Site occupancy of the Indian giant squirrel *Ratufa indica* (Erxleben) in Kalakad–Mundanthurai Tiger Reserve, Tamil Nadu, India

V. Srinivas¹,²*, P. Dilip Venugopal¹ and Sunita Ram¹,²

¹Foundation for Ecological Research, Advocacy and Learning, Post Box 28, Puducherry 605 001, India
²Centre for Wildlife Studies, 823, 13th Cross, 7th Block West, Jayanagar, Bangalore 560 082, India

The status report on the Indian giant squirrel speculates a declining population trend for the species and suggests that a further decline can be expected. Given the wide distribution of the species and the limited resources to accurately estimate abundances to monitor population trends, the proportion of the area occupied by the species could be used as an alternate state variable. Arriving at occupancy rates involves repeated detection/non-detection surveys and analysis of the data in a capture–recapture framework. We estimate the site occupancy rates for unstudied populations of Indian giant squirrel within the Kalakad–Mundanthurai Tiger Reserve (KMTR) using a model that allowed us to estimate this parameter even when the species was not detected. About 180 evidences of the occurrence of the species were recorded from 486 km of trails. The estimated occupancy rate for Indian giant squirrel in KMTR was 0.82 (with a SE of 0.08) with a detection probability of 0.71 (± 0.05). An examination of the species–habitat relationship showed that contiguous patches of moist deciduous and evergreen forests were preferred by the species. The occupancy rates were low in areas with degraded dry deciduous forests and scrub, which were associated with high levels of human disturbance. The estimates from this study provide a benchmark for long-term monitoring and metapopulation studies.

Keywords: Detection probability, Indian giant squirrel, site occupancy, species–habitat relationship.

Introduction

The Indian giant squirrel (*Ratufa indica*) is widely distributed in peninsular India¹, in forests south of 22⁰N. Although widely distributed, there are few studies that have estimated the population status of the species using standard sampling techniques². At present all that is available are a handful of reports relating to the presence and relative abundance of the species across its distributional range³–⁶. Recent estimates speculate a population decline of 20–30% for this species that has been attributed to loss of habitat and hunting. The total population is estimated at less than 5000 individuals occurring in fragmented subpopulations and the decline in population is expected to continue⁷.

Given that there are no programmes to monitor the species across its range and that accurate population abundance estimation requires considerable amount of effort and resources⁸, alternate state variables that are easily gathered will be useful to monitor the status of the species. The effort and costs further increase when the species occurs at very low densities and habitats are severely fragmented. To circumvent these problems, it has been suggested that occupancy rate can be used as a state variable using presence/absence surveys across several sampling sites⁸–¹⁰. In metapopulation studies, patch (or site) occupancy is used as a state variable to estimate local extinction and colonization probabilities¹¹–¹³.

However, one of the key problems with presence/absence (henceforth detection/non-detection) surveys is the non-detection of the target species. Non-detection does not necessarily translate to true absence of the species, but could mean that the species was present but was not detected during the surveys⁹. Failing to account for imperfect detectability will result in underestimates of site occupancy and biased estimates of local colonization and extinction probabilities¹⁴. This has been overcome by estimating the detection probability using a capture–recapture framework while analysing data from detection/non-detection surveys⁸,⁹,¹⁴,¹⁵. The method requires multiple detection/non-detection surveys to be conducted at the monitoring sites (or sampling sites) in order to estimate the detection function and to correct for non-detection⁹,¹⁶,¹⁷. Habitat covariates can be built in to reduce variance in the estimated detection probability and occupancy⁹. If counts are also available, relative abundances of target species might then be estimated by incorporating the detection probability⁸,¹⁸.

In addition to reducing efforts and costs, surveys directed at site occupancy are useful for long-term monitoring,
SPECIAL SECTION: ARBOREAL SQUIRRELS

metapopulation studies and for conservation planning. Several studies have examined environmental and habitat correlates with site occupancy. Occurrence of species in poorly sampled areas and habitat selection patterns of unstudied populations have been predicted using occupancy-based habitat models. Site occupancy has also been used for studying populations in fragmented landscapes.

