HOME RANGE AND MOVEMENTS OF ROOF RATS (RATTUS RATTUS) IN AN OLD-GROWTH RIPARIAN FOREST, CALIFORNIA

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Information on the spatial ecology of nonnative roof rats (Rattus rattus) is important for developing management strategies to reduce their impacts on native wildlife in riparian habitats. We determined home-range size and movement patterns of nonnative roof rats (Rattus rattus) in an old-growth riparian forest in California by radiotracking 12 individuals in August and September 2002. Males had larger home ranges than females. There was considerable overlap of ranges within and between sexes. Rats nested from 2 to 15 m high in trees, and used multiple nests that were sometimes shared simultaneously with other rats. Rats were most active at night, spending most of their time on, or close to the ground, and favoring areas of dense cover of blackberry and grape.

Key words: black rat, California riparian forest, home range, radiotelemetry, Rattus rattus, roof rat

Roof rats (Rattus rattus) are responsible for the decline and extinction of many species of birds, small mammals, and lizards worldwide, especially on islands (Atkinson 1985). They may also negatively impact agricultural production, with major economic losses reported for Hawaiian sugarcane (Lefebvre et al. 1989), macadamia nut plantations in Hawaii and Australia (Elmouttie and Wilson 2005; Horskins et al. 1998; Tobin et al. 1996), and citrus orchards in California (Clarke 1994). Although roof rats have historically been recorded at high densities in natural habitats in California (Dutson 1973; Stroud 1982), little is known of their ecology in these ecosystems, or their impacts on other species. Roof rats have been implicated as threatening the recovery of 2 endangered species: the riparian wood rat (Neotoma fuscipes riparia—D. F. Williams, in litt.), and the riparian brush rabbit (Sylvilagus bachmani riparius—D. F. Williams, P. A. Kelly, and L. P. Hamilton, in litt.). They also may be important nest predators of open-cup–nesting songbirds in riparian habitats of the Central Valley of California (Small 2005; Whisson et al. 2004). Therefore, understanding the population dynamics and behavior of rats in natural habitats, together with active management, may be necessary for conservation and restoration of native wildlife species.

Although there is considerable information on the social behavior and biology of roof rats in captive colonies (Barnett 1958; Ewer 1971), relatively little has been reported on their populations and movements in natural habitats. From studies in New Zealand forests (Dowding and Murphy 1994; Harper 2005; Hickson et al. 1986; Hooker and Innes 1995; Innes and Skipworth 1983; Pryde et al. 2005), Australian heathland (Cox et al. 2000), and Hawaiian macadamia orchards (Tobin et al. 1996), it is clear that the spatial ecology of roof rats varies according to habitat structure and species composition. Home-range estimates range from 0.05 ha (Innes and Skipworth 1983) to 11.4 ha (Pryde et al. 2005), with seasonal variation reported in New Zealand but not in Hawaii. Habitat use also varies, with rats mostly using the tree canopy in orchards (M. M. Hoque and L. A. Fiedler, in litt.; Tobin et al. 1996), and the ground in forests (Dowding and Murphy 1994; Layton 1986). In California, Brooks (1966) and Recht (1988) examined the home range of roof rats in urban areas; however, only 1 study has investigated home range and population dynamics of roof rats in natural areas. That study, conducted in riparian woodland along Putah Creek near Sacramento in central California, used trapping grids to determine home range (Stroud 1982). Dutson (1973) examined the statewide distribution of roof rats, and their association with Himalayan blackberry (Rubus discolor).

We conducted this study to provide information on habitat utilization and movements of roof rats in a riparian habitat in the Central Valley of California. This information improves our understanding of the ecology of roof rats in natural habitats, and provides a basis for developing effective management strategies to reduce the impacts of roof rat populations on native species.
**Materials and Methods**

