Feeding ecology of a lesser-known arboreal giant; Grizzled Giant Squirrel (*Ratufa macroura*), Southern Western Ghats, India.

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Abstract

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Keywords: Sciuridae-Rodentia, foraging behaviour, habitat use, riparian forest, conservation

1. INTRODUCTION

The ecological role of an animal in an ecosystem can be revealed by understanding its diet and feeding behaviour (Bookhout, 1994; Dell'Agnello et al., 2019). The feeding behaviour might be specific to the place where an animal lives. It influences all the decisions of the animal about food resources available along with predator avoidance strategies (Pyke, 1984; Sih, 1980). Feeding has a considerable impact on animal fitness through its effect on animal growth, survival, activity patterns and reproductive ability (Foley & Cork, 1992; D. Raubenheimer & Simpson, 1997; David Raubenheimer et al., 2015), thus it is an important aspect of animal conservation. The availability of food in an area is vital in supporting a minimum viable population for the animal to thrive (Palmer & Koprowski, 2014). The variation in food availability by the seasonal fluctuation can challenge the animal to meet its requirements. Seasonal shift or facultative adjustment in food material preference gives an animal large dietary breadth and flexibility to cope with situations of resource scarcity (Dunn et al., 2010; Masi et al., 2015).

Herbivorous mammals may impact the plant resources near its foraging sites either negatively or positively and can affect the composition and structure of plant communities (Olff & Ritchie, 1998; Palmer & Koprowski, 2014). Small mammalian herbivores, such as rodents, modify their environment by consuming plant biomass and redistributing materials across the landscape (Moorhead et al., 2017). In particular, small mammals can stimulate soil nutrient cycling through the faecal deposition (Bakker et al., 2004). Tree squirrels (order Rodentia) are cosmopolitan in distribution on almost every continent except Australia and Antarctica (Koprowski & Rajamani, 2008; Thorington Jr et al., 2012) and play key ecosystem services, including seed dispersal and pollination (Miyaki, 1987; Steele et al., 2005; Zong et al., 2010). The giant squirrels are tree squirrels and the largest in the world, and they belong to the genus *Ratufa* (Thorington & Cifelli, 1989).

The Grizzled Giant Squirrel (hereafter GGS) belongs to the genus*Ratufa* , has three distinct subspecies and India harbour only one,*Ratufa macroura dandolena* and it is one among the other three species of the giant squirrels in India (Ellerman, 1961; Johnsingh & Nameer, 2015; Menon, 2014). This Near Threatened squirrel is primarily diurnal, but their increased activity has been observed during the early and late hours of the day (Paulraj, 1991). The GGS shows one of the most important examples of isolated populations, and the habitat of the animal is extremely unique and is confined primarily to a narrow stretch of riparian vegetation along the Pambar and Chinnar rivers and their major tributaries in the Chinnar Wildlife Sanctuary (Ramachandran, 1993), in the southern Western Ghats. In India, Chinnar Wildlife Sanctuary in Kerala supports the second-big population of GGS. To protect and improve the conservation measures directed to an animal, especially a habitat specialist like the GGS, a proper understanding of the habitat requirement is vital (Mills, 1992). We focused on the foraging ecology of the GGS, to understand the seasonal variation in food preference, food composition and feeding technique. The diet and feeding behaviour of the GGS is not well known so far thus, it would help in making specific management prescriptions for protecting the Near-Threatened GGS in one of its prime refugia in India.

2. METHODS

2.1 The study area

The study area, Chinnar Wildlife Sanctuary, is located between 10°15'- 10°21'N latitude and 77°16'- 77°5' E longitudes in the Idukki district of Kerala state (Figure 1) and has a total extent of 90.44 km^2. The significant variation in altitude and rainfall leads to a wide array of habitat types like deciduous forests, dry thorny scrub, riparian forests, shola forests and grasslands that are interspersed with plains, hillocks, rocks and cliffs, which provide microhabitats for varied forms of life (Management Plan of Chinnar Wildlife Sanctuary., 2012).

