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Epigeal movement of the smoky shrew *Sorex fumeus* following precipitation in ridgetop and streamside habitats

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Epigeal movement of smoky shrews *Sorex fumeus* (Miller, 1895) following precipitation was examined in two habitats with different moisture conditions. Shrews and invertebrates were collected in pitfall traps over several consecutive nights each month from August to November 1996 and from March to August 1997. Capture rates of smoky shrews significantly increased following rainfall at dry ridgetop sites ($p = 0.001$) but not at moist streamside sites ($p = 0.335$). In mesic environments, favorable conditions on the forest floor not associated with precipitation may increase movements of shrews. Available invertebrate biomass did not increase significantly with rainfall in either habitat type ($p = 0.121$ and 0.368). Increased surface activity by smoky shrews after rain events is probably related more to their ecophysiology than to increased prey availability.

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Introduction

Surface activity of shrews is greatly influenced by precipitation (Mystkowska and Sidorowicz 1961, Vickery and Bider 1978, Pankakoski 1979, Kirkland *et al.* 1998, Merritt and Vessey 2000). However, it is unclear whether increased epigeal movement by shrews during rainy periods is directly related to their metabolism (Buckner 1964) and high water requirements (Chew 1951), or indirectly to increases in availability of invertebrate prey (McCay and Storm 1997). A thick layer of leaf litter on the forest floor retains moisture following rains (Sites 1978, Jaeger 1980b). As the litter dries, shrews may have difficulty maintaining water balance (Getz 1961). Consequently, mobility of shrews may be reduced during periods of drought (Kirkland *et al.* 1998, Bellows *et al.* 1999), and invertebrate prey, although abundant in leaf litter (Gist and Crossley 1975), may become inaccessible (Fraser 1976, Jaeger 1980a).

Shrews are most abundant in areas with high levels of environmental moisture (Getz 1961, Wrigley *et al.* 1979, Kirkland 1991), which may reflect increased opportunities for foraging. Capture rates are direct indicators of surface movement (Sarrazin and Bider 1973). Increases in capture rates of shrews following precipitation events in dry habitats should be greater than in mesic habitats, where normal levels of epigeal activity are relatively high (McCay 1996).

The response of shrews to rainfall has been the subject of several studies (Mystkowska and Sidorowicz 1961, Doucet and Bider 1974, Vickery and Bider 1978, Pankakoski 1979, McCay 1996). However, few researchers (Kirkland *et al.* 1998) have examined the effect of precipitation on the activity of the smoky shrew *Sorex fumeus* (Miller, 1895). My objective was to determine if increases in surface movement by smoky shrews on rainy nights are a result of improved humidity levels for foraging, or a response to increased availability of invertebrate prey items in the forest floor leaf litter. Factors that increase epigeal foraging by shrews during rainfall may be the same factors that contribute to increased abundance of shrews in moist habitats. I therefore predicted that the effect of precipitation on the surface activity of smoky shrews and invertebrates at mesic sites would be less than at drier sites where normal levels of activity are relatively low.

Study site

Research was conducted in the Gingercake Creek drainage of the Pisgah National Forest, Burke County, western North Carolina (35°55'30"N, 81°52'0"W). This area was characterized by steep (20–38°) slopes with numerous streams. Stand ages were approximately 55 years and elevations averaged 787 m. Vegetation near ridges consisted primarily of white pine *Pinus strobus*, chestnut oak *Quercus montana*, red oak *Q. rubra*, and red maple *Acer rubrum*, whereas riparian zones were dominated by tulip poplar *Liriodendron tulipifera*, black birch *Betula lenta*, and eastern hemlock *Tsuga canadensis*. Dominant understory species were *Rhododendron maximum* and mountain laurel *Kalmia latifolia*. Abundant fallen logs in the late stages of decomposition and a deep layer of leaf litter and existed throughout the area.

Material and methods

Twelve 50- by 50-m plots ≥ 100 m apart were established along contours. Six of these plots were placed near ridgetops, and the other 6 were located at the bottom of slopes in streamside habitats. In the center of each plot was a drift fence array consisting of 3 arms of 3.0-m-long by 61-cm-tall aluminum flashing in a "Y" configuration (Kirkland and Sheppard 1994). One 20-l pitfall (plastic bucket) was positioned at each end and another was located at the central intersection. Each of the 4 pitfalls was partially filled with water to drown shrews quickly and prevent predation within traps (Brannon 2000). Each pitfall was open for 5 to 7 consecutive nights each month from August 1996 to November 1996 and from March to August 1997, for a total of 2544 trap nights (TN). Shrews were removed daily and deposited in the collections of Appalachian State University. Capture rates (number of captures per 100 TN) of shrews at each plot were calculated for rainy and non-rainy nights during each trapping period.

In addition to effectively capturing shrews, pitfall arrays collected substantial numbers of epigeal invertebrates, which represented the food-resource base (McCay and Storm 1997). Although shrews may take whatever prey they encounter within the constraints imposed by their body dimensions

(Churchfield 1991), they forage selectively when prey are abundant (Hamilton 1930, Churchfield 1990). Smoky shrews prefer larger invertebrates such as earthworms, centipedes, adult and larval insects, spiders, slugs and snails (Hamilton 1930, 1940, Whitaker and French 1984, Whitaker and Cudmore 1987). Invertebrates were collected from pitfalls on a daily basis during each trapping period and sorted to the ordinal level. Invertebrate taxa that are not regularly eaten by smoky shrews, such as millepedes, were excluded from analyses. Small invertebrates (≤ 3.0 mm in length) were also excluded as they are of negligible importance in the diets of larger shrews (Churchfield 1982, McCay and Storm 1997). Remaining invertebrates from each plot were collectively weighed to calculate available biomass per TN on rainy and non-rainy nights during each trapping period.