**Study area.—** The Cosumnes River Preserve (38°19′N, 121°23′W), 20 km south of Sacramento, California, comprises some of the largest tracts of valley oak riparian forest remaining in California. These habitats provide critical nesting habitat for many species of migratory songbirds (The Riparian Bird Conservation Plan: A Strategy for Reversing the Decline of Riparian Associated Birds In California; Riparian Habitat Joint Venture, 2000, California Partners in Flight, http://www.prbo.org/CPIF/Riparian/Riparian.html). They also support high-density populations of roof rats (Whisson et al. 2004). Our study was conducted in a 6-ha area of an old-growth forest dominated by valley oak (*Quercus lobata*), Fremont cottonwood (*Populus fremontii*), Oregon ash (*Fraxinus latifolia*), box elder (*Acer negundo*), and willow (*Salix*), with a dense understory of California blackberry (*Rubus ursinus*), Himalayan blackberry (*R. discolor*), California wild grape (*Vitis californica*), and poison oak (*Toxicodendron diversilobum*). The Cosumnes River is the only unregulated river on the west slope of the Sierra Nevada mountain range. Because river flows are not controlled, winter rainfall usually results in annual flooding of the forest floor from December to March.

**Telemetry.—** We conducted the study from July to September 2002. This period was chosen to minimize disturbance on nesting birds, and to occur at a time when rat control would be desirable (i.e., outside of peak nesting periods and before winter flooding). We trapped rats from 5 locations separated by at least 50 m in the forest, to encompass the general variation in forest habitats. At each location, we placed 9 Sherman live traps (7.5 × 7.5 × 25.2 cm; H. B. Sherman Traps, Inc., Tallahassee, Florida) baited with a mixture of rolled oats and peanut butter and spaced 5 m apart in a 40-m-diameter circular area. In 2 nights we trapped 16 adult rats (8 males and 8 females). Each rat was restrained in a cloth bag and fitted with a single-stage radiotransmitter with an external antenna and 3-month battery life, attached to a nylon zip-tie collar (Sirtrack, Havelock North, New Zealand). We recorded the animal’s sex, weight, and reproductive condition, and released it at its point of capture. Within a week, we lost the signal for 3 individuals. Another individual stopped moving after 3 weeks in an inaccessible area, suggesting it had died or lost its collar. At the end of the study we trapped 4 of the radiocollared animals. None showed any sign of injury due to the collars.

Using handheld Yagi antennas and Telonics TR4 receivers (Telonics, Mesa, Arizona), we located each of the 12 remaining animals once during the day and up to 7 times during the night once per week for 8 weeks. This provided 47–60 locations per animal. Because signal bounce from the many thick tree trunks in the study area precluded locating rats via triangulation from set points, we located rats on foot. From 51 visual sightings of rats and tracking error tests we surmised that we usually came within 10 m of the rat. Rats rarely flushed to more than a few meters from their initial location, suggesting that we were having minimal effect on their behavior. Tracking error was tested by 1 person placing transmitters in the field and a 2nd person locating them. Transmitters were hidden so that they could not be seen until the person attempting to locate it was very close. Each test involved 1st predicting the location of the transmitter by triangulating from 2 points that were approximately 20 m from the transmitter, and then locating it directly. In 20 triangulation tests, the difference between actual and predicted location of the transmitter was always less than 2 m. Transmitters were always found when walking in on the signal.

Nighttime locations were recorded at a minimum of 1-h intervals for each rat during the periods 1800–0100 h and 0300–0700 h. We chose a 1-h interval to optimize the number of locations recorded, while minimizing the potential for autocorrelation. Post hoc analysis of sampling interval indicated that the time to independence (Swihart and Slade 1985) was 1.6 h (95% confidence interval [95% CI] = 0.5), suggesting that some points may be autocorrelated. Our sampling regime may therefore have resulted in a negative bias to home-range estimates. However, because all animals were tracked at equal intervals and for the same sampling period comparisons between individuals and sampling periods are still valid (De Solla et al. 1999; Otis and White 1999). In addition, even when data are autocorrelated, they are still important for describing habitat use within an animal’s range (De Solla et al. 1999). We considered that a rat was in a nest or burrow if the animal was immobile (signal not modulating) in its daytime location.

For each location of a nest or active animal, we recorded the approximate height of the animal in the vegetation (ground; low: >0–2 m; medium: >2–5 m; high: >5 m), if it was moving (indicated by signal modulation), and the vegetation type within a 2-m radius. We flagged each location and subsequently mapped it by measuring the distance and compass bearing to 1 of 15 reference points that had been mapped with a global positioning system unit.

All procedures were approved by the University of California Davis Animal Use and Care Administrative Advisory Committee and meet guidelines recommended by the American Society of Mammalogists (Animal Care and Use Committee 1998).

