ECOLOGY OF GRIZZLED GIANT SQUIRREL *R. macroura* IN CAUVERY WILDLIFE SANCTUARY, KARNATAKA, SOUTHERN INDIA

BY

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THESIS

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Certificate

This is to certify that this dissertation entitled "***Ecology of Grizzled Giant Squirrel R. macroura in Cauvery Wildlife Sanctuary, Karnataka, Southern India***" towards the partial fulfillment of the BS-MS dual degree program at the Indian Institute of Science Education and Research (IISER), Pune represents study carried out by ***Upendra Arya*** under the supervision of ***Dr. H N Kumara***, senior scientist in conservation biology at Sálim Ali Centre for Ornithology and Natural History (**SACON**), during the academic year 2017-2018.

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Declaration

I hereby declare that the matter embodied in the report entitled "***Ecology of Grizzled Giant Squirrel R. macroura in Cauvery Wildlife Sanctuary, Karnataka, Southern India*** "are the results of the work carried out by me at the Department of Conservation biology, Sálim Ali Centre for Ornithology and Natural History (**SACON**), under the supervision of ***Dr. H N Kumara*** and the same has not been submitted elsewhere for any other degree.

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Abstract

Grizzled Giant squirrel is an endangered species. In India, its mainly confined to the Eastern and Western Ghats in peninsular region. Cauvery wildlife sanctuary is known to hold the northernmost population of this animal. However, proper status and distribution of this mammal were not accessed for this sanctuary. A grid-based field survey for their distribution and population status was carried out in riparian forest of this Wildlife Sanctuary. A total of 43 individuals of GGSs and 255 dreys were recorded as direct sighting during the survey. Further, in each grid cell, the independent variables like stand structure and resource availability were assessed using vegetation sampling. Occupancy modeling was done software PRESENCE ver. 2.12.10. Basal area (BA) was seen as playing a very important role in the occupancy and influencing it positively. Four different habitats in the same study area were chosen for recording activity pattern and home range. A total of 10 days data for each habitat (Nov.'17- Jan.'18) was collected and analyzed separately. Later time-activity budget was prepared. This study will help in further planning any developmental projects in the area.

Keywords: *Activity budget* ▪ *Cauvery Wildlife Sanctuary*▪ *Distribution* ▪ *Grizzled giant squirrel* ▪ *Home range* ▪ *Occupancy*

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- Upendra Arya

1. Introduction

Rodents are of order Rodentia and are very commonly seen all over the world. Squirrels are small-medium sized rodents and are the member of family Sciuridae. Squirrels are considered as living fossils as the share very similar morphology with the oldest known fossils of squirrels (Emry and Thorington, 1982). Indian-sub continent is home to 28 species of squirrels which includes, tree squirrel, ground squirrels, and flying squirrels (Nameer,2000).Giant squirrels are part of genus *Ratufa*. There are only four species of arboreal giant squirrels recorded so-far. Indian sub-continent has three species of arboreal giant squirrels namely; Malabar Giant squirrel (*Ratufa indica*) or Indian giant squirrel, Malayan Giant squirrel (*Ratufa bicolor*) recorded from North East India and, Grizzled Giant squirrel (*Ratufa macroura*) recorded from Western and Eastern Ghats of peninsular India and Sri Lanka (Walker, 1975; Menon, 2003). Only *R. macroura* is present in Sri Lanka this may be due to their early descend towards southern India during the period when Sri Lanka got separated from the Indian Sub-continent which then created a geographical barrier. *R. macroura* is found to be the oldest of all the squirrels in genus *Ratufa* (Ellerman1961).

1.1 Background and Literature

Grizzled Giant squirrel *R. macroura* (Pennant, 1769) is the smallest of arboreal giant squirrels. Grizzled Giant Squirrel (GGS) has three subspecies; *Ratufa m. macroura*, *Ratufa m. dandolena* and, *Ratufa m.melanochra* (Pennant, 1769; Thomas and Wroughton, 1915). These three sub-species can be easily differentiated due to significant variations in their fur colors. Only one sub-species *Ratufa macroura dandolena* (Figure 1) among known three sub-species of GGS is found in India (Ellermen, 1961). *R macroura* is commonly named grizzled giant squirrel (Figure. 1) because of its grizzly furs on the dorsal part of its body (Moore et al., 1965). This animal has a grey or brownish black colored fur cover on the dorsal part and a pale yellowish or creamy colored ventral part. There is a difference in fur color between the individuals of this species (Joshua, 1992). They have a big grayish-black fluffy tail and their forehead have some black-brownish colored patches. Toes are dark black colored resembling to gloves and they have a pinkish snout. For a matured individual the head to body length is in between 323-365 mm and tail length is between 361-423 mm whereas the weight is in the range 1.5- 2 kg (Menon, 2004; Joshua and Johnsingh 2015).

Fig. 1 Grizzled Giant Squirrel feeding on *Muntingia calabura* in Cauvery Wildlife Sanctuary.

GGS is a canopy dweller i.e. it mostly uses the canopy for movement, Foraging and nesting purposes thus the animal is found distributed in patches (Joshua, 1992). This animal bears big eyes which indicate their diurnal activity type (Joshua, 1992). GGSs are generally solitary or in pairs during the breeding season. Dreys are made by using green leaves and twigs (Vanitharani and Bharathi, 2011). In most of the case single squirrel roosts in one drey but during the breeding season both male and females are found to roost together in a single drey (Nowak, 1999).

Fig. 2 A dis-intact drey of Grizzled Giant Squirrel

Not much literature is available on their breeding habit or reproductive cycle. Novak (1991) recorded that GGS produce a litter of 1-2 offspring after a gestation period of about 28 days. Young ones are pasteurized in the drey and are kept in it for first 2-3 months (Joshua and Johnsingh, 1994). GGS has been observed with Indian Giant Squirrel in a close proximity and even interbreed is also recorded between the two species (Joshua, 1996). This animal mostly feeds on fruits, leaves, flowers, barks and sometimes on small insects (Nowak 1999; Menon, 2014). Young one's diet mainly consists of fruits (Joshua and Johnsingh, 1994). Even adults prefers to eat fruits over other feeding parts. Therefore it is considered as frugivorous and in absence of fruits, they go for young leaves (Payne, 1980). A major factor for food preference is the nutrient content which provides them an educate amount of energy (Gurnell, 1981). Besides feeding, grooming is seen very often in this animal and is considered as one of its major activities. During morning time, these squirrels are found resting on tree branches under a good canopy cover (Prater 1971). Interactions like inter-individual communication and territorial defense is a commonly seen behavior in this squirrel (Novak, 1991). These squirrels communicate with their distinct loud voice. This animal is observed giving threatening calls when they encounter the presence of a predator (Prater, 1971). Freezing behavior is very often seen in these squirrels when disturbed which lasts as long as for 30 hrs (Joshua and Johnsingh, 1994).

In India, this species is mainly found in the riparian forest types and a good forest cover with canopy contiguity. The word 'riparian forest' refers to forest type close to the water body (Naiman and Decamps 1997). CWS is known to hold the northernmost population of GGS and is named ''Betta alluva'' in vernacular by local people (Bhaskaran, 2010; Kumara & Singh 2006). As GGS is endemic to Southern India it's been earlier reported from parts of Western Ghats and Eastern Ghats; Chinnar Wildlife Sanctuary (Joshua, 1992; Ramachandran 1989) holds the second largest population (150-200 individuals) and Annamalai Reserve Forest (Kumar et al. 2002), Kerala along with Srivilliputhur Grizzled Squirrel Wildlife Sanctuary, Tamil Nadu, is known to hold the largest population (around 200 individuals, Joshua et al., 2008). Fragmented population of GGS was recorded from Theni forest division (Babu et al. 2013), Palani hills (Davidar 1989), Tamil Nadu; Hosur forest division (Baskaran et al., 2011) and its adjoining Dharmapuri forest division(Paulraj 1991; Paulraj & Kasinatthan 1993) , and Sirimalai Hills (Sathasivam et al. 2008), in Tamil Nadu. And recently the easternmost population is recorded from Gingee (Vimalraj, S. et al., 2018) in Tamil Nadu. Members of this species are also recorded from Cauvery Wildlife Sanctuary (Karthikeyan et al. 1992; Kumara & Singh 2006), in Karnataka.

According to the IUCN 2010 and 2014 data, less than 500 mature individuals of this species are remain in Indian sub-continent which is a very critical number (Joshua, 1992, Jathana *et al*., 2008).

