SMALL MAMMAL COMMUNITIES IN A RAPIDLY DEVELOPING SOUTHERN INDIAN CITY

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Abstract

Four sites around Bangalore city were chosen for survey of non-volant small mammals (rodents and insectivores). The sites were chosen in scrub patches and plantations that are typical of Bangalore landscape. Species composition, population and microhabitat preference were studied. The study assessed changes in species composition and community structure with the change in land use patterns and levels of anthropogenic disturbances. In areas of high anthropogenic disturbance, number of species, and abundance was recorded to be very low, as compared to areas of relatively low disturbance. Shivanahalli (least disturbed site, and most representative of wild habitats around Bangalore) recorded seven species, with Cremnomys blanfordi *and* Rattus rattus wroughtoni *being dominant. Microhabitat preference was studied only in Shivanahalli, as the other sites did not have sufficient captures for analysis. Most of the captures were recorded in rocky areas, with dense shrub cover. The two dominant species appeared to avoid each other's territories.*

Keywords

Bangalore, Cremnomys blanfordi*, rodents,* Rattus rattus wroughtoni*, small mammals, urban ecosystems.*

Urban ecosystems harbour certain groups of wild taxa, of which small mammals form an important group. Small mammals can be defined as those mammals whose live weights do not exceed 5kg when adult. These include members of orders Insectivora, Rodentia, Carnivora and Chiroptera (Stoddart, 1979). The study focussed on nocturnal insectivores and rodents.

Small mammals contribute to energy flow and nutrient cycling, and play important roles as seed predators, dispersal agents and pollination agents in tropical ecosystems, making them an important functional component of wild communities (Fleming, 1975; Chandrasekar-Rao & Sunquist, 1996). They form important prey base for carnivores and raptors (Emmons, 1987; Hayward & Phillipson, 1979). Some species like *Bandicota bengalensis, Millardia meltada, Tatera indica* and *Mus booduga* are abundantly found in agro-ecosystems (Tripathi *et al*., 2002), while some may be found in close association with humans: *Rattus rattus* and *Mus musculus* are commonly found inside houses (Tripathi *et al.*, 2002); rodents like *Bandicota indica* are found abundantly in urban areas in garbage dumps and sewers (Prater, 1971; Parshad, 1999). Several small mammals that have adapted to modified habitats, such as agricultural fields and urban developments, have established themselves as agricultural pests (eg. *Bandicota bengalensis*, *Rattus rattus*, *Mus booduga*, *Millardia meltada*, *Tatera indica* - Advani, 1987; Brooks *et al*., 1988; Parshad, 1999; Siddique & Arshad, 2003; Lathiya *et al*., 2003) and disease carriers (eg. *Rattus rattus*, *Bandicota indica* - Gangadhar *et al*., 2000; also see Kao *et al*., 1996; Chanteau *et al*., 1998; Tanskul *et al*., 1998; Ellis *et al*., 1999).

Small mammals comprise most of the known living mammals of the world (Fleming, 1979; Stoddart, 1979). They are an extremely successful group of animals due to their immense breeding potential and easy adaptability to a wide variety of habitats, thus enabling them to acquire cosmopolitan distribution (Southern, 1979). Though members of Rodentia and Insectivora constitute most of the threatened species of the world, they are relatively less studied as compared to other groups such as Carnivora, which add to only 6% of the global threatened species list, but are the highest studied mammalian group worldwide (Amori & Gippoliti, 2000).

There appears to be little published scientific studies on small mammals (Rodentia and Insectivora) in Bangalore, except for a checklist compiled by Karthikeyan (1999). The present study inventoried the rodent and insectivore community of urban and rural Bangalore. Habitat associations were examined. Population estimates were attempted, but quantifiable data was obtained from only one site. Here populations and distributions were investigated in relation to microhabitats. The study also examined the change in land-use patterns and its influence on rodent community structure and diversity. This study was a preliminary attempt at understanding the small mammal community structure in semi-natural habitats around a rapidly growing urban ecosystem.

Methodology

Study area

The district of Bangalore in southern India lies between the latitudes $12^0$39'-$13^0$18'N & $77^0$22'-$77^0$52'E. It covers an area of 2191km^2, with Bangalore city occupying 151km^2, an area that is fast increasing. The temperatures in the district range from a summer average of 33^{0}C and winter average of 14^{0}C. The average annual rainfall is 92cm (Meteorological Centre, pers. com.).

