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HABITAT USE BY BRUSH MICE (*PEROMYSCUS BOYLI*) IN SOUTHEASTERN ARIZONA

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Key words: Arizona, brush mouse, habitat, hantavirus, *Peromyscus boylii*.

Hantavirus pulmonary syndrome (HPS) is a group of zoonotic diseases transmitted from rodents to humans. Transmission occurs primarily through inhalation of excrement, in the form of dust, from an infected rodent (Tsai 1987, Wells et al. 1997). Hantavirus pulmonary syndrome came to the attention of biologists after an outbreak in the southwestern United States in 1993 (Mills et al. 1999a). Following this outbreak, researchers began exploration into the cause of this illness. Deer mice (*Peromyscus maniculatus*) were the principal carriers (Nichol et al. 1993, Childs et al. 1994). Since the initial outbreak, the virus has been identified in >25 states in the United States and in numerous species of rodents, including the brush mouse (*P. boylii*).

Ongoing studies have identified brush mice as a primary host of Sin Nombre virus (i.e., the etiologic agent of HPS) in southern Arizona (Abbott et al. 1999, Kuenzi et al. 1999, Mills et al. 1999b). In southeastern and central Arizona, adult male brush mice have a greater prevalence of the virus compared with other species of *Peromyscus* (Abbott et al. 1999, Kuenzi et al. 1999). Information on habitat use of the genus *Peromyscus* is available (Brown 1964, King 1968, Price 1984, Snyder and Best 1988, Scott and Dueser 1992), but recent habitat data for brush mice are scarce.

Hantavirus pulmonary syndrome is often found concentrated in specific areas, and this has been related to habitat for the host (Abbott et al. 1999, Kuenzi et al. 1999). In southeastern Arizona, brush mice are most abundant in association with riparian vegetation along watercourses (Kuenzi et al. 1999). Due to the availability of water and shade, humans also find

these areas desirable for recreation and homes. Consequently, a high possibility exists for human-rodent interactions in these areas. To avoid potential risks and to aid in the prediction of future HPS outbreaks, more knowledge about the ecology of brush mice is needed. Our objectives were to determine which habitat characteristics are unique to areas used by brush mice, seasonally and by sex, in the Santa Rita Experimental Range (SRED) in southeastern Arizona and to determine if brush mice use artificial structures (e.g., cabins, sheds) when available. We used radiotelemetry to assess mouse habitat use, which has advantages over the use of live-trapping (e.g., Hall and Morrison 1997, Bias and Morrison 1999).

We conducted our study near the Florida Headquarters of the SRED, Pima County, approximately 48 km south of Tucson, Arizona. SRED (20,234 ha) is representative of the 8,094,000 ha of the semidesert, grass-shrub range found throughout the Southwest. SRED is located on a broad, sloping plain, cut by numerous shallow, dry washes, with elevations from 883 m to 1372 m (Martin 1966). The elevation of our study site ranges from 1270 m to 1350 m. Temperatures ranged from a mean of 16.5°C in winter (September–December) to 24.5°C in summer (May–August), with an annual mean temperature of 17.8°C (National Oceanic and Atmospheric Administration 2001). Annual mean rain and snowfall were 53 cm and 11.2 cm (measured at SRED), respectively, about average for the area (National Oceanic and Atmospheric Administration 2001).

Two main vegetation types, semidesert grassland (upland) and oak-riparian, occur at these elevations. The upland is characterized by

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Lehmann lovegrass (*Eragrostis lehmanniana*), three-awn (*Aristida* spp.), prickly pear cactus (*Opuntia* spp.), ocotillo (*Fouquieria splendens*), acacia (*Acacia* spp.), and mesquite (*Prosopis velutina*). The oak-riparian vegetation type, which occurs in drainages where water flow is seasonally intermittent, is characterized by deciduous trees, including Arizona white oak (*Quercus arizonica*), netleaf hackberry (*Celtis reticulata*), and an understory characterized by mimosa (*Mimosa biuncifera*) and various grasses (Martin 1966).

