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ORIGINAL ARTICLE

Food resources, distribution and seasonal variations in ranging in lion-tailed macaques, *Macaca silenus* in the Western Ghats, India

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Abstract The distribution and availability of food was examined to see how it influenced ranging patterns and sleeping site selection in a group of lion-tailed macaques. The home range and core area were 130.48 ha (95 % kernel) and 26.68 ha (50 % kernel) respectively. The lion-tailed macaques had a longer day range, had a greater number of sleeping sites and used more core areas in the summer as compared to the monsoon and the post-monsoon seasons. The ranging patterns and sleeping site use were influenced by the major food resources used in a particular season. The ranging was mainly influenced by *Artocarpus heterophyllus* in monsoon, *Cullenia exarillata* and *Toona ciliata* in post- monsoon, and *Artocarpus heterophyllus* and *Ficus amplissima* in summer. The distribution of these four plant species is, therefore, critical to ranging, and thus to conservation of the lion-tailed macaque.

Keywords Daily travel path length · Feeding ecology · Food availability · Home range · Keystone species · Sleeping site use

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Introduction

Habitat quality influences ranging patterns, time spent feeding and travelling, and has strong influence on the social behavior of primates (Bonnell et al. 2013). This, in turn, limits the time available for other activities (Gill and Wolf 1978; Chapman and Chapman 1999; Vogel and Janson 2007). Ranging patterns influence foraging ecology (Orians and Pearson 1979; Stone 2007; Bonnell et al. 2013), seed dispersal (Vellend et al. 2003; Bonnell et al. 2013) and disease dynamics of a species (Bartel et al. 2011; Bonnell et al. 2013). The study of ranging has also contributed much to the conservation and management of a species in the wild (Bonnell et al. 2013).

The availability and distribution of resources influences ranging (Robbins and McNeilage 2003; Fashing et al. 2007; Riley 2008), population density (Fleury and Gautier-Hion 1999; Gómez-Posada et al. 2007), group size (Robbins and McNeilage 2003; Gómez-Posada et al. 2007) and patterns of competition (Doran-Sheehy et al. 2004; Hoffman and O’rian 2012). Since most primates in tropical forests are frugivorous (Peres 1994), their resources vary in space and time. Their adjustments to resource distribution and abundance are largely behavioral, leading to seasonal expansion and shrinkage of home ranges (Peres 1994; Stone 2007; Albert et al. 2013). Expansion and shrinkage of home ranges in relation to the variations in the availability and distribution of food resources across seasons are often observed (Peres 1994; Stone 2007; Albert et al. 2013). Population density and group size also correlate with the ranging patterns which in turn correlate with interactions among conspecifics (Grove 2012).

Macaques are primarily frugivorous (Albert et al. 2013), and hence are a good model for studying the effect of distribution of resources on ranging behavior. The seasonal variation in fruit availability has been suggested to affect ranging of northern-pig tailed macaques *Macaca leonina* (Albert et al. 2013), Japanese macaques *Macaca fuscata* (Tsuji and Takatsuki 2004; Go 2010) and Sulawesi crested macaques *Macaca nigra* (O'Brien and Kinnaird 1997). The ranging pattern of Japanese macaques is also influenced by plant distribution (Tsuji and Takatsuki 2004; Go 2010). Sulawesi crested macaques (O'Brien and Kinnaird 1997) expanded their home range and time spent on feeding and foraging during fruit scarcity periods in accordance with the energy-maximizing strategy hypothesis (Hall 1962; Schoener 1971) and bottleneck hypothesis (Hanya et al. 2006). Hanya et al. (2006) reported that the quality of fallback foods may be crucial during periods of fruit scarcity, affecting density of primates.

The choice of sleeping site is an important aspect of ranging (Chapman 1989; Liu and Zhao 2004). The availability of suitable sleeping sites influences travel costs and risks of predation, and these costs in turn determine the suitability of a potential sleeping site (Chapman et al. 1989; Albert et al. 2011). Multiple central place foraging theory (MCPF) explains how some species may choose many sleeping sites close to some feeding areas to reduce travel costs, in contrast to the use of a single central sleeping site (Chapman et al. 1989). The MCPF strategy was observed in southern pig-tailed macaques *Macaca nemestrina* (Caldecott 1986) and northern pig-tailed macaques (Albert et al. 2011). Also, long-tailed macaques *Macaca fascicularis* (Kurland 1973) and stump-tailed macaques *Macaca arctoides* (Estrada and Estrada 1976) used trees with large open crowns as sleeping sites for greater visibility of approaching predators.

