Choice and Characteristics of Sleeping Sites in a troop of Central Himalayan Langurs *(Semnopithecus schistaceus)*

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Under the guidence of

Himani Nautiyal and Dr. N.G.Prasad

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Certificate of Examination

This is to certify that the dissertation titled

"Choice and Characteristics of Sleeping Sites in a group of Central Himalayan Langurs *(Semnopithecus schistaceus)*"

submitted by **Virendra Mathur** (Reg. No. MS14129) for the partial fulfillment of BS-MS dual degree programme of the Institute, has been examined by the thesis committee duly appointed by the Institute. The committee finds the work done by the candidate satisfactory and recommends that the report be accepted. This report has also been examined by the students external guide and recommends that the report be accepted.

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Dated: 25.04.2019

Declaration

The work presented in this dissertation has been carried out by me under the guidance of Himani Nautiyal at the field site in Mandal-Gopeshwar and under Dr. N. G. Prasad at the Indian Institute of Science Education and Research Mohali.

This work has not been submitted in part or in full for a degree, a diploma, or a fellowship to any other university or institute. Whenever contributions of others are involved, every effort is made to indicate this clearly, with due acknowledgement of collaborative research and discussions. This thesis is a bonafide record of original work done by me and all sources listed within have been detailed in the bibliography.

Virendra Mathur
(Candidate)

Dated: April 25, 2019

In my capacity as the supervisor of the candidate's project work, I certify that the above statements by the candidate are true to the best of my knowledge.

Himani

Dr. N. G. Prasad
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Himani Nautiyal
(External Supervisor)

Acknowledgement

The work for this thesis took place in two different environments - under the calm and clear of the winter sky and the shadow of the mighty Garhwal Himalayas, and latter half in the invigorating atmosphere of the esteemed institute. The duration spent on field could not have become more joyous then it was, where the morning breeze echoed with the cheerfulness of a valley rising up to the lush yellow of the sun coming up from behind the valleys and peaks that sprawled beyond the towering Rudranath. I possibly could not express the gratitude I felt towards the natural beauty that was holding all of the threads together and how comfortable it made me feel in its lap.

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The absence of the names of any of the persons who have helped me during this study period is not due to the lack of gratitude but just because of lack of memory and space. I apologize if anybody has been left out.

Virendra Mathur

List of Figures

List of Tables

Contents

"Fair is Fair. This is who we are. These are our numbers."

- Mr. Joe Willis (*Mr. Willis From Ohio, The West Wing*)

"So on he fares, and to the border comes,
Of Eden, where delicious Paradise,
Now nearer, Crowns with her enclosure green,
As with a rural mound the champain head
Of a steep wilderness, whose hairie sides
With thicket overgrown, grottesque and wilde,
Access deni'd; and over head up grew
Insuperable highth of loftiest shade,
Cedar, and Pine, and Firr, and branching Palm,
A Silvan Scene, and as the ranks ascend
Shade above shade, a woodie Theatre
Of stateliest view. Yet higher then thir tops
The verdurous wall of paradise up sprung"

- John Milton, *Paradise Lost*

Introduction

Hey! Mr. Tambourine man, play a song for me
I'm not sleepy and there is no place I'm going to
Hey! Mr. Tambourine man, play a song for me
In the jingle jangle morning I'll come following you

Mr. Tambourine Man, Bob Dylan

Existing studies have helped to project sleep as a state of brain, and have analyzed the phenomenon of sleep as a physiological process and as a behavioral state (Samson & Nunn, 2015), which was observed to occur in almost all vertebrates, and likewise in invertebrates (Rasch & Born, 2013). Sleeping consumes almost one third of our lifetime, sometimes amounting to 25 years of an average life span (Purves et al., 2001). A number of studies on sleep-related principles, like sleeping site selection, social dynamics at sleeping site, nocturnal activities, and safety have continued to contribute towards elucidating the evolutionary and adaptive aspects of sleep-related behavioral and psychological complexes in the order Primates (J. R. Anderson, 1998) which had helped in organizing and interpreting the research on the vitality of sleep in humans as humans have come to evolve as the newest extension of the order Primates (Byrne, 1995), as well as further contribute towards the required understanding for conservation efforts of old world and new world non-human primate species (S. Russo & Chapman, 2011). Although the focus of this study is a troop of large-bodied colobine monkeys, the wider implications of studying the sleeping site ecology can help us to infer the sleep behavior of early hominids since they had arboreal mode of living (for foraging and sleeping) (Coolidge & Wynn, 2006; Nunn et al., 2016) despite developing bipedalism which was a derived characteristic (Ko, 2015).

Choosing trees to sleep in night in a sleeping patch and the reuse of sleeping patches can be expected to be governed by minimizing the risks arising from predators or sudden changes in meteorological parameters. Nearness to food resource in the evening and in the morning

might also govern the location of a sleeping site where energy conservation will play its role, as well as the need to defend the home range (Smith et al., 2007).

Various incidental night-time activities in non-human primates, involving vocalizations, have been cited in a comprehensive review by (J. R. Anderson, 2000) though despite these events, a general silence and alert prevailing at sleeping sites can be seen as an anti-predation strategy, as mentioned in (J. R. Anderson, 2000). Reported as a strong ecological factor which affect various facets of the ecology of non-human primates, (Isbell, 1994) reviews adaptations in behavior, social structure, and morphological traits to various affects of consequences of predation in the primate world. (Meddis, 1979) mentions that sleep has evolved in its present form owing to the necessity to maintain stillness and remain inconspicuous during the time when the predator might be on move or is active, indicating towards the role of sleep in behavioral repression during the part of the day for which the animal is not properly adapted (Kandel et al., 2013). A combination of behavioral strategies and suitable sleeping site characteristics can be used by non-human primates in the wild to avoid contact with the predator while sleeping.

A preference for trees taller than average height, having higher DBH than average, and higher basal diameter than average have been said to confer stability while sleeping in night and deter the approach of terrestrial as well as arboreal predators. Such a preference has also been recorded in nest-building non-human primate species. The choice of such trees might depend on group size and structure of the studied species giving rise to ”detection and dilution effects” (Washburn, 1965; De Ruiter, 1986; Fruth, 1995; Tutin et al., 1995; Fruth & Hohmann, 1996; Reichard, 1998; Ancrenaz et al., 2004; Liu & Zhao, 2004; Cui et al., 2006; Law et al., 2008; Pruetz et al., 2008; Phoonjampa et al., 2010; Holmes et al., 2011; Cheyne et al., 2012). Additionally trees with closed canopy and partially exposed or exposed crown structure can provide better concealment along with providing the ability to keep a watch over a larger area. Choosing to sleep in the topmost canopy could be related to the presence of many smaller branches growing away from the main trunk such that they make noise when twitched and might work as an alarm signal for the sleeping individuals (Bert et al., 1967; Gautier-Hion, 1970; J. Anderson & McGrew, 1984; Teichroeb et al., 2012) Closed canopy might also link to a better escape strategy in case the predator approaches the sleeping individuals from below (Hamilton III, 1982; J. Anderson & McGrew, 1984; Stewart & Pruetz, 2013). Within colobines, (Ruhiyat, 1983; Von Hippel,

1998; Liu & Zhao, 2004; Chhangani & Mohnot, 2006; Cui et al., 2006; Qihai et al., 2009; Teichroeb et al., 2012) shows the support towards anti-predatory choice of the sleeping trees and sleeping sites by comparing various tree characteristics and behavior at sleeping sites. The choice of cliff faces, caves, krantzes etc. also makes the approach of the predator difficult (Stoltz & Saayman, 1970; Sigg & Stolba, 1981; Hamilton III, 1982; Barrett et al., 2004; Wang et al., 2011), and the usage has been more prominent in langur species ranging in an area represented by Karst topography where the habitat is devoid of tall trees (Huang et al., 2003; Cyril, 2006; Li et al., 2011).

While moving towards sleeping sites, it has been observed that the individuals become alert and move quietly so as to not attract the attention of a lurking predator or giveaway the location of sleeping sites (Chivers, 1974, 1976; Van Schaik & Hooff, 1983; Caine, 1987; Reichard, 1998; Day & Elwood, 1999; Liu & Zhao, 2004; Xiang et al., 2010; Souza-Alves et al., 2011; Wang et al., 2011). Observational notes on usage of ground to traverse across gaps in forest canopy during daytime (Hamilton III, 1982) and absence of such behavior in night underlines the importance of trees to deter the approach of predator. A quick flight response in Patas(*Erythrocebus patas*) monkeys by running on ground in open woodland type habitat must have contributed towards their sleeping grooves being distributed in open woodland type terrain, suggested (Hamilton III, 1982). A realistic model leopard was successful in making the Bonnet macaques(*Macaca radiata*) abandon their sleeping site to move to another site for refuge in the night (Ramakrishnan & Coss, 2001b).

Shifting of sleeping sites can also be seen as a strategy to prevent the predator from ascertaining the position of the primate species (Chapman et al., 1989; Heymann, 1995; Von Hippel, 1998; Cui et al., 2006), as well as to maintain nearness to feeding patch (Rahaman & Parthasarathy, 1969; Hamilton III, 1982). The continuous usage of a sleeping site for a long time can result in large amounts of fecal deposition which might act as a cue for the predator (Hrdy, 1980). Fecal deposition can also become a cause of parasite infestation (Dawson, 1979; Hausfater & Meade, 1982; J. R. Anderson, 2000) affecting host survival directly in terms of decreasing fitness or decreasing competitive ability, thereby increasing predation-risk (Scott, 1988). Primates may be susceptible to infections due to their social living structure (Stoner, 1996) which could be balanced by intense grooming sessions (Kowalewski & Zunino, 2005).

Another factor that affects the choice of a sleeping site is the need to protect oneself from environmental disturbances while sleeping in the night (Kummer, 1981; C. M. Anderson, 1982; Zhao & Deng, 1988). (Stoltz & Saayman, 1970) mentioned that troop members did not move much on days of harsh weather and take shelter in and around the cave where they slept in the night. The study also reported the gathering of troop at a place near the sleeping site to bask in sun. Indeed sleeping sites might be located such that they receive the first sun rays in the morning (Goodall, 1962; MacKinnon, 1974; Smith et al., 2007).
(N. H. Bishop, 1979; Liu & Zhao, 2004; Cui et al., 2006) observed similar selection of sleeping sites in colobines ranging at higher altitude regions of Himalayas and its flanking mountain ranges. Such selection of sleeping sites aid in maximizing the time for sunbathing (Furuichi et al., 1982). It has been observed that the sleep duration increases during low temperature in winter (Liu & Zhao, 2004; Xiang et al., 2010). Thermoregulatory aspects also govern the choice of sleeping site in many non-human primate species (Gaulin & Gaulin, 1982; Takahashi, 1997) dictated by the need to maintain a constant body temperature during the night (Chivers, 1974; J. Anderson & McGrew, 1984; Aquino & Encarnación, 1986) while sleeping on trees. Huddled sleep can provide warmth while sleeping, and also tends to provide stability during the night (J. Anderson & McGrew, 1984). The huddle size might be constrained by the weight a particular branch can hold, or in the case of cliff faces or ledges by the size of the ledge (J. R. Anderson, 2000). Cavity like spaces might offer comfort for the non-human primates sleeping on a tree (Di Bitetti et al., 2000; Cheyne et al., 2013). Many of the old world monkey species sleep in an upright position or squatting position with their hands and feet tucked together between the flexed legs. The individuals in langur troop under observation also lowered their head frontally while sleeping which might further help in preventing heat dissipation, as well as lower the centre-of-gravity to maintain stability.

Proximity to feeding patches can also shape the choice of sleeping sites for non-human primates (Goodall, 1962; Chapman et al., 1989; Heymann, 1995; Day & Elwood, 1999; Basabose & Yamagiwa, 2002). Sleeping near a feeding patch is a way to minimize energy expenditure from travelling between patches, reduce resource competition, and increase foraging efficiency (Kinzey et al., 1977; Rasmussen, 1979; S. E. Russo & Augspurger, 2004; Smith et al., 2007; Fan & Jiang, 2008; González-Zamora et al., 2012). Sleeping in a fruiting tree can work as a cue for the predator (Sugardjito, 1983) and becomes risky in

case of competition for the same food in conspecific or inter-specific presence. Though (Teichroeb et al., 2012) suggested that this might not be the case for folivorous species of non-human primates simply due to the abundance of leaves and thus sleeping in the food tree might not bring the same level of harm as for frugivorous species. Colobine species have been observed to sleep near the feeding patches as well (Von Hippel, 1998; Teichroeb et al., 2012) and range in smaller areas during winter as compared to summer for feeding while reducing energy expenditure from travel (Liu & Zhao, 2004). Costs associated with travel can be reduced by choosing multiple sleeping sites (Multiple Central Place Foraging) (McLaughlin & Montgomerie, 1989; Chapman et al., 1989) as compared to the travel costs involved in returning to a single centrally located sleeping site (Central Place Foraging) (Schoener, 1979; Andersson, 1981).