2.2 Observation methods

The information on the composition and seasonal variation in the GGS diet was collected through foraging observations. Focal Animal Sampling was used following (Altmann, 1974). Each encountered individual was followed, and observation on the time spent on feeding, plant species eaten, plant part eaten, pick up rates of plant parts such as fruit, leaves and flowers were also recorded. The activities occur in bouts that are periods of, for example, feeding activity within a food source or movement between two sources. During the period spent in the food source, some of the time was allotted to searching for a food item, selecting by smelling, remaining inactive or other grooming activities. The length of the bout was judged as the period between entry into and exit from the source. The incidence of feeding on different food items across different seasons was categorised. This was done for the three different seasons summer (December to May), southwest monsoon (June to September) and northeast monsoon (October to November).

Observations were made for 10 months between April 2013 to May 2014, and within a month, at least one week was spent in the field. Five transects were selected after reconnaissance, and observations were made for each transect both in the forenoon and afternoon for an equal duration. Squirrels were observed using 8x40 Olympus standard binoculars (Olympus Global, Tokyo, Japan). Different feeding postures and feeding techniques used by the GGS were interpreted by direct observation during the sampling.

2.3 Data analysis

To understand the food composition of GGS, collected data were analysed by three complementary approaches. The percentage contribution of different food items to the squirrel diet was analysed based on the duration of feeding on a particular item and the number of times of feeding incidence on a particular item. The non-parametric test, "Mann Whitney U" was performed to determine whether there was any significant difference in the feeding bout and duration between the forenoon and afternoon hours. $?^2$ test for association was used to find out the seasonal variation on the preferred tree species and the plant parts fed by the GGS across different seasons. A constrained analysis, species as response variable against the environmental variables (Residualized predictors were permuted), canonical correspondence analysis (CCA) was performed to check the food choice and season using Canoco 5 (Braak & Smilauer, 2012; Jiangshan et al., 2014).

3. RESULTS

Food composition

The GGS found to be feeding on different plant parts including the leaves, seeds, flowers and sap of different trees and other vegetation (Table 1).

A total of 1314 minutes (in 10 months) in 42 encounters of feeding observation were taken during the study. A total of 30 different species of plants *per se* , which included 22 tree species, four climbers, one liana,

one paraphyte, one shrub and one cactus species, formed the diet. The maximum duration of feeding was observed on *Bauhinia racemosa* (19.79%), followed by *Tamarindus indica* (14.08%),*Nothopegia beddomei* (9.89%), *Strychnos potatorum* (7.23%) and *Terminalia arjuna* (6.47%; Table 1).

The feeding varied by the food availability in various months. The GGS fed on *Terminalia arjuna* (January, April and September) and*Tamarindus indica* (May, November and December) in three different months, followed by *Bauhinia racemose* (February and March), *Ficus macrocarpa* (February and November) and *Syzygium cumini*(August, May) in two different months. However, the other species were found fed only once during the study period. The climbers that formed part of the diet were *Derris brevipes, Diplocyclos palmatus* and*Cayratia trifolia* . The GGS also used shrubs like *Hibiscus rosa-chinensis* , cacti - *Euphorbia trigona,* and liana -*Entada rheedii* for feeding. These species come under 18 different families. Among them, the most preferred family was Fabaceae, with eight species found to be part of the GGS diet. This was followed by Moraceae, four species, and Anacardiaceae, two species.

3.2 Contribution of different vegetation parts

The total feeding incidence across the whole study period was found to be 62. Out of it, 30 incidences were on leaf feeding (48.39%), followed by seed feeding (27.32%), flower feeding (16.13 %), and sap-feeding (8.06 %) (Figure 2. A). The duration of feeding on different items is on seeds (52.12 %), followed by leaves (32.55 %), flowers (10.58 %) and sap (4.76 %) (Figure 2. B).