The lion-tailed macaque (*Macaca silenus*), an endangered species (IUCN 2013), is a habitat specialist of the primary broadleaf evergreen forests of the Western Ghats (Fooden 1982; Kumar 1987; Singh et al. 2002; Sushma and Singh 2006; Umapathy et al. 2011). They are arboreal, frugi-insectivorous macaques feeding mainly on fruits, flowers and canopy invertebrates (Kurup and Kumar 1993; Sushma and Singh 2006; Krishnadas et al. 2011). There is a marked seasonal variation in the availability and abundance of resources in lion-tailed macaque habitats (Roy et al. 2010; Krishnadas et al. 2011). Previous studies indicated that lion-tailed macaques have home ranges that vary between 1.25 km^2 (Kumar 1987) and 5 km^2 (Green and Minkowski 1977). We believe that the variability is greatly related to the distribution of food. We therefore propose to assess the food availability and correlate it with home ranges. Seasonal variation is expected to influence day ranges and home range use. Furthermore, we hypothesize that the number of core areas and sleeping sites will be strongly influenced by the distribution of food in the home range. Since most habitats of the endangered lion-tailed macaques are now highly fragmented and are deteriorating (Singh et al. 2009), a study of ranging in relation to resources will be very useful in the management of this species.

Methods

The study adhered to the ethical guidelines of the University of Mysore and an official permit was obtained from the Chief Wildlife Warden of the state of Kerala for conducting this research.

Study area

We carried out this study in Nelliyampathy Reserve Forest, Nenmara Forest Division (10°25′–10°30′N and 76°35′–76°45′E) in the Palakkad District of Kerala, southern India (Fig. 1). The area lies south of the Palakkad gap in the western flank of the Anamalai Hills making it one of the important endemic centers of the Western Ghats and covers an area of 736 km^2 (Ramachandran and Suganthasakthivel 2010; Baskaran et al. 2013). The altitude ranges from 500 to 1,100 m. The average annual rainfall of the area has been 3,378 mm during the past 10 years, measured at a weather station 2 km from the study site. The mean annual temperature ranged from 15 °C in December to 30 °C in April. The area is interspersed with tea, coffee, and cardamom gardens in continuity with some forest tracts. Approximately 200 lion-tailed macaques lived in the study area, and they were distributed in 14 groups (Ramachandran and Suganthasakthivel 2010). The present study group, called the "Victoria group" occupied the evergreen forests surrounding the Victoria Estate.

Subjects

The study group comprised 38 animals composed of 3 adult males (10 years+), 2 sub-adult males (5–10 years), 21 adult females (5 years+), 9 juveniles (1–4 years) and 3 infants (up to 1 year) (Kumar 1987). The infants were defined as unweaned individuals. Juveniles were young but weaned individuals. The group was habituated to the presence of the observers and all animals were individually identified. The macaques spent most of their time in the canopy, and we maintained a distance of 20 m from the trees occupied by the subjects.

Study period

We conducted this study from July 2011 to July 2012. We divided the year into three seasons: monsoon (June–September, average rainfall = 2,548 mm), post-monsoon