The lowland counterparts of Central Himalayan Langurs have been widely studied owing to the widespread distribution of their population across the Indian subcontinent (N. Bishop, 1975; N. H. Bishop, 1979; V. Singh & Thakur, 2017). Sleeping sites of three sympatric primates - Bonnet macaques (*Macaca radiata*), Nilgiri langurs (*trachypithecus johnii*), and Hanuman Langurs (*Semnopithecus entellus*), facing similar predation pressure, were compared for a brief period of 5 days. It was observed that all the three species used trees with higher bole and which also extend further away from the main trunk, probably a measure to deter the predator from climbing up (Ramakrishnan & Coss, 2001a). Two bisexual and an all male troop of Hanuman langurs were studied in Morni Hills which form a part of lower Shiwalik ranges (Chopra et al., 2012). Both bisexual troops faced Leopard(*Panthera pardus*) threat, though the troop at highest altitude (1132m) faced primary threat from dogs. The choice of sleepimg site was shown to be affected by predator presence as well as environmental factors for the three troops. Only a handful of studies have looked at the sleeping site choice and behaviour of the Himalayan counterpart. Earlier reports observed that the troops slept split in studies carried out in Shimla and Bhimtal respectively (Vogel, 1971; Sugiyama, 1976). Nonetheless, all the studies reported by (N. H. Bishop, 1979), which were carried out in Himalayan belt, mentioned the usage of multiple sleeping sites. It also mentions observations such as sun basking, huddling on cold nights, no clear relation between the sleeping sites and feeding patches, as well as delayed exit from the sleeping sites at the time of heavy snow. A typical behavior while descending from the sleeping site involved a loud display by the adult male, often accompanied by whooping (N. H. Bishop,

1979). (Sayers, 2008) mentioned that they usually found one of the studied troop near their sleeping sites which were generally cliff face, whereas the other troop used large trees as sleeping sites.

Through this study, I tried to understand the sleeping site characteristics and the factors that affect the choice making for a troop of Central Himalayan Langur in Garhwal Himalayas. A few qualitative descriptions of sleeping sites are present in studies related to ecology and behavior of the Himalayan population, though their habitat ecology and behavior is different from their lowland counterparts (N. H. Bishop, 1979; Sayers, 2008; Nijman, 2014). Hence, this report aims to present the first detailed qualitative as well as quantitative observations from a continuous data collection period, for this species. We also tested the choice making for the predictions arising from three of the above mentioned factors - the anti-predatory choice of sleeping sites, the choice of sleeping sites according to foraging constraints, and that due to thermoregulatory constraints. Moreover, this study also quantifies factors like density dependence in the preference of species chosen for sleeping, as well as the effect of temperature on the sleep duration and day-activity time. These preliminary results about the sleeping behavior and sleeping ecology of this primate species stands to contribute in understanding the adaptation of this species and how does any changes in forest cover or climate can affect them. This species alongwith neighboring species of Himalayan langurs (Groves, 2001; Wilson & Reeder, 2005; V. Singh & Thakur, 2017) can face the first and foremost effect of climate change because of their habitat in a sensitive Himalayan ecosystem (Beniston, 2003; Nautiyal, 2015). Further changes in food abundance from forest or agricultural crops and predator pressure will effect the home range size of the langurs. Change in the patterns of agricultural activities and the resulting human interference can also potentially disturb the home range sizes (Chhangani & Mohnot, 2006). Such a change might result in the decrease of density of preferred species for sleeping, affecting the ecology and behavior of these highland species of langurs since they prefer to sleep high on trees (Ruhiyat, 1983; Stanford, 1991; Ramakrishnan & Coss, 2001a). Loss of suitable sleeping sites will also render the individuals unsafe during the night affecting their population density as well. The importance of *Quercus spp.* can be understood from the fact that it has formed the part of the sleeping sites for various Himalayan populations of langurs as reported in (N. Bishop, 1975; N. H. Bishop, 1978; Laws & Laws, 1984; Minhas et al., 2010). A decrease in forest cover will not only affect the availability of sleeping

sites, but also increase the dependence of these species on provisioned food and increased human wildlife conflict. The imminent threat to ecology of these non-human primates are from looping, overgrazing, and agricultural and development activities (V. Singh & Thakur, 2017).

Chapter 1

Study Site

1.1 Location

Kedarnath Wildlife Sanctuary (KWS) is one of the largest protected areas in Western Himalayas harboring a luxurious and varied growth of vegetation which finds its importance in medicinal, aesthetic, or nutritional usage (G. Singh & Rawat, 2011). Kedarnath Wildlife Sanctuary (N$30°25'57.36''$ - N$30°45'15.99''$, E$78°54'26.55''$ - E$79°26'32.82''$) stretches between the inner valley of Mandakini River on its left extreme and Alaknanda gorge on the N-E flank covering an area of 975km^2 (I. Rai et al., 2017). This wildlife sanctuary was established in 1972.

This study was conducted at and in the surrounds of Mandal in the state of Uttarakhand, India. Mandal (N $30°27'36.396''$, E $79°16'40.26''$; 1450-2000m asl) is a small village located at the southern outer fringe of KWS in Chamoli district in Garhwal Himalaya region, and forms one of the many gateways to travel inside the wildlife sanctuary. Mandal village is located on the famous pilgrim route to Tungnath, Rudranath, and Kedarnath which forms the part of *Panch Kedar* and holds a high religious reverence. Amritganga and Balkhila are the two major rivers that drain this area, and merge into Alaknanda.

1.2 Climate

The study site lies in the Mandal Valley which covers an area of 100km^2. The valley covers a wide altitude range of 1500 to 3680m (G. Singh, Rawat, & Jalal, 2009). The Mandal-Trishula forest counts among one of the immaculate forest patches in Uttarakhand. There

is a influence of alpine climate on the vegetation of this valley, characterized by dense fog, frost, heavy hailstorms, extreme low temperatures, high solar radiation and wind velocity, and heavy snow during winter season in its high altitudes. At times, the weather might fluctuate sharply on the same day. This valley receives heavy rainfall during rainy season at lower altitudes. Owing to the frequent rains, this place is also known as Cherrapunji of Garhwal Himalaya. This region is one of the most agriculturally productive valleys of the region situated between 1200-1500m amsl (I. Rai et al., 2017).

(Gairola et al., 2010) reported mean annual maximum temperature as 16.41 $\pm$ 3.60 °C and mean annual minimum temperature as 6.14 $\pm$ 1.98 °C. Mean annual rainfall was measured to 2044.47 $\pm$ 476.01mm. Mean Relative humidity ranged from 15% to 86% round the year. The rainy season accounts for about three-quarters of the annual rainfall. The study site experiences three main seasons around the year in form of the cool and relatively dry winter (December to March), the warm and dry summer (mid-April to June), and a warm and wet period (July to mid-September) called as the monsoon or rainy season. A transition period interconnecting rainy and winter, and winter and summer was referred to as autumn (October to November) and spring (February to March), respectively.

1.3 Flora

KWS has a rich heritage of floristic species, as well as medicinal stock in its abundant floral diversity (G. Singh & Rawat, 2011). Not only does this wildlife sanctuary attracts pilgrims, naturalists, and ecologists for its panoramic view but also for the kind of ecosystem services its forests provide (I. D. Rai et al., 2012). The major vegetation types include subtropical needle forest formed by *Pinus roxburghii* (Chir Pine), mountain broadleaved forest, hill side grasslands, subalpine conifer forest, birch-rhododendron forest, stunted forests of *Rhododendron campanulatum* (Simru), alpine moist scrub, montane grasslands, and various types of alpine herbaceous meadows (bugyal) (I. Rai et al., 2017).

Mandal forest are spread across an altitude range of 1,400m to 2,900 m amsl and represent temperate, sub-alpine, and alpine habitats (G. Singh, Naithani, & Rawat, 2009). The dominant vegetation cover in forests is represented by various species of Oak [*Quercus glauca* (Harinje), *Quercus leucotrichophora* (Banj), *Quercus floribunda* (Moru), and *Quercus semecarpifolia* (Kharsu)], as well as Fir (*Abies pindrow*,*Abies spectabilis*), Alder (*Alnus*

neplaensis), *Carpinus viminea*, *Carpinus faginea*, *Betula alnoides*, *Cornus macrophylla*, *Rhododendron arboreum*, and several members of family *Lauraceae*. The understory of these forests is dominated by hill bamboo species (*Sinarundinaria falcata*, *Thamnocalamus falconeri*) and provides an ideal habitat many of the wild fauna. These species form the climax vegetation in different climatic zones. These forests of Oak support abundant growth of epiphytes, and also help in maintaining the ecological anhydrological balance. These forests provide resources to cater to the day to day requirements of local inhabitants (G. Singh, Rawat, & Jalal, 2009).

1.4 Fauna

The pristine forests of Mandal valley plays host to a large avifaunal diversity. This area is an important wintering range of several high-altitude animals. Out of the 23 mammalian species recorded from the sanctuary, 11 have been declared threatened. Rhesus Macaques (*Maccaca mulata*), alongwith Central Himalayan Langur (*Semnopithecus schistaceus*) represent the primate species. Carnivores include Jackal (*Canis aureus*), Red Fox (*Vulpes vulpes*), Asiatic Black Bear (*Ursus thibetanus*), Yellow-throated Marten (*Martes flavigula*), Leopard Cat (*Prionailurus bengalensis*), Common Leopard (*Panthera pardus*), and Snow Leopard (*Panthera uncia*). Ungulates are Wild Boar (*Sus scrofa*), Musk Deer (*Moschus chrysogaster*), Indian Muntjac (*Muntiacus muntjak*), Sambar deer (*Rusa unicolor*), Goral (*Naemorhedus goral*), Himalayan Serow (*Capricornis thar*), Himalayan Tahr (*Hemitragus jemlahicus*), and Himalayan Blue Sheep (*Pseudois nayaur*). Over 230 species of birds are reported from the area. Himalayan Monal pheasant (*Lophophorus impejanus*), Kalij pheasant (*Lophura leucomelanos*) and Koklass Pheasant (Pucrasia macrolopha) are common in occurrence (Nautiyal, 2015).

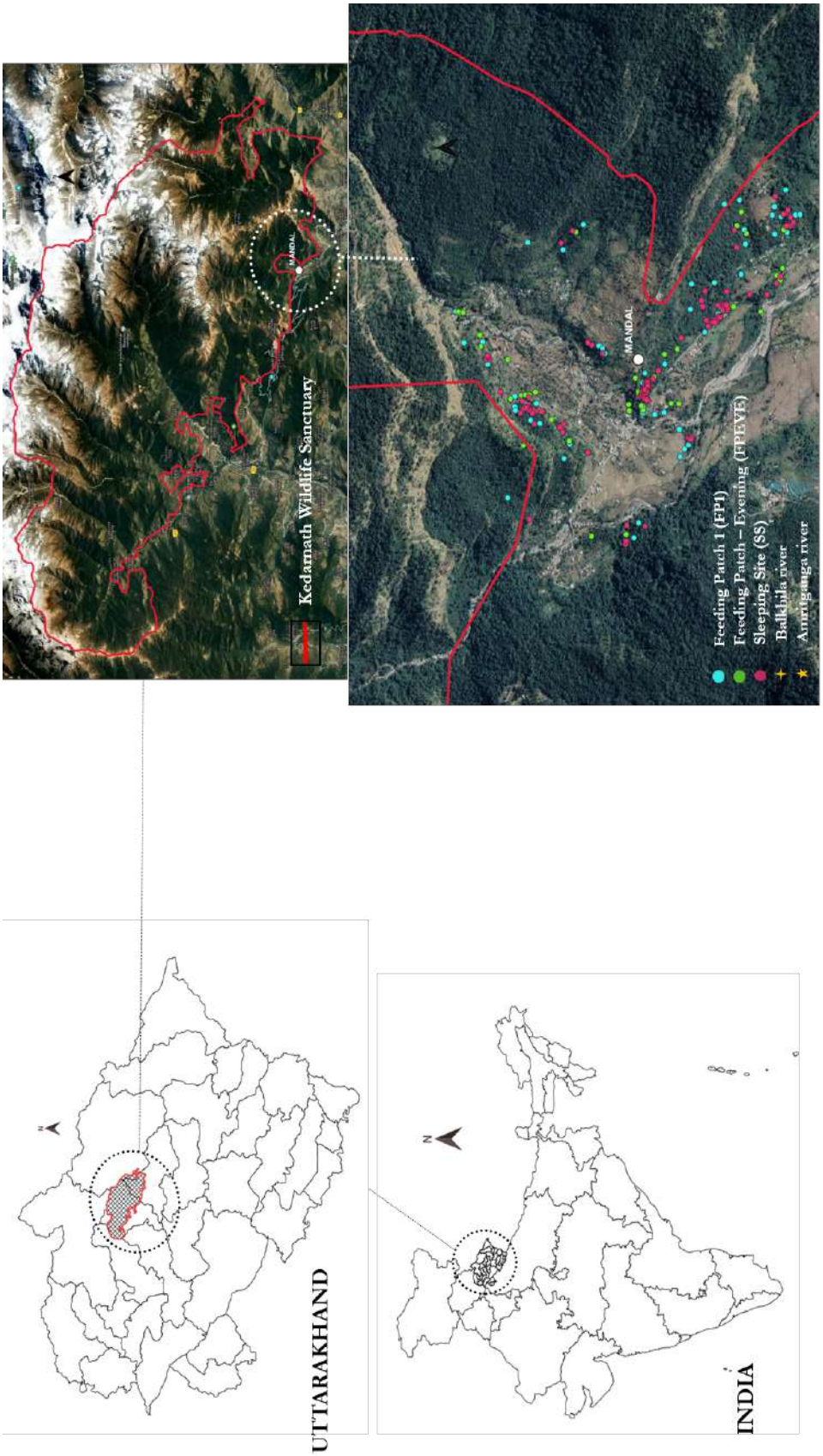

Figure 1.1: Map of Study Site and Kedarnath Wildlife Sanctuary.