The natural vegetation of Bangalore comprises of scrub forests. Typically the landscape of urban and rural Bangalore is a mosaic of scrub patches, plantations, orchards, agricultural fields and built-up areas. With the increase in urbanisation there has been a consequent significant decrease in natural and semi-natural habitats (Behera *et al*., 1985), which are home to most urban wildlife. The sites chosen for the study represented the habitats surrounding Bangalore. Locating undisturbed patches was extremely difficult. Four sites were chosen, all within a distance of 30km from the centre of the city.

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Site 1: The Bangalore University campus lies on the southwest outskirts of Bangalore city. The vegetation is a mix of scrub and *Eucalyptus* plantations. The area chosen for the study was a patch with such a mix. The campus is under moderate to high levels of anthropogenic pressure, with local people regularly collecting firewood and grass, and grazing their cattle. The grass is fired during the dry season to encourage new flush to provide fodder for the cattle.

Site 2: Gandhi Krishi Vidya Kendra (GKVK), or the Agricultural University Campus, lies on the northern outskirts of the city. The GKVK campus is mainly covered with *Eucalyptus* plantations, open fields, orchards and scrub vegetation. For the study, a *Eucalyptus* plantation and a small scrub patch were chosen. The ground cover in the *Eucalyptus* patch was extremely sparse. This region is also under moderate levels of anthropogenic pressure. Metalled and un-metalled roads crisscross the landscape, and people pass through and around it on a regular basis. We also observed that firewood is collected regularly.

Site 3: Shivanahalli, a village that is located on the borders of the Bannerghatta National Park, lies to the south of Bangalore city. The national park is comprised of scrub forest habitat sprawling across gently undulating rocky hills. The patch chosen for the study in Shivanahalli was a farm belonging to the Ramakrishna Mission Ashram. The farm, stretching down the slope of a rocky hill, is a mix of scrub and bamboo, as well as planted forest species, and teak and mango plantations. The land is fenced in, and is relatively undisturbed.

Site 4: Jindal, close to Hessarghatta, lies towards the western part of Bangalore. Hessarghatta, the biggest watershed area in Bangalore, is almost completely an agricultural region. The Jindal area is more of a mix of agricultural fields, plantations and industries. A farm was chosen for the study here, comprising of coconut and Persian lilac plantations. Farmhands working in the area, frequent removal and burning of weeds, and people moving from the main road to a lake situated behind the farm proved to be constant sources of disturbance.

METHODS

Sampling was conducted in the months of January and February 2003 at sites 1, 2 and 3. Site 4 was sampled in May 2003.

Sampling was done representatively, keeping in mind the heterogeneity of the sampling site. The pattern of laying traps varied from site to site as described below, depending on habitat characteristics and feasibility. In all sites, Sherman traps were laid for a period of six consecutive nights - two nights of baiting and four nights of trapping. Baiting involved laying traps with bait through the night, and releasing trapped animals without recording measurements, the next morning. This was done in order to acclimatise the animals to the traps. Trapping, which was done after the animals were assumedly acclimatised, involved recording measurements of trapped animals after a night of baiting. Traps were laid between 1700 and 1830 hours, and checked between 0700 and 0900 hours daily. Trapped animals were released without marking on the first two nights of baiting. Animals trapped during the next 4 nights were marked, weighed, measured, sexed and released. Animals captured on the first night of trapping were marked by clipping fur on the left rump; those captured on the second night were clipped on the right rump, and on the third night were clipped on the back.

Trap laying patterns at the different sites:

Bangalore University Campus: The patch chosen for the study in this site was a narrow strip of land bound by roads on three sides, and traps were laid in three lines of 16 traps each in an area of 0.72ha. A distance of 15m separated the lines from each other, and traps in each line were separated from each other by a distance of 10m. Bait used was dry coconut and dry fish.

GKVK Campus: Traps were laid in the *Eucalyptus* plantation in a grid of 7x7, each trap being separated from the other by 10m. Bait used was dry coconut and dry fish. Trapping frequency was found to be extremely low, and after two trapping nights the methods and bait was changed to test if there was any change. The bait used was dry coconut and jaggery. The question of whether the animals were rather thinly distributed, was tested by removing 14 traps from two alternate lines in between. Thus some traps were separated from each other by 10m and some by 20m. The 14 removed traps were laid in a small scrub patch in a random order, roughly at separations of 20m from each other. A total area of 0.63ha was sampled in GKVK.

Shivanahalli: Here the traps were laid in such a fashion as to represent all habitat types. Two lines of traps traps each were laid in the planted forest patch. The traps were placed 20m from each other. The rest of the traps were placed in straight lines through all the habitat types. Inter trap distance in each line was 20m. The total area sampled was 2ha. Bait used was jaggery and dry coconut. However, after two nights, the use of jaggery was discontinued as ants attracted by it bit animals that were trapped.