3.3 Diurnal variation in feeding habit

The feeding recorded for the whole study period was 1314 minutes, including 915 feeding bouts. 42% of the total feeding duration was contributed by forenoon observation and the rest 58% by afternoon observation, sampling hours are equal for both times of the day. when the feeding bout took into consideration forenoon hours, 321 bouts, while the afternoon had around twice the value, 594 bouts. However, the GGS was found to be inactive in a food source for some time before commencing the feeding or after feeding, before going elsewhere in search of a new source or for other activities. In some cases, the GGS was found to be inactive or resting at a food source between periods of intensive feeding. The GGS were not significantly different in the duration of feeding between the forenoon and afternoon (U = 189.5 p =0.319) as well as in the feeding bout (U = 205.50 p =0.542).

3.4 Seasonal variation in diet

The feeding incidence on all food items was maximum in the summer, followed by the North-East and South-West monsoon. Univariate analysis was done in the absence of a correlation between different variables under consideration; there was no effect of season and time of the day on the duration of feeding and the feeding bouts. To check if the animal prefers food items with respect to different seasons,**?** ^{2} test for association was performed. However, no significant association (**?** ^{2}= 6.32, p= 0.70), could be observed.

The canonical correspondence analysis (CCA) (Figure 3) to check the association of species and season is also done for selected species based on maximum incidences and duration of feeding and found no significant association. The food species choice of the GGS was found not affected by the seasons, but it is based on the availability of various food resources across different seasons.

Feeding technique

The GGS were found to be highly selective in picking the food items. The selection of food items appears to be done by the smell of the items (Figure 4A). The GGS was found to be handling its food with both mouth and forelimbs (Figure 4B). The GGS goes to the tip of the branch or other areas of the crown of the tree according to the availability of food sources and cuts the pod, fruit, leaves or flower with its mouth (Figure

4C). Occasionally the food item was brought to the mouth with the help of the forelimbs. Holding the fruit in the mouth, the squirrel then moves to the thick horizontal branch to sit firmly, sometimes the feeding started at the place of harvest itself. The squirrel holds the branch with the help of the claws of the hind limbs and the tail hanging down, which gives further balance to the body (Figure 4D). It then gnaws the epicarp of the fruit to extract the seed to be consumed. During feeding, the forelimbs were used effectively to manipulate food items, whether long pods of *Bauhinia racemosa* or small fruit of

Grewia tiliifolia.

3.6 Feeding posture

Mainly three postures were observed during the present study. The most common feeding posture is the squirrel perching itself on a horizontal branch of the tree and feeding, second posture is that of the animal hanging upside down from small branches, supporting with the hind limbs and the tail, and reaching down to the food in the hanging posture. The third feeding posture had the squirrel on the bole of the tree and feeding upside down.

During most of the instances of observations on feeding posture, the squirrels were found feeding by sitting on the branch, holding the branch with hind limbs and the tail hanging down. The hanging tail helps the animal in balancing the body. This kind of posture was observed during the feeding incidence of *Bauhinia racemosa* and*Grewia tiliifolia* (Figure 5A). The second body posture consisted of GGS feeding while hanging upside down on the tree branch with the help of claws of hind limbs, while the tail was kept curled over the branch. This posture was observed mainly in instances of feeding clustered fruits and flowers on small branches which cannot support the body weight of the squirrel. Sometimes this posture was used only for harvest. This was observed while GGS was feeding on *Strychnos potatorum* and *Nothopegia beddomei* (Figure 5B).

The third feeding posture observed was a GGS lying on the vertical bole of the tree, anchoring onto the tree trunk with the claws of the hind limbs and manipulating the food with mouth and forelimbs (Figure 5C). The observed instances are while feeding on the climbers found on the trees or the barks.