Chapter 2

Study Species

I studied a single langur troop near the vicinity of Mandal village. The troop ranged in an area of about 2km^2. The home range of these langurs is also shared by small human settlements. Their home range is bordered by dense forest patches on the southern and north-eastern boundary, the road running through Mandal and turning towards Herbal Research and Development Institute, forms the north-western boundary. Besides this troop, another troop of langurs (AT1) resides near the cliff face running parallel to the southern edge of the study troop. A yet another troop (AT2) was twice observed near the north-western boundary.

The troop has been well habituated by Himani Nautiyal since 2014 and most of the individuals were identified by the year 2017. Due to this long term habituation, the langurs can be approached within a close range. This long term habituation made the data collection possible without impacting the natural ranging behavior of the langur troop. The data collection and observations were limited more by the weather, the habitat characteristics, and on several occasions by the impediment arising due to human-wildlife interaction. Thus they were not followed into certain areas of their home range. During such cases, we did record the name of the sleeping patch where they retired for the night.

Our study troop lives in a multi-male multi-female societal structure. The troop travels as one group through out its territory. The highest count for this group involved 66 individuals. This area is also inhabited by two groups of Rhesus Macaque *(Macaca mulata)*. These two groups divide into smaller sub-groups and intersperse in the complete area during daytime. These groups congregate at a sleeping site in night, occasionally the same as chosen by langurs (Personal Observation).

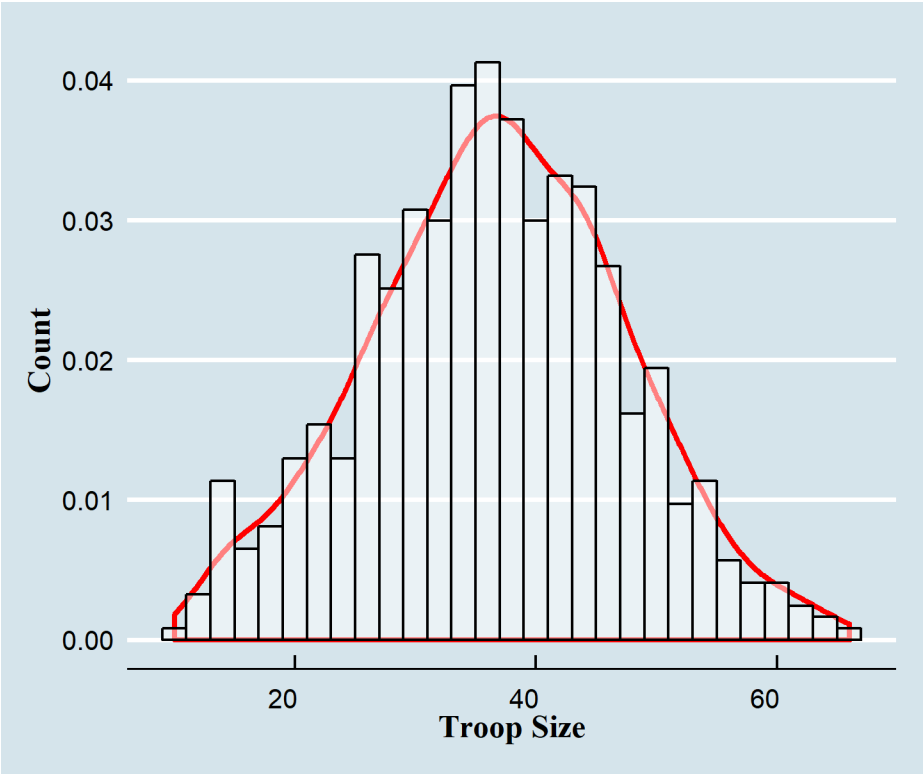

Figure 2.1: Count of Individuals

2.1 Taxonomic Identification

The Hanuman langurs found in Central Himalayas is one of the various species under the genus *Semnopithecus* found throughout the Himalayas. They belong to subfamily *Colobinae* under family *Cercopithecidae* (Nautiyal, 2015), forming a part of the Asian taxa of Colobines, their counterpart being the Colobines found in Africa (Disotell, 2000). This species was classified as a sub-species along with others under *Semnopithecus entellus*, also known as Gray Langur. The Gray Langur are distributed across the Indian subcontinent and occupy various habitats (N. H. Bishop, 1978, 1979). It could be possible that Himalayan Hanuman Langurs have adapted to permanent mountainous dwellings and atleast seasonally extend their altitude range upto 4,000m a.s.l (N. H. Bishop, 1978; Nijman, 2014). As of 2001, the Himalayan Langur have been declared as a species under the *Semnopithecus* genus (Minhas et al., 2010).

Chapter 3

Materials and Methods

3.1 Observation and Data Collection

3.1.1 Locating the troop

The data collection took place between August 2018 and mid December 2018. The troop was located in the early hours before sunrise in their sleeping sites. The troop was then followed until they enter the next sleeping site in evening and observations were recorded till the troop settled down.
(Von Hippel, 1998; Phoonjampa et al., 2010; Teichroeb et al., 2012) amongst others used the same technique to locate sleeping sites. This was done to ensure the starting point for the next day. During the month of August, contact with the troop was not guaranteed on some days due to continuous and heavy rainfall. Sudden change in weather conditions was also a source of discontinuity in data collection process on some days in later months. On the nights when the langur troop chose to sleep in a patch very close to, or in immediate vicinity of a human settlement, we prevented from going early the next morning at their sleeping site though we tried to make sure that the sleeping site for that day can be traced in the evening session. Observational data was collected by naked eye or through binoculars. To maintain uniformity in the scoring of categorical variables and estimation of height, I myself scored and estimated these variables.

3.1.2 Sleeping Trees

A “Sleeping Tree” was considered as the one which was used by individuals of the troop to sleep in the night(Reichard, 1998). Only when sleeping on cliff faces that the troop used one or two trees to sleep in, otherwise troop individuals always settled on multiple (>2) trees to sleep in the night.

A “Unique sleeping tree” was considered one which has been used only once to sleep when the troop was in that sleeping site and was not used after that again, whereas a “Reused sleeping tree” was one that had been used more than once after the first use when the troop visited that sleeping site (Day & Elwood, 1999; Hernandez-Aguilar, 2009) . Though the reuse of the tree was separately counted, it was assigned only one data point in the count of total unique sleeping trees (Teichroeb et al., 2012).To count for the unique trees used for sleeping in the night, the trees were marked with a unique alphabetical code and the data set was continuously updated by adding the unique trees for each nights sleep. These markings were used for subsequent re-identification in case of reuse of sleeping trees. After a tree has been used for the first time during the observation period, each reuse of that tree from then on was recorded by noting down the alphabetical code given to the tree. At the end of study period, the total reuse per tree was counted. In the case of trees which were multistem below 137cm, a single alphabetical code was given to it conserving the naming scheme and its reuse was also counted as a single datum in the reuse count.

3.1.3 Sleeping Tree Characteristics

For data entry, I used an alpha numeric code as an identity for each unique tree. The assigned code consisted of: **Patch Code/Day/Month/Alphabetical Code**.

The measurements for the sleeping trees after each nights usage were recorded under the following variables:

Table 3.1: Measured variables for Sleeping trees.

ID	ID Label	Category
SS	Sleeping site	-
Sp	Species of the tree used for sleeping	-
C137(m)	Circumference at 137cm (in metres)	-
BCrm (m)	Basal Circumference (in metres)	-

AppHt (m)	Approximate Height (in metres)	-
FeP	Fecal Patch under sleeping tree	**1**:Presence; **0**:Absence
Canopy	Canopy Type	**1**:Open; **2**:Closed
Crown	Crown Type	**1**:EXPO; **2**:PEXPO; **3**:NEXPO
MST	Multistem	**1**:Yes; **0**:No
MSTHt (m)	Multistem height above ground (in metres)	-
Forked	Forked branching pattern	**1**:Presence; **0**:Absence
Vertical	Vertical or Slanting tree	**1**:Yes; **0**:No
Phenology	Phenology scores under given categories	**FL**:Flush Leaves; **ML**:Mature Leaves; **YL**:Young Leaves; **FLO**:Flower; **UFR**:Unripe Fruit; **RFR**:Ripe Fruit

3.1.3.1 Canopy Type

Canopy type was defined as Open or Closed type (Hamilton III, 1982). An Open type canopy was scored when the sleeping tree does not offer the langurs to traverse without coming to the ground indicated by the trees surrounding the sleeping tree and rising to the level of sleeping tree. Vice versa a Closed canopy was the one where langurs can travel out of the sleeping tree without coming to the ground.

3.1.3.2 Crown Type

The categorization was adapted from (Cheyne et al., 2012) to assess the predator access routes to the sleeping trees. Crown type was scored as -

EXPO when the top of the crown of the sleeping tree was “Emergent” relative to the general canopy layer of the patch.

PEXPO when the top of the crown of the sleeping tree was “Equal” relative to the general canopy layer of the patch.

NEXPO when the top of the crown of the sleeping tree was “Lower” relative to the general

canopy layer of the patch.

This categorization is a modification from (Phoonjampa et al., 2010).

3.1.3.3 Multistem Property

During the measurement, multistem trees were measured according to the criteria listed here: A tree was counted as a multistem whenever the main trunk divides into two or more trunks growing to an almost equal lengths. The basal area of trunks for a MST remains the same. If the trunk divide at an height lesser then 137cm above the ground, the parameters for each trunk were recorded separately under the same code. If the tree was multistem above 137cm, we scored 1 for MST but parameters were not recorded separately.

3.1.4 Sleeping Sites

The sleeping sites were identified with codes given based on the nearest village or landscape feature of that area. A sleeping site consisted of multiple sleeping trees, and few of the sleeping sites include cliff faces and crevices which were also used for sleeping. Two methods were used to determine sleeping sites. In the case where the troop was followed to the sleeping site, a direct observation was made. A sleeping site was also confirmed the next morning with the presence of fresh fecal patches around the sleeping trees (Liu & Zhao, 2004; Cui et al., 2006; Stewart & Pruetz, 2013).

Table 3.2: Sleeping Sites.

Code	Patch Name	Type of Sleeping Site
FC	Forest Chowki	Trees
GoCl	Gondi Cliff	Trees,Cliff face
GoRi	Gondi River	Trees
GurT	Gurukripa Top	Trees
KAG	Kunkuli Agriculture	Trees
KOP	Kunkuli Oak Patch	Trees
KSAL	Kunkuli Shivalaya	Trees
KVi/MakVi	Kunkuli Village/Makroli Village	Trees
MSAL	Mandal Shivalaya	Trees
SF I	Sanso Forest I	Trees

SF II	Sanso Forest II	Trees
SiB	Siroli Bridge	Trees,Cliff face
SOAG	Sanso Agriculture	Trees,Cliff face
SOP/SROP	Siroli Oak Patch/Siroli Road Oak Patch	Trees

3.1.5 Foraging Strategy

The comparison of the foraging strategy of the langur troop was performed with the expected results from a "Central Place Foraging Model" and a "Multiple Central Place Foraging Model". To test for the above strategies, the linear distance of the location of sleeping site from the location of last feeding patch before entering the sleeping site, was used. These distances formed the "Observed" distance class. Following (Smith et al., 2007), the "Central Place" was generated from the mean latitude and mean longitude of all sleeping sites located during the observation period. Thus, the linear distance of the location of last feeding patch of the day was calculated from the "Central Place". The linear distance of the last feeding patch of the day was calculated from the nearest sleeping site was obtained under the "Nearest" category (Multiple Central Place Foraging).

3.1.6 Behavioral Data Collection

Since it was generally dark in the early morning hours and in the evening till the troop settles, it became difficult to see the faces of individuals and identify them. Calls produced by male and female adult individuals were easy to distinct, and similarly the crying or screaming of a juvenile or infant. Thus, data was recorded in form of frequency tables (Altmann, 1974) under the categories **Mating**, **Macaque Presence**, **Inter Specific Threat**, **Display**, **Alarm Call**, **Female-Female Aggression**, **Grunt call**.

We also recorded the composition of huddle, substrate for the huddle, position on the branch, weather, observed time of sun rays, and elevation. Time of entry and exit of the first individual, as well as the time of settling of the troop and time when greater than 50percent of the individuals were out of the sleeping tree was also recorded whenever permitted by the conditions. The Number of individuals exiting from the same and alternate tree was also recorded whenever possible. The activity of various individuals of the troop was also noted

down during full day follows, in form of scan samples taken at an interval of 10 minutes for a duration of 20 minutes each.

3.2 Control Data

The control data to compare for and to assess the general forest characteristics was collected towards the end of the data collection period. I followed the protocol for Point Centred Quartered Method (PCQM) technique, as explained in (Mitchell, 2010) to carry out the measurements for the control data. PCQM (Cottam et al., 1953) is one of the plot-less methods which uses the spacing distances for the sampling of plant community in an area. Such plot-less methods have been shown to produce good results while providing flexibility with sample sizes and requiring lesser manpower and are faster (Cottam & Curtis, 1956). Not only is this method fast but also minimizes the harm to understory of a forest (Cunningham, 2001). This method has been cited by (Xiang et al., 2010; Cheyne et al., 2012) to procure the data for control trees. 30m line transects were drawn out and measurements were taken at 10m intervals so as to avoid the possibility of repeats. At the points where measurements were taken, we drew a line perpendicular to the transect line to generate four quarters and measured the nearest tree in all these four quarters. Although ideally no limit should be set for the "nearest" tree , we set out with a limit of 30m (equal to one transect length) to be the limit for searching for the nearest tree. Some modifications were also made to the original protocol to collect the data. The trees chosen for sleeping in the wild were considered as a part of the overall biomass of the forest area and therefore we recorded a tree used for sleeping as a transect tree if it happens to fall at the nearest point. When comparing between characteristics of non-sleeping trees and sleeping-trees, we carried out the analysis by removing the sleeping tree readings from the control data. All the data points were considered while calculating the absolute density and absolute frequency from the PCQM data, as explained in (Mitchell, 2010).