Although GGSs has been recorded and studied for their distribution and status in Kerala and Tamil Nadu (Joshua, 1992; Babu et al. 2013; Joshua and Johnsingh 2015). However, no long-term or detailed study has been done so far for some states which include Karnataka. CWS holds the only population of GGS in Karnataka state. As habitat loss, hunting for food, poaching for their coat or fur (Gurnell, 1987) and predation by black eagle, brahminy kite and other aerial predators (Senthilkumar et al., 2007; Borges, 1989; Joshua, 1992) population of this animals are facing immence threat (Joshua et al., 2017)and therefore Red list has categorized it as Near Threatened (IUCN 2017). However, some studies show that hunting is no longer a major threat to this animal (Kumara and Singh, 2006). According to Molur et al., (2009), GGS population is declining at the rate of 30 percent in last 25 years. Due to unavailability of literature on proper distribution and status of this animal in Karnataka, making effective conservation plans is very challenging. As an effective or long-term conservation and management plan need a systematic study of distribution, abundance, home range and activity patterns of the animal.

1.2 Scope of Study

In Karnataka, including some southern districts like Kollegal, a large number of sites are proposed to harvest wind power. Further, the question raised by the forest department states that the proper distribution of the GGS is crucial while providing the permit to establish wind turbines in different sites in Karnataka. GGS is an integral part of food chain act as an agent for seed dispersal of tree species mostly confined to the riparian forests (Gurnell, 1987; Ramachandran 1993; Smythe 1989). Also, not much literature is available on the behavior of these squirrels which includes daily activity pattern and range. As resource availability and within the same niche dives an intra-species competition. Such competitions may stress this animal to confined to a very narrow range. Keeping this in the view, the study has been proposed to assess the distribution, population status and behavior of GGS for the state Karnataka. A proper management and conservation of the species can only be done after knowing the behavior and habitat factors that determine both occurrence and abundance of GGS All the dependent and independent variables expected to affect the species distribution and occurrence are recorded. Later a relationship is developed between all the dependent and independent covariates (i.e. Distance covered, Duration of walks, Basal area, Tree height, Percent forest cover, Percent canopy cover, and Tree density). Due to the limited time period for the survey, this study mainly covers almost entire riparian forest in the sanctuary.

1.3 Objectives of Study

1. Accessing the population and distribution of GGSs in the study area.

2. To estimate the parameters affecting the occurrence of the animal in the study area.

3. To estimate the vegetation type and its usage by GGSs.

4. To analyze its Activity pattern and home range.

5. Further contributing for making the conservation plans based on the study results.

Project Goal

The condition of GGS is very critical in Indian sub-continent. Population status and distribution of this animal will help the forest department and scientific community to get a proper picture of this mammal in the study area. Also, conservation plans will be more effective when including covariates responsible for the occurrence of the species. Activity pattern and home range study will help researchers to study the intro/intergroup interactions and social behavior among these animals in detail.

2. Methodology

2.1 Study Area

The entire study was conducted in Cauvery Wildlife Sanctuary (CWS) and Kanakpura forest division from June 2017 to January 2018. CWS is located in South Western Ghats between 11°56'-12°24'N & 77°9'-77°46'E is around 100km from the south Bangalore, Karnataka, India. The Sanctuary was named after the river Cauvery which drains from west to east through the sanctuary and covers a distance of 101kms. Cauvery River acts as a natural barrier and separates the Karnataka and Tamil Nadu region in the Northeastern and Eastern part of the sanctuary. It was declared as wildlife sanctuary in 1987 with a total area of 527 Sq. Kms which was later increased to 1027.52 Sq. Kms (Gubbi et al., 2016). The terrain in sanctuary varies from lowest to "Hogenakkal" with an altitude of 254 mts above MSL to the highest in "Ponnachi Beta" with an altitude of 1514 mts above MSL. The Sanctuary receives an average rainfall of 700mm to 800 mm and an average min. and max. temperature is around 15°C and 38°C respectively. CWS is divided into seven ranges namely, Halguru, Sangam, Hanur, Kowtnur, Muddur, Kaudalli, and Gopinatham. These ranges are then further divided into several beats. Dharmapuri forest division is adjoining to the eastern part of CWS. Also the South Eastern part of sanctuary is connected to MM Hills wildlife sanctuary. The forest type in this sanctuary is mainly dry deciduous. It is home for a variety of herbs, shrubs, plants and tree species. Most dominant tree species in the sanctuary are Albezia amara and Hardwikia binata. However, the predominant tree species in the riparian forest type of the sanctuary are; *Terminalia arjuna, Tamarindus indica*, *Pongamia pinnata*, and *Syzgium cumini*. CWS also supports a huge verity of faunal species which includes; Elephant *Elephas maximus*, leopard *Panthera pardus*, sambar *Cervus unicorn*, wild boar *Sus scrofa*, *spotted deer* Axis axis,*black horned antelope* Tetracerus quadricoris, monkey *Bonnet macaques*, and grizzled giant squirrel *Ratufa macroura*. Various species of reptiles and fishes are also found in the river Cauvery which flows though the sanctuary. Mahasheer fish *Tor putitora* is one of the major and important fish species found I this sanctuary. CWS supports about 100 species of birds including the endangered vulture species, eagles, kites, and small birds like; different species of king fisher, large-billed warbler, rosefinch etc. There are many tourist spots like; Anjaneya or Maruthi temple in Muthathi, Mekedatu- Sangam, and Hogenakkal falls which attracts a large number of tourists to visit. Three nature camps are constructed in the sanctuary to provide the nature education and forest safari. Due to its rich flora and fauna including some endangered species, CWS yields a huge importance.

Fig. 3 A Scenery of Cauvery Wildlife Sanctuary with the river Kaveri.

2.2 Survey design and Data collection

To design the study survey without being familiar with the forest and vegetation type of CWS seemed challenging. Therefore an initial survey of major parts of wildlife sanctuary was done between June and July 2017. Later the whole study landscape was gridded using the shape-files provided by forest department with the help software QGIS 2.18. All the grids were of same sizes. Grid size was taken to be 1X1 Sq. km as not much information was available on the home range size of the animal. A priority for selection was given for girds covering the riparian forest as R. macroura is mainly confined to the riparian forest (Joushua, 1992).

Along with the river Cauvery, the riparian forest of some of its tributaries like, Shimsha, Arkavati, and few seasonal tributaries were also considered for the study. Grid selection in the riparian forest for getting a potential site was majorly based on the initial survey and with the help of Google Earth for getting the terrain idea. An intensive survey was carried out for collecting the data from Aug'17 to Oct'17. Within each selected grids data was collected on both the banks of the river (Srinivas et al., 2008).

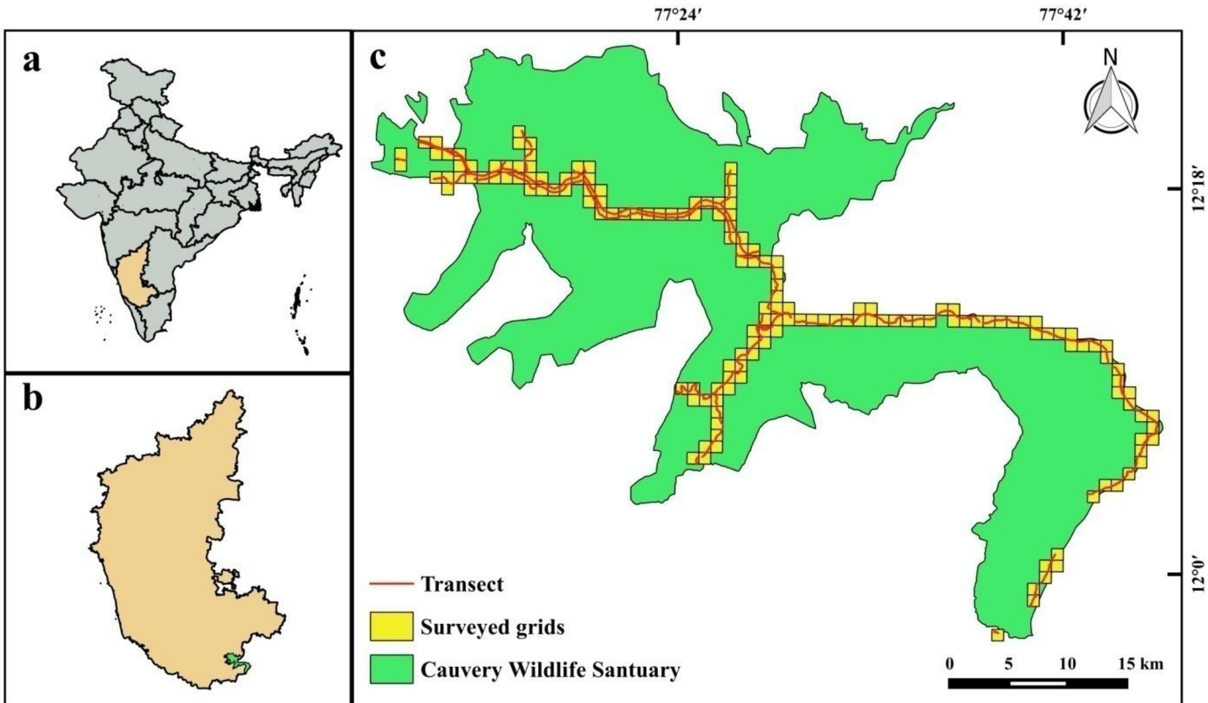

Fig.4 Map of showing (**a**) Karnataka in the Indian subcontinent (**b**)Cauvery Wildlife Sanctuary (CWS)in Karnataka state (**c**)CWS with sampled grid cells and their transects.