In this article, we present the site occupancy estimates for unstudied populations of the Indian giant squirrel (Ratufa indica) within Kalakad–Mundanthurai Tiger Reserve (KMTR), Tamil Nadu. To investigate species–habitat relationships, we formulated the following hypotheses a priori, based on existing literature: (i) the Indian giant squirrel prefers moist or wetter forest types and (ii) they prefer large contiguous forest patches. We used remotely-sensed covariates as surrogates for habitat attributes. We illustrate how such methods can be used to study and monitor species of squirrels with limited detectability and those that are found in fragmented habitats. The work presented here is part of a larger project to estimate herbivore densities in KMTR and to develop long-term monitoring protocols.

The Indian giant squirrel R. indica (Erxleben) is a large-bodied squirrel, mostly solitary and territorial with arboreal, diurnal and herbivorous habits. This endemic species is found in deciduous, mixed deciduous and evergreen forests south of 22°N. It is listed under Schedule II of the Wildlife Protection Act (1972) of India and in Appendix II of CITES (2005). The species is more widely distributed when compared to the other large squirrel found in southern India, the grizzled giant squirrel (Ratufa macroura), a highly endangered species of the subcontinent.

Earlier studies have shown that the Indian giant squirrel preferentially uses large trees and requires canopy continuity, especially near nest trees. It seems to be able to adapt to some extent to disturbed forests with some gaps in the canopy, but cannot be found in forests regenerating from clear felling. Other than habitat loss, poaching has been identified as a major threat to the species.

Study site

The KMTR (8°25’–8°53’N and 77°10’–77°35’E) is the southern-most Tiger Reserve in India, situated at the southern tip of the Western Ghats (Figure 1). The Reserve was notified in 1988 and covers an area of ~900 km². It ranges in altitude from about 50 m to 1867 m, and the topography is variable with steep rocky slopes in the northern and southern boundaries to gentle undulating areas on the plateau. The annual rainfall ranges from 750 mm in the rain-shadow eastern slopes to over 3000 mm in the western slopes.

Figure 1. Map showing Kalakad–Mundanthurai Tiger Reserve, Tamil Nadu, India.
KMTR includes a large variety of habitat types, including west coast tropical evergreen forest, Tirunelveli semievergreen forest, southern hilltop tropical evergreen forest, southern moist mixed deciduous forest, dry teak forest, southern dry mixed deciduous forest, Carnatic umbrella thorn forest, Ochlandra reed breaks, pioneer Euphorbiaceae scrub and southern Euphorbia scrub\(^{41}\).

The Reserve is noted for its high faunal and floral diversity\(^{42,43}\), and, other than the Indian giant squirrel, harbours five species of squirrels (Funambulus palmarum, F. sublineatus, F. tristriatus, Petaxotupa philippensis and Petinomys fuscocapillus). There are also unconfirmed reports of the grizzled giant squirrel in the northern parts of the Reserve. Within the Reserve, there are only two concentrations of human settlements: some on the Mundanthurai Plateau and the plantations of Kakachi and Kodayar, which together constitute about 4% of the total Reserve area\(^{41}\). The eastern boundary of the Reserve is surrounded by more than 150 villages that exert considerable pressure and disturbance on the forest with respect to fodder and fuel-wood extraction. In the recent past, the implementation of an eco-development programme had reduced\(^{45}\) fuel-wood removal from the park by 95%. The western side of the park is mostly free from large human settlements, as it is contiguous with protected areas of Kerala and the reserve forests of Tamil Nadu and Kerala.

**Methods**

**Base maps**

A detailed base map of the Reserve was prepared by digitizing known features from a 1:50,000 scale georeferenced Survey of India toposheet. This was updated by incorporating additional information on trails and paths, which were collected by carrying out a survey using handheld GPS units.