We established 3 trapping webs (Kuenzi et al. 1999) as areas for monthly trapping from April 2000 to March 2001. Trap locations were within webs, consisting of 12 trap lines, each with 12 traps per line. All lines radiated out 100 m from the web's center. The first 4 trap locations of each line nearest the web's center were set 5 m apart, with the remaining 8 traps set 10 m apart. Each web had 144 trap locations in vegetation ranging from grassland to riparian deciduous and oak (*Quercus* spp.) woodland. This trapping configuration was established as part of a related study on hantavirus prevalence at SRER (M.L. Morrison unpublished data). Brush mice select riparian vegetation at the SRER (Morrison et al. 2002). Each month, therefore, we set only the 6 trap locations farthest from the web's center with Sherman live-traps (7.6 × 8.9 × 22.9 cm) on the 5 downslope trap lines that entered riparian vegetation to catch animals to be radio-collared (90 traps total). Riparian and upland vegetation types are clearly separated in our study locations. To increase chances of catching brush mice, we set 18 additional traps in a straight line on each side of a stream (36 total) at a riparian site next to buildings at the Florida Headquarters. Brush mice caught on this riparian line were considered living "near" (within ~200 m) artificial structures. All other captures were defined as living "far" (>1000 m) from artificial structures. All traps were run for 3 consecutive nights during each monthly session.

We set traps in late afternoon, each containing a small handful of polyester fiberfill for thermal protection and baited with approximately 8.5 g of a 30:70 combination of oatmeal and peanut butter. We checked traps at dawn and identified, processed, and radio-collared the first 5 healthy adult animals captured (transmitters averaged 1.24 g, MD-2C Mouse Style,

Holohill Systems, Ltd., Carp, ON, Canada). We did not collar juveniles and subadults because the collars could not be adjusted for growth. We toe-clipped animals to ensure we did not repeatedly sample the same individual throughout our study.

Animals were anaesthetized with Metofane™ for processing. We secured collars, averaging ~6.0% of the body weight of brush mice, around the animal's neck by tightening a crimp around the collar. By design, we attempted to radio-collar up to 5 animals per month. A variety of conditions, including transmitter malfunction (prior to attachment) and failure to capture an adequate number of adults, resulted in 3–5 animals being radio-collared monthly. Radio-collars transmitted for approximately 4 weeks.

We released each animal at its capture location and did not attempt to locate a mouse for ≥6 hour following release. We located animals from signals picked up by portable receivers (Telonics, Mesa, AZ, and AVM Instrument Company, Livermore, CA) and a 2-element Yagi antenna.

We monitored approximately 5 animals, 3 evenings per week, 3 times per evening (i.e., 1800, 2100, and 0100) each month. These times were selected to spread our observations across the nocturnal period and thus sample various activity periods. Because of thick vegetation and our travel time between study animals, we could visit each animal only about 3 times nightly. We located signals (multiple fixes) well away from the animal to avoid disturbing its activities. We gathered locations each month until the collars failed, the animal died, or the animal left the area.

We determined percent cover of grass, shrubs (i.e., vegetation <1.5 m, excluding grasses), trees (i.e., vegetation ≥1.5 m), succulents, bare ground, rocks, and litter (i.e., leaf litter, downed vegetation, and dead debris) at each relocation using the line-intercept method (Canfield 1941, Etchberger and Krausman 1997). We randomly laid two 6-m transects perpendicular to each other through the center of the point, counting all vegetation touching or passing over or under the transect as a percentage of the line. Later these data were used to calculate percent cover. Percent bare ground, litter, and rocks were quantified in the same manner as the vegetation composition.

Using a spherical densiometer (Forest Densimeters, Arlington, VA), we calculated cover produced by overstory. We took 4 readings from the midpoints of each transect (i.e., at 1.5 m and 4.5 m along both 6-m transects). We measured horizontal cover (i.e., any habitat variable contributing to a horizontally obstructed view) with a Robel pole at these same midpoints (Robel et al. 1970). We measured litter depth at the transect midpoints. Values for these variables were combined to obtain an average for each plot. We recorded slope, aspect, vegetation association, and distances to the nearest tree, artificial structure, and seasonally intermittent channel for each plot.

We selected a random plot near each animal location plot measured by walking 6 m to 60 m in a random direction. We followed the distance and direction from the center of the original animal location plot, where we subsequently carried out all the same measurements.