Jindal: Two patches - a coconut plantation and a Persian lilac patch - were chosen for the study. The Persian lilac patch was a rather square patch; traps were laid in a grid of 5 x 5, with 10m spacing between traps. Another 25 traps were laid in the coconut plantation in three and a half lines of seven traps each, inter-trap distance in each line being 10m, and the distance between the lines also measuring the same. The total area sampled measured was 0.5ha. Dry coconut was used as bait.

Microhabitat parameters were recorded at each trap station in all four sites (Table 3).

Small mammals captured were identified on the field using Prater (1971) and Pradhan (2002). Unidentified animals were collected and preserved in 5% formaldehyde solution for identification in the lab. Identification of samples was verified by Dr. Shakuntala Sridhara, University of Agricultural Sciences, Bangalore.

Table 3. Parameters for assessing habitat were measured in a circle of radius 2m around the trap station.

S.No.	Parameters	Measurement
1	Shrubs	Number of stems <10cm gbh
2	Trees	Number of stems >10cm gbh
3	Bamboo clumps	Number of clumps
4	Ground cover	Percentage coverage (visual estimation)
4.1	Grass-	Presence/absence
4.2	Leaf litter	Presence/absence
5	Canopy	Scale of 0-3 (0- no canopy, 1- branches not meeting, 2- branches just meeting, 3- branches overlapping). Percentage coverage (visual estimate)
6	Soil substrate	Percentage coverage (visual estimate)
7	Rock substrate	Distance in meters from trap station
8	Distance to nearest tree	Presence/absence of strata I, II, III (strata I: 0-1m,
9	Stratification	strata II: 1-2m, strata III: 2-5m).

Data Analysis

The following variables were analysed.

1. Species composition represents the proportion of each species captured among all the captured animals.

$$\text{Species composition} = \frac{\text{Total number of individuals of } i^{th} \text{ species x 100}}{\text{Total no. of captures of small mammals}}$$

This was calculated across all sites as well as separately for Shivanahalli.

2. Abundance

An index that reflects the abundance of rodents and insectivores at each site was calculated. This is given by (Prakash & Singh, 1999).

$$\text{Trap Index (I)} = \frac{\text{Total number of captures x 100}}{\text{No. of traps x No. of trapping nights}}$$

The same was calculated separately for the two dominant species in Shivanahalli, *Cremnomys blanfordi* and *Rattus rattus wroughtoni*.

3. The population was estimated using the Schnabel Mark-Recapture method. In this method animals are captured and marked on several successive occasions. The method depends upon observing the increase in the proportion of marked animals captured in successive catches as the number of marked animals increase. When this proportion equals 1.0, the total number of animals previously marked must be the number in the population (Sutherland, 1997).

The data was analysed using the regression method of Schumacher and Eschmeyer (Sutherland, 1997).

The total population size (N) was estimated as

$N = A/B$

where $A = \Sigma n_i M_i^2$

$B = \Sigma m_i M_i$

where n_i = number of animals in the i^{th} sample

m_i = number of animals in i^{th} sample that are already carrying marks

M_i = number of animals marked prior to the i^{th} sample, $\{M_i = \Sigma u_i, 1 \leq j \leq i\text{-}1\}$

$u_i = n_i - m_i$ = number of unmarked animals in i^{th} sample

95% confidence limits for the population estimate was given by

$$A / \{B \pm t \sqrt{[(AC - B^2) / (S - 2)]}\}$$

where $C = \Sigma m_i^2/n_i$

S = number of samples

t = Student's t for S-2 degrees of freedom at the 5% significance level.

This was calculated only for the small mammal population of Shivanahalli, as other sites did not have sufficient number of captures or recaptures for estimating population.

4. Average weight of adults for each species was calculated across sites as well as for each site.

5. Sex ratio and ratio of adults to juveniles were calculated for dominant species in Shivanahalli only as the high number of captures made this possible.

6. Habitat

A Principal Component Analysis (PCA) was conducted to examine the habitat preferences of the small mammal community in Shivanahalli. Other sites did not have sufficient number of captures, and therefore they were not included in the analysis. Certain parameters were excluded, as they appeared redundant. The principal components were extracted by subjecting the data to a Varimax Normalised rotation. The test further assessed the habitat niche separation between the two dominant species in Shivanahalli.

MS Office Excel 2000 and STATISTICA 5.0 were used for the analyses.