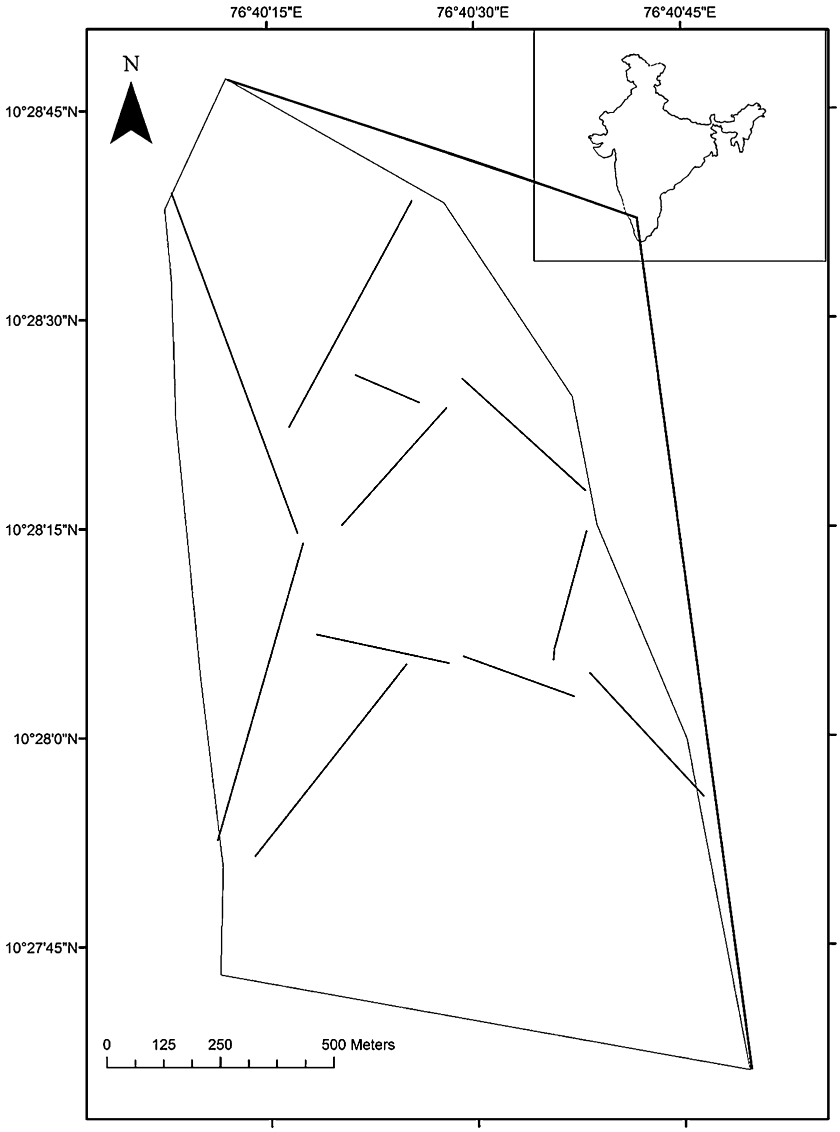

Fig. 1 Map of the home range of the group of lion-tailed macaques, with placement of line transects

(October–January, average rainfall = 520 mm) and summer (February–May, average rainfall = 309 mm) (source: Kerala Forest Development Corporation, Pakuthipalam). The total observation time was about 845 h, with 280, 300, and 265 h in monsoon, post-monsoon and summer, respectively. Observations were spread over 30–40 days in a season. Home range data were taken on days with more than 6 h of observation (monsoon = 24 days, 284 GPS points; post-monsoon = 23 days, 279 GPS points; summer = 31 days, 361 GPS points). Previous researchers reported that lion-tailed macaques are active between 0600 and 1800 hours (Singh et al. 2011), but in the present study, the macaques emerged from the sleeping site at around 0800 hours and entered the sleeping site at around 1600 hours in the monsoon and post-monsoon seasons. Hence, data collected between 0800 and 1600 hours were used in the analysis.

Ranging

We followed the group continuously throughout the day and recorded locations every half hour by GPS (Garmin eTrex Vista, Garmin international, Inc., KS, USA). The accuracy was around 5–8 m. From this data, we derived estimates of home range using a fixed kernel density estimation method (ad-hoc method) (henceforth referred to as kernel) (Berger and Gese 2007). Worton (1989) suggested that this method can be used for obtaining all information for a utilization distribution. The commonly used least-square cross-validation method could not be applied since each dataset had more than 150 points and the data seemed to be clumped (Steiniger and Hunter 2012). The output cell size was set at 110 × 110 m based on the average group spread of lion-tailed macaques which was 110 m [personal observations in the present study area as well as in other lion-tailed macaque groups in the adjoining hill ranges (Kumar 1987; Singh et al. 2001)]. The seasonal home range was defined as 95 % kernel and the core area as 50 % kernel. The analysis was performed in OpenJump HoRAE (Steiniger and Hunter 2012). We calculated the daily path length by connecting different ranging points, when the data was available for complete days (emergence from a sleeping site to retreat to a sleeping site). We did not perform kernel density estimation for the sleeping sites as the macaques used only a few trees in each sleeping site.

Time-activity budget

We recorded the time spent on different activities using focal animal sampling (Altmann 1974). The focal animal was followed for 5 min and the duration of each activity was recorded in seconds. The focal animals were selected at random for each sample and the time spent observing each animal was equalized every month. The sampling was done for all animals except infants. We divided the major activities into feeding (included drinking), foraging (the time spent searching for insects, which included scratching, breaking and removal of bark, processing fruits, etc.), passivity, locomotion, self-directed activities and social behavior (including grooming, play, aggressive interactions, sexual interactions). Total time spent on focal animal sampling was 385 h with 125, 130 and 130 h spent on sampling in monsoon, post-monsoon and summer, respectively. The time spent on each activity was pooled for a period of 4 months each for the respective seasons. From this data, the total time spent on feeding in seconds was extracted. The total time spent on feeding was further divided into time spent feeding on each tree species. The time-activity budget analysis was performed for 2-h time periods between 0800 and 1600 hours to compare the daily activity pattern of feeding and foraging among seasons.

Distribution of tree species

We laid 11 line-transects of varying lengths in the area to study the distribution of resources (200–700 m for a total length of 4,970 m). Transects were laid on already existing forest tracks. Some areas of the home range were not covered by transects due to inaccessibility. However, transects were laid in the areas where lion-tailed macaques ranged most frequently. Transects were 70 m wide on each side. A transect was included in the analysis if 70 % of its length was within the seasonal range of the group. Assuming that the ranging pattern would be affected by the distribution of trees (>20 cm girth) used for feeding by the macaques, we took GPS locations of five major tree species (the trees accounting for more than 4 % of the diet in any particular season) within a transect. The percentage of these trees was calculated as the number of each major tree species in a transect/total number of major trees in a transect × 100. Further, the density estimates were calculated using Distance 6 software for each tree species (Thomas et al. 2010). The data for estimating density was obtained by measuring perpendicular distances from transect to the respective major trees. The shape of the detection function was improved by truncating the data at different distances for the farthest sightings (Buckland et al. 2001) and the best models were selected for analysis based on Akaike information criterion (AIC) values (the model with smallest AIC value among the models we tested). The percentage coefficient of variation (CV) was calculated to observe the changes in the precision of the model with relation to truncation of the data.