4. DISCUSSION

The present study observed that GGS fed on items from 30 different species of vegetation including 22 tree species and eight species including climbers, lianas, paraphytes, shrubs and cacti in Chinnar Wildlife Sanctuary, Western Ghats, south India. It is higher compared to a previous report of 21 tree species (Kumar et al., 2007). They were found primarily feeding on the tender leaves, flowers, bark and seed of these species, including lianas, climbers, shrubs and even one cactus. While in the earlier studies, there has not been any mention of the plant or plant parts being fed by the GGS. The squirrels were observed to feed on tender leaves and flowers of the plant species such as*Derris brevipes* and *Diplocyclos palmatus* (climbers),*Entada rheedii* (liana), *Hibiscus rosa-chinensis* (shrub) and *Euphorbia trigona* (cactus). Joshua (1992), reported the GGS feeding on the tender leaves and flowers of two trees,*Tamarindus indica* and *Bauhinia purpurea.*

4.1 Food composition

The optimal foraging theory proposed by (Pyke, 1984) suggests that a forager should eat only the most preferred or highest-ranked item if there is an adequate amount of that item to fulfil its daily diet requirements. As the highly preferred food item is depleted, the forager should include the next ranked item in its diet. The percentage contribution of each item based on the duration of feeding showed a trend as maximum by the seeds, followed by leaves, flowers and sap (Figure 2). This indicates that the GGS choose to have more seeds in their diet, switching to leafy food items, flowers and sap when seeds are scarce or unavailable. However, the present observation corroborates the findings of (Thorington & Cifelli, 1989) on *R. indica* at Mudumalai

Wildlife Sanctuary and Ramachandran (1992) at Periyar, Parambikulam and Silent Valley. In the present study, we observed that the GGS at Chinnar acts as an important seed-dispersing agent for many of the riverine tree/plant species.

The rodents depend heavily on hoarding for survival and reproduction (Vander Wall, 1990; Wang et al., 2018). Unlike a report on hoarding by*R. indica* (Somanathan et al., 2007), there was no instance of hoarding by GGS during the study period. This may be either a clear indication of the optimal availability of food in the habitat (Ando et al., 1985) or that the GGS does not possess this habit. More studies are required on the energetics of the GGS as this animal is a generalist plant feeder feeding on seeds, sap, leaves and flowers.

4.2 Diurnal variation in feeding habit

The feeding observations across different hours of the day show that the animal was highly active in the morning and evening hours of the day, and the resting occurred in the mid-day time. Thus, the animal's feeding activity appeared affected by the weather factors in the area. In the hours of high sunlight and rainfall, animal activity was found to be very low. Temperature dependant activity patterns to avoid extreme weather conditions are already observed in diurnal squirrels (Lee et al., 1990; Skibiel et al., 2002).

4.3 Feeding posture and technique

The mouth and forelimbs are the organs that help in manipulating the food item, while hind limbs and tail play roles as supporting organs for body balancing during feeding. All the three feeding postures, such as sitting, hanging and clinging postures, were found to be effectively used by the animal for feeding. This was found according to the availability and nature of food items foraged. Similar feeding postures were reported by (Ramachandran, 1992) on *Ratufa indica* .

The Chinnar wildlife sanctuary, southern Western Ghats, India, has a very small patch of 1.6 km^2 of riparian habitat which holds a very small population of the GGS and is already under serious threats of various forms (K. Thomas & Nameer, 2018). Further fragmentation and deterioration of the habitat will lead to food scarcity and increased predation risk (Gurjar et al., 2013; Justus Joshua & Johnsingh, 1994; K. Thomas et al., 2017). Food scarcity persuades the animal to increase the duration of feeding, which is positively correlated with stress (Dunn et al., 2010; Laurance et al., 2011). Habitat fragmentation accelerates the mortality of large and mature trees (Laurance et al., 2000), which holds a greater quantity of food resources (Chapman et al., 1992) and potentially can limit the availability of food of choice for GGS. The GGS was also found to be associated with many of the riparian species for their drey construction (Kiran Thomas & Nameer, 2021). A detailed investigation of the energetics of GGS along with habitat restoration, including species associated with GGS ecology, can ensure long-term survival possibilities for this mammal in this part of the world.

5. Tables

Table 1: The details of each feeding incident of the grizzled giant squirrel on a particular species.