Results

A total of 43 individuals of eight species were captured from four sites. Bangalore University, GKVK and Jindal recorded only one species from each of the sites; we captured three individuals of *Millardia meltada* from each of Bangalore University and GKVK, and one individual of *Suncus murinus* from Jindal. Thrity-six individuals from seven species were recorded from Shivanahalli (Figure 2).

Species composition

The composition of small mammal taxa in Bangalore has been tabulated in Tables 1 and 2. *Rattus rattus wroughtoni* and *Cremnomys blanfordi* were the two dominant species captured during the study. The data has been represented graphically in Figures 1 and 2.

Abundance

The abundance of small mammals was found to be highest at

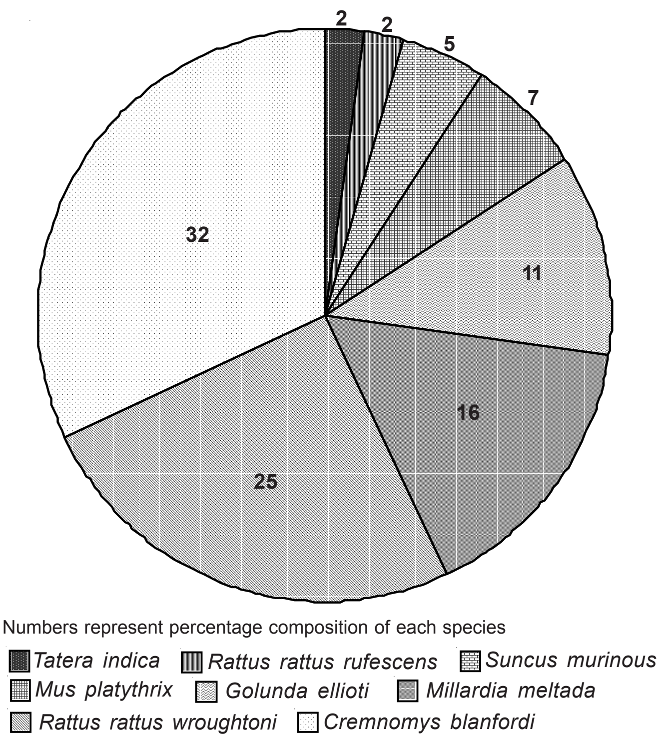

Figure 1. Species composition of small mammals captured in Bangalore.

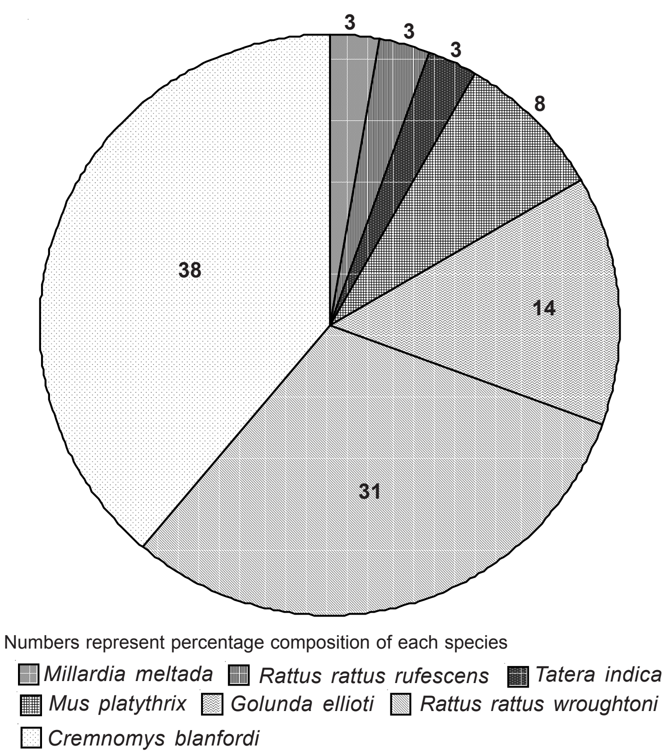

Figure 2. Species composition of small mammals captured in Shivanahalli.

Table 1. Small mammal taxa captured during the study. These, along with species listed in Table 2, coincide with those recorded in Bangalore by Karthikeyan (1999).

Species	Common Name
Tatera indica (Hardwicke, 1807)	Indian Gerbil
Rattus rattus rufescens (Gray) *	Common House Rat
Suncus murinus (Linnaeus, 1766)	Grey Musk Shrew
Mus platythrix (Bennett, 1832)	Spiny Field Mouse
Golunda ellioti (Gray, 1837) *	Indian Bush Rat
Millardia meltada (Gray, 1837)	Soft-furred Field Rat
Rattus rattus wroughtoni (Hinton) *	White-bellied Rat
Cremnomys blanfordi (Thomas, 1881)	White-tailed Wood Rat

* represents species not recorded by Karthikeyan (1999).