Data analysis

We used a χ^2 test for proportions for comparing range use, sleeping sites and feeding in three different seasons, as well as for comparison of different resources fed on by the lion-tailed macaques. We transformed the data into percentages before applying the tests. Marascuilo's post hoc analysis was carried out for each test. A Kruskal–Wallis H test was performed to compare the average daily path length in each season, with a Mann–Whitney U test for post hoc comparisons with adjusted alpha at 0.02. We set alpha at 0.05 and used SPSS 20.0 for statistical analysis.

Results

Daily path length and home range use

Mean (±SD) daily path length during the study period was 1,512 ± 262 m ($N = 40$ complete days of observation, range 1,000–2,100 m) per day, with the mean daily path length in monsoon, post-monsoon and summer being 1,203 ± 95 m ($N = 14$, range 1,000–1,300 m), 1,385 ± 41 m ($N = 12$, range 1,350–1,450 m) and 1,893 ± 116 m ($N = 14$, 1,700–2,100 m) respectively. These differences were significant (Kruskal–Wallis H test: $\chi^2 = 25.97$, $df = 2$, $P < 0.001$; Mann–Whitney U test: monsoon and post-monsoon: $U = 0$, $P < 0.001$; monsoon and summer: $U = 0$, $P < 0.001$; post-monsoon and summer: $U = 0$, $P < 0.001$) with more distance travelled in summer. The size of the total home range was 130.48 ha and the core area was 26.68 ha (Fig. 2a). The size of the seasonal home range was larger in summer (129.62 ha) and monsoon (124.66 ha), followed by post-monsoon (93.63 ha) ($\chi^2 = 40.04$, $df = 2$, $P < 0.001$; Marascuilo's post hoc test: monsoon and post-monsoon: $\chi^2 = 18.75$,