Analysis of variance (ANOVA) was used to quantify the difference between random and animal locations (nonrandom points) for the mean percent of grass, shrubs, trees, succulents, leaf litter, rocks, bare ground, cover (horizontal and canopy); slope and aspect; litter depth; and all distance measurements in brush mouse habitat. General vegetative association was not included in this analysis because random and nonrandom plots were always in the same type. We blocked our data by individual animal to account for variation between the areas each animal used. We paired each random and nonrandom point within each animal's group of points and grouped variables by spring (January to April), summer (May to August), and winter (September to December). By contrasting differences between means of the paired nonrandom and random plots for each habitat variable, we identified features of brush mouse habitat used disproportionately by individuals. Mean responses between males and females were compared for all variables measured. When necessary, we used a $(\log + 1)$ transformation to meet the assumptions of ANOVA. Nontransformed data are presented, and the magnitude of difference between random and nonrandom habitat plots is discussed. Statistical tests were considered significant when $P < 0.05$ (JMP IN Statistical Software, Version 4.0, 2001).

Of 47 radio-collared brush mice (26 males, 21 females), 3 died shortly after being released.

Thirteen animals ceased movement within 2 weeks, preventing us from receiving enough data for analysis (i.e., movement to ≥ 3 discrete locations). Attempts to recover apparently stationary radios were difficult because of the substantial number of large rocks and amount of down wood used as den sites, and because of our desire not to disturb the study site. These activities did, however, cause several signals to move, indicating that these animals were alive; hence we chose to cease our efforts and exclude these data from our analyses because of the uncertain condition of the animals. We also lost signals from 3 transmitters before sufficient data were collected. We thus collected data on use of habitat variables for 14 males and 14 females on 231 plots and compared these data with 231 paired, random plots. Not all animals could be located during every telemetry session, and we did not resample vegetation plots when subsequent locations for an animal were identical (e.g., den sites). Thus, the total number of plots sampled was lower than the potential number of relocations of an animal.

We did not detect significant differences in habitat use between sexes ($P > 0.15$ for all variables). Brush mouse (sexes and seasons combined) habitat was characterized by 74% ($s_{\bar{x}} = 77.8$) tree cover, 60% ($s_{\bar{x}} = 58.4$) leaf litter cover, 21% ($s_{\bar{x}} = 17.6$) shrub cover, and 16% ($s_{\bar{x}} = 11.1$) rock cover. Overall, brush mice were most frequently relocated in the riparian area (67% of total relocations), followed by uplands (17%) and the creek channel (16%). The majority (55%) of nonrandom plots were within 10 m of a seasonally intermittent channel. Random (95%) and nonrandom (100%) plots were within 10 m of a tree. Litter depth, aspect, and all distance measurements did not differ significantly between random and nonrandom plots.

We trapped and radio-located 7 animals near the Florida Headquarters on the SRER. Only 3 animals were found in or around buildings during radio-telemetry. Two of the mice were inside and around a few storage sheds. They were found inside structures 16% and 27% of the time. The 3rd animal was using an area around a human-inhabited cabin, but never entered the building. We did not observe any animal travel > 50 m to be in or near any artificial structures.

Although litter was significantly different during all seasons and formed a substantial part of mouse habitat (i.e., 45%–75% cover), the use of litter never varied by more than 1.2X between random and nonrandom plots. Likewise, tree cover (all species combined) also formed a substantial and consistent (i.e., 70%–93%) proportion of mouse habitat in all seasons. In summer, mice used plots with significantly more tree cover ($93\% \pm 5.1 s_{\bar{x}}$) than random plots ($72\% \pm 5.1 s_{\bar{x}}$).

Brush mice used areas with significantly higher rock cover in winter and spring months. In winter, brush mice used areas with 1.8X more rock cover ($22\% \pm 2.4 s_{\bar{x}}$) than random areas ($12\% \pm 1.7 s_{\bar{x}}$). In spring, brush mice used areas with 2.4X more rock cover ($19\% \pm 3.6 s_{\bar{x}}$) than random areas ($8\% \pm 2.5 s_{\bar{x}}$). We found shrub use to be statistically significant in spring, with nonrandom plots containing 1.5X more shrubs ($21\% \pm 3.6 s_{\bar{x}}$) than random plots ($14\% \pm 3.3 s_{\bar{x}}$).