Detection and Distribution

We used line transect method for GGS detection along the natural trails for the survey (Pollard, 1977; Burnham, 1980; Krishna and Hiby 2001). Within the laid 1 Km^2 grids each walk of 200m was taken to be one transect/segment. However, the number of such segments varied within grids. All the tracks and waypoints were recorded for each studied grid using a handheld GPS Garmin etrex10. The occupancy survey was carried out usually in the morning from 06:00hrs to 10:00hrs when GGS are very active (Joshua, 1992; Senthilkumar, 2013; Kumara & Singh 2006). Within every segment, presence and absence of animal and its drey were recorded (Kumara and Singh 2006, Borges et al 1998). Later a detection history for animal and drey was developed using segments for all the grids. Parameters like; Tree GBH (Girth from breast height), animal/drey height, tree height o which animal/drey detected were also recorded. For canopy connectivity, all the connected trees along with their GBH and heights within a radius of 100m from the point of animal or drey detection were written down

Vegetation sampling

Vegetation sampling was done using the quadrate method. At the end of every 200m walk (segment) in the grid, vegetation sampling was done. Each quadrant was 10X10 Sq. m in size. Within each quadrant parameters like; tree species, GBH, tree height and percent canopy cover were noted down along with the coordinates of quadrants. For each quadrant only those tree species whose GBH ≥ 20cm were considered for the count. Tree species names were written in their vernacular which later used in identifying their botanical names. Percent canopy cover was measured using the densitometer. Percent forest cover was measured for each grid using the software *Google Earth*. All grids were first divided into several small-sized grids or pixel and then the percentage forest cover was measured separately. The final percent forest cover for each grid was then calculated as the sum of all the forest cover values of every pixel under that grid. A trigonometric approach was made for measuring the tree height (H). for which a protector was used for measuring the angle to the tree top and distance (L) and height (h) from the ground at which the angle was taken using a measuring tape, then the height is directly measured by putting the both the values of angle (ϴ) and distance in the formula:

$$H = \tan \Theta \, X \, L + h$$

Activity Pattern and Ranging

The behavioral part of this study was conducted from Nov.'17 to Jan.'18 within the same study area. Four habitats (significantly apart) were selected based on the animal sighting from the occupancy survey. The study was conducted from 06:00hrs to 18:00hrs for 10 days at all four habitats. That is, 40 days data with 12hrs data for each day was taken. Focal animal sampling was done for recording the data for activity pattern of R. macroura using *Nikon Aculo* 12x50° binocular. All the sighting for data collection was done by maintaining a significant distance from the animal so that it won't feel any kind of threat. Time spent on major activities like; Feeding, movement, resting, grooming, calling, urinating, defecating, drey building, and chasing were recorded. Activities like foraging, playing and freezing are recoded as movement and resting only. For ranging, waypoints of the squirrel was recorded for every 30min interval along with the tree species, tree strata (on which animal detected), animal height and weather conditions were recorded. For each habitat, only one individual of GGS was followed. That is only four individuals were followed for entire 40 days study. Roosting dreys were recorded every day so that data can be easily collected for the following day without any fail. These squirrels have variation in fur color which helped to differentiate them during the study (Joshua 1992).

2.3 Data Analysis.

Occupancy Modeling: The data collected from occupancy survey recorded as presence/absence of GGS/drey for every segment within each grid. For every presence of the GGS/drey in the segment, the value '1' is assigned, while for the absence of the same '0' was assigned in this way detection histories were constructed for both GGSs and its dreys. We used likelihood functions for estimating the probability of occurrence of species in the grid (psi) and the probability of detection (p) of species in the grid (MacKenzie et al., 2002). The occupancy analysis was done using the program *PRESENCE* version 2.12.10 (*Hines et al., 2010*). PRESENCE allows estimating the maximum likelihood for the parameters used in the model (MacKenzie et al., 2006). Thus we run multiple models using the same data set with different parameters by applying single season model in PRESENCE. A rank is given for each model run with the same data set which is based on Akaike's Information Criterion (AIC). However, AIC only chooses the best candidate model among all the models run with the same data. Also, model selection can never be combined with hypothesis testing.

For species/drey detection we have taken duration of walk (DUR) and total distance covered (KM) as sampling covariates whereas, mean basal area (BA), Mean tree density (TD), mean percent canopy cover (MPC), percent forest cover (PCF) and mean tree height (TH) were selected as site covariates for occupancy for each grid (Table 1 &2).

A logistic model was applied with the logit and binomial error. Later using this logistic model in a step-wise manner, the effect of selected covariates for the probability of detection and then occurrence was estimated. The duration of the walk (DUR) for each trail within the grid differs due to the difference in the terrain and trail lengths. However, a significant correlation was found between mean basal area, mean tree density and mean tree height but mean basal area was taken in account for occupancy over mean tree density (TD) as it was considered to be a better parameter for floral estimation. All the covariates were used to check their influence on the occurrence of species/drey by making a candidate 10 a priori models. We adopted the method used by Burnham and Anderson (1988) for selecting the models, calculating their AIC weights and average all the parameters used for modeling. All the models are arranged in a table in the ascending order according to their AIC weights. To check the influence of covariates on the occupancy of animal, an average AIC weight was calculated for each covariate across all the models (with that covariate) considered for occupancy probability (Burnham and Anderson 1998).

This approach was made because none of the models for occupancy of GGS/Drey was having an AIC weight more than or 0.5 i.e. none of the models achieved the highest support

Table I Prior hypothesis on species response for the different covariates

Covariates	ψ	p
Mean Basal Area [BA]	+	0
Mean Tree Density [TD]	+	0
Mean % Canopy Cover [MPC]	+	-
Percent Forest Cover [PFC]	+	0
Mean Tree Height [TH]	+	-
Distance Cover [KM]	+	+
Duration of walk [DU]	0	+

ψ = *Probability of occurrence*; **p =** *Species detection probability;* **0**= no effect; **+ =** positive effect**;**

- = *negative effect.*

Table II Prior hypothesis on species drey's response for the different covariates

Covariates	$\boldsymbol{\psi}$	***p***
Mean Basal Area [BA]	+	0
Mean Tree Density [TD]	+	0
Mean % Canopy Cover [MPC]	+	-
Percent Forest Cover [PFC]	+	0
Mean Tree Height [TH]	+	-
Distance Cover [KM]	+	+
Duration of walk [DU]	0	+

$\boldsymbol{\psi}$ *= Probability of occurrence*; ***p*** **=** *Species detection probability;* **0**= no effect; **+ =** positive effect**;** **-** **=** *negative effect.*

Vegetation: The table III below shows the approach made or calculating the parameters (site covariates) of vegetation. These covariates later used in running the occupancy models.

Table III Calculating the parameters or quantitative structure for each Grid cell.

Parameters	Approach for Calculation
Basal area (BA) (m^2 ha^{-1})	$BA = \frac{(GBH)^2}{4\pi}$
Mean percent canopy (MPC)	Sum of percent canopies of all the quadrants in grid / No. of quadrants in the gird.
Tree Density (TD)	No. of trees in the grid/area covered by all the sampled quadrants in the grid.
Mean tree height (TH) (m^2)	Sum of all the tree heights in grid / No. of trees in the grid.
Percent Forest Cover (PFC)	Sum of all forest cover in the cells formed in the grid.

Activity pattern:

Ranging pattern and Home range: Using the waypoints recorded for the interval of every 30 min daily path length (DPL) for the species was estimated using the software Ranges7.For calculating the home range software QGIS was used. Using the geo-coordinates collected for the animal in each habitat and provided shape files of that habitat, grids cells of size 0.25 ha was laid on the area covering the geo-coordinates. Later the home range for GGS in every habitat was calculated by adding the area of all grid cells occupied in the outer boundaries of the geo-coordinates in the habitat.