Shivanahalli (I = 18.37) and lowest at Jindal (I = 0.50). Bangalore University (I = 1.56) and GKVK (I = 1.53) had comparatively low abundance. The two dominant species occurring at Shivanahalli were *Rattus rattus wroughtoni* (I = 5.61) and *Cremnomys blanfordi* (I = 6.63).

In GKVK, the increase in inter-trap distance did not affect capture rates. This is suggestive of the fact that the population itself is very low, and distribution is not patchy.

Population

Population of small mammals sampled within an area of 2ha at Shivanahalli was estimated to be 80.17 individuals, within 95% confidence limits of 74.64 and 86.58. The populations of *Rattus rattus wroughtoni* and *Cremnomys blanfordi* in the same site were estimated at 12.45 and 18.76, within 95% confidence limits of 11.71 - 13.30 and 15.19 - 24.52 respectively. The two species made up almost 70% of the animals captured, as can be seen from figure 2.

Average weight

Average weight of adults of all species could not be calculated as adults of only *Rattus rattus wroughtoni* and *Cremnomys blanfordi* were captured from one site only (Shivanahalli). One adult *Golunda ellioti* was also captured here. Other species captured at this site were all juveniles, and similarly all animals captured at other sites were also juveniles.

At Shivanahalli, the average weight of *Rattus rattus wroughtoni* was 59.2g and *Cremnomys blanfordi* was 97.83g. The single *Golunda ellioti* captured weighed 32g.

Sex ratio

Males of both the dominant species at Shivanahalli seemed to be captured more frequently than females. The ratio of male to female animals captured at Shivanahalli for *Rattus rattus wroughtoni* and *Cremnomys blanfordi* were 8:3 and 9:2 respectively.

The ratio of adults to juveniles for *Rattus rattus wroughtoni* and *Cremnomys blanfordi* individuals captured at Shivanahalli were 10:1 and 3:8 respectively.

Combining data from all sites, 51% of all captured animals were

Table 2. Other rodent taxa not encountered in the traps, but have been observed by the investigators within Bangalore urban city as well as in the study sites.

Species	Common name	Habitat where observed
Funambulus palmarum (Linnaeus, 1766)	Indian Palm Squirrel	urban, semi-urban, plantation and natural scrub habitats
Bandicota indica (Bechstein, 1800)	Larger Bandicoot Rat	within urban limits
Bandicota bengalensis (Gray and Hardwicke, 1833)	Lesser Bandicoot Rat, or Indian Mole-rat	within urban limits
Mus musculus (Linnaeus, 1758)	Common House Mouse	inside house within urban limits
Rattus rattus rattus (Linnaeus, 1758)	European Black Rat	inside house within urban limits
Vandeleuria oleracea (Bennett, 1832)	Long-tailed Tree Mouse	scrub habitat in Shivanahalli

juveniles or sub-adults, and 35% were adults (14% unknown).

Habitat

The PCA extracted three components that accounted for 65.67% of the total variance. Six of the nine habitat parameters included for the test were found to be significant (Table 4). Principal Component 1 (PC 1) combined the mutually correlated parameters leaf litter, canopy and rock; PC 2 represented trees and bamboo, and PC 3 corresponded to shrub cover.

Scatter plots (Figure 3) illustrated the importance of each of these with respect to occurrence of small mammals.

It was seen that large numbers of small mammals were captured around rocky areas, having low level of canopy and leaf litter. The animals were found to have a slight preference for shrub cover, though this was not significant.

Graphs showing habitat preference were plotted for the two dominant species (Figure 4). There was no clear separation of habitat preference of the two species as seen from the graphs. However *Rattus rattus wroughtoni* seemed to be a more generalist species, while *Cremnomys blanfordi* was more particular regarding microhabitats used.

Rattus rattus wroughtoni is likely to be found in rocky regions with less canopy and leaf litter. It seemed to have a preference for open areas, but some individuals were captured from regions having some shrub cover. Further, the graphs (Fig. 4) indicated non-specificity with respect to trees and bamboos.

Clustering of data points on the graph was seen for *Cremnomys blanfordi*. This species had a preference for areas that were less open with some amount of shrub cover. This was also observed on the field. Trap stations where *Cremnomys blanfordi* were captured had less rock and higher levels of canopy and leaf litter as compared to stations where *Rattus rattus wroughtoni* were captured.