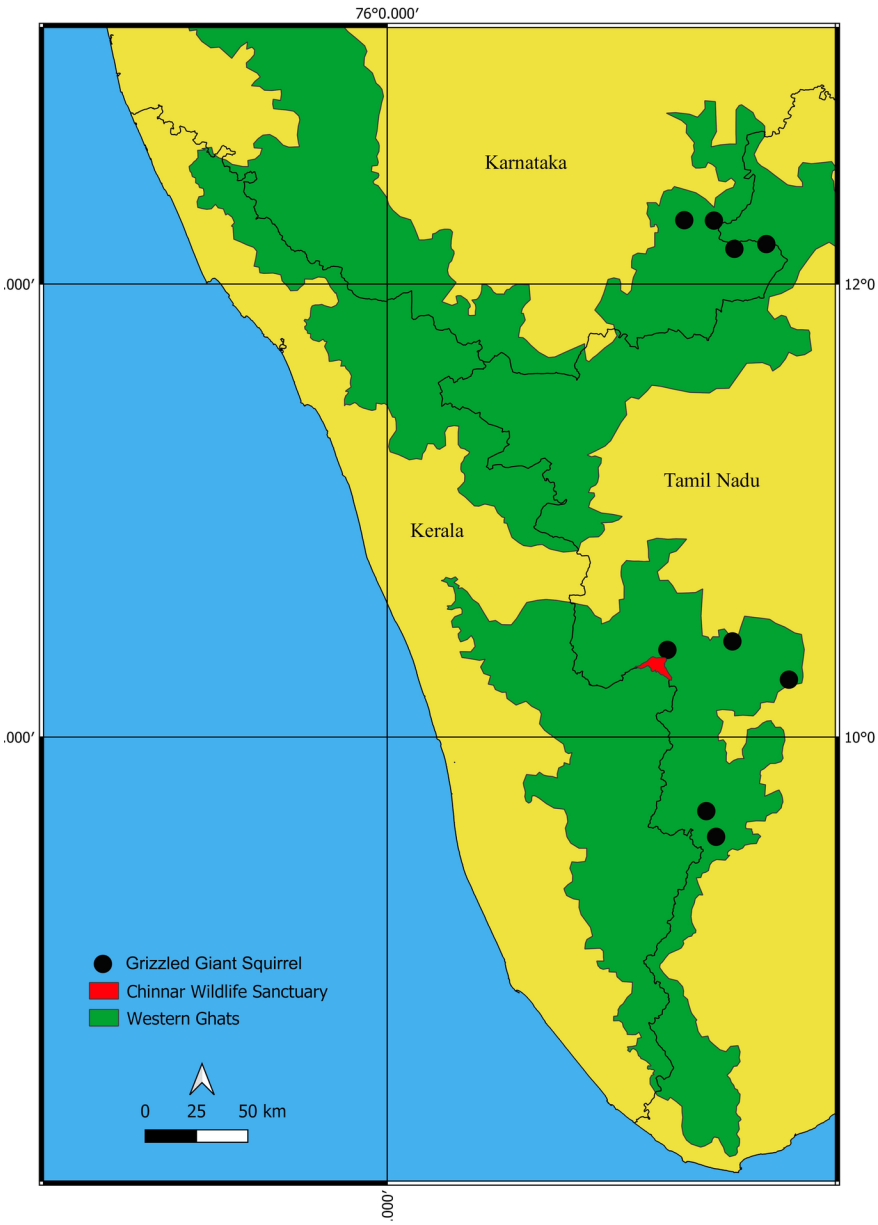
Species	Family	Month	Part eaten	Total duration (minutes)	Duration of feeding (%)
Mangifera indica	Anacardiaceae	October	Leaves and flowers	15	1.14
Nothopegia beddomei	Anacardiaceae	May	Immature seeds	130	9.89
Commiphora caudata	Burseraceae	March	Bark and tender leaves	10	0.76