3.3 Instruments Used

- The measurements involving length (C137(m), BCrm(m), MSTHt(m)) were completed using a 30m/100ft measuring tape. The data was recorded upto two decimal

places.

- Temperature data was extracted from TR-51*i* Data Logger using TR-50U2 Communication Port. Both of these devices were manufactured by T&D Corporation.
- Garmin GPSMAP 62s device was used to mark the GPS points for sleeping sites and feeding patches during the study period.

  All the support, including logistics and instruments for this project, was provided by Himani Nautiyal under whom I worked on this project.

3.4 Methods used for Analysis

- All the analysis and plotting was done using R- language (Team, 2018). Data management was done using Microsoft Excel2014. The libraries used in R were: chron (James & Hornik, 2018), coin (Hothorn et al., 2006, 2008), dplyr (Wickham et al., 2018), extrafont (Chang, 2014), geosphere (Hijmans, 2017), ggmap (Kahle & Wickham, 2013), ggplot2 (Wickham, 2016), ggpubr(Kassambara, 2018), ggridges (Wilke, 2018), ggthemes (Arnold, 2019), lubridate (Grolemund & Wickham, 2011), RVAideMemoire (Hervé, 2019), scales (Wickham, 2018)
- Wilcoxon Rank Sum test with continuity correction was used to compare for significant differences for comparisons of parametric as well as non-parametric variables. The test can be run for. The following arguments were used wherever required: alternative = c("two.sided", "greater", "less"); paired = logical (TRUE or FALSE). The test statistic and the p-value as returned by the test has been reported in the results. All tests were carried out at an alpha level of 0.05 and bonferroni correction was applied wherever required.
- χ^2 test of independence was used to compare the data for categorical variables to a theoretical distribution defied by the test.
- Shapiro-Wilk test was used to check whether the data is normally distributed or not. QQ plots were also generated to check for normality.
- Pearson rank correlation test was used to check for relationship between normally distributed variables. Spearman rank correlation test was used while checking the relationship between non-normally distributed variables.

Chapter 4

Observations and Results

We were able to collect data for the characteristic of sleeping trees on 96 days (i.e. on 96 mornings after the troop has used the trees on the previous night) during the field study. Although the sleeping site was recorded by distant observation, sleeping tree characteristics were not always recorded due to aforementioned reasons. We were able to record the sleeping site usage for 117 out of total 137 nights.

4.1 Sleeping Trees

The langur troop chose a total of 306 unique trees to sleep on 96 nights for which the data is available. These trees belonged to 17 different species. The count for the species was independent of each other (G-test: df=16, p-value $< 2.2*10^{-16}$). 60 out of the 306 unique trees (19.61%) were multistem. Out of these 60, 37 (61.66%) were multistem above 137cm and only one measurement of such trees was recorded.

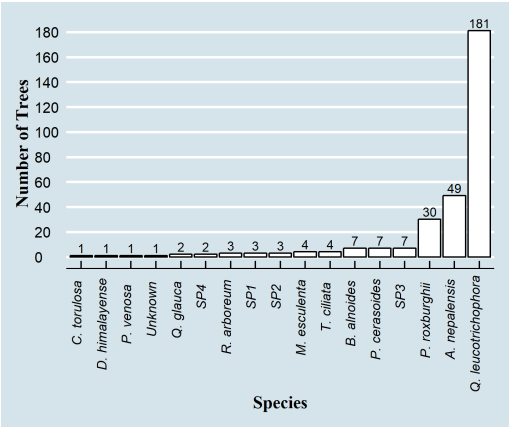

Figure 4.1: Sleeping Tree Usage Across Species

Table 4.1: Species represented by sleeping trees.

Species	Common name	Code
Cupressus torulosa	Surai	*Ct*
Daphniphyllum himalayense	Ratnela	*Dh*
Prunus venosa	Gadaru	*Pv*
Unknown	NA	UNK
Quercus glauca	Harinje	*Qg*
SP4	Kathui	SP4
Rhododendron arboreum	Burans	*Ra*
SP1	Dauwa	SP1
SP2	Ghenduri	SP2
Myrica esculenta	Kafal	*Me*
Toona ciliata	Toona	*Tc*
Betula alnoides	Shodh	*Ba*
Prunus cerasoides	Payaan	*Pc*
SP3	Kakaru	SP3
Pinus roxburghii	Chir Pine	*Pr*
Alnus nepalensis	Uttish	*An*
Quercus leucotrichophora	Oak (Banj)	*Ql*

The troop added 3.2 unique trees for each night they entered in a sleeping patch to sleep. Over a total of 117 nights, the cumulative curve of the unique trees used reached an asymptote.

Table 4.2: Sleeping trees across months.

Month	Unique	Reused	% Unique	% Reused	Total
Aug	43	15	74.13793	25.86207	58
Sept	111	168	39.78495	60.21505	277
Oct	82	249	24.77341	75.22659	331
Nov	70	267	20.77151	79.22849	337
Dec	0	192	0	100	192

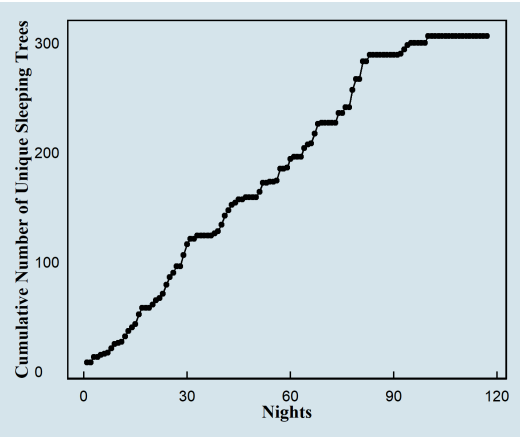

Figure 4.2: Unique sleeping trees (Cumulative).

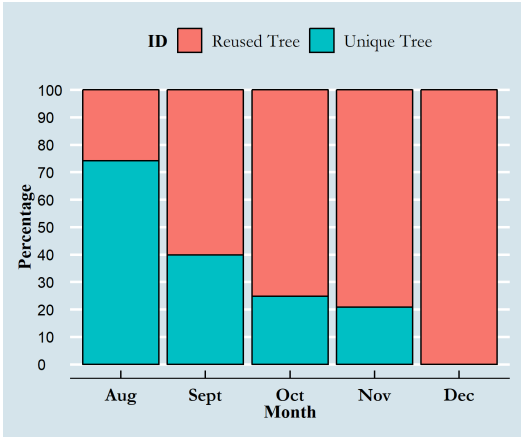

Figure 4.3: Tree count across months.

Active reuse of the sleeping trees was also observed after the trees have been chosen once to sleep by langurs. 180 sleeping trees (59.2%, *n*=304) were reused more than once during the observation period. The highest reuse of a tree was for 11 times. When categorized by species, all of the species were reused (at least once) except four.

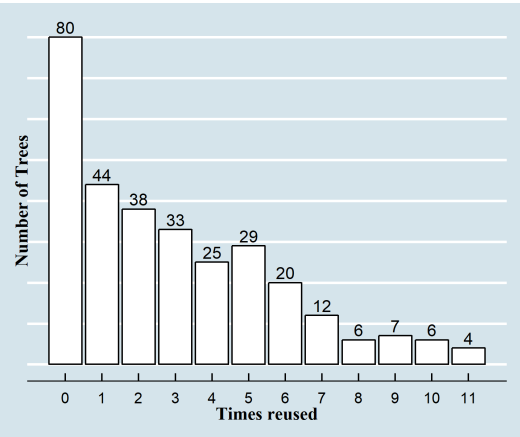

Figure 4.4: Sleeping Trees Reuse Frequency

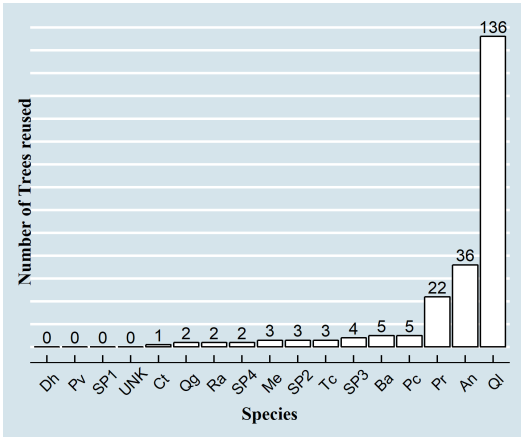

Figure 4.5: Reuse Across Species

To check for the correlation between absolute frequency of trees of a species and it's observed proportion in the count of sleeping trees, Spearman correlation test was used. A linear regression was performed to derive the value of goodness of fit between response and predictor variable.

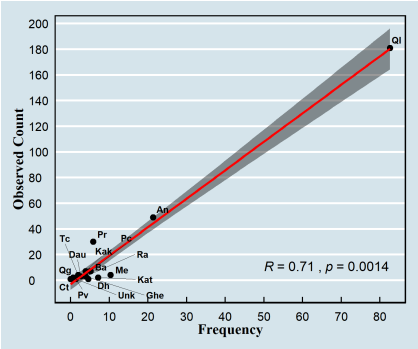

Figure 4.6: Frequency dependent usage

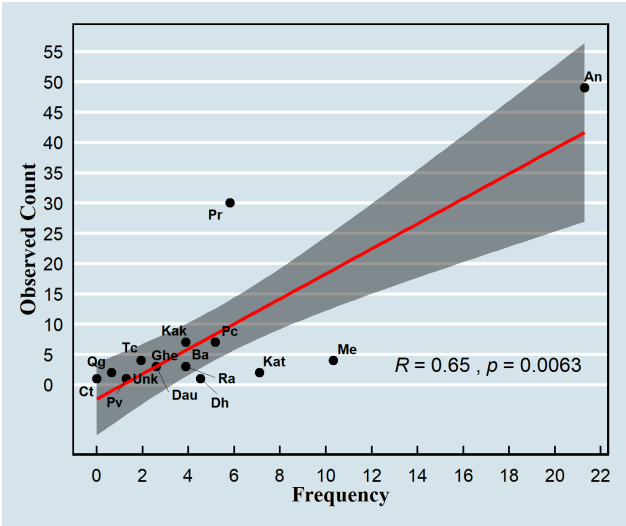

Figure 4.7: Frequency dependent usage(Without *Quercus)*

The results showed a significant correlation between the frequency and the observed usage of the trees of different species for sleeping from the data collected (Spearman: cor.coeff=0.71, p $<$ 0.05; R^2 = 0.96). When we removed the highest usage species from the comparison, the relationship still was significant, though a decrease in the strength of the correlation was observed(Spearman: cor.coeff=0.65, p $<$ 0.05; R^2 = 0.6287). Thus, the langur troop we observed happen to use trees of certain species fewer than others due to the fact that they are present like that in their home range. The langur troop does not tend to show preference for any species, except *Pinus roxburghii*. The cumulative number of species used for sleeping reached an asymptote for this observation period. This shows that langurs have exhausted their search for suitable species to sleep in.

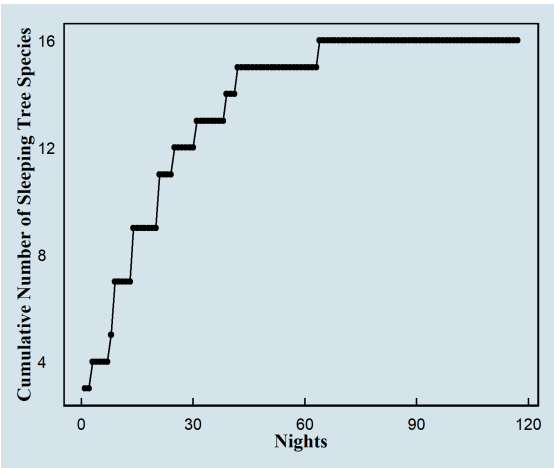

Figure 4.8: Cumulative number of species slept in by the group.

4.1.1 Characteristics of Sleeping Trees

4.1.1.1 Diameter at Breast Height (DBH)

The measurements for all the trees (sleeping and non-sleeping) were made at 137cm above the ground. The average DBH of sleeping trees were found to be significantly greater than the DBH of non-sleeping trees (Wilcoxon: W=133910, p-value = $3.14*10^{-16}$, p-signif<0.0001).

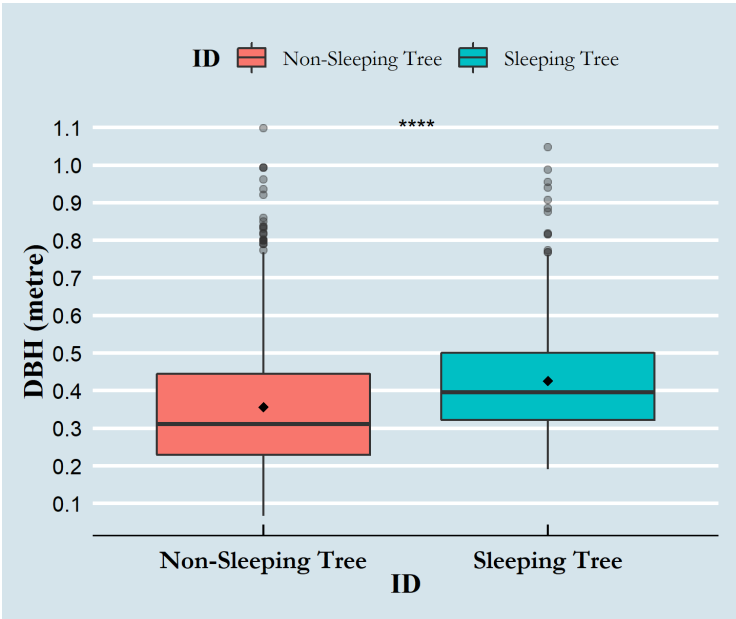

Figure 4.9: DBH(137cm) comparison between Sleeping and Non-sleeping tree.