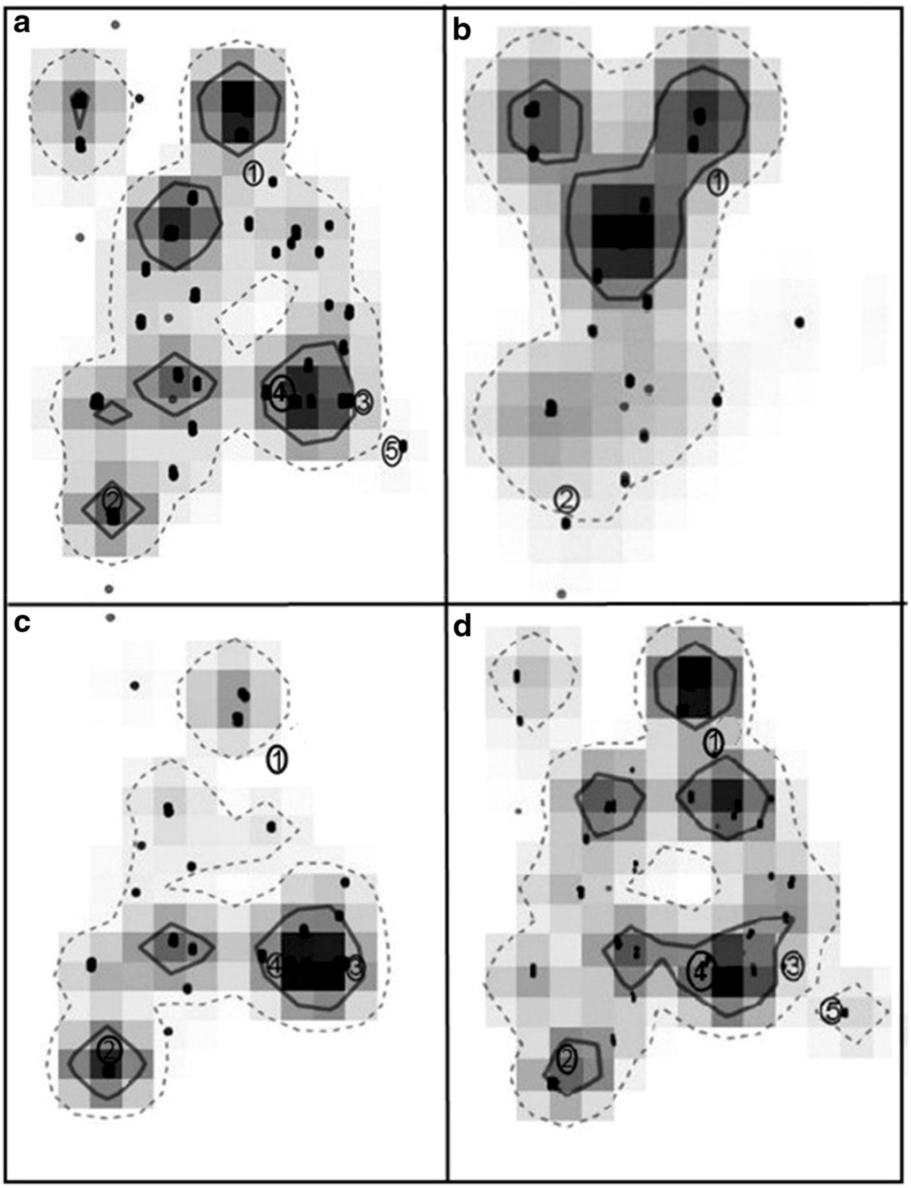

Fig. 2 Maps of home range of lion-tailed macaques in the present study (July 2011–July 2012) with kernel density of each cell (110 × 110 m) representing **a** annual home range, **b** monsoon home range, **c** post-monsoon home range, **d** summer home range. The kernel density increases as colour changes from *white* to *black* in each cell. The *black dotted line* represents 95 % kernel. The *black solid line* represents 50 % kernel. The *numbers in circles* represent different sleeping sites. *Big black dots* indicate the GPS locations of lion-tailed macaques during the study

$P < 0.001$; post-monsoon and summer: $\chi^2 = 34.46$, $df = 2$, $P < 0.001$; monsoon and summer: $\chi^2 = 3.77$, $df = 2$, $P = 0.15$). The size of the core area did not significantly differ among monsoon (30.61 ha, 24.55 of 95 % monsoon kernel), summer (29.20 ha, 22.53 of 95 % summer kernel) and post-monsoon (17.04 ha, 18.79 of 95 % post-monsoon kernel) ($\chi^2 = 1.45$, $df = 2$, $P = 0.48$). The number of core areas in summer, post-monsoon and monsoon seasons was 5, 3 and 2, respectively. The mean (±SD) distances among the core areas were 492.14 ± 350, 341.33 ± 227 and 90.5 ± 0 m in summer, post-monsoon and monsoon, respectively. The parts of the home range used across seasons also differed (Fig. 2b–d).

Sleeping site use

The group used five places as sleeping sites. They used all five sleeping sites in summer ($N = 65$), followed by four in post-monsoon ($N = 43$) and two in monsoon ($N = 46$). In monsoon, the macaques used sleeping site 1 (71.74 %) more than sleeping site 2 (28.26 %) and spent more time in the vicinity of site 1 (Fig. 2b). In post-monsoon, the macaques used sleeping site 3 more (55.81 %) than sleeping sites 1 (20.93 %), 2 (11.63 %) or 4 (11.63 %) ($\chi^2 = 71.57$, $df = 3$, $P < 0.001$). The subjects also used the area around sleeping sites 3 and 4 more than around sites 2 and 1 (Fig. 2c). In summer, the macaques showed significant differences in sleeping site use ($\chi^2 = 13.38$,

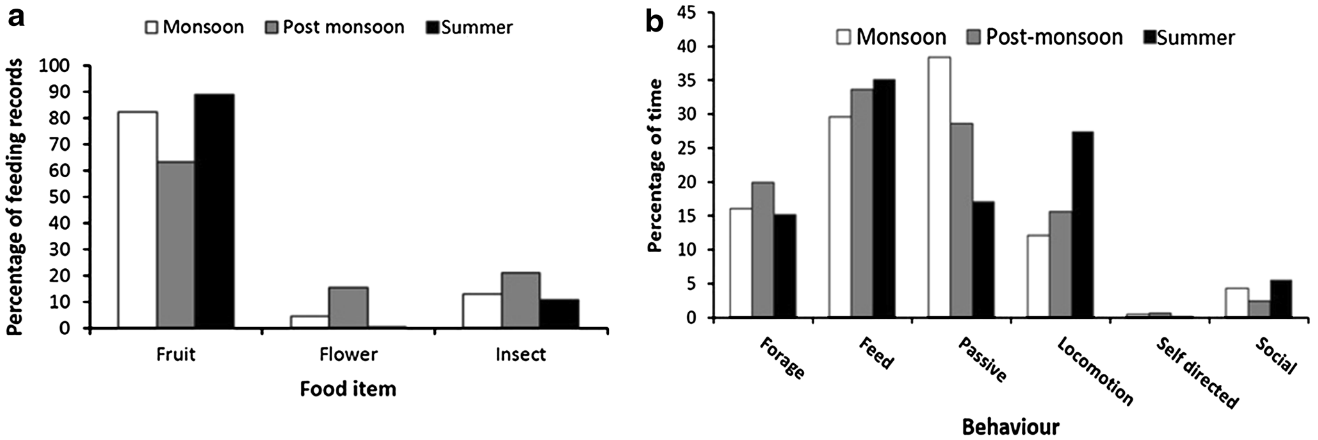

Fig. 3 Seasonal variation in **a** percentage time spent on different food items, and **b** percentage time spent on different activities in the group of lion-tailed macaques in the present study (July 2011–July 2012)