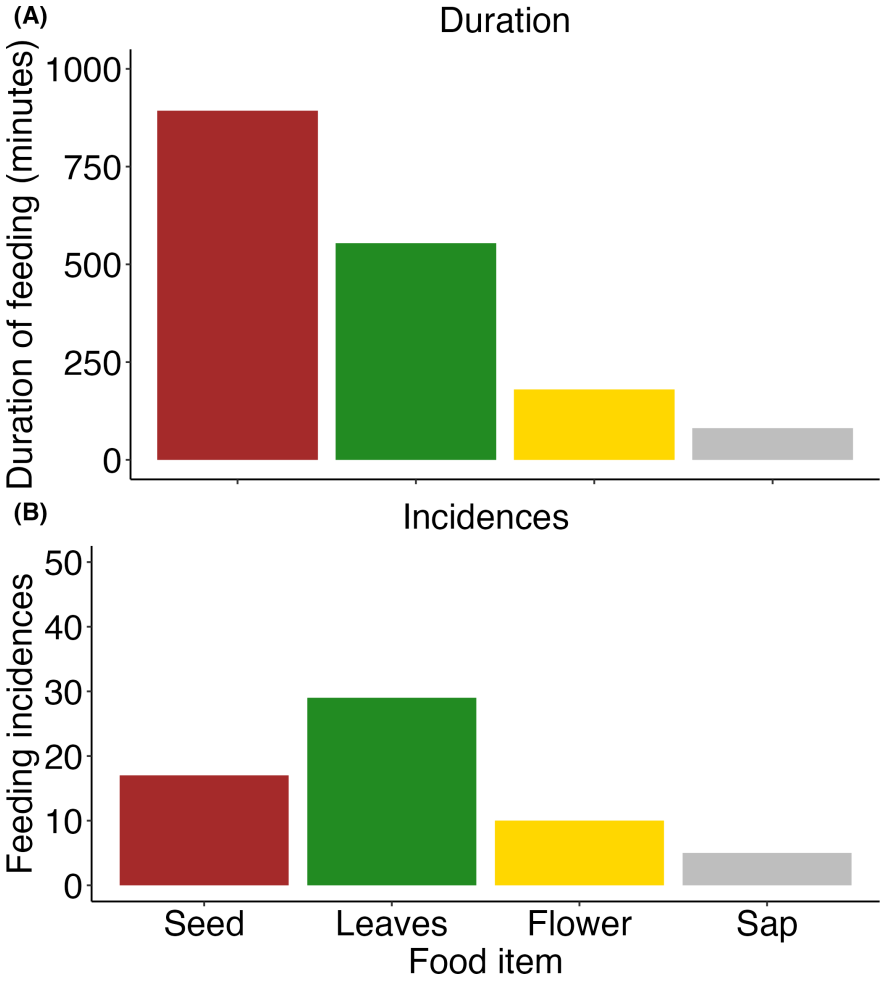
Species	Family	Month	Part eaten	Total duration (minutes)	Duration of feeding (%)
Terminalia arjuna	Combretaceae	April, September, January	Leaves and fruits	85	6.47
Diplocyclos palmatus	Cucurbitaceae	November	Immature leaves and seeds	45	3.42
Hopea parviflora	Dipterocarpaceae	February	Leaves	8	0.61
Euphorbia trigona	Euphorbaceae	August	Leaves	27	2.05
Acacia spp.	Fabaceae	March	Seeds of immature fruit	35	2.66
Albizzia lebbeck	Fabaceae	March	Tender leaves and flowers	36	2.74
Bauhinia racemosa	Fabaceae	February, March	Immature seeds	260	19.79
Derris brevipes	Fabaceae	March	Tender leaves and flowers	17	1.29
Entada rheedii	Fabaceae	March	Tender leaves and flowers	15	1.14
Pongamia pinnata	Fabaceae	April	Immature leaves	23	1.75
Tamarindus indica	Fabaceae	November, December, May	seeds of immature fruit and flowers	185	14.08
Cassia fistula	Fabaceae	May	Bark	3	0.23
Strychnos potatorum	Loganiaceae	January	Immature seed	95	7.23
Macrosolon capitellatus	Loranthaceae	May	Immature seeds	55	4.19
Hibiscus rosa –chinensis	Malvaceae	March	Tender leaves and flowers	15	1.14
Melia dubia	Meliaceae	September	Leaves	37	2.82
Ficus albiphyla	Moraceae	February	Tender leaves and bark	40	3.04
Ficus microcarpa	Moraceae	November, February	Leaves and immature seed	29	2.21
Ficus spp.1	Moraceae	November	Leaves and immature seed	16	1.22
Ficus spp.2	Moraceae	September	Leaves	16	1.22
Syzygium cumini	Myrtaceae	August, May	seeds of immature and mature fruits and leaves	52	3.96
Psychotria subintegra	Rubiaceae	September	Leaves, flowers and sap	13	0.99
Aegle marmelos	Rutaceae	October	Leaves	3	0.23