Precipitation data were collected approximately 14.5 km from the study site at the Morganton, North Carolina weather station (National Climatic Data Center 1997). Rainy nights were defined as those during which 2.5 mm of precipitation was recorded between 18:00 and 08:00 h (McCay 1996, Kirkland *et al.* 1998). Differences in shrew capture rates and in available invertebrate biomass between rainy and non-rainy nights, and between rainy and non-rainy nights in each of the two habitat types, were examined using one-way analysis of variance conducted on $\log_{10}$-transformed data (Zar 1984).

A 0.25-m^2 sample of leaf litter was collected at a randomly selected point within each plot on the first and last day of each trapping period. Samples were weighed immediately on 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. Differences in percentage litter moisture between ridgetop sites and streamside sites were examined using Student's t-test conducted on arcsine-transformed data (Zar 1984).

Results

Overall capture rates of smoky shrews significantly increased with rainfall (F = 7.45, df = 1, 238, p = 0.007). A total of 71 smoky shrews were captured on 19 rainy nights (912 TN), whereas 34 shrews were captured on 34 non-rainy nights (1632 TN). Mean overall capture rate (± 1 SE) was 3.7 times greater on rainy nights (7.8 ± 1.2 shrews per 100 TN) than on non-rainy nights (2.1 ± 0.7). There was no significant difference in available invertebrate biomass per TN between rainy and non-rainy nights (F = 2.85, df = 1, 238, p = 0.293).

Leaf litter from streamside plots had higher levels of moisture than that of ridgetop sites (t = –5.49, df = 232, p < 0.001). Mean litter moisture content was 60 ± 1.1% at streamside sites compared to 50 ± 1.4% at ridgetop sites.

Capture rates of smoky shrews at ridgetops were significantly higher on rainy nights (F = 11.13, df = 1, 118, p = 0.001). Mean capture rate on ridges was over 11 times greater on rainy nights (7.9 ± 1.5) compared to non-rainy nights (0.7 ± 0.4). Ridgetop plots yielded a total of 36 shrews on rainy nights but only 6 shrews on non-rainy nights. At sites with streams however, mean capture rates on rainy nights (7.7 ± 1.9) did not increase significantly from those on non-rainy nights (3.4 ± 1.3; F = 0.94, df = 1, 118, p = 0.335). At streamside plots I captured a total of 35 shrews during nights with rainfall and 28 shrews during nights without rainfall. No significant differences in available invertebrate biomass per TN existed at ridgetop sites (F = 2.45, df = 1, 118, p = 0.121) or at streamside sites (F = 0.82, df = 1, 118, p = 0.368) between rainy and non-rainy nights.

Discussion

Increased surface activity of smoky shrews following precipitation is consistent with their ecophysiology (Kirkland *et al.* 1998). Because of their high metabolic rates, shrews experience relatively high respiratory water losses and may be unable to regulate such losses at low humidities (Getz 1961). For example, Chew (1951) found that the rate of water loss by the northern short-tailed shrew *Blarina brevicauda* increased 3.5 times with only a 12% reduction in relative humidity. For a predator with high moisture requirements, mobility under dry conditions is regulated by the frequency of rains (Sites 1978).

Mesic habitats yield more shrews than do xeric habitats (McComb and Rumsey 1982, Cudmore and Whitaker 1984, Laerm *et al.* 1999). In this study, rainfall was associated with large increases in capture rates of shrews at dry ridgetop sites, but not at moist streamside sites where greater numbers of shrews were collected. Precipitation may have little effect on the movement of smoky shrews near streams because ordinary levels of surface activity in mesic habitats are relatively high. Riparian areas often represent isolated zones of moisture in otherwise dry environments (Laerm *et al.* 1999). Leaf litter in these areas is usually not far above the water table and may retain moisture in the absence of a recent rain (Sites 1978). Habitats that remain constantly moist, such as streamside areas, provide more favorable conditions facilitating active movement of shrews than do habitats like mountain ridges, where the leaf litter dries between rain events.

Smoky shrews have been found to be associated with structural features of the microhabitat such as rocks and heavily decomposed logs (McCay *et al.* 1998, Brannon 2000), which can serve as moisture refugia in more xeric environments. Although the availability of prey may be reduced under cover objects and in burrows (Fraser 1976, Jaeger 1980b), to avoid dessication shrews must retreat to these small patches of moisture as the litter dries. However, during and shortly following a rain, shrews are no longer constrained by low humidity and may forage freely in the forest leaf litter where invertebrates are usually abundant and readily accessible (Gist and Crossley 1975, Jaeger 1980a).

Although precipitation may increase the availability of certain invertebrate taxa (McCay and Storm 1997), in this study the biomass of prey for smoky shrews was not significantly affected by rainfall in either habitat. Availability of food may be set by the mobility of the shrews. When the leaf litter is wet, shrews can forage on the forest floor where prey are abundant, but when the litter is dry they may be restricted to small, isolated pockets of moisture. Results of this study suggest that increases in epigeal movement of smoky shrews following precipitation events are probably related to enhanced environmental conditions associated with their physiology, rather than to an increased food supply.

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