**Vegetation.—** To determine the relative availability and use by rats of the predominant vegetation types present in the study area, we digitized the boundaries of blackberry thickets, grape patches (occurring only in areas without tree canopy), and areas of low (<10%) vine cover occurring within the study area (Arcview 3.2—Environmental Systems Research Institute 1992–1999).

**Home-range measures.—** We used the Animal Movement Extension (Hooge and Eichenlaub 2000) for Arcview 3.2 to calculate 50% (K50, core use area) and 95% (K95, total area) home-range kernels for each animal. Least-squares cross-validation was used to determine smoothing factors for fixed kernel estimators (Seaman et al. 1996; Silverman 1986). To compare home-range estimates with other studies, we calculated the 100% minimum convex polygon (MCP) home range for each animal (Mohr 1947).
Statistical analysis.—We used Spearman’s rank ($r_s$) correlation analysis to investigate the relationship between home-range measures. A $t$-test was used to compare home-range estimates of males and females. A 2-way analysis of variance was used to compare the distance moved in an hour during the night and between sexes. All analyses were completed in S-Plus (Insightful, Seattle, Washington).

RESULTS

Home-range size and overlap.—Home-range size of rats varied from 0.22 to 1.87 ha (K95), and from 0.28 to 1.20 ha (MCP; Table 1). Home-range measures were highly correlated (K95 and K50: $r_s = 0.97$; K95 and MCP: $r_s = 0.91$; K50 and MCP: $r_s = 0.82$). Males had larger home ranges (K95) than females ($t_{10} = 2.55$, $P = 0.0287$). Core areas (K50) comprised a mean 15.5% of the K95 range of each rat. Females each had 1 or 2 discrete core areas, whereas males each had 2 or 3 discrete core areas in their range. There was a high degree of home-range overlap both within and between sexes (Fig. 1).

Activity.—Most activity by rats was nocturnal. Over the entire study period, active animals accounted for 60% of observations between 1900 and 2000 h, /C21/80% of observations per hour between 2000–0100 h and 0300–0600 h, and 45% of observations between 0600 and 0700 h. Only 15% of daytime observations were of active rats.

Within each sex, movement distances per hour did not vary during the night ($F = 1.03$, $d.f. = 9$, 507, $P = 0.42$), although movement distances varied between sexes ($F = 22.70$, $d.f. = 1$, 507, $P < 0.0001$), with males moving an average of 38 m/h ($SE = 33.4$, $n = 263$) compared to 27 m/h ($SE = 20.2$, $n = 264$) for females.

Movements and nests of rats.—Of 638 locations of active animals, most were on the ground (54.1%) or in the low stratum (31.5%). Only 10.3% and 4.1% of locations were in the medium and high strata, respectively.

![Fig. 1](https://academic.oup.com/jmammal/article-abstract/88/3/589/1064892)

**TABLE 1.**—Kernel (50% and 95%) and 100% minimum convex polygon (MCP) home-range measures for rats tracked at the Cosumnes River Preserve during August and September 2002.

<table>
<thead>
<tr>
<th>Sex</th>
<th>Animal frequency</th>
<th>No. locations</th>
<th>Kernel (ha)</th>
<th>MCP</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>50%</td>
<td>95%</td>
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<tr>
<td>Male</td>
<td>020</td>
<td>50</td>
<td>0.09</td>
<td>0.71</td>
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<td></td>
<td>040</td>
<td>57</td>
<td>0.08</td>
<td>0.47</td>
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<td></td>
<td>080</td>
<td>56</td>
<td>0.26</td>
<td>1.33</td>
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<td></td>
<td>200</td>
<td>48</td>
<td>0.23</td>
<td>1.49</td>
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<td></td>
<td>360</td>
<td>47</td>
<td>0.05</td>
<td>0.39</td>
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<tr>
<td></td>
<td>380</td>
<td>59</td>
<td>0.35</td>
<td>1.87</td>
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<td></td>
<td>$\bar{x}$</td>
<td></td>
<td>0.18</td>
<td>1.04</td>
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<tr>
<td>Female</td>
<td>060</td>
<td>59</td>
<td>0.04</td>
<td>0.22</td>
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<td></td>
<td>160</td>
<td>50</td>
<td>0.03</td>
<td>0.29</td>
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<tr>
<td></td>
<td>240</td>
<td>60</td>
<td>0.06</td>
<td>0.66</td>
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<tr>
<td></td>
<td>260</td>
<td>49</td>
<td>0.11</td>
<td>0.43</td>
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<tr>
<td></td>
<td>280</td>
<td>49</td>
<td>0.05</td>
<td>0.38</td>
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<td>300</td>
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<td>0.05</td>
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Active rats were most frequently (75% of locations) located in dense blackberry thickets. A further 19% were in grape patches. Only 6% were not associated with any vine cover. This is in contrast to the availability of those habitats within the study area ($\chi^2 = 517$, $d.f. = 2$, $P < 0.005$). Blackberry thickets covered 30% of the study area, with grape patches covering
10% of the study area. In 60% of the study area there was only light (<20%) vine cover.