Table 4.3: DBH(137cm) parameters.

ID	Count	Mean	SD	Median	IQR	Min	Max
Non-Sleeping Tree	638	0.356	0.176	0.310	0.216	0.0669	1.10
Sleeping Tree	317	0.426	0.149	0.395	0.178	0.191	1.05

4.1.1.2 Basal Diameter

The measurements for all the trees were made at the point where the base touches the ground. The average basal diameter of sleeping trees was found to be significantly greater than the DBH of non-sleeping trees (Wilcoxon: W=127470, p-value = $1.17*10^{-14}$, p-signif<0.0001).

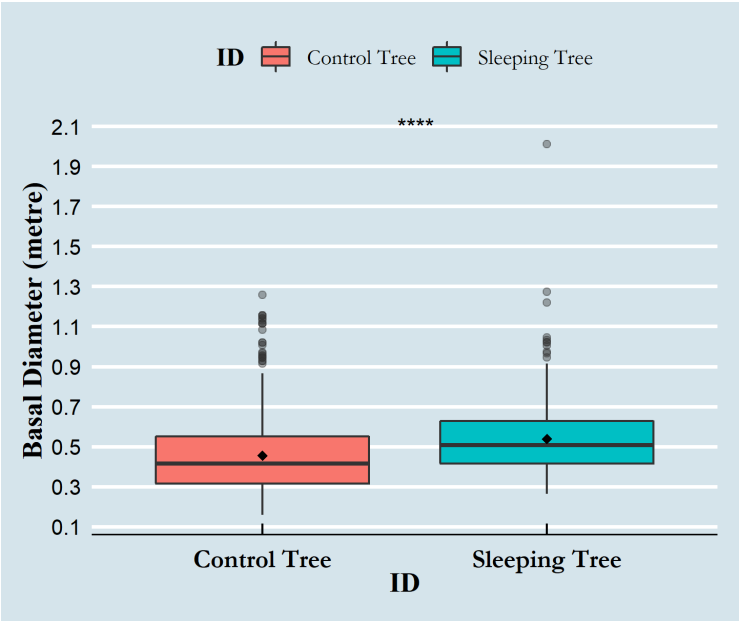

Figure 4.10: Basal Diameter comparisons between Sleeping and Non-sleeping tree.

Table 4.4: Basal Diameter parameters.

ID	Count	Mean	SD	Median	IQR	Min	Max
Non-Sleeping Tree	628	0.455	0.196	0.414	0.236	0.159	1.26
Sleeping Tree	310	0.538	0.189	0.506	0.212	0.264	2.01

4.1.1.3 Approximate Height

The average height of the trees used for sleeping was observed to be significantly greater than the trees not-used for sleeping (Wilcoxon: W=150560, p-value = $1.01*10^{-34}$, p-signif<0.0001)).

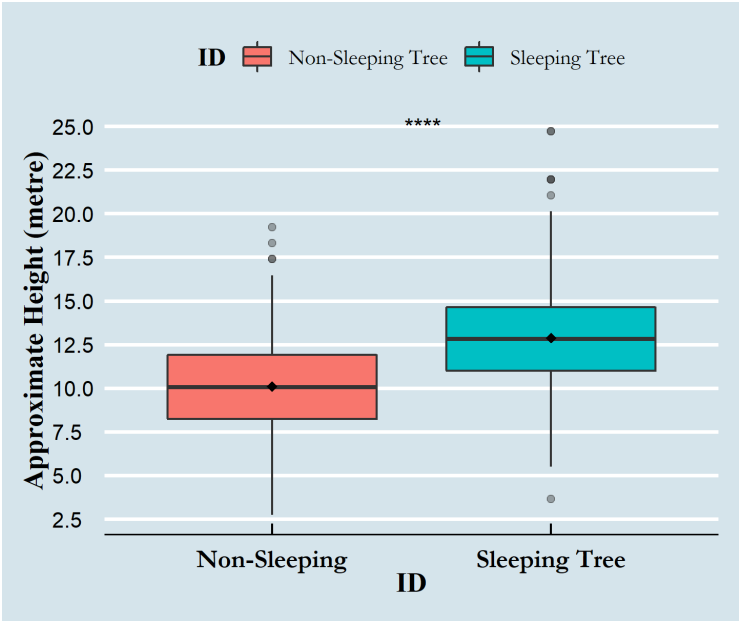

Figure 4.11: Approximate height comparison between Sleeping and Non-sleeping tree.

Table 4.5: Tree height parameters.

ID	Count	Mean	SD	Median	IQR	Min	Max
Non-Sleeping Tree	640	10.1	2.87	10.1	3.66	2.74	19.2
Sleeping Tree	316	12.9	3.20	12.8	3.66	3.66	24.7

4.1.1.4 Crown Characteristics

The proportionate usage of crowns which were emergent, equal, or lower relative to the general canopy layer of the forest were recorded for each sleeping tree. From a stacked percentage graph, it could be seen that the langurs have preference for EXPO crowns, as seen by the high proportion of trees with EXPO crowns chosen to sleep when compared to non-sleeping tree. Similarly, it can also be observed that the preference for NEXPO crowns which stay below the general canopy level was depreciated when compared to non-sleeping tree.

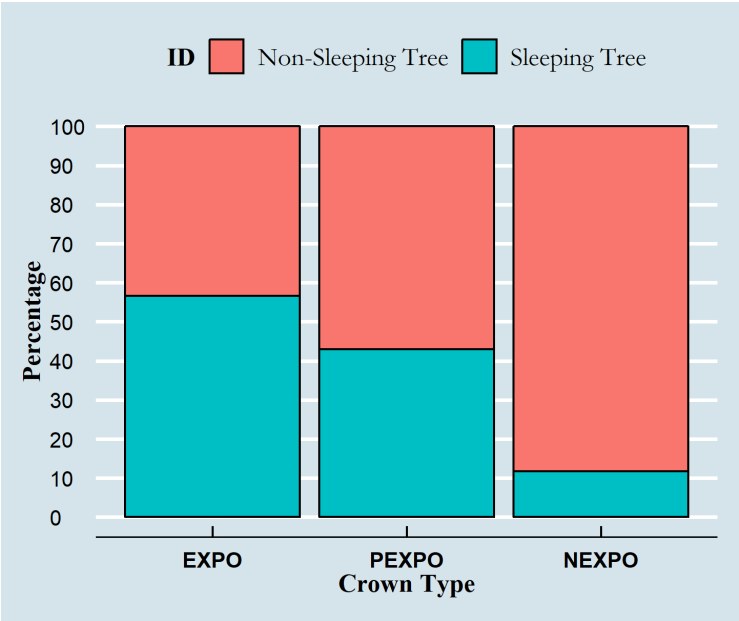

Figure 4.12: Crown Type comparisons in Sleeping and Non-Sleeping tree.

A comparison between the observed count of the crown types and expected proportion observed from non-sleeping tree revealed significant difference in usage of trees with crowns equal to general canopy level (PEXPO) or below the general canopy level (NEXPO). There was no significant difference in the use of trees with emergent crowns (EXPO) above the general canopy level.

Table 4.6: Crown Type comparisons in Sleeping and Non-Sleeping tree.

Type	% in Non-Sleeping Tree	% in Sleeping tree	χ^2 (p-value)
EXPO	7.62	20	1.19912 (0.1582)
PEXPO	44.32	67.19	9.8 (0.001745)
NEXPO	48.05	12.81	205.21 ($<2.2*10^{-16}$)

4.1.1.5 Canopy Characteristics

The canopy structure was assessed for both the sleeping trees and non-sleeping trees to study the usage of the lateral movement from one tree to another tree in the troop. The results showed the preference for closed type canopy rather than open type canopy where the chances of lateral movement decreases.

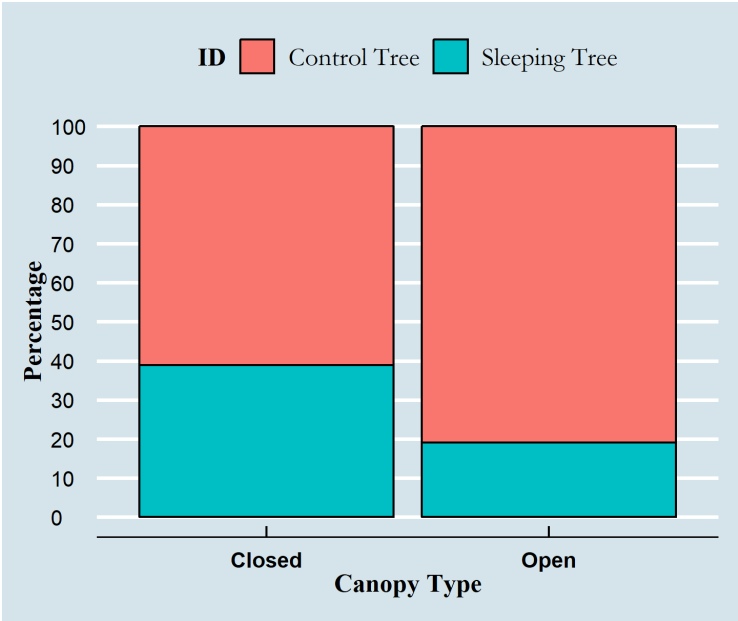

Figure 4.13: Canopy type of Sleeping and Non-Sleeping tree.

4.2 Sleeping Sites

The langurs chose various sleeping sites spread throughout their home range to sleep in. They chose 14 sleeping sites across 117 nights, therefore at random, each site was expected to be used an average 8.35 times by the troop.

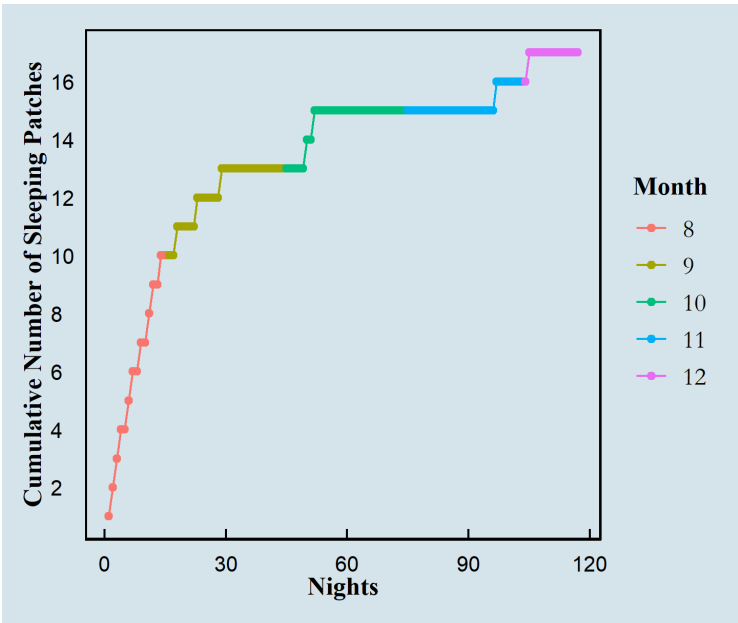

Figure 4.14: Cumulative number of sleeping patches across nights.

It could be seen that the during the month of August, there was a continuous increase in the usage of new sleeping site which settled down by December. The data indicates that a plateau of 14 sleeping sites was reached after 60 days of data collection. The three new additions after that were single point usage of those sleeping sites towards the end of observation period and were clubbed with the nearest sleeping site.

A frequency table for the usage of the sleeping sites was generated from the available data. A large difference in the observed counts of the use of each sleeping site was visible from the data, having a range of 1-32 stays for the recorded sleeping sites.

Table 4.7: Sleeping Site use by langur troop

SS	Observed Usage Count	Number of Trees used
FC	32	71
GoCl	3	1
GORI	2	16
GurT	7	29
KAG	7	3
KOP	19	69
KSAL	2	9
Kvi/MakVi	8	26
MSAL	2	4
SFI	2	8
SF II	1	3
SiB	7	6
SOAG	6	14
SROP	14	47

From the value of mean usage per patch , probabilities from a Poisson distribution were generated for the observed frequency range. These probabilities were multiplied with the total sleeping site count to get expected usage values (Day & Elwood, 1999; Sokal & Rohlf, 1995).