Results

Detection

During the intensive survey total number of detection for the GGS are 27. Whereas the total number of individuals of GGS detected was 43 and no. dreys detected was 255 (Figure 5 and 6). Out of 255 dreys, a total of 115 old, 130 new, and 10 dis-intact nests were found during the survey period. In present study *Tamarindus indica, Pongamia pinnata, Mangifera indica and Terminalia arjuna* are the most dominant trees for drey building by GGS. Calling helped in detecting the animal in the field study. Such callings (range or threatening calls) may last up to 15-16 minutes as per records from this study. Male-male fighting for their territory is also observed for habitat 4.

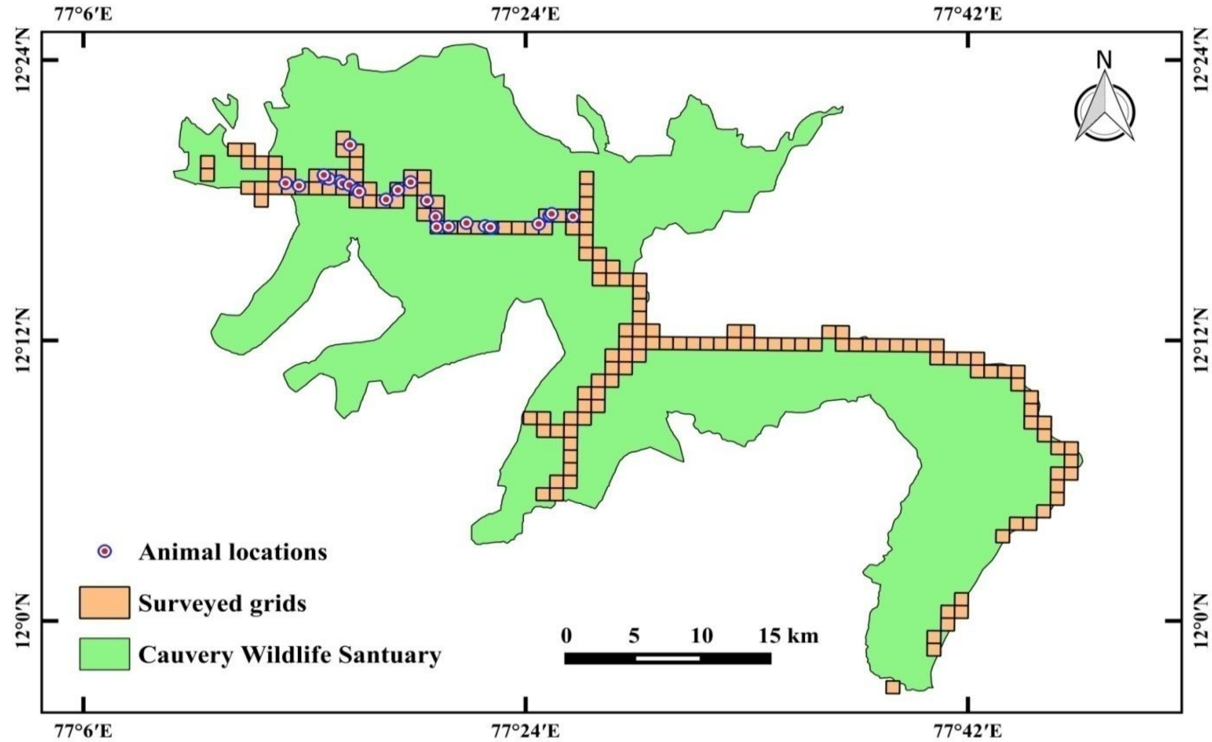

Fig.5 Image showing the direct animal detection locations during the survey in study

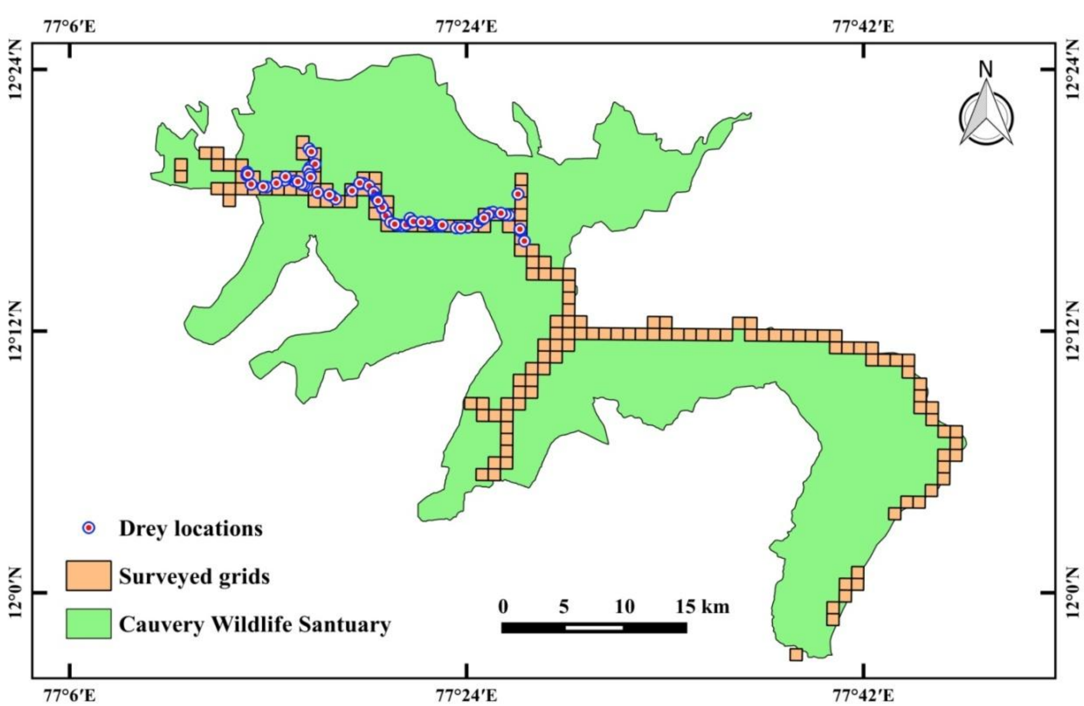

Fig. 6 Image representing GGS's dreys detection points during the survey in study

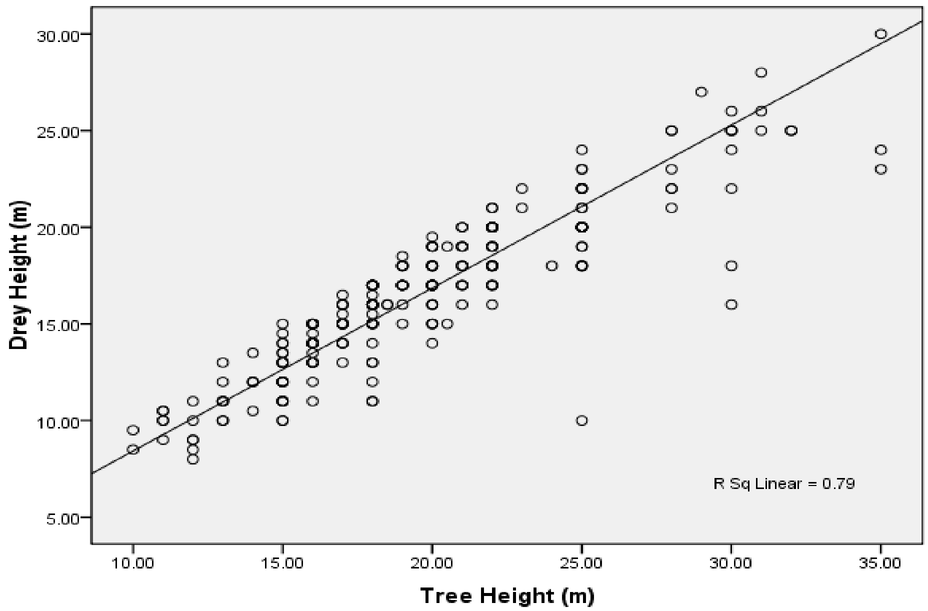

Fig.7 Plot for tree heights vs. drey heights

The plot (figure 7) shows a linear relationship (r^2=0.79) between the drey height and the tree height.