From observations of immobile rats, 40 nests were located; with 14 (35%) low, 12 (30%) at medium height, and 12 (30%) high in live or dead oak and cottonwood trees. Only 2 (5%) were underground burrows. Rats used an average of 5 nests (2–7 nests) scattered throughout their range. Twenty-two (54%) nests occurred within core areas with no intrasexual difference ($\chi^2 = 0.13, d.f. = 1, P < 0.005$). Distance between nests for each rat ranged from 6 to 97 m for females and from 11 to 179 m for males. The mean distance between nests was correlated with K95 home range for each individual ($r_p = 0.79$). On 4 occasions 2 adult male rats (animals 20 and 40; Fig. 1) were observed in the same nest.

**DISCUSSION**

The home-range estimators used in this study provided similar estimates with K95 sizes of 0.22–1.87 ha and MCP sizes of 0.28–1.20 ha. Although the kernel estimators better describe the pattern of home-range use, the MCP estimator allowed for comparison of home-range sizes with those reported in other studies. The MCP estimates are similar to the 0.86 ha reported for roof rats in a kauri (Agathis australis) forest (Dowding and Murphy 1994), and 0.54 ha in a regenerating coastal forest on Stewart Island, New Zealand (Hickson et al. 1986). Home ranges measured in our study are larger than the 0.19-ha home ranges previously reported for this species in similar riparian habitat along Putah Creek in the Central Valley of California (Stroud 1982); although that estimate was based on trapping results from a small trapping grid that may have underestimated home-range size (Stroud 1982).

In our study, male rats had a larger mean K95 home-range size (1.04 ha) than female rats (0.39 ha). Intersexual differences in home-range size may have been due to reproductive behavior, with males searching larger areas for mates (Dowding and Murphy 1994) or females reducing home ranges to meet the energy requirements of reproduction. We did not determine if breeding was occurring but it is likely, following the observations of Stroud (1982) of year-round breeding of roof rats in similar riparian habitats in California.

In our study, overlap of home-range areas within and between sexes, and the likelihood of there being many uncollared rats within the area, suggests that rats were not actively defending territories. Dowding and Murphy (1994) also observed home-range overlap within and between sexes; however, other studies in New Zealand have observed range overlap only in males (J. G. Innes, S. Hooker, and D. Williams, in litt.), or little overlap of ranges of any animals (Hickson et al. 1986). Dowding and Murphy (1994) suggested that these differences may be due to the seasons in which studies were conducted, and that females may become more territorial during the breeding period. However, with year-round breeding potentially occurring in riparian habitats in California (Stroud 1982), lack of territoriality observed in our study may reflect the high abundance of preferred food resources, or simply be the result of very high population densities (Carpenter 1987).

In our study, rats did not utilize their home range uniformly. Each rat spent a disproportionate amount of time in core (K50) areas that comprised a relatively small part ($X = 15.5\%$) of its range. Females had 1 or 2 discrete core areas and males had 2 or 3 discrete core areas. This pattern of home-range use also has been observed in New Zealand (Dowding and Murphy 1994), and may be due to patchy distribution of preferred food resources in natural areas. In contrast, in Hawaiian macadamia plantations, Tobin et al. (1996) observed rats to use their home range uniformly. Rats had a small mean home-range size of 0.2 ha that did not vary throughout the year or between sexes. Tobin et al. (1996) suggested that rats do not need to move far to satisfy their daily nutritional requirements because of the high availability of nuts and the prolonged period over which they are available.