It was observed that in sections where *Rattus rattus wroughtoni* were captured in large numbers, *Cremnomys blanfordi* were either not captured or captured in low numbers, and *vice versa* (Fig. 5). There was overlap in some sections, but in general it appeared that the two did not venture into each other's territory. Trap stations 1 to 10 seem to be the domain of *Cremnomys blanfordi*, stations 11 to 20 that of *Rattus rattus wroughtoni*, and so on. There was some overlap in stations 44 to 49. However, it can be seen that each species was never captured in the station where the other had been captured. The Spearman's rank correlation between numbers of *Rattus rattus wroughtoni* and numbers of *Cremnomys blanfordi* captured at each trap station was –0.87 ($p = 0.000001$).

Discussion

Over the past few decades, Bangalore has expanded tremendously in area, from roughly 67km^2 in 1961 to six times that in 1991 (Krishna *et al.,* 1995), and is still growing rapidly. The city has seen a diminishing trend in natural and semi-natural habitats with the increase in industrialisation and urbanisation (Behera *et al.,* 1985).

Among the four sites, Jindal had the highest levels of disturbance and Shivanahalli had the lowest. The study site in Jindal was a monoculture farm surrounded by industrial set-ups, and was an isolated patch of semi-natural habitat. Shivanahalli was a mosaic of agricultural land, plantations and the natural scrub habitat of Bannerghatta National Park. Bangalore University and GKVK campuses had monoculture patches of *Eucalyptus* sp., though Bangalore University was different in having layers of shrub and grass cover. While the habitat in Shivanahalli was heterogeneous, that of Jindal was almost homogeneous in its structure. GKVK and Bangalore University were also homogeneous, though less so compared to Jindal. Studies have attributed healthy communities of small mammals (with respect to population, density and species composition) to heterogeneity in habitat (Chandrasekar-Rao & Sunquist, 1996), contiguity and habitat quality (Meena, 1997). There were marked differences in the population characteristics of small mammals in Shivanahalli when compared to the other three sites. Seven species captured in Shivanahalli was rather

Table 4. Habitat descriptors summarized by Principal Component Analysis. Factor loadings > 0.7 were considered important components of their respective Principle Components (PC).

	PC 1	PC 2	PC 3
Eigen values	3.42	1.33	1.16
Cumulative variance (%)	38.00	52.78	65.67
Habitat parameters:			
Shrubs	0.10667	0.06320	**0.89092**
Trees	0.43238	**-0.73169**	-0.02140
Bamboos	0.42583	**0.80043**	0.07629
Ground Cover	0.69674	-0.03613	0.04937
Grass	-0.64852	-0.05629	-0.00565
Leaf Litter	**0.70708**	-0.10645	0.35723
Canopy	**0.78037**	0.09941	0.09145
Rock	**-0.74385**	0.06892	0.45537
Distance to nearest tree	-0.63133	0.33501	-0.30811

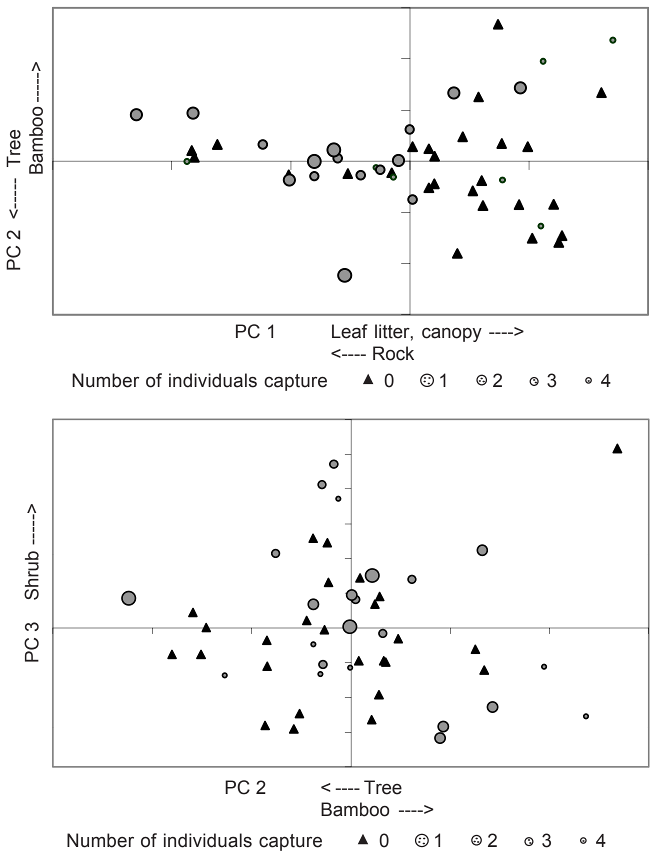

Figure 3. Number of small mammals captured in Shivanahalli and its relation to microhabitat parameters.