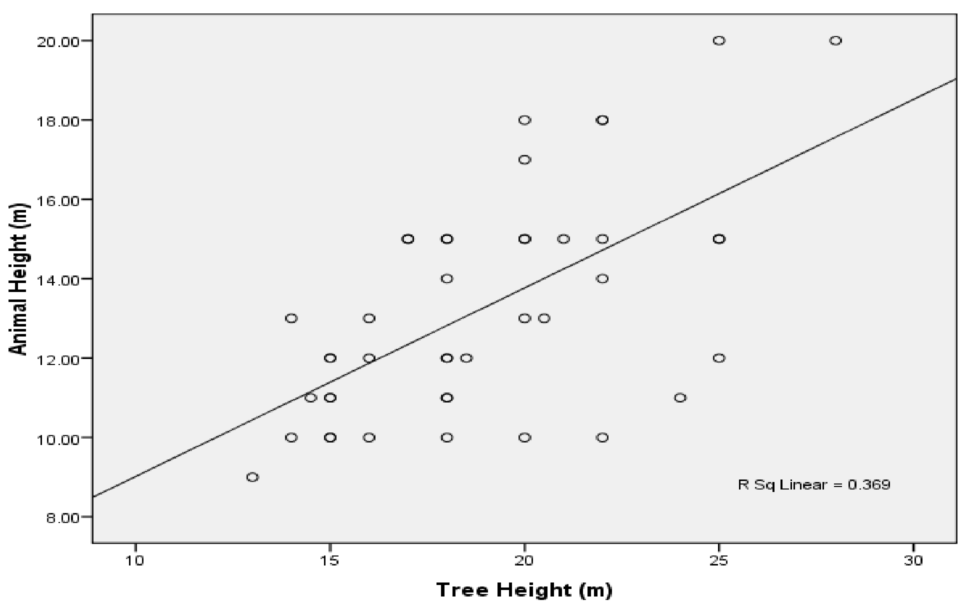

Fig. 8 Plot showing the relation between tree heights and heights of animal when detected.

The above plot (figure 8) for animal height at detection time and the tree height shows that there is a linear relationship exist between the two (r^2=0.37).

Occupancy modeling

(A) *GGS***:** The average detection probability ($\hat{p}$) was estimated and found to be 0.10 ± SE 0.03 i.e. the chance to detect the species in the area (grid) occupied by it is approximately 10 percent. It is found that none of the covariate; duration of the walk (DUR), trail length (KM), and mean percent canopy over (MPC) have any effect on the detection probability (*p*) as their AIC weight is 0 (Table IV). Therefore we ran our models after excluding DUR, KM, and MPC as a function of detection probability (*p*).

Table IV Direct Detection Probability of GGS

Model	$\hat{p}$	$\hat{SE}$	AIC	ΔAIC	w_i	K
ψ (.), p(.)	0.10	0.03	222.95	0.00	1.00	2
ψ (.), p(KM)	0.29	0.03	237.37	14.42	0.00	2
ψ (.), p(DUR)	0.30	0.03	239.44	16.49	0.00	2
ψ (.), p(MPC)	0.50	0.03	273.24	50.29	0.00	2

Where, $\hat{p}$*= species detection probability*; $\hat{SE}$ = associated standard error; AIC = *Akaike's Information Criterion*; Δ AIC = *difference in AIC values between each model and the model with the lowest AIC* ; w_i = *AIC model weight*; K = *number of parameters*; KM = *trail length*; DUR = *duration of the walk*, MPC= *Mean percent canopy cover*.

Out of all the models ran for estimating occupancy none of the model is found to be the best of all (Table V). Therefore we estimated the overall occupancy ($\hat{\psi}$) by averaging the psi values across all the models. The average value estimated for occupancy was found to be 0.42 ± SE 0.11. All the sampled grids were then plotted with the occupancy estimated from the model having the lowest AIC value (figure 9). From the five covariates, only three (BA, MCP, and PFC) were considered for the modeling and all these three parameters are found to have some influence on the occupancy (Table VI). However, basal area (BA) is found as most positively influencing covariate for the occupancy. From the beta value it is concluded that basal area and mean percent canopy cover have a positive influence on occupancy. However percent forest cover is influencing the occupancy negatively.

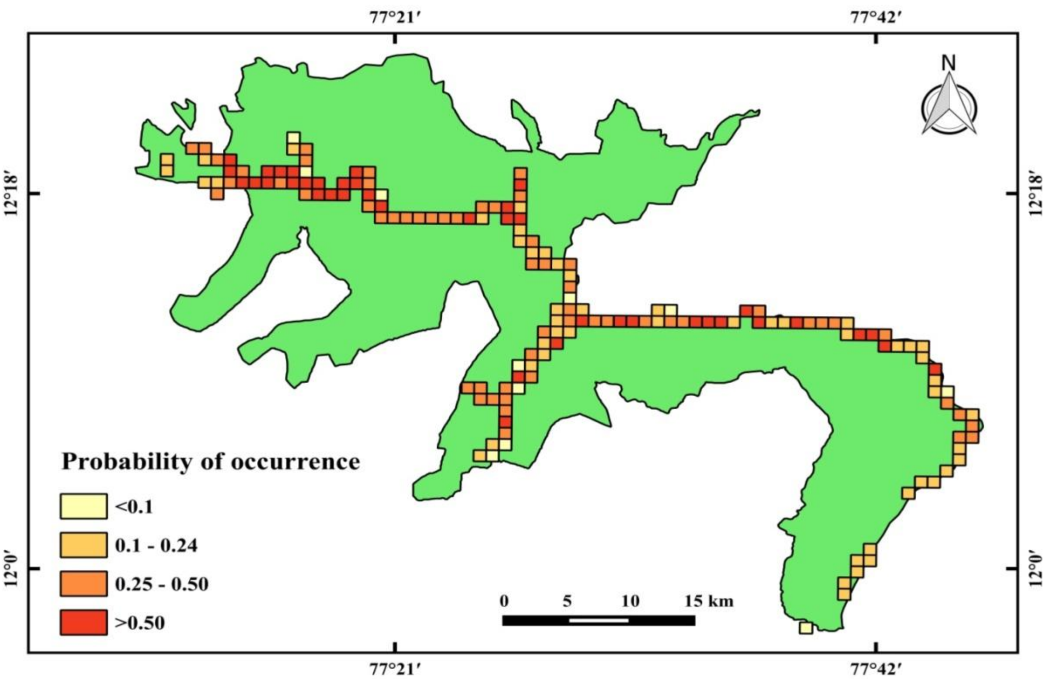

Fig. 9 Image showing the occupancy (ψ) for GGSs in the study area.

Table V Model for Occupancy of Grizzled Giant squirrel

Model	$\hat{\psi}$	SÊ	AIC	ΔAIC	w_i	K
ψ (BA+MPC),*p*(.)	0.43	0.12	214.04	0	0.30	3
ψ (BA+PFC),*p*(.)	0.42	0.10	214.08	0.04	0.30	3
ψ (MPC),*p*(.)	0.50	0.07	215.43	1.39	0.15	2
ψ (BA+MPC+PFC),*p*(.)	0.43	0.14	215.48	1.44	0.15	4
ψ (MPC+PFC),p(.)	0.50	0.10	216.35	2.31	0.10	3
ψ (.),*p*(.)	0.10	0.03	222.95	8.91	0.00	2

Where, $\hat{\psi}$ = *species occupancy probability*; SÊ = *associated standard error*; AIC = *Akaike's Information criterion*; ΔAIC = *difference in AIC values between each model and the model with the lowest AIC* ; w_i = *AIC model weight*; K = *number of parameters*; BA= *mean basal area*; MPC= *mean percent canopy cover*; PFC= *percent forest cover*.

Table VI Covariates affecting the GGS occupancy are arranged in descending order of summed AIC weights.

Covariates	Summed AIC weights	β	SE associated with β
Mean Basal Area [BA]	0.75	2.79	1.38
Mean percent Canopy Cover [MPC]	0.70	1.22	.82
Percent Forest Cover [PFC]	0.54	-0.39	0.51

(B) *Drey*: Estimation for average detection probability ($\hat{p}$) was 0.25± SE 0.03, indicating that there is approximately 25% chance to detect the dreys in study area when they are present(Table VII). Here out of all four selected covariant none of them found to

Table VII Direct Detection Probability of Drey

Model	$\hat{p}$	$S\hat{E}$	AIC	ΔAIC	w_i	K
ψ (.), p(.)	0.25	0.03	424.95	0.00	0.99	2
ψ (.), p(DUR)	0.37	0.03	436.38	11.43	0.00	2
ψ (.), p(MPC)	0.32	0.03	436.38	11.43	0.00	2
ψ (.), p(KM)	0.37	0.02	436.56	11.61	0.00	2

Where, $\hat{p}$= *species detection probability*; $S\hat{E}$ = associated standard error; AIC = *Akaike's Information Criterion*; Δ AIC = *difference in AIC values between each model and the model with the lowest AIC* ; w_i = *AIC model weight*; K = *number of parameters*; KM = *trail length*; DUR = *duration of the walk*, MPC= *Mean percent canopy cover.*

affect the nest detection probability (DUR, KM, & MPC).Subsequently, all the models were run without duration of the walk (w_i=0.00), trail length(w_i=0.00), and mean percent canopy cover(w_i=0.00) as a function of *p*.