$df = 4$, $P = 0.009$) with sleeping site 1 (30.76 %) being the most used, followed by sleeping site 2 (21.54 %), sleeping site 4 (20 %), sleeping site 5 (15.38 %) and sleeping site 3 (12.31 %). The macaques ranged more around sleeping sites 3 and 4, followed by sleeping site 1, sleeping site 2 and sleeping site 5. All the sleeping sites were inside or near the core areas (Fig. 2d), and adjacent to feeding trees. All the sleeping sites were located in valleys with narrow streams. The macaques generally used 2–3 *Ficus* trees as sleeping sites.

Feeding ecology

Lion-tailed macaques were found to feed on 16 out of 24 fruiting tree species in the study site. Their diet primarily included fruits (79.11 %), followed by insects (13.79 %) and flowers (7.08 %) ($\chi^2 = 141.87$, $df = 2$, $P < 0.001$) (Fig. 3a). They spent only about 0.02 % time feeding on 'other items' such as gum, pith, mushrooms, small vertebrates etc., and hence this time duration was not included in the analysis. Lion-tailed macaques did not feed on leaves at all. Three major tree species including *Artocarpus heterophyllus*, *Cullenia exarillata* and *Ficus amplissima* accounted for about 74 % of their diet (Table 1). Overall, lion-tailed macaques spent 32.06 % of their time feeding with no seasonal differences ($\chi^2 = 0.75$, $df = 2$, $P = 0.68$) (Fig. 3b). The lion-tailed macaques spent most time feeding on fruits between 0800 and 1000 hours (47.5 % of the total activities), followed by 1400 and 1600 hours (30 %), 1000 and 1200 hours (21.75 %) and 1200 and 1400 hours (15 %) ($\chi^2 = 29.62$, $df = 3$, $P < 0.001$). Foraging for fruits was predominant between 1400 and 1600 hours (15 % of the total activities), followed by 0800 and 1000 hours (12.5 %), 1000 and 1200 hours (6.5 %) and 1200 and 1400 hours (4 %) ($\chi^2 = 9.87$, $df = 3$, $P = 0.02$).

Table 1 Percentage time spent by lion-tailed macaques, annually and seasonally, on fruits and flowers of different tree species, insects and other items

Species	% in diet (annual)	% in diet (monsoon)	% in diet (post-monsoon)	% in diet (summer)
Artocarpus heterophyllus	37.77	68.90	0	44.40
Climber	0.85	1.51	1.04	0
Coffea robusta	0.25	0	0	0.75
Cullenia exarillata	24.60	11.05	62.74	0
Elaeocarpus sp.	0.69	1.03	1.04	0
Erythrina stricta	1.58	2.10	2.63	0
Ficus amplissima	11.94	0	0.36	35.45
Ficus beddomei	2.10	0	4.73	1.56
Garuga pinnata	0.32	0.95	0	0
Holigarna grahamii	0.08	0	0	0.25
Litsea floribunda	0.09	0	0	0.26
Macaranga peltata	0.01	0	0.02	0
Mesua ferrea	0.14	0	0	0.43
Palaquium ellipticum	1.00	0	0	2.99
Syzygium cumini	1.33	0	0	3.98
Toona ciliata	3.44	1.18	9.14	0
Insect	13.79	13.19	18.30	9.90
Other items	0.02	0.09	0	0.03

The peak fruiting season was from February to August for *Artocarpus heterophyllus*, September–February for *Cullenia exarillata*, January–May for *Ficus amplissima*, and October–February for *Toona ciliata* and *Ficus beddomei*. The macaques mainly fed on *Artocarpus heterophyllus* in monsoon ($\chi^2 = 756.61$, $df = 15$, $P < 0.001$), on *Cullenia exarillata*, *Toona ciliata* and *Ficus beddomei*

($\chi^2 = 641.99$, $df = 15$, $P < 0.001$) in post-monsoon and on *Artocarpus heterophyllus* and *Ficus amplissima* ($\chi^2 = 465.72$, $df = 15$, $P < 0.001$) in summer (Table 1).