No significant difference was found in cover of succulent plants in random and nonrandom plots. In spring, however, nonrandom plots had 4.5X the amount of succulent plants ($9\% \pm 3.2 s_{\bar{x}}$) that random plots had ($2\% \pm 1.7 s_{\bar{x}}$).

Horizontal cover was used substantially by brush mice in spring, summer, and winter. In spring, nonrandom plots had 2.4X the amount of horizontal cover ($78\% \pm 7.7 s_{\bar{x}}$) that random plots had ($33\% \pm 6.8 s_{\bar{x}}$). Nonrandom plots in summer had 2.0X more horizontal cover ($52\% \pm 4.1 s_{\bar{x}}$) than random plots ($27\% \pm 3.0 s_{\bar{x}}$). In winter, nonrandom plots had 1.6X more horizontal cover ($14\% \pm 2.1 s_{\bar{x}}$) than random plots ($9\% \pm 2.0 s_{\bar{x}}$). The average slope was 1.5X greater in nonrandom plots ($15\% \pm 2.4 s_{\bar{x}}$) compared with random plots ($10\% \pm 2.4 s_{\bar{x}}$) during summer.

Because we concentrated our trapping efforts in riparian vegetation, we were not surprised that most radio-collared mice were found in that vegetative type. Brush mice are known, however, to preferentially use riparian vegetation (Morrison et al. 2002). Although our study was limited in time and geographic coverage, brush mice in our southeastern Arizona study area used rocky areas surrounded by dense cover. This complements previous findings, where brush mice were most commonly found in association with rocks and heavy brush (Jameson 1951, Brown 1964, Garner 1967,

Goodwin and Hungerford 1979, Hoffmeister 1986). Rocks and dense vegetation may protect mice from avian and mammalian predators and provide a thermal buffer from extreme weather fluctuations that occur in southeastern Arizona. Rocks were utilized more extensively in winter and spring than in summer, suggesting heightened importance of this resource for protection in times when vegetation is less dense than during summer monsoon months. In addition, freezing temperatures are possible during these months (National Oceanic and Atmospheric Administration 2001).

Previous studies suggested that understory vegetation is the critical factor establishing the structure of desert riparian animal communities (Szaró and Belfit 1987, Andersen and Nelson 1999). Horizontal cover, which is correlated with denseness of the understory, is significant all year. This supports the idea that plant community structure is an important feature to brush mice.

Slope was significant in our study during summer. In summer, brush mice used areas almost twice as steep as random areas. However, most steep areas were actually a by-product of channel banks, which oftentimes were nearly vertical. Our slope results may reflect the fact that brush mice inhabit riparian watercourses in this area rather than reveal anything extremely important about slope in brush mouse habitat. However, previous studies have found brush mice selecting steep areas (Brown 1964, Wilson 1968, Geluso 1971, Goodwin and Hungerford 1979). Further, the seasonal significance might warrant additional research into the role of slope in brush mouse habitat.

Of 7 animals tracked near buildings, 3 used storage sheds, which were the structures closest to the riparian area. However, none of the 3 animals were found inside any human habitations (i.e., homes or offices), likely because such buildings were farther from the wash than the structures where we located the mice. The storage sheds were, however, frequented by humans. Furthermore, even a single visit to these sheds presents an opportunity for an infected mouse to defecate, making it dangerous to disregard risk of disease transmission to humans. The animals likely lived in the area and simply used what was immediately available to them. Our sample size of radio-tagged mice was small, however, and so our results should be verified by additional studies.

Mills et al. (1999b) recognized that patterns of HPS in rodents differ between sites and species. Therefore, if an understanding of HPS is to be achieved, host species must be identified and studied in areas where there is a threat of disease. At SRER about 9% of brush mice tested positive for Sin Nombre virus (M.L. Morrison unpublished data). These animals live in areas with high cover of rocks and understory vegetation along riparian watercourses and do not appear to seek out structures occupied by humans. They will, however, use human structures already present in their home areas.

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