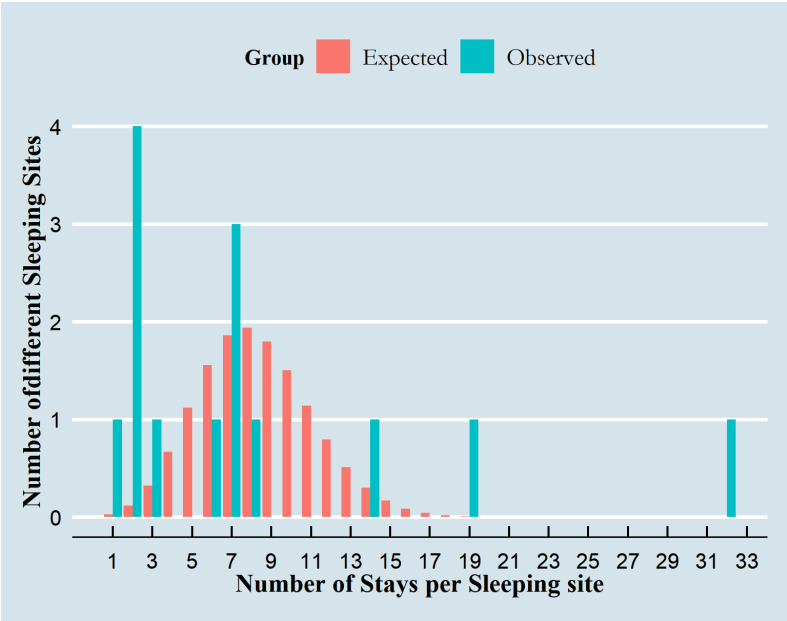

Figure 4.15: Frequency of use of Sleeping Sites by a troop of Central Himalayan Langurs. The observed and expected values derived from a Poisson distribution are shown. One can see that certain sleeping sites have been used once or twice, whereas some have been used multiple times.

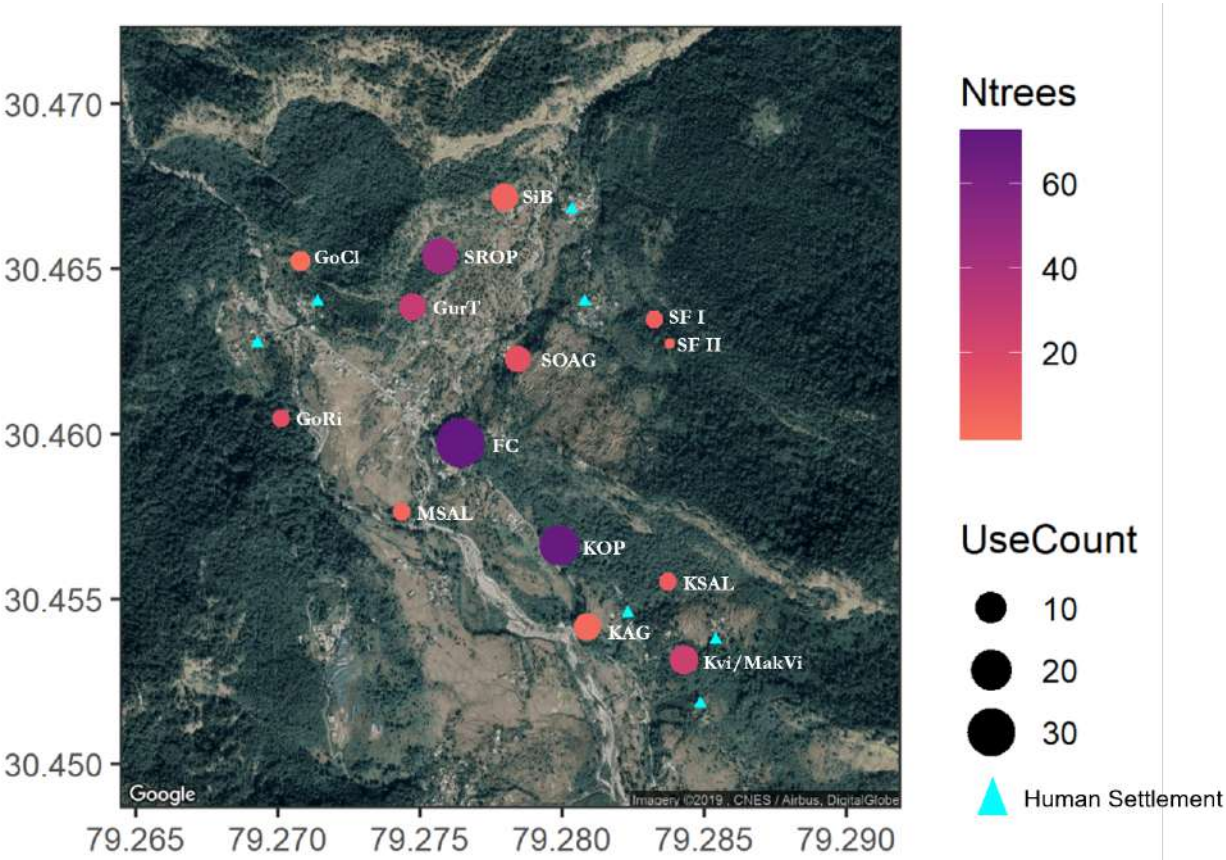

Figure 4.16: Usage Count of Sleeping Sites with Number of Trees used at each patch.

A visible difference was also present between the number of sleeping trees used at each sleeping site. To test whether the distribution of observed sleeping sites differ from an expected Poisson distribution, we used the Kolmogorov-Smirnov statistic to test for the difference. The test showed a significant difference between the two distributions establishing that there is a choice of sleeping site not similar to that expected by chance (Kolmogorov-Smirnov two sample test: D = 0.71875, p-value=$1.323*10^{-7}$).

To check for the correlation between abundance of trees at a sleeping site and the observed usage of that sleeping site, Spearman correlation test was used on the data for ten sleeping sites. These ten sleeping sites contain 88.24% of all sleeping trees amongst themselves(n=270). A linear regression was performed to derive the value of goodness of fit between response and predictor variable.

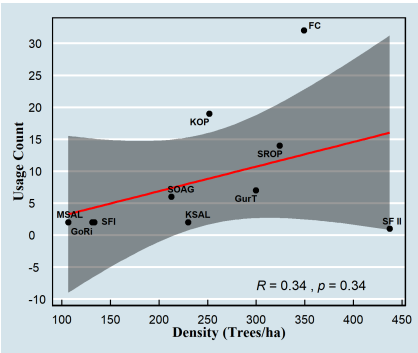

Figure 4.17: Density dependent usage

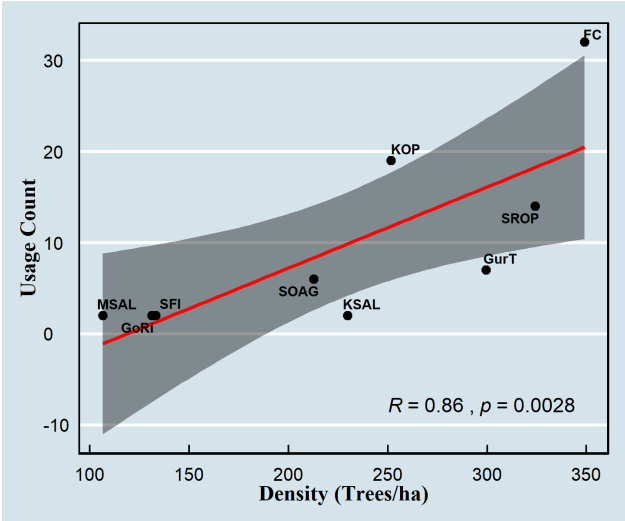

Figure 4.18: Frequency dependent usage(Without SF II)

There was no significant correlation observed between the abundance of trees in a site and its usage by the langur troop (Spearman: cor.coeff=0.34, p = 0.34; R^2 = 0.06086). KOP and FC show a huge deviation from the observed fit, though SF II lies at the other extreme. It shows a very high density of trees and has been used the least number of times (only once). From Fig. 4.16, it can be seen that SF II lies inside the dense forest and SF I lies just outside of it. At the study site, SF I has been converted to an agricultural land by clearing the forest. SF II which lies further up from SF I, is relatively undisturbed with a water stream flowing through it. Because of it's location at the boundary of a dense forest, SF II might host some of the big carnivores for whom a langur individual makes a good prey. It might be possible that because of such factors, langurs chose SF II as a sleeping site only once. When

we removed SF II from the comparison, a significant correlation was observed between the abundance of trees at a sleeping site and it's use for sleeping (Spearman: cor.coeff=0.86, p = 0.0028 ; R^2 = 0.5179). Removal of SF II shows that other sites have been used according to the abundance of trees at those sleeping sites. Further analysis is required of the individual characteristics of sleeping site located close to the centre of their home range (KOP, FC) versus those located at the periphery.

The longest continuous usage of a sleeping site was for five nights (26th October - 30th October). The next highest continuous usage was for three nights (9th September - 11th September). Langurs slept in the same sleeping patch as previous night on 36 out of 117 nights (30.8%).

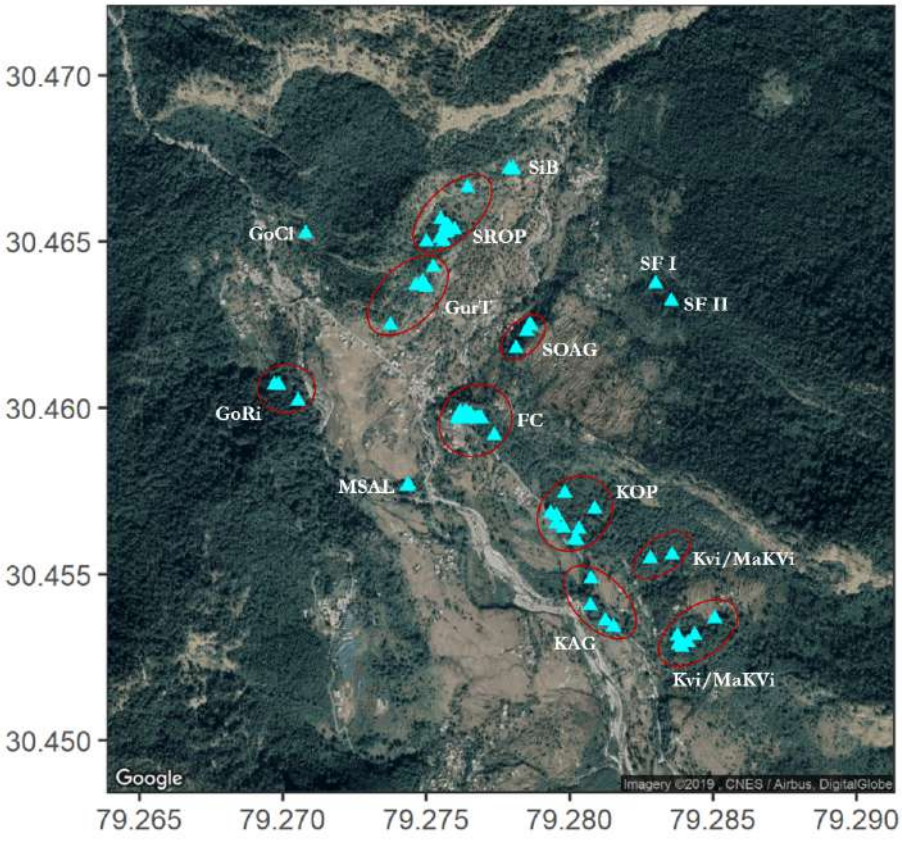

Figure 4.19: A total of 80 sleeping nights for the observed langur troop have been represented here.

Table 4.8: Continuous Usage of a Sleeping Site.

No. of Nights	**Patch Name**	**Dates *(dd/mm)***
5	FC	26/10 - 30/10
3	FC	9/9 - 11/9
2	FC	18/9 - 19/9
2	FC	22/9 - 23/9
2	FC	18/11 - 19/11
2	FC	3/12 - 4/12
2	FC	9/12 - 10/12
2	GurT	27/11 - 28/11
2	KAG	3/9 - 4/9
2	KAG	1/10 - 2/10
2	KOP	13/10 - 14/10
2	KOP	29/11 - 30/11
2	SOP/SROP	25/9 - 26/9
2	SOP/SROP	10/11 - 11/11
2	SOP/SROP	20/11 - 21/11
2	SOP/SROP	11/12 - 12/12

We observed the troop choosing the crevices on the cliff face to sleep on seven occasions. The cliff face forms the sleeping site at four of the fourteen locations in their home range. At these locations, the troop members divide amongst themselves the crevices as well as trees to rest for the night. Thus, some of the group members sleep on the trees and some sleep in the crevices on the face of the cliff.

4.3 Entry into, and Exit from Sleeping Site

4.3.1 Entry Time

The first individual climbed into the sleeping tree at mean time of 17:48h(SD=38minutes, *n*=86). There was no significant difference between the average entry time of adult males and adult females into the sleeping tree across all nights for which we have the data(*N*=81, Wilcoxon sum test with continuity correction; W=953, p-value=0.9693).

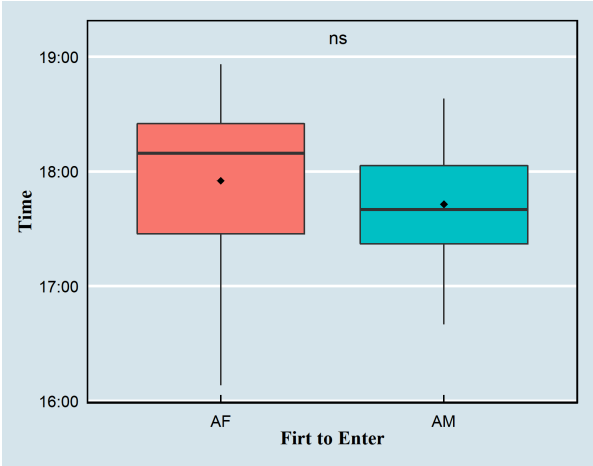

Figure 4.20: Entry Times for Adult Males and Adult Females.

Table 4.9: Entry Times for Adult Males and Adult Females.

ID	Count	Mean	SD	Minimum	Maximum
Adult Female (AF)	46	17:55h	41.6minutes	16:07h	18:55h
Adult Male (AM)	34	17:42h	32.3minutes	16:40h	18:37h

The individuals took a mean of 44.18 $\pm$ 15.80 minutes (n=81) to settle down from the time of first individual entering the sleeping tree. To compare mean settling time for the troop across months, multiple pairwise wilcoxon test were performed and none of the comparisons were significant. The average time of settling did not change significantly across months.

