not absent, in dry habitats (Cudmore and Whitaker 1984, Getz 1961, Laerm et al. 1999, Owen 1984). North-facing slopes are generally cooler and moister than south-facing slopes (Wales 1972) and consequently yield greater numbers of shrews (Laerm et al. 1999, McComb and Rumsey 1982).

Greater sunlight exposure on south-facing slopes results in higher temperatures and evaporative drying of the leaf litter (Wales 1972). In this study maximum temperatures increased gradually from north- to south-facing slopes, but environmental moisture did not decrease along this gradient. Although temperatures were higher at streamside sites, leaf litter moisture content in these areas was similar to that of cooler north-facing slopes and consequently, had similar capture rates of shrews. Streamside habitats often represent isolated zones of moisture in otherwise dry environments (Laerm et al. 1999) because leaf litter in these areas is often not far above the water table (Sites 1978). Habitats such as riparian areas that remain moist regardless of temperature provide favorable environmental conditions that facilitate the active movement of shrews.

The primary importance of structural components of the microhabitat to shrews is their effect on humidity (Getz 1961, McComb and Rumsey 1982, Pagels et al. 1994, Parmley and Harley 1995). The percentage of logs that were heavily decomposed was high on north-facing slopes and in streamside habitats in the study area but extremely low on south-facing slopes of the same stand age, presumably because logs decompose more slowly under xeric conditions (Abbott and Crossley 1982). Although most logs can function as protective cover and as foraging sites (Loeb

Table 2. Correlation coefficients (r) between measured habitat variables and shrews in the study area in autumn 1996 and spring and summer 1997.

Habitat variable	Sorex cinereus (n = 41)	S. fumeus (n = 105)	Combined (n = 146)
% litter moisture	0.443	0.559 *	0.490 *
Average maximum temperature	-0.254	-0.484	-0.481
Invertebrate biomass	-0.267	-0.873 *	-0.785 *
% heavily decomposed logs	0.393	0.553 *	0.593 *

* p ≤ 0.05

1993), those in the advanced stages of decomposition may be optimal microhabitats for shrews (Brannon 2000) because they contain high concentrations of water (Maser et al. 1979) and can serve as moisture refugia during dry periods. Shading from the dense understory of rhododendron likely also contributed to favorable environmental moisture conditions for *S. cinereus* and *S. fumeus* on north-facing slopes and along streams (Laerm et al. 1995, Pagels et al. 1994).

Environmental moisture is also important to the distribution of shrews because it may affect the availability of invertebrate prey (Gist and Crossley 1975, Kirkland 1991, Parmley and Harley 1995, Wrigley et al. 1979). Although in this study no significant differences in invertebrate biomass existed between mesic and xeric habitats, in moist environments prey may be more accessible because mobility of the shrews is enhanced (McCay 1996). If the litter is wet, shrews may increase their activity on the forest floor where invertebrates are abundant, but if the litter is dry, they may be restricted to small isolated patches of moisture where availability of prey may be reduced (Jaeger 1980). Although other prey items such as salamanders are abundant in mesic habitats of the southern Appalachian Mountains (Petranka et al. 1993), they constitute only a very small percentage of the diets of most shrews (Hamilton 1930). Greater numbers of shrews in mesic environments probably have more to do with better environmental conditions for foraging associated with their ecophysiology than to an increased food supply.

For small mammals associated with mesic environments, species presence and abundance may be most predictable at a habitat scale with a high degree of resolution (Orrock et al. 2000). The southern Appalachian Mountains are comprised of a complex mosaic of habitats (Laerm et al. 1995, Laerm et al. 1999, Pagels et al. 1994, Whittaker 1956). Shrew species diversity is greatest at higher elevation sites where environmental conditions resemble those of more northern forests (Laerm et al. 1999, Pagels et al. 1994). Habitats that provide shaded, moist conditions with complex structural microhabitats are especially important to the distributions of shrews (Cudmore and Whitaker 1984, Ford et al. 1997, Kirkland 1991, Laerm et al. 1999, Mitchell et al. 1997, Parmley and Harley 1995). My results are consistent with those of others (Getz 1961, Spencer and Pettus 1966, Wrigley et al. 1979) who found that the primary factor governing the distributions of shrews is environmental moisture. Moreover, this study suggests that the distribution of *S. cinereus* and *S. fumeus* is strongly influenced by heterogeneity of moisture across landscapes, such as between north- and south-facing slopes.

their guidance during this project, and J. K. H. Brannon and many others for field assistance. I also thank J. F. Merritt, J. F. Pagels, and an anonymous reviewer for their suggestions for revision of the original manuscript.

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