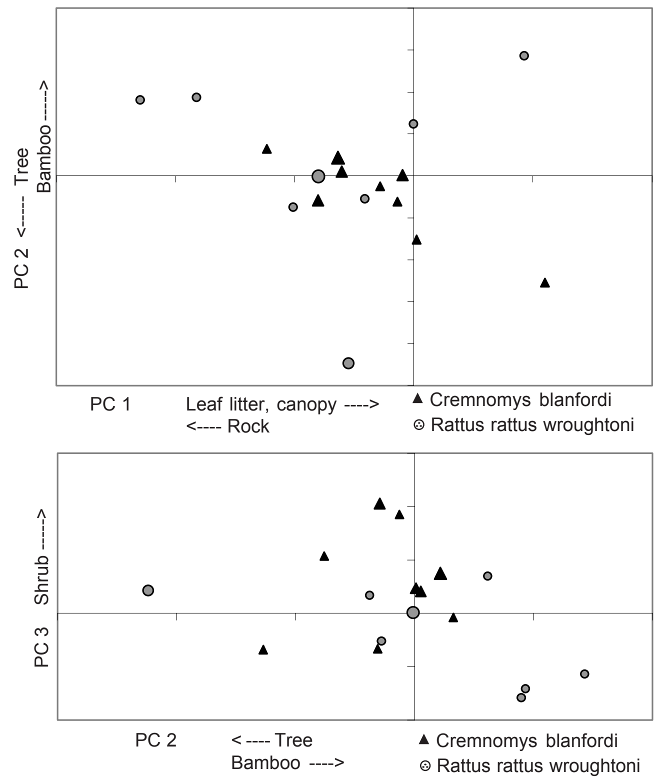

Figure 4. Habitat parameters and their importance to Rattus rattus wroughtoni and Cremnomys blanfordi in Shivanahalli. Increasing sizes of data points of either species implies increasing number of individuals captured.

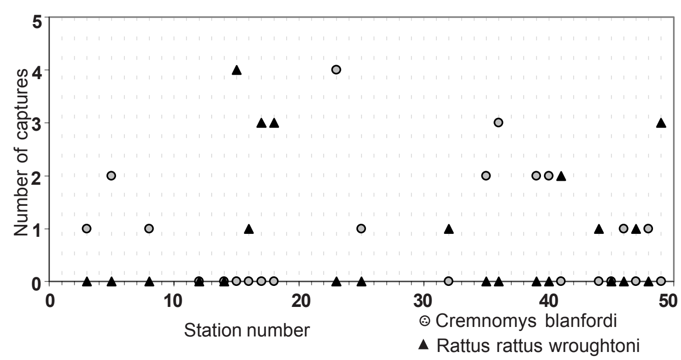

Figure 5. Distribution of Rattus rattus wroughtoni and Cremnomys blanfordi as reflected by capture data in Shivanahalli. Dotted vertical lines represent individual trap stations. The two species were never captured at the same trap stations.

contrasting to one species captured elsewhere. Similar patterns were also seen in the case of abundance of small mammals in these areas (see results).

Suncus murinus, which was the only species captured in Jindal is commonly found in houses, and within cities and towns (Prater, 1971). Bangalore University and GKVK recorded *Millardia meltada*, which is indicative of the fact that the habitat tends towards openness and homogeneity; in India, this species has been recorded mostly in grasslands (Meena, 1997; Shanker, 2001), wattle plantations (Shanker, 2001) and agricultural fields (Prakash & Singh, 1999; Shakuntala Sridhara, pers. com.).

Microhabitat selection

Microhabitat preference was examined only in Shivanahalli as other sites were deficient in the number of captures. Shivanahallli is the most natural of the habitats surveyed, and is representative of the wild habitats around Bangalore.

Preference for shrub cover, as seen in the results, could be related to predator avoidance (Chandrasekar-Rao & Sunquist, 1996). Along similar lines, one would expect these animals to have a preference for high levels of canopy cover. But this was not seen in this study. A possible explanation could be that the dominant species were found in rocky areas that do not support dense growth of trees. Another could be that shrub cover offers more protection than canopy cover, which allows for some amount of openness up to some height above the ground level. Chandrasekar-Rao and Sunquist (1996) also found that high bamboo densities proved preferred habitats of small mammals in the Anaimalai hills of southern India. In Shivanahalli, a substantial number of rodents were captured in bamboo patches. However, this was not apparent from the analysis. The parameters were measured within a radius of 2m around each trap station. Bamboo clumps did not grow densely; rather they were spread out somewhat thinly. Possibly, if parameters had been measured within a larger area around the stations, such discrepancies may have been avoided.