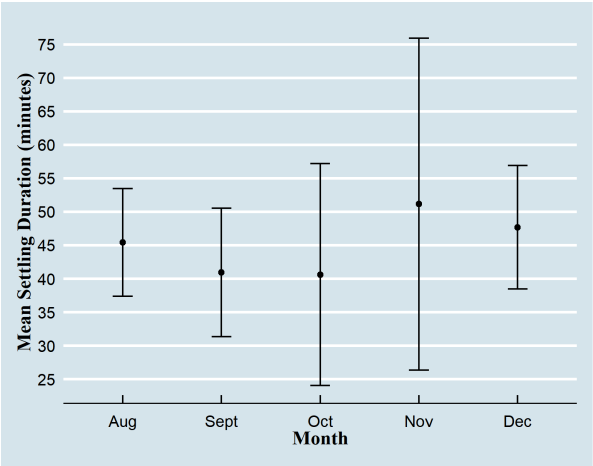

Figure 4.21: Mean durations for settling of the troop across months. Dots represent mean values, bars represent standard deviation around mean.

Table 4.10: Mean Settling Duration across Months. Time is shown in minutes.

Month	Count	Mean	SD	Median	IQR	Minimum	Maximum
August	13	45.38462	8.036774	47.0	8.0	33	60
September	23	40.91304	9.577023	40.0	12.50	24	64
October	22	40.59091	16.580709	35.5	16.75	25	94
November	17	51.11765	24.758540	40.0	38.0	17	104
December	6	47.66667	9.201449	47.0	10.0	34	60

4.3.2 Exit Time

The first individual exited the sleeping tree at mean time of 06:08h(SD=17.07 minutes, n=67). There was no significant difference between the average exit time of adult males and adult females from the sleeping tree across all nights for which we have the data(N=67, Wilcoxon sum test with continuity correction; W=623.5, p-value=0.2464).

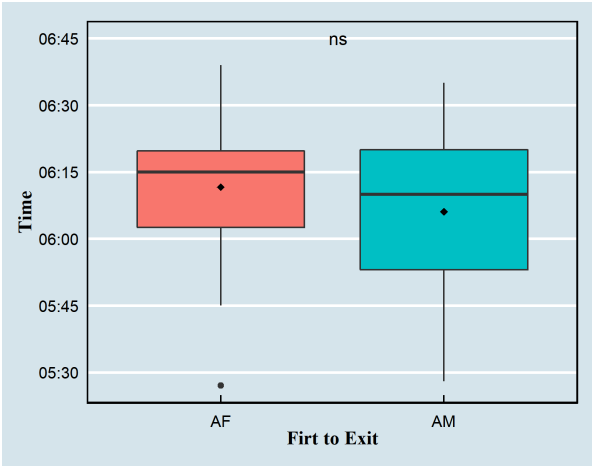

Figure 4.22: Exit Times for Adult Males and Adult Females.

Table 4.11: Exit Times for Adult Males and Adult Females.

ID	Count	Mean	SD	Minimum	Maximum
Adult Female (AF)	26	06:11h	15.15minutes	05:27h	06:39h
Adult Male (AM)	41	06:06h	18.03minutes	05:28h	06:35h

Greater than 50% of the troop took a mean time of 37.32 $\pm$ 18.77 minutes (n=77) to exit from the sleeping trees, after the first individual has exited. To compare mean exit duration for the troop across months, multiple pairwise Wilcoxon test were performed and some comparisons came out to be significant.

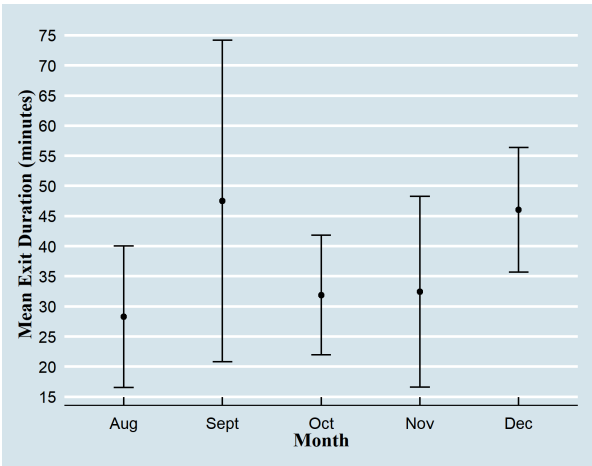

Figure 4.23: Mean duration for exit of >50% troop from the sleeping tree. Dots represent mean values, bars represent standard deviation around mean.

Table 4.12: Mean duration for exit of >50% troop across months. Time is shown in minutes.

Month	Count	Mean	SD	Median	IQR	Minimum	Maximum
August	13	28.23077	11.748431	24.0	11	17	56
September	21	47.47619	26.660118	39.0	20	21	122
October	20	31.85000	9.911583	30.5	14	14	49
November	13	32.38462	15.840552	30.0	21	10	60
December	9	46.0000	10.319884	49.0	7	24	60

Table 4.13: Comparisons of Mean Exit Duration across Months.

Month1	Month2	p-value	p-significant
August	September	0.0041	<0.01
August	October	0.1609	ns
August	November	0.6075	ns
August	December	0.0056	<0.01
September	October	0.0292	<0.05
September	November	0.0791	ns
September	December	0.3415	ns
October	November	0.8973	ns
October	December	0.0040	<0.01
November	December	0.0353	<0.05

4.4 Foraging Strategy

For this study, the location of sleeping sites was recorded with the help of a GPS device (Garmin GPS MAP62s). Additionally, GPS points of the last feeding patch of the day (FPEVE), and that of the first feeding patch (FP1) in the morning were recorded whenever possible. From the GPS points, linear distances were calculated between (i) the last feeding patch of the day and the sleeping site, labelled as FPEVE-SS and (ii) the sleeping site and the first feeding patch of the day, labelled as FP1-SS.

The comparison of observed FP1-SS to observed FPEVE-SS showed no significant difference between the two sets (Wilcoxon: W=606, p-value=0.36). Thus, langurs didn't chose to sleep closer to any of the two, the last feeding patch before entering the sleeping trees or the first feeding patch after exiting the sleeping trees.

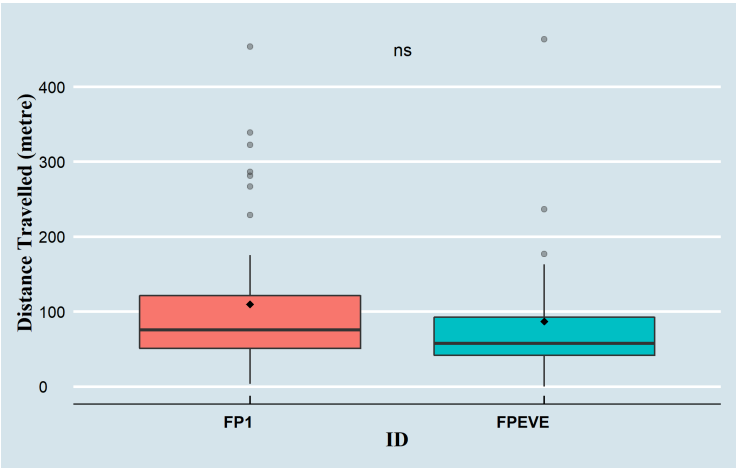

Figure 4.24: Comparison of distances travelled by the langur troop from the last feeding patch(FPEVE) and the first feeding patch(FP1) to the sleeping site.

Table 4.14: Observed distances from the last feeding patch and from the first feeding patch to the sleeping site.

Distance from	Count	Mean	SD	Median	IQR	Minimum	Maximum
FP1	42	109.62	101.67	75.45	70.36	3.34	453.72
FPEVE	33	86.91	83.84	57.42	50.91	0	463.19

The comparison of "Observed" distances from the last feeding patch to the sleeping site, to those expected by "Central Place" strategy and "Nearest" (MCPF) strategy resulted in

a significant difference between all the groups of distances. The groups were tested using pairwise Wilcoxon test. Though all differences came out to be significant, the observed distances closely resemble those predicted from a multiple central place foraging strategy as compared to a central place foraging strategy. Out of the three groups, a multiple central place foraging strategy resulted in the lowest average distance travelled to a sleeping site.

Table 4.15: Distances to the last feeding patch, calculated for "Central Place", "Nearest", and "Observed" foraging strategy.

Strategy	Count	Mean	SD	Median	IQR	Minimum	Maximum
Central Place	33	492.68	255.05	537.52	412.22	51.7	969.00
Nearest	33	50.69	45.74	34.00	42.77	0	181.82
Observed	33	86.91	83.84	57.42	50.91	0	463.19

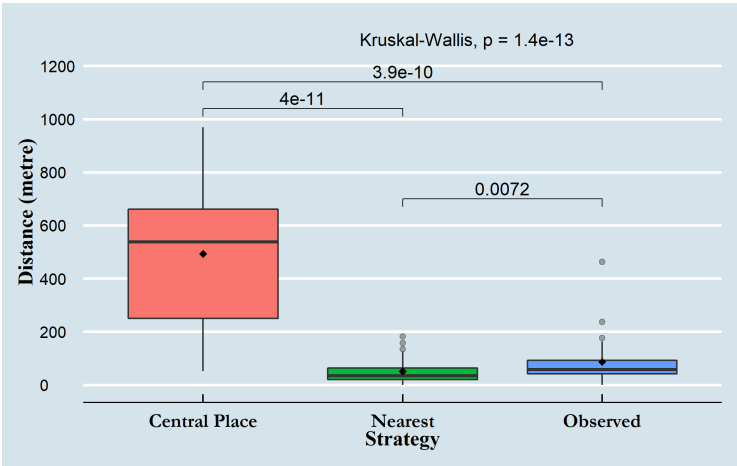

Figure 4.25: Distance comparisons between the last feeding patch of the day and the sleeping site, as expected from the "Central Place" strategy, the "Nearest" (MCPF), and the "Observed" strategy for a troop of Central Himalayan Langur.

Table 4.16: Comparisons of distances derived from "Central Place" and "Nearest" strategy with "Observed" strategy.

Strategy1	Strategy2	p-value	p-significant
Central Place	Nearest	$3.98*10^{-11}$	<0.0001
Central Place	Observed	$3.88*10^{-10}$	<0.0001
Nearest	Observed	0.007	<0.01

4.5 Thermoregulatory Aspects

During the period of August and September, the study site experienced a wet monsoon period. Towards end of September, temperature had started to drop and autumn had taken over. Autumn gave way to Winter by mid October and the upper reaches of Mandal valley started to receive snowfall. Occasional rainshowers carried well into the month of November. By the month of December, high altitude areas surrounding the study site had received considerable amount of snowfall. Cold winds began to blow down in the valley and added to the drop in temperature around the study site.

The temperature data for the months of September, October, November, and December has been used for analysis. Temperature data for the month of August was not recorded by the device or was missing. Temperature was recorded at every ten minute interval by the device, in total 15330 data points from September 1st to December 16th.

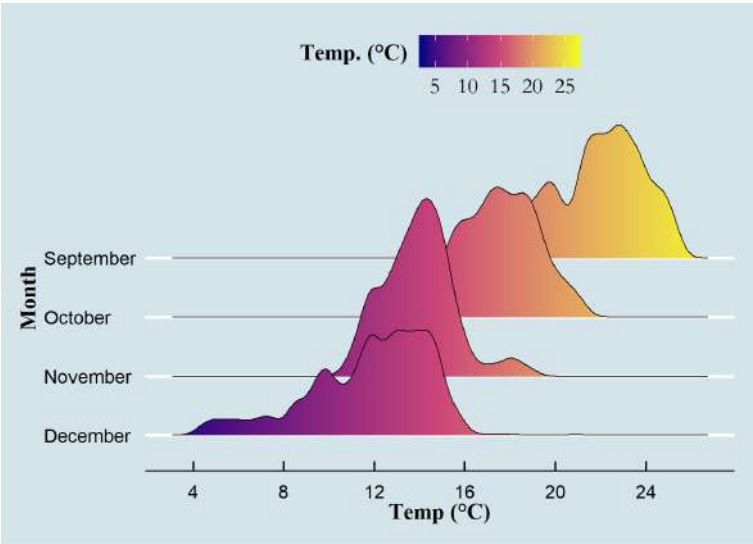

Figure 4.26: Temperature variation at study site.

Table 4.17: Temperature variation at study site.

Month	Count	Mean	SD	Median	IQR	Minimum	Maximum
September	4241	22.04	1.85	22.20	2.7	17.4	25.7
October	4464	17.36	1.82	17.45	2.7	12.4	21.5
November	4320	13.96	1.58	14.00	2.0	10.5	19.1
December	2304	11.77	2.66	12.20	3.8	4.1	21.0

To check for a correlation between the entry and exit times with the immediate temperatures at those time points, the temperature reading nearest to the observed time was selected and Pearson correlation test was used. A linear regression was done to check for the goodness of fit between the predictor and the response variable.