Average occupancy probability ($\hat{\psi}$) was calculated by taking the value of best model (Table VIII) and thus estimated average occupancy was 0.39± SE 0.07.

Table VIII Model for Occupancy of Drey

Model	$\hat{\psi}$	$S\hat{E}$	AIC	ΔAIC	w_i	K
ψ (BA+PFC),*p*(.)	0.39	0.07	415.24	0.00	0.69	3
ψ (BA+MPC+PFC),*p*(.)	0.39	0.08	417.13	1.89	0.27	4
ψ (MPC+PFC),*p*(.)	0.41	0.08	422.40	7.16	0.02	3
ψ (BA+MPC),*p*(.)	0.45	0.08	423.42	8.18	0.01	3
ψ (PFC),*p*(.)	0.38	0.05	424.24	9.00	0.01	2
ψ (.),*p*(.)	0.25	0.03	424.95	9.71	0.01	2

Where, $\hat{\psi}$ = *species occupancy probability*; $S\hat{E}$ = *associated standard error*; AIC = *Akaike's Information criterion*; Δ AIC = *difference in AIC values between each model and the model with the lowest AIC* ; w_i = AIC *model weight*; K = *number of parameters in model*; BA= *mean basal area*; MPC= *mean percent canopy cover*; PFC= *percent forest cover*.

Again plotting was done for all the grids sampled during the survey for drey using the model with lowest AIC value (Figure 10). All the four covariates selected are found to affect the occupancy probability for dreys where the basal area (BA) is seen to affect most. Basal area and mean percent canopy cover are affecting the psi positively whereas percent forest cover is affecting negatively (Table IX). However, the basal area was found to affect the drey occupancy most positively and percent forest cover as the most negative.

Table IX Covariates affecting the drey occupancy are arranged in descending order of summed AIC weights.

Covariates	Summed AIC weights	β Coefficients	SE associated with β
Percent Forest Cover [PFC]	0.98	-0.03	0.01
Mean Basal Area [BA]	0.97	0.02	0.01
Mean % Canopy Cover [MPC]	0.30	0.00	0.01

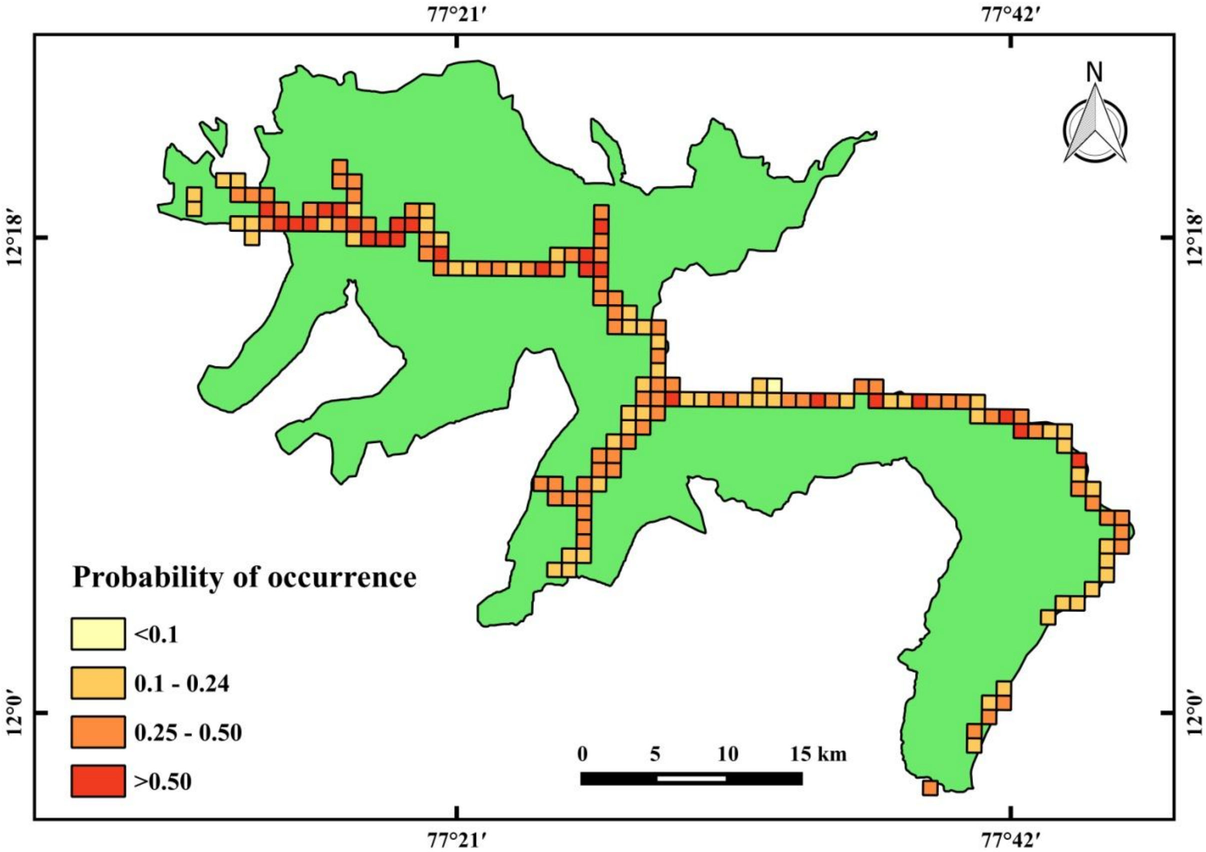

Fig.10 Image showing the occupancy (ψ) for GGS's dreys in the study area.

Home Range

The home range for each GGS in each habitat was calculated and listed in the following table no. X. and fig.11.

Table X Home range size for individual GGS in four different habitats

Habitat	Habitat type	Male/Female	Home Range
a/1	Forest	Female	3.25 ha
b/2	Forest	Male	2.5 ha
c/3	Nature Adventure Camps	Female	2.75 ha
d/4	Nature Adventure Camps	Male	2.25 ha

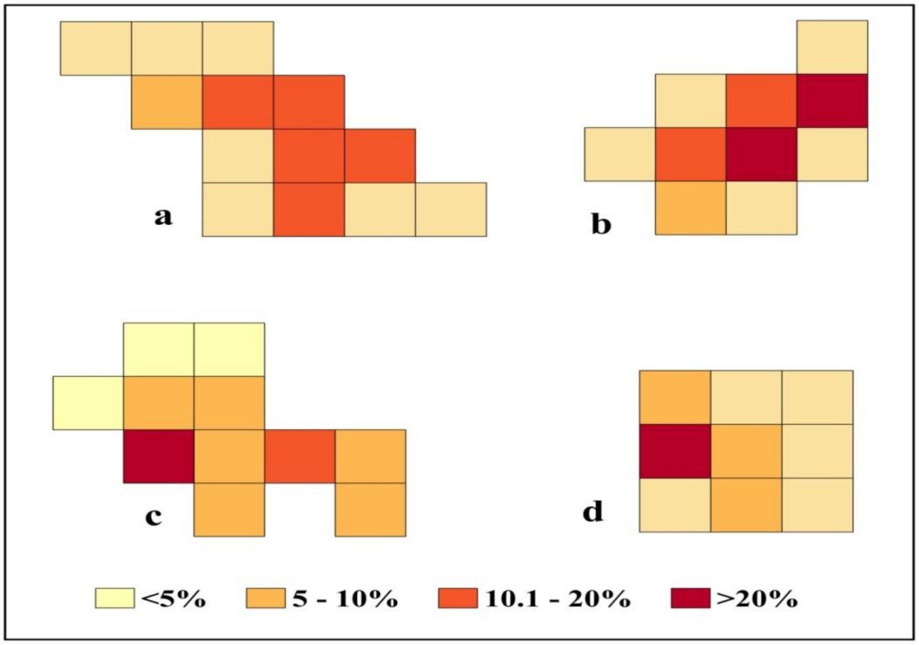

Fig. 11 Image representing the home range size (**a-Female** & **b-Male**) for forest habitat (**c –Female** & **d-Male**) for adventure camps in the study site. Area occupied by each cell is

Activity Budget for GGS

The activity pattern that is calculated as percent time spent on different activities; feeding, resting, movement, grooming, and roosting inside nest between animals at different habitats is not different (Friedman test; χ^2 = 2.52, d.f. = 3, p= 0.472 or p >0.05).

In the activity budget plot of GGS in habitat 1, the peak time for feeding is achieved in the morning and in the evening. This represents a bimodal feeding pattern. Whereas resting peak is likely found in the noon (~ 1100-1300 hrs). Movement is generally constant throughout the day.