Analysis of tree distribution

We obtained 782 locations of major trees along transects. The total area covered by the transects was 54.16 % (69.58 ha) of the total home range of the lion-tailed macaques. The most frequently occurring tree species included *Toona ciliata* (34.20 %) and *Artocarpus heterophyllus* (34. 08 %), followed by *Ficus amplissima* (20.45 %) and *Cullenia exarillata* (10.09 %). In the monsoon ranging area, the most frequently occurring tree species was *Artocarpus heterophyllus* (38.27 %), followed by *Toona ciliata* (28.30 %), *Ficus amplissima* (20. 5 %), and *Cullenia exarillata* (12.67 %). In the post-monsoon ranging area, these tree species included *Toona ciliata* (39. 43 %), followed by *Artocarpus heterophyllus* (26.70 %), *Ficus amplissima* (24.64 %), *Cullenia exarillata* (8.11 %) and *Ficus beddomei* (1.11 %). All the *Ficus beddomei* trees ($N = 7$) were located exclusively within the post-monsoon and summer ranges.

Further, we calculated the densities of trees per hectare, $\widehat{D}$, (Table 2) using Distance 6 software. In monsoon, the lion-tailed macaques ranged in areas where *Artocarpus heterophyllus* was relatively high in abundance and they also fed on *Artocarpus heterophyllus* mainly in monsoon. In post-monsoon, the lion-tailed macaques ranged in areas where the presence of *Cullenia exarillata, Toona ciliata* and *Ficus beddomei* (all the trees were present in post-monsoon and summer ranges) was higher than in the monsoon range, and the lion-tailed macaques mainly fed on *Cullenia exarillata, Toona ciliata* and *Ficus beddomei* in post-monsoon. The summer range of the lion-tailed macaques covered both monsoon and post-monsoon ranges. This was due to feeding on *Artocarpus heterophyllus* and *Ficus amplissima*: the former was most abundant in the monsoon range, and the latter in the post-monsoon range.

Discussion

Ranging and resource distribution

Many primates seasonally adjust their home ranges, including macaques [Sulawesi crested macaques (O'Brien and Kinnaird 1997), Japanese macaques (Tsuji and Takatsuki 2004; Go 2010) and northern pig-tailed macaques (Albert et al. 2013)]. In the present study, the lion-tailed macaques used a higher number of core areas and had longer daily path lengths in summer compared to monsoon and post-monsoon. The shift in range use appears to be primarily influenced by the availability of food (Di Fiore 2003; Kirkpatrick 2007; Lambert 2007). The availability of certain fruiting keystone tree species influences the variation in fruit diet composition across seasons for some primate species (Russo et al. 2005; Di Fiore et al. 2008) and these primates are mainly found to depend on these trees when they are abundant (Tsuji and Takatsuki 2004; Matsuda et al. 2009; Albert et al. 2013). In the present study, we found that lion-tailed macaques mainly relied on *Artocarpus heterophyllus* during monsoon, *Cullenia exarillata* and *Toona ciliata* in post-monsoon and *Ficus amplissima* and *Artocarpus heterophyllus* in summer. The studies on Japanese macaques have reported that the presence of some particular fruit species was positively correlated with the ranging behavior of the macaques (Go 2010). Overall, the lion-tailed macaques in the present study fed on only 16 tree species. By plotting the distribution of these tree species, we found that in the monsoon range, *Artocarpus heterophyllus* trees were most abundant. In the post-monsoon range, *Cullenia exarillata* was more abundant than in the monsoon range, while *Toona ciliata*

Table 2 Total number of detections (*N*), effective strip width (ESW), density estimate($\widehat{D}$), percentage coefficient of variation of the density (CV) and 95 % confidence interval (CI) acquired for major trees used by lion-tailed macaques for feeding in different seasons after running the model in the program Distance

Species	Range	*N*	ESW (m)	$\widehat{D}$ (ha^{-1})	CV ($\widehat{D}$) %	95 % CI (ha^{-1})
Artocarpus heterophyllus	Monsoon	211	11.66	25.46	36.74	9.72–66.67
	Post monsoon	153	17.41	11.81	34.34	5.56–25.11
	Summer	249	14.80	16.93	29.46	8.97–31.92
Cullenia exarillata	Monsoon	29	24.06	1.73	22.45	1.06–2.81
	Post monsoon	47	23.83	2.65	27.73	1.45–4.83
	Summer	67	22.93	2.93	22.10	1.83–4.68
Ficus amplissima	Monsoon	63	22.91	4.32	32.48	1.13–16.38
	Post monsoon	113	20.92	7.26	52.29	3.74–14.07
	Summer	127	24.09	5.30	29.85	2.63–10.66
Toona ciliata	Monsoon	46	27.76	2.60	69.14	0.43–14.30
	Post monsoon	184	23.06	10.73	35.76	4.85–23.78
	Summer	208	22.51	9.30	34.00	4.50–19.19

was most abundant in this seasonal range. In the summer range, the macaques travelled both in monsoon and post-monsoon ranges. This was because the occurrence of *Ficus amplissima* was higher in the post-monsoon range and *Artocarpus heterophyllus* was higher in the monsoon range as compared to other ranges.