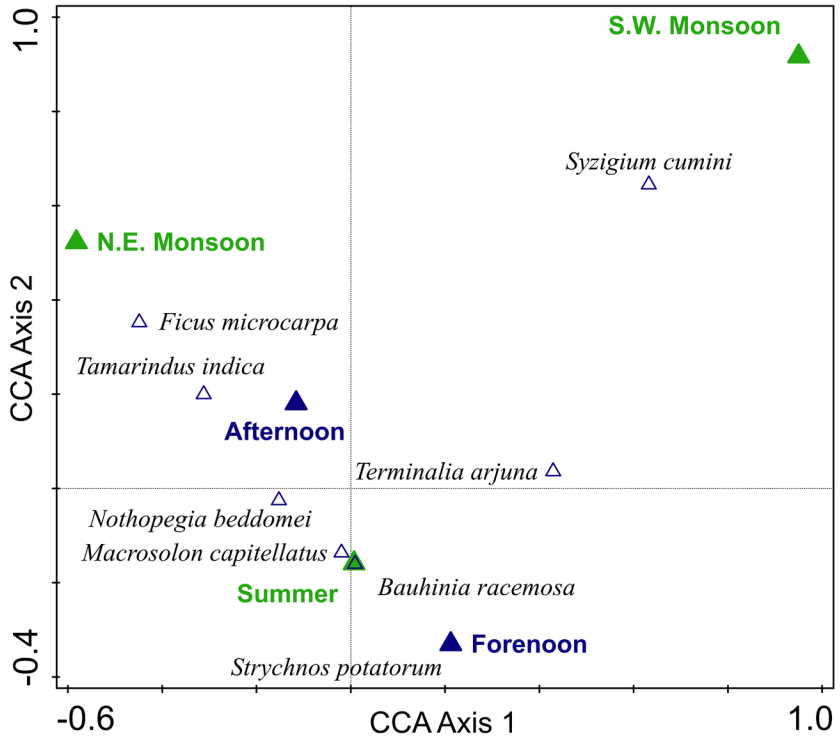
Species	Family	Month	Part eaten	Total duration (minutes)	Duration of feeding (%)
Santalum album	Santalaceae	November	Immature leaves and flowers	9	0.68
Grewia tiliifolia	Tiliaceae	October	Leaves, flowers and fruits	25	1.90
Grewia spp.	Tiliaceae	May	Leaves	5	0.38
Cayratia trifolia	Vitaceae	March	Tender leaves and flowers	10	0.76

6. Figure legends

Figure 1. The study site and the other locations from where the Grizzled Giant Squirrels are reported from the Western Ghats, India.,**Figure 2.** The contribution of each food item to total feeding based on (A) the duration of feeding on a particular item, (B) the number of times feeding on a particular item occurred, **Figure 3.** The canonical correspondence analysis shows the association of season and time of the day to the species fed (Eight species are given in the figure, selected based on the number of months and more feeding duration observed). **Figure 4.** Feeding Technique, A) Selection by smell B) Making the food reach to mouth with the help of forelimbs C) Cutting the fruit with the mouth D) Feeding the seeds by sitting on a firm branch, **Figure 5.** Feeding Postures, A) Sitting posture B) Hanging posture C) Clinging posture.







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Author Contribution Statement

Kiran Thomas : Investigation, Data curation, Writing- Original draft, Visualization. **Marek Šmejkal** : Supervision, Writing- Reviewing and Editing. **Nameer Paingamadathil Ommer:**Methodology, Supervision, Writing- Reviewing and Editing, Funding acquisition.

Conflict of interest statement

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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