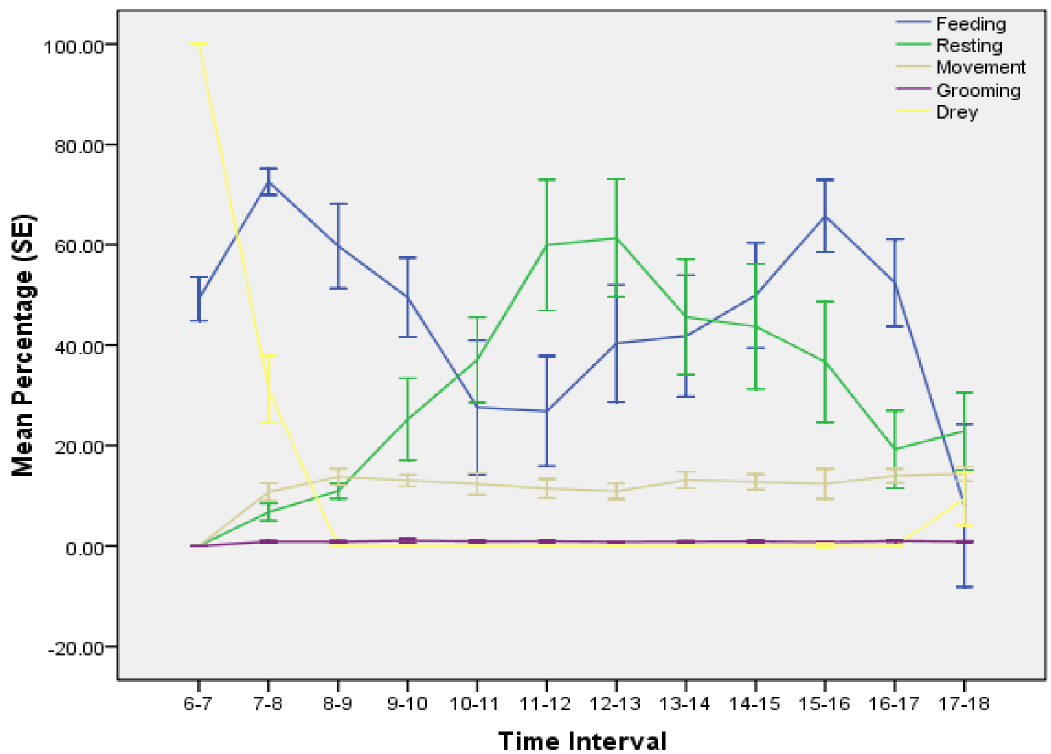

Fig. 12 Time activity budget for GGS in Habitat 1(Forest).

For the habitat 2, the animal is seen to start the feeding at noon. Resting (~80%) have a peak value in the morning (0900-1000 hrs). Movement is found increasing slowly throughout the day.

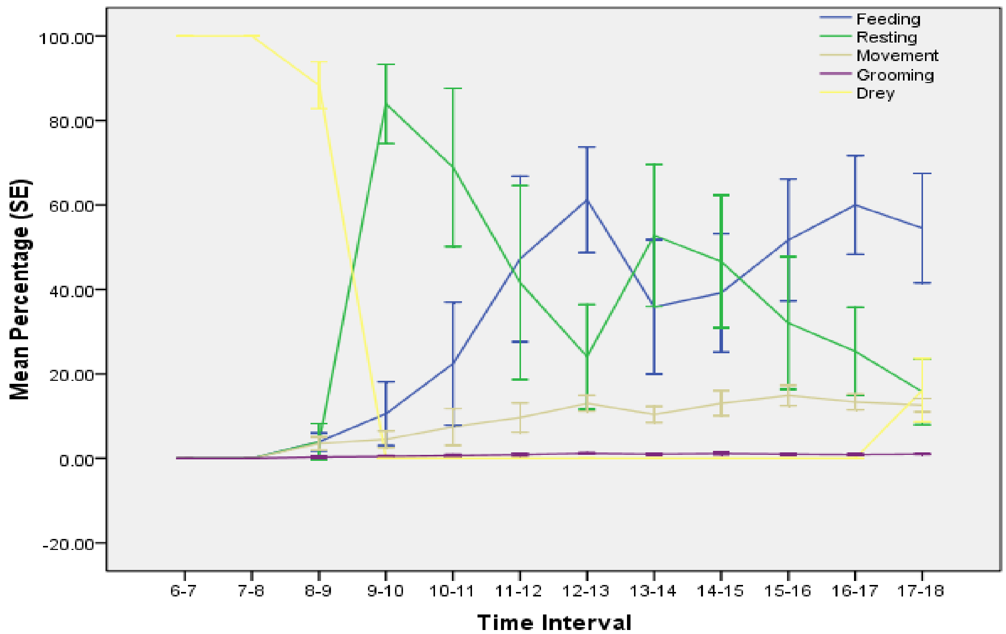

Fig. 13 Time activity budget for GGS in Habitat 2 (Forest).

In habitat 3, the feeding activity is found to be at a large interval from morning to noon. Also, it is active for feeding in the evening time too. Here the movement of the animal is quite constant.

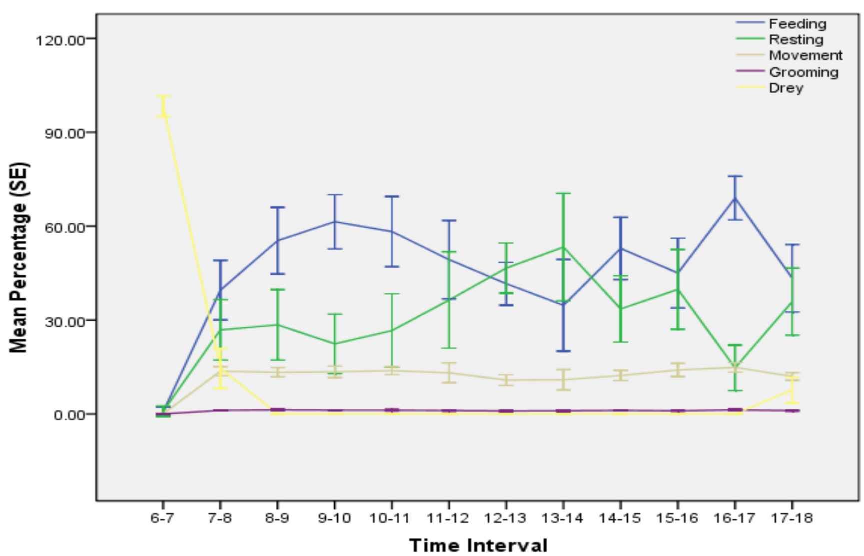

Fig. 14 Time activity budget for GGS in Habitat 3 (Nature adventure camps).

For the habitat 4, a bimodal curve is seen for the feeding activity (~80% in 800-900 hrs and ~70% in 1500-1700 hrs).This shows that the animal is very active in early morning hours and the evening. Here, unlike the animals in other habitats, roosting in drey is observed in the noon to evening. Resting outside the nest is generally seen very less and the movement is also seemed to have a bimodal curve.

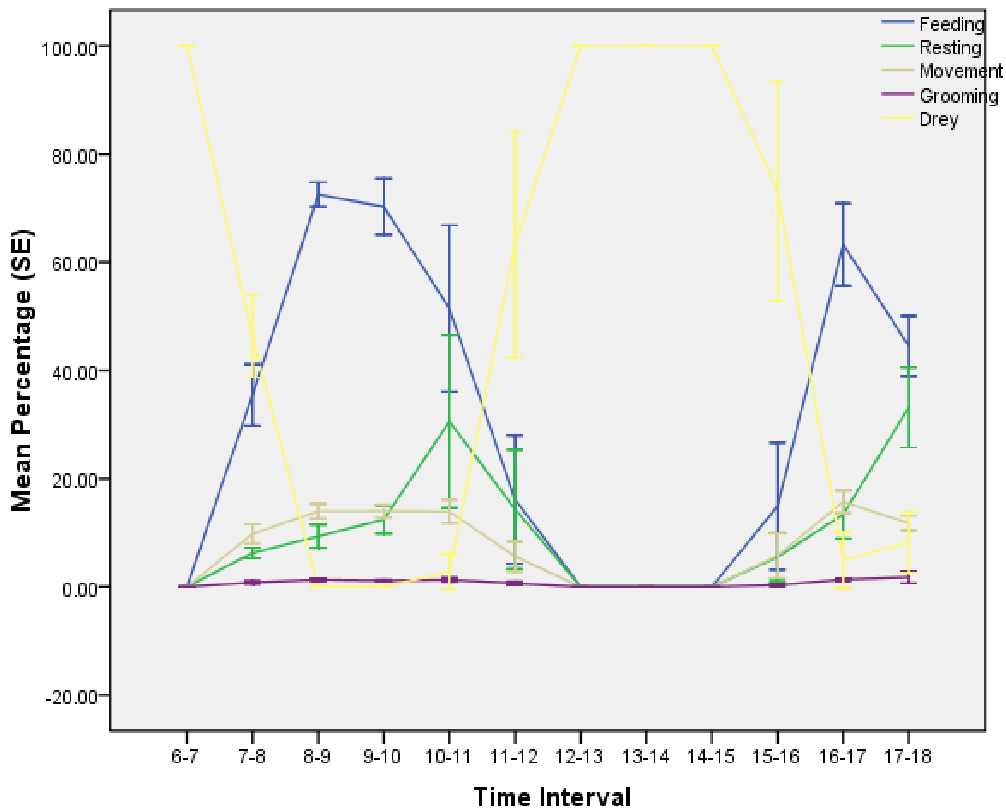

Fig. 15 Time activity budget for GGS in Habitat 4 (Nature adventure

Feeding Ecology

From the current study GGS was observed to feed on 25 plant species including major trees and shrubs (Table X).