Previous studies have also shown that the size of the home range is mainly influenced by the abundance of food resources (Kirkpatrick 2007; Lambert 2007; Matsuda et al. 2009). It was reported that when the resources were abundant, the home range size decreased, at least in capuchin monkeys (*Cebus apella*: Di Bitetti 2001) and provisioned Japanese macaques (Koganezawa and Imaki 1999). Although this is in accordance with the energy-maximizing hypothesis (Schoener 1971), Hanya et al. (2006) reported contradictory results. In the present study, the lion-tailed macaques covered a longer daily path and used a higher number of core areas during summer when the food was scarce. This is in accordance with the energy-maximizing hypothesis. Though it was reported that lion-tailed macaques may not feed on *Ficus* due to its low nutritional content, rarity and stochastic fruiting (Krishnadas et al. 2011), it was found to be the major food tree during the period of food scarcity in the present study, in accordance with the bottleneck hypothesis (Hanya et al. 2006). The lion-tailed macaques depended on a larger number of food trees during summer. However, the total size of the core area in summer was similar to that of the monsoon and post-monsoon seasons, and only the number of core areas and the average distance among the core areas differed. The total home range was larger in summer and monsoon than in post-monsoon seasons. Since the resources were abundant in monsoon and post-monsoon seasons, the macaques may have employed an energy-maximizing strategy by ranging less in a day. Macaques ranged more in a day during summer, possibly due to the higher number of core areas used and the longer distance between core areas. The rainfall and temperature also might have affected ranging during monsoon and post-monsoon seasons, as already reported in other studies (Kirkpatrick et al. 1998; Baoping et al. 2009). The day length in monsoon and post-monsoon seasons was shorter and the macaques emerged later from the sleeping sites and entered earlier, which might have affected the distances travelled in a day.

The density of *Artocarpus heterophyllus* was high in the monsoon range, especially in the core area. The area is located at the border of a coffee garden. *Artocarpus heterophyllus* is used by humans as a food item, and it is also planted inside coffee gardens to provide shade for the coffee plants. Hence, the density of *Artocarpus heterophyllus* was high near human dominated areas. In the present study, it was found that the most important diet of the lion-tailed macaques was *Artocarpus heterophyllus*. Most of the other lion-tailed macaque groups in Nelliyampathy also fed on *Artocarpus heterophyllus* when these fruits were available (unpublished data). However, people plucked the fruits before they ripened and side lopped the trees to avoid invasion by elephants (*Elephas maximus*), bonnet macaques (*Macaca radiata*) and lion-tailed macaques. This may lead to deficiency of resources for these species in similar habitats during resource-scarce seasons.

The two earlier studies on lion-tailed macaques reported that their total home range was 5 km^2 in a continuous forest (Green and Minkowski 1977) and 1.25 km^2 in a forest fragment (Kumar 1987). While the former study was descriptive, the latter study actually calculated the home range size by the number of occurrences in quadrats. It was found in the present study that the total home range was 1.30 km^2. Most of the lion-tailed macaque groups inhabit rainforest fragments of varying sizes and population densities (Singh et al. 2002), and the home range differences could simply be due to the number of groups and size of the groups inhabiting a fragment.

Sleeping site use

The use of sleeping sites may be highly variable across seasons (Wang et al. 2011). One of the main drivers of sleeping site choice is the distribution of resources (Tsuji 2011). In all seasons, the major sleeping sites used were near the core areas of the home range and near the feeding trees. The macaques spent more time feeding in the morning just after they came out from the sleeping sites. The above two observations indirectly suggest that the macaques used MCPF strategy for the selection of sleeping sites. Another main driver of sleeping sites selection appears to be predator avoidance (Liu and Zhao 2004) and early detection of predators (Treves 2002). Hence, some primate species choose cliffs or valleys or river sides since these places are less accessible to predators (Albert et al. 2011; Wang et al. 2011). They also use trees with open crowns, for better detection of predators (Albert et al. 2011). In the present study, all the sleeping sites were present in valleys with narrow streams and the reason may be predator avoidance and early detection of predators, especially leopards, as macaques can detect any predator approaching from a distance. Also, they used *Ficus* trees with open crowns possibly for early detection of predators.

The lion-tailed macaques primarily relied on only 5 plant species for food with seasonal dependence on either 1 or 2 species. They are therefore very vulnerable to habitat disruption. The loss of even one plant species may affect their very survival. Further, because tropical trees do not grow in clumps of single plant species but are, instead, diversified, the lion-tailed macaques require a moderately sized home range to provide them with food over the year. Therefore, their home ranges must encompass all of their food resources. Since they cannot go for more than a few weeks without eating, any area that fails to provide a year-round food supply is impossible for them to live in. At present, there are about 3,500 lion-tailed macaques distributed in 49 subpopulations across the Western Ghats (Singh et al. 2009). The ranging patterns are expected to be strikingly different in small to medium sized forest fragments compared to relatively larger contiguous habitats. The present study group inhabited a place that is partially surrounded by tea gardens and partially by reserve forests. The study of ranging in this type of habitat will be useful in planning management strategies for this endangered species.

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