Each rat used 2–7 nests during the 8-week period. Nests were most frequently at heights above 2 m in tree hollows. This would enable rats to escape floodwaters during the winter period. Nests were scattered throughout a rat’s entire home range, with locations independent of core areas. Rats alternated between nests and frequently visited several nests during each nighttime activity period. Maintenance of multiple nests throughout their range may be a strategy rats have adopted to more efficiently use a habitat where food resources vary spatially and temporally. That is, although nest sites remain fixed, core areas may change according to the distribution of food resources. Use of multiple nests has been observed in other natural habitats (Dowding and Murphy 1994; Dutson 1973), but not in macadamia orchards where food resources are more uniformly distributed and abundant year-round (Tobin et al. 1996). Dutson (1973) observed rats to alternate between 2 or 3 nest sites over a 2-week period in blackberry habitats. Dowding and Murphy (1994) observed rats to use between 2 and 9 nests in a kauri forest, New Zealand, during a 5-week study period. Similar to our study, they noted that nest-site location was not dependent on the location of core areas, with several rats having most or all of their dens outside their core areas. They also suggested that this may be due to the distribution of preferred food resources.

We observed 2 male rats sharing a nest, and other male and female rats may have been sharing nests with uncollared individuals. Nest sharing both between and within sexes was reported by Dowding and Murphy (1994), who suggested that rats sharing nests may be related and therefore more tolerant of each other, even during breeding periods. Nest sharing has not been reported in other studies of roof rats in natural areas.

Most rat activity in our study was recorded 1–2 h after sunset until 1 h before sunrise, with daytime activity infrequent. Rats nested in trees but spent most of their active time on or near the ground. Roof rats also have been reported to spend a large proportion of time on the ground in forests in New Zealand (Hooker and Innes 1995), Australia (Cox et al. 2000), and Puerto Rico (Layton 1986). However, in cultivated orchards where ground cover of vegetation or debris usually is low, rats spend the day in underground burrows, and forage at night in
the canopy (M. M. Hoque and L. A. Fiedler, in litt.; Tobin et al. 1996). In an urban area of California, Recht (1988) reported home-range sizes of rats to be 0.2–0.5 ha, and movement patterns were determined primarily by the presence of aerial pathways such as telephone wires and fences. Predators such as cats and dogs in urban areas may limit the amount of time that rats spend on or near the ground (Recht 1988).

When active, rats were located frequently in areas of dense vine cover (blackberry and native grape) that probably protects them from predators, as well as providing food resources. This pattern is in contrast to the availability of those habitats within the study area. Although there are patches of dense vine cover usually associated with openings in the canopy, approximately 60% of the study area is dominated by box elder, Oregon ash, and Fremont cottonwood trees, where there is less than 10% ground cover of vines. Dutson (1973) observed a close correlation between trapping records of roof rats and the ground cover of vines. Dutson (1973) observed a close correlation between trapping records of roof rats and the distribution of Himalayan blackberry (R. discolor) in California, and suggested that this plant is of primary importance in determining occurrence of roof rats, providing them with food, nesting habitat, and protection from predators and adverse weather. However, low population densities recorded for 3 Himalayan blackberry thickets along the Napa River, California, led Dutson (1973) to suggest that additional food sources also are necessary to support high population densities of rats.

Our study is the 1st to provide detailed information on movements and habitat use of roof rats in a riparian forest in California. Because of seasonal changes in habitat, our study probably does not reflect the spatial ecology of roof rats at other times of the year. However, it provides important information for developing a fall–winter management strategy to reduce populations and impacts of this species. The large home-range sizes of males and females, high degree of home-range overlap between individuals, ground foraging behavior, and preference for areas of dense vine cover should be considered in developing a management strategy. Careful consideration also should be given to the potential impacts of rat management on nesting bird species and other native wildlife that may be present. For example, removal or modification of preferred rat habitat also would reduce nesting habitat for birds. Baiting or trapping strategies similar to those used in Hawaii (Nelson et al. 2002) may be more appropriate for rat management in riparian areas in Central California.

Acknowledgments

We thank R. Cooper, Cosumnes River Preserve manager, for allowing us to conduct this study on the Preserve. We also thank our field assistants M. Collins, E. Gibson, S. Gillespie, and M. Park.

Literature Cited


Submitted 22 July 2006. Accepted 26 October 2006.

Associate Editor was Douglas A. Kelt.