**Field surveys**

Hexagonal grids (hex) of 25 km\(^2\) were overlaid on the map of the study area to define sampling sites. The hex size was determined to ensure that the sites were properly defined and that it was larger than the home range of the animal, enabling estimation of true occupancy rather than intensity of use; it also had to be determined by field logistics. The grids were clipped to the administrative boundary and only those sites that were larger than 10 km\(^2\) were chosen for sampling. Using the above criteria, we identified 37 hexes, covering about 675 km\(^2\) of the Reserve for sampling. Of the 37 hexes, seven could not be sampled, as there were no trails or paths within them. Similarly, the trails sampled across different hexes also varied based on availability of trails and paths within them. Four temporal replicates were used to collect detection/non-detection data, with every morning and evening session spread across two days, each being treated as a replicate. Trails were also chosen such that they were as far apart from each other as possible. On each sampling session, two teams of two biologists each traversed about 3 km of the existing trail network recording both sightings and calls of giant squirrels. The latitude and longitude of each evidence were noted down using a handheld GPS. The habitat description of the point location was also noted down. The hexes were sampled between February and September 2005, except for two, which were sampled in July 2004. The data were analysed using single-season models available in the program Presence\(^{45}\).

The covariates used to describe each cell were average slope (Slope); percentage dry forest cover (Dry); percentage wet forest cover (Wet); area under water (Water); a Habitat Homogeneity Index (HHI) (the average area-to-perimeter ratio for different habitat type within each hex), a higher score indicating a more heterogeneous cell with several smaller patches of different forest types; and the number of habitat fragments (Frag).

The influence of these covariates on the occupancy (\(\psi\)) and the influence of time of sampling (morning/evening) on the detection probability (\(p\)) were explored. The simplest model keeping the variability in \(\psi\) and \(p\) constant was first undertaken. Each variable and combination of variables was then used as a predictor in the models to estimate \(\psi\) and \(p\). Models were ranked on their AIC\(_c\) (Akaike’s Information Criteria for small subsets) value and the best model was selected based on \(\Delta\text{AIC}_{c}\). To understand the influence of a covariate on occupancy, computed model weights were summed over all models containing the particular covariate\(^{46}\).

**Results**

A total of 486 km of trails and paths were sampled and 91 direct sightings and 89 calls of giant squirrels were recorded during the study period. The frequency of evidences observed in the sampling unit is provided in Figure 2.

**Figure 2.** Frequency of evidences observed in the sampling units.
Table 1. Models assessed to estimate occupancy rates

<table>
<thead>
<tr>
<th>Model</th>
<th>AICc</th>
<th>ΔAICc</th>
<th>ΔICc, weights</th>
<th>$\hat{\psi}$</th>
<th>SE($\hat{\psi}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>pst(Slope, HHI), p(Sam)</td>
<td>141.18</td>
<td>0.00</td>
<td>0.25</td>
<td>0.814</td>
<td>0.087</td>
</tr>
<tr>
<td>pst(Slope), p(Sam)</td>
<td>141.39</td>
<td>0.21</td>
<td>0.23</td>
<td>0.844</td>
<td>0.063</td>
</tr>
<tr>
<td>pst(Wet), p(Sam)</td>
<td>141.50</td>
<td>0.32</td>
<td>0.22</td>
<td>0.797</td>
<td>0.055</td>
</tr>
<tr>
<td>pst(Slope, HHI, Wet), p(Sam)</td>
<td>142.56</td>
<td>1.38</td>
<td>0.13</td>
<td>0.811</td>
<td>0.103</td>
</tr>
<tr>
<td>pst(Slope, Wet), p(Sam)</td>
<td>142.78</td>
<td>1.60</td>
<td>0.11</td>
<td>0.842</td>
<td>0.088</td>
</tr>
<tr>
<td>pst(HHI), p(Sam)</td>
<td>145.66</td>
<td>4.48</td>
<td>0.03</td>
<td>0.806</td>
<td>0.073</td>
</tr>
<tr>
<td>pst(*) , p(Sam)</td>
<td>145.74</td>
<td>4.56</td>
<td>0.03</td>
<td>0.808</td>
<td>0.074</td>
</tr>
<tr>
<td>pst(<em>) , pst(</em>)</td>
<td>146.72</td>
<td>5.54</td>
<td>0.02</td>
<td>0.808</td>
<td>0.074</td>
</tr>
</tbody>
</table>

Slope, Average slope; HHI, Habitat Homogeneity Index; Sam, sampling occasion; Wet, percentage of wet forest cover. *Constant.