Interspecific competition

Small mammals are known to be highly competitive (Shanker, 2001). Competitition and habitat features may determine distribution and diversity of species in an area, but to what extent is not clear (Meena, 1997). With respect to micro-habitat selection, there was no significant segregation between the two dominant species *Rattus rattus wroughtoni* and *Cremnomys blanfordi*. While the former appeared to be somewhat generalist in its habitat usage, the latter was more specific, choosing to stay in areas having higher densities of shrubs. *Rattus rattus wroughtoni* favoured rocky regions more than *Cremnomys blanfordi*. The difference in site selection with respect to canopy cover was less significant between the two species. Meena (1997) found that the distributions of *Rattus rattus* and *Cremnomys blanfordi* were strongly negatively correlated. Shanker (2001) suggests that habitat selection by small mammals at the micro-habitat level is rather weak, but is definitely strong at the scale of the macro-habitat. This could not be tested in the present study, as sampling was not done across different macro-habitats.

Interestingly, though the segregation at the micro-habitat level was not discernable, territoriality between the two species was displayed, as was seen in their spatial distribution (see Results). The Spearman's correlation between numbers of each species captured at each trap station was strongly negative. Clearly the two species display strong territorial instincts and are mutually exclusive. Phillips (1981) remarks that *Rattus rattus* is a very adaptable and aggressive rodent and has been known to exclude other species from an area.

It is rather remarkable that most of the animals captured were sub-adults or juveniles, except in the case of *Rattus rattus wroughtoni*. Certain species were represented only by young ones, and no adults were captured. We speculate that juveniles disperse to establish territories, and more so the males, which would encounter opposition from other males. As this quest for a territory would continue for a somewhat extended period of time, the chances of a wandering juvenile male being captured is greater. It was found that the sex ratio of captured animals was biased in favour of males. This trend was seen in the case of adults of the two dominant species in Shivanahalli as well. Another possible explanation for this biased sex ratio could be the fact that males often tend to range over more extensive areas than females (Prakash, 1977) and are therefore more likely to be trapped. There is also the possibility that females are dispersing or are subjected to higher mortality rate than the males. Neither of these can be proved. Shanker and Sukumar (1998) suggest that in smaller patches, dispersal of females could lead to higher mortality or emigration, and therefore are less likely to be trapped.

Low populations in three of the four sites sampled have significant conservation implications. Populations at low densities are susceptible to local extinctions (Chandrasekar-Rao & Sunquist, 1996). Rodent populations in disturbed habitats fluctuate much more than those in natural forest habitats (Isabirye-Basuta & Kasenene, 1987). Disturbance levels appear to have an effect on characteristics of small mammal community structure. Firewood collection, cattle grazing, burning of pastures observed on Bangalore University campus are obvious threats to an already dwindling population. Shanker (1998) believes that the spread of plantations will alter the demography of small mammal communities in the wild, as well as that of carnivores dependent on them. The increase in urbanisation and fragmentation of natural and semi-natural habitats would demolish these communities entirely, allowing only for the hardy and adaptable species to thrive. The appreciable number of small mammals captured in Shivanahalli reinforces the fact that semi-natural habitats are pivotal in conserving these species. This is a key aspect for urban wildlife management - these species may not necessarily require heavily forested regions; rather habitat heterogeneity and semi-natural patches may be preserved in and around developed areas for the conservation of small mammal communities. It has been observed that in urban and suburban areas, small mammals are found in higher numbers in semi-natural heterogeneous patches than in manicured and groomed parks (Mahan & O'Connell, 2005).

This study has only glimpsed into the world of small mammals inhabiting the semi-natural and agro-ecosystems around a rapidly expanding Indian city. Certain constraints such as time prevented us from further sampling that might have added interesting dimensions to this study, such as: were the higher abundance and diversity of small mammals in Shivanahalli an artefact of the habitat type or a consequence of contiguous natural and semi-natural habitats? This could be easily tested by sampling in various habitat types (*Eucalyptus* plantations, for example) around Shivanahalli and Bannerghatta, and comparing with similar habitat types in other areas that are not contiguous with natural habitats. More detailed studies building on similar questions would provide deeper insights into the effects of urbanization and development on small mammal communities, the understanding of which is crucial to conservation of these animals, as well as other aspects of urban ecosystems.

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