Table XI Relative frequency of occurrence (%) of plant species consumed by GGS in different habitats.

Tree Species	Relative Frequency of occurrence (%)			
	Animal 1 (Habitat 1)	Animal 2 (Habitat 2)	Animal 3 (Habitat 3)	Animal 4 (Habitat 4)
Alangium salviifolium	0.00	15.87	0.00	0.00
Albezia amara	5.98	15.87	19.23	12.05
Albezia lebbeck	2.56	0.00	19.23	0.00
Boondkalimara	0.00	0.00	3.85	0.00
Cassine glauca	3.42	1.59	0.00	4.82
Citrus limon	0.00	0.00	15.38	6.02
Citrus medica	8.55	0.00	0.00	0.00
Delonix regia	0.00	0.00	0.00	2.41
Diospyros embryopteris	8.55	0.00	0.00	0.00
Emblica officinalis	0.00	0.00	0.00	4.82
Feronia elephantum	8.55	3.17	0.00	0.00
Grrocarpus americanus	0.00	0.00	3.85	0.00
Mangifera indica	4.27	0.00	0.00	0.00
Glycosmis mauritiana	0.00	15.87	0.00	0.00
Muntingia calabura	8.55	3.17	0.00	12.05
Pongamia pinnata	4.27	15.87	0.00	7.23
Sapindus emerginatus	1.71	1.59	0.00	12.05
Spondias pinnata	7.69	9.52	0.00	0.00
Tamarindus indica	8.55	0.00	19.23	12.05
Terminalia arjuna	6.84	0.00	0.00	6.02
Unknown 1	0.85	0.00	19.23	1.20
Vitex altissima	2.56	0.00	0.00	0.00
Unknown 2	8.55	0.00	0.00	0.00
Unknown 3	0.00	1.59	0.00	7.23
Ziziphus oenoplia	8.55	15.15	0.00	12.05

Fig. 16 Image showing some of the plant species parts consumed by GGS during the study.(1) *Tamarindus indica* fruit without seed, (2) *Tamarindus indica* leaves (3) *Sapindus emerginatus* leaves, (4) *Ziziphus oenoplia* fruit, (5) unidentified plant fruit (uluchimara), (6) *Feronia elephantum* fruit.

Plant species like; *Albezia amara, Muntingia calabura, Pongamia pinnata, Terminalia arjuna, Tamarindus indica* and *Ziziphus oenoplia,* was found to be mostly used for the feeding purpose.

Discussion

In the present study, I have examined the population and distribution of GGS in CWS. Site covariates such as; Basal area, percent forest cover, mean canopy cover were taken as the ecological determinants for the habitual selection. Behavior study on ranging pattern and activity pattern was also carried out.

GGS has a patchy distribution in the riparian forest where it is found. It mainly uses canopies for the movement and occasionally comes to the ground. A linear relationship was found between the dreys height and trees height. Based on these results (figure 7) it is found that this animal prefers to live in the upper canopy. A similar linear relationship is deducing from figure 8 between the height of animal at the time of detection and tree height on which animal was detected. This again provides an idea that these squirrels avoid the lower canopy area. The reason could be to avoid the disturbance from ground animals such as; cats and snakes.

According to the occupancy models, the approximate detection chance for animal and nest are 10% and 25%. The direct detection probability and occupancy for animal and drey ($\hat{p}_{animal}$=0.10, $\hat{\psi}_{animal}$=0.42; $\hat{p}_{drey}$=0.25, $\hat{\psi}_{drey}$=0.37) are very low which indicates the rarity of the animal in the study area. Basal area (BD) has the most positive influence on the occupancy of the animal. In the present study a single individuals GGS was found to use more than one drey in the same season. Also, many new dreys were observed during the behavior study from Nov'17- Jan'18 which is known as their breeding season from the previous studies conducted by Joshua, 1992.   As the correlation is found between basal area and tree height which indicates that this animal prefers the plants having more basal area because such plants are generally old found to have a larger height. Percent forest cover was found to influence the animal and drey occupancy negatively, which indicates that the animal prefers a less percent forest cover area or a narrow zone for its habitat and here riparian forest is one of these kinds. Therefore this species is largely confined to the riparian forest. Tourist places such as, Muthathi temple doesn't hold a good population of GGSs. Although the reserve forest area of the CWS have a good number of individuals of this species. This suggests that tourist visits should be limited and people must be notified about the rarity of this animal and its status.

There is no difference in the percent time spent on activities by animals in all four habitats. The male GGS in habitat 4 is seen to roost inside the nest even in the morning time. This behavior was not seen in other three animals during the study period. A similar behavior is observed in Indian giant squirrels R. indica which was found to be a strategy to avoid the predation (Datta, 1999). This indicates a possible reason for the drey usage in morning also. Also, this particular individual was old but its age was not known to claim whether its due to the old age. A Bimodal feeding pattern is also observed for all four GGS individuals studied which follows the same pattern with the studies conducted by, Joshua and Johnsingh (1994), Joshua (1992), and Senthilkumar et al., (2007). In most of the individuals feeding was the highest activity observed which is followed resting and then movement. Although there are some other behaviors such as; playing and freezing which was difficult to differentiate for the small creature were taken in movement and resting only. Grooming is seen throughout the day when the animal is active. Auto-grooming is very common in this animal but a case was seen were allo-grooming was also observed in between a female and young one where a female GGS groomed its young one. GGS is mainly a canopy dweller but in the present study its individuals was seen to use the ground as well for the movement purpose. Bonnet macaque was seen to live in a very close proximity with the GGS. This sometimes makes threats to this small animal. Bonnet macaque was also seen to destroy the drey and food resources used by the GGS. However, no fight was observed between Bonnet macaques and GGSs. From table X, it is seen that in both the habitats (forest/ nature camps) females are having a larger home range than male. This could be due to the breeding season when a female needs a good diet and therefore good resource availability is needed. And thus having a bigger home range will have a positive impact on getting more feeding resources.

The home range size found in the present study is way more than the previous studies done by Joshua (1992). Here in my study the home range is coming out as; 3.25 ha (Habitat 1), 2.5 ha (Habitat 2), 2.75 ha (Habitat 3) and 2.25 (Habitat 4). Whereas in Joshua (1992) estimated the mean annual home range as 0.82 ha +SE 0.14 which is less than one-third of the current study and is very small. Joshua (1992) calculated the home range using the MCP method. In his study the DPL was more than the present study for an individual. But this contradicts with the home range size. As in general a larger DPL indicates bigger home range, which is not the case seen here. Also a smaller home range indicates a good resource availability or more a larger territorial competition. This suggests that the home range calculated by Joshua (1992) is not significant when compared to the present study or the resource availability in the present study area was not that good as that was in Joshua (1992)study area. Table XI shows that certain tree species like, *Albezia amara, Muntingia calabura, Pongamia pinnata, Terminalia arjuna, Tamarindus indica* and *Ziziphus oenoplia* are the major diet of GGSs. Frits of *Muntingia calabura and Ziziphus oenoplia* were the most consumed resource for feeding. During the present study Tamarindus *indica* was most used plant species for drey building as well as for the feeding and resting purposes. Therefore such important plant species should be planted or taken care in the riparian forest of the sanctuary to conserve this animal species. Also, distribution and activity budget information of GGS in the present study will encourage organizations for its effective conservation plans for the study area. As a very small population of this species was found with a patchy distribution, a special care should be taken for this species to maintain the food chain. Forest department should start focusing on the resources required by the species and to maintain those throughout the sanctuary.

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