Table 2. Summed weights of covariates indicating their importance in determining occupancy

<table>
<thead>
<tr>
<th>Covariate</th>
<th>Summed AICc weights</th>
<th>Average $\beta$ coefficient</th>
<th>Average SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slope</td>
<td>0.722</td>
<td>0.147</td>
<td>0.071</td>
</tr>
<tr>
<td>Wet</td>
<td>0.457</td>
<td>2.670</td>
<td>1.968</td>
</tr>
<tr>
<td>HHI</td>
<td>0.407</td>
<td>-24.832</td>
<td>22.056</td>
</tr>
</tbody>
</table>

Slope, Average slope; Wet, Percentage of wet forest cover; HHI, Habitat Homogeneity Index.

Our analysis showed that none of the models could be judged as the best. Hence model-averaging or averaging $\hat{\psi}$ and $\hat{\beta}$ across all models was undertaken. This gave the estimated occupancy rate as 0.82 (with a SE of 0.08), with an average detection probability of 0.71 (± 0.05; i.e. probability of detecting squirrels on each walk). Only 29% of the sampled hexes had occupancy rates lower than 0.8. Using the first model (the model with the lowest AICc value; Table 1) and the same set of variables, the occupancy rates for those hexes that were not sampled were estimated (Figure 3). The difference between the sampled and the predicted occupancy rates did not appear to be different from each other ($\hat{\psi}_{\text{sampled}} = 0.8114 ± 0.103$, $\hat{\psi}_{\text{predicted}} = 0.8111 ± 0.099$).

The summed weights (Table 2) were calculated to infer the relative influence of each covariate on occupancy of the Indian giant squirrel. It was seen that slope, per cent wet forest and HHI were the three main factors (in that order) influencing the occupancy of this species. The $\beta$-coefficient (Table 2) shows that the HHI has a negative influence on their occupancy and per cent wet forest and slope are positively correlated to the occupancy.

**Discussion**

This study demonstrates how data from detection/non-detection surveys can be used to determine occupancy rates when species are not always sighted. Although our results show that the estimated occupancy did not largely differ from the naïve estimate, the study provides a framework for improving estimates. Also, given that the number of sightings differed in the morning and evening, we
demonstrate the methods that can be employed to account
for this variation and its influence on detection probability.

There has been no prior population estimates of the
Indian giant squirrel in KMTTR, and this is the first at-
ttempt to estimate occupancy rates for giant squirrels in
any Indian forests. The occupancy rates estimated in this
study show that the Indian giant squirrel is widely dis-
tributed in KMTTR and the high detection probability
shows that they are easily sighted. This indicates that
the species is common in this landscape both in terms of
detectability as well as distribution.

Habitat characteristics that influenced the occupancy
of these squirrels in this protected area were also identified
in this study. Of the six covariates used, only three influ-
enced the occupancy of giant squirrels in KMTTR. The
remaining three variables (area under water, percentage
dry forests and number of habitat fragments) did not have
any influence. The models where these covariates were
incorporated showed lower AIC values than the models
where $w$ and $p$ were held constant.

Slope had the highest influence on the observed occu-
pancy. This indicates that the giant squirrel prefers undu-
lating terrain in KMTTR. This could be an artefact of
the distribution of moist and evergreen habitats, which are
mostly found in highly undulating terrain in the study
site. These habitats cover about half of KMTTR. The pos-
tive trend with the proportion of wet forest cover and the
negative trend with the habitat homogeneity indicate that
the squirrels prefer large contiguous patches of the moist
and wetter forest types. These findings corroborate with
earlier reports on the habitat preference of the species.

Low model weights suggest that remotely sensed co-
variates do not explain the underlying pattern well, and
account only for 25% variance even in the best model.
However, this can be substantially improved if ground-
based covariates are taken into consideration.

The rate of occupancy was low in areas with high per-
centage of degraded dry deciduous forests and scrub. This
constitutes the eastern side of the park and includes areas
like the Mundanthurai Plateau, Manimuttar and the lower
reaches of the Kalakad range. Human disturbance, by
way of settlements and tourists, is high in these grids and
these areas are also severely affected by heavy fuel-wood
extraction by local residents. The vegetation around settle-
ments comprises of short trees and is dominated by
thorny shrubs.

Although poaching is reported to be a major threat in
other parts of its distribution range$^{3,4}$, this alone might
not explain the lower occupancy rates of squirrels closer
to human settlements, as poaching of the giant squirrel is
not widespread in KMTTR. Based on interactions with lo-
cals and field knowledge, we infer that poaching occurs
at very low intensities around human settlements. Occup-
cy rates were also low in regions with rocky slopes and
high elevation grasslands, like the Panditheri Pass
bordering Kerala.

With subsequent surveys, probabilities of site coloniza-
tion and extinction using multiple season models can be
estimated. Such studies will be of use for future manage-
ment and conservation of the species. Also, during occu-
pancy surveys, information on presence and number of
breeding animals can also be collected. It has been sugges-
ted that this can be used as an indicator of habitat
quality$^{3,4}$.

The occupancy approach has several advantages over
traditional density estimation techniques: it is cost-
effective in terms of equipment and trained manpower,
and can be carried out relatively more quickly compared
to other abundance-estimation techniques like line tran-
sects and mark-recapture surveys. Although in the present
study we make use of only direct evidence (sighting and
loud calls), this technique also allows the use of indirect
evidences like nests and pellet-droppings. In sites with
very low densities, it is most likely that one will be able
to detect indirect evidences more easily than direct evi-

dence. Advances in the technique also allow estimation of
animal abundances if an occupancy framework is fol-

dowed while collecting data$^{3,4}$. Often, it may suffice for
field managers and conservation biologists to monitor
trends in populations or trends in occupancy as a re-
sponse to specific conservation/management interven-
tions rather than monitoring actual abundances using
effort-intensive methods.

1. Abdulali, H. and Daniel, J. C., Races of giant squirrel (Ratufa

2. Jathanna, D. N., Kumar, S. N. and Karanth, K. U., Estimating In-
    dian giant squirrel Ratufa indica abundances in forest habitats us-
    ing distance sampling. In Abstracts of the Fourth International
    Tree Squirrel Colloquium and First International Flying Squirrel
    Colloquium (eds Nandini, R., Robin, V. V. and Sinha, A.), Na-
    tional Institute of Advanced Studies, Bangalore, 2006, p. 55.

    and conservation of the Indian giant squirrel (Ratufa indica),
    Technical Report No. 1, Wildlife Institute of India, Dehradun,

4. Sridhar, H., Effects of rainforest fragmentation and degradation on
    the Indian giant squirrel Ratufa indica and other small mammals
    in the Anamalai hills, southern Western Ghats, India. In Abstracts
    of the Fourth International Tree Squirrel Colloquium and First In-
    ternational Flying Squirrel Colloquium (eds Nandini, R., Robin,
    V. V. and Sinha, A.), National Institute of Advanced Studies,
    Bangalore, 2006, p. 29.

5. Babu, N. V. and Varma, S., Distribution and abundance of the In-
    dian giant squirrel (Ratufa indica) in Bandipur Tiger Reserve. In
    Abstracts of the Fourth International Tree Squirrel Colloquium
    and First International Flying Squirrel Colloquium (eds Nandini,
    R., Robin, V. V. and Sinha, A.), National Institute of Advanced
    Studies, Bangalore, 2006, p. 74.

6. Kumara, H. N. and Singh, M., Distribution and relative abundance
    of giant squirrel and flying squirrel in Karnataka, India. Mam-
    matla, 2006, 70, 40–47.


8. Royle, J. A. and Nichols, J. D., Estimating abundance from repea-
    ted presence-absence data or point counts. Ecology, 2003, 84,
    777–790.
SPECIAL SECTION: ARBOREAL SQUIRRELS


ACKNOWLEDGEMENTS. This study was catalysed and supported by Science and Society Division, DST, New Delhi (SP-YO/006/2001). We thank the Tamil Nadu Forest Department for permission to undertake this work. We also thank the Field Director and Eco-Development Officer, Kalakad–Mundanthurai Tiger Reserve for their support and cooperation. We are grateful to our field assistants for their support during data collection. Constructive criticism from William Duckworth, Arjun Gopalaswamy and another anonymous reviewer helped in improving the manuscript.