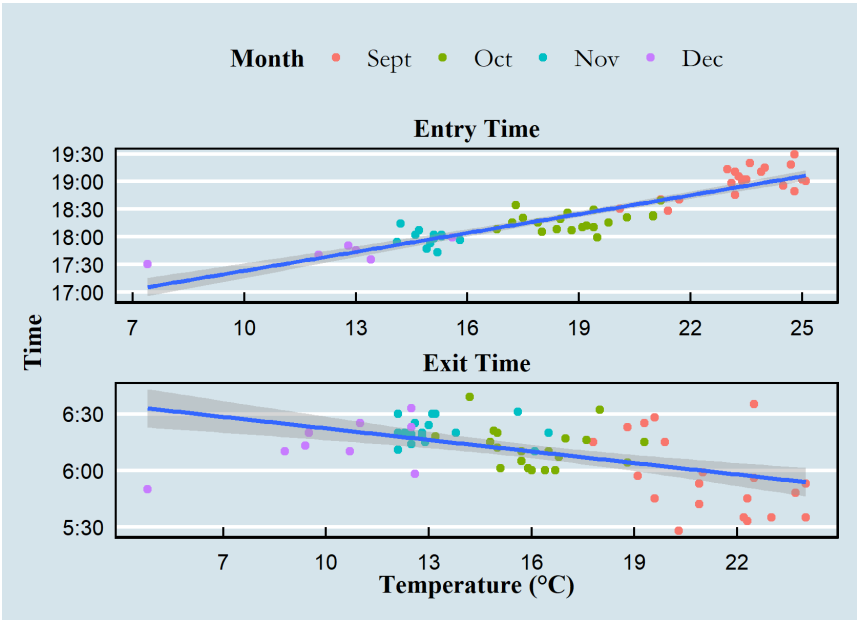

Figure 4.27: Temperature variation at study site.

Table 4.18: Effect of Temperature on Entry and Exit Time.

Group	Count	R^2	p-value	p-significant	cor.coeff
Entry Time	59	0.8362	$<2.2*10^{-16}$	< 0.001	0.914461
Exit Time	67	0.2632	$9.02*10^{-06}$	< 0.001	-0.5130719

It was observed that the entry time is much more affected by the temperature variation as compared to the exit time, by the temperature at the time of entry and exit respectively. It can also be seen that that langurs used a longer range of time to enter their sleeping site as compared to the time range used while exiting from the sleeping site.

The results also hinted towards a variation in the time for which the troop remain active during the day. As the temperature decreased, the activity period of the langur troop also shortened due to exiting the sleeping site late and entering the sleeping site early. Thus, an overall increase in the sleeping duration was expected with the decrease in temperature.

To check for the relation between the sleeping duration (in hours) and the temperature variation, Pearson correlation test was used. For this analysis, the average temperature on

the date of sleeping was used. A linear regression was done to check for the goodness of fit between the predictor and the response variable.

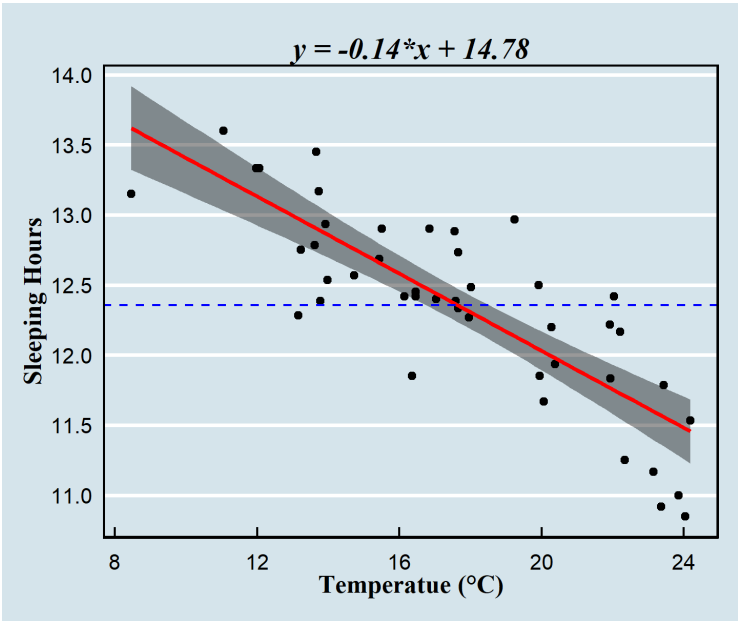

Figure 4.28: Variation in duration of sleep with Temperature.

A significant correlation was found between the duration of sleeping and the average temperature of the day. The sleeping hours were observed to increase as the temperature decrease (Pearson: cor.coeff = -0.8206814, p-value = $9.12*10^{-12}$, p-significant = <0.001; R^2 = 0.6735).

Chapter 5

Discussion

5.1 Sleeping Tree Species

The preference for species of sleeping trees was directly related to their abundance in the forest area at the study site. The most frequently used species, Banj Oak (*Quercus leucotrichophora*), was also the most frequently present species in the study area. *Quercus spp.* is widespread in the Central Himalayan region and dominates the climax forests of Central Himalaya along with other tree species like *Pinus roxburghii*, *Lyonia ovalifolia*, *Rhododendron arboreum* (Champion et al., 1968; Gairola et al., 2010; B. Kumar et al., 2009; Awasthi et al., 2003). In the forests of Mandal-Chopta, *Quercus leucotrichophora* had been found to have a very high Importance Value Index along with *Pyrus pashia* (G. Singh, 2008). *Quercus leucotrichophora* also had the highest relative density (58.62647 trees per hectare) and highest relative frequency (41.69381) from our calculations, indicating a widespread distribution of that species (Mitchell, 2010).

Three of the species used for sleeping, namely, *Quercus leucotrichophora*, *Prunus cerasoides*, and *Rhododendron arboreum* have been listed as three of the top five species preferred by this troop in their diet (Nautiyal, 2015). The trees of *Quercus leucotrichophora* bore fruit after September. *Prunus cerasoides* was also laden with flush leaves, young leaves, and flowers respectively during October to December. *Rhododendron arboreum* did not possess any of the vegetation types during the observation period. Apart from these three species, *Alnus nepalensis* and *Tonna ciliata* also form a part of the diet of langurs (Nautiyal, 2015).

The importance of Oak forests arises due to the large amount of services it provide. Oak forests provide fodder in the form of dried green leaves, and are a source of fuel, firewood, timber, and edible fruits for the the local inhabitants of the Garhwal Himalaya (G. Singh, Naithani, & Rawat, 2009; Makino, 2011) and their presence is intricately associated to the management of hydrological balance (J. Singh, 2006). The resilience of these forests and their productivity is highly affected by the human activities since a long time (Gorrie, 1936). These Himalayan forests play an important role in the soil and water conservation and have an economic value for the village societies living at the fringes of these forests by supporting the basic economic activities of agriculture and livestock rearing (Moench & Bandyopadhyay, 1986; Moench, 1989). The compost required for agricultural activities has been preferred by the village inhabitants over synthetic fertilisers (J. Singh et al., 1984) and is prepared by mixing manure with the dried leaves of oak (Pandey & Singh, 1984). Though the forest products play an important role for the dependent communities both inside and outside protected areas (R. Kumar & Shahabuddin, 2005; De Boer & Baquete, 1998), these forests are experiencing a change in their structure (G. Singh et al., 2016).

With an increased anthropogenic pressure (Sagar & Singh, 2004), more compost is required to increase the crop yield. This would further mean more foliage for the livestock to eat and to mix with the manure, which could be procured by looping of the oak trees (Makino, 2011). (Sharma et al., 2009) reported a high pressure on the *Quercus leucotrichophora* dominated mixed forest growing near the Mandal village area with this tree species getting overexploited due to uncontrolled looping, grazing, and stem cutting. Such a treatment can negatively affect the forest regeneration capability and produce canopy gaps (Shibaji et al., 2014) and reduced leaf fall. Such an event will have consequences on the sleeping tree availability for the langur troop ranging around the forest of Mandal and the surrounding villages and require concentrated efforts for further planning for conservation of the natural habitat (G. Singh et al., 2016) of wildlife dwelling around the fringes of a protected area.

Though langurs showed preference for the trees to sleep in depending on the frequency of the species in the forest area, Chir Pine (*Pinus roxburghii*) was chosen to sleep more number of times as predicted from its frequency in the forest area. The presence of Chir Pine in the Himalayan belt has been first reported as stock plantations in the Shivaliks (Troup et al., 1916; Sinha, 2002). Chir Pine has also been exploited for resin tapping and for Pine timber when Deodar and Sal became scarce. Due to easy regeneration of Chir

Pine, its growth was promoted by silvicultural practices (Sinha, 2002). This species has been reported to encroach upon the Oak forests in higher elevations and mixed broadleaf forests at lower elevations (Tewari, 1982). Its successional approach and encroachment on Oak forests render the soil devoid of moisture and reduces the water holding capacity, results in low grass cover, and subsequent erosion of the soil surface. At the study site, Chir Pine has taken over the oak distribution at one of the sleeping patches and its unusually high use might arise due to the same. The trees of Chir Pine grow up to be tall, straight with long branches jutting outwards at the top. Such characteristics might also help to deter the approach of a predator.

5.2 Avoiding Predation Risk at the Sleeping Site

The state of sleep could be seen as part of a general mechanism to maintain inactive and active periods, serving the function of inducing immobility when it is beneficial for the animal to remain immobile (Meddis, 1975). Predation is a risk that continuously looms over an animal who is resting and immobility could be seen as a way to remain undetected when the predator is active (J. R. Anderson, 2000). Likely trade-offs between the predation risk and sleep duration could be observed in the choice and usage of sleeping site(s) or construction of protective shelters (Stewart & Pruetz, 2013).

The most common predators of langurs are reported to be large canids like Common Leopard (*Panthera Pardus*), feral dogs, large birds of prey like Crested Serpent Eagle (*Spilornis cheela*) (Laws & Laws, 1984; N. Bishop, 1975; N. H. Bishop, 1979; Ramakrishnan & Coss, 2001a), and Crested Honey Buzzard (*Pernis ptilorhynchus*).

Hanuman langur (*Semnopithecus entellus*) have been shown to be a potential prey for leopard (*Panthera pardus*) preferably owing to to the astute climbing skills of leopard and its cryptic behavior (Karanth & Sunquist, 1995). Hanuman langurs have been observed to produce alarm call (Hohmann, 1989) in the presence of leopard as well as wild and domestic dogs and hurriedly climb on the trees. Such an activity is risky for it diverts all the attention of the attacker towards the actor (Ross, 1993; Hohmann, 1989). Similar behavior has been observed in high altitude langur population where the author reported a shrill “bark” by the adult males much louder as compared to that by females(N. Bishop, 1975). During our observation period, alarm calling was observed on four occasions in the pre-sleeping and

post-awakening hours, thrice in the early morning hours and once in the evening hours. All of these were produced by Adult Males. All the alarm calls were towards feral dogs.

NOTE: On 21st October, inhabitants from Siroli Village reported heavy alarm calling by the langurs resting for the night on the top of cliff face behind the village. Such an alarm calling, according to villagers, was an indication of the presence of leopard.

Though no such interactions of the langur troop with the large predators was observed during the study period, feral dogs posed a constant risk to the langur troop and there were various close interactions between the feral dogs and the troop members while crossing through agricultural fields towards sleeping sites, as well as at sleeping sites. (J. R. Anderson, 1986) could only state killings of individuals belonging to seven primate species by feral dogs, majority of which were macaque and langur species living around the high density human settlements in Asia. The ability of these primates to quickly climb the trees help them escape more fatal attacks from the feral dogs while ranging around human settlements. In more extreme cases, a combination of feral dogs and a marksmen could prove fatal(Kavanagh, 1980; Pi, 1972; Whitten & Whitten, 1982).

The study troop moved quietly and quickly into the sleeping site, and showed cryptic behavior while entering the sleeping site. Such vigilant behavior while moving into the sleeping site has been proposed as an adaptation to avoid detection by the predator(s) (Chivers, 1974, 1976; Caine, 1987; Reichard, 1998; Day & Elwood, 1999; Liu & Zhao, 2004; Xiang et al., 2010; Souza-Alves et al., 2011). There were occasional bouts of aggression between the males, involving grunt calls and display by the males, while moving into the sleeping sites or near the sleeping sites. In comparison the *Macaca mulata* population supported by same habitat were usually highly vocal at their sleeping sites. There were frequent bouts of grunt calls and threats, involving chases and aggressive shaking of the branches, at the macaque sleeping sites. (Personal Observation)

After having climbed into the trees for sleeping, the individuals were expected to conceal and hide themselves from being identified against the environment so as to avoid the approach of a predator. Moreover choice of a sleeping site could be made so as to make it difficult for the predator to attack and approach, in case the individual(s) have been detected (Reichard, 1998; Gautier-Hion, 1970; Heymann, 1995). Therefore the preference of trees with greater Diameter at Breast Height (DBH) and greater basal diameter than the

surrounding trees might have important survival consequences (Phoonjampa et al., 2010; Ramakrishnan & Coss, 2001b). Such trees tend to provide stability while sleeping(Law et al., 2008). In events of excessive bad weather, sleeping on trees that provide stability from the disturbances (swaying due to fast winds, weak base and the risk of falling) and protect the individuals from any possible injury in night(Cheyne et al., 2012, 2013) might prove crucial. The choice for trees with higher average height then the surrounding trees might also help to deter a strictly terrestrial predator from attacking the individuals (Reichard, 1998; Liu & Zhao, 2004).

A significantly large proportion of trees with exposed crowns was chosen to sleep, and similarly, significantly lesser trees whose crown were not exposed were chosen to sleep when compared to proportions present in the surrounding population of trees. Choosing trees with exposed crowns give access to a wider field of view and increases the probability of apprehending an approaching predator at a considerable distance. A predator trying to access the sleeping tree from a nearby tree would be noticed from a sleeping tree with an exposed crown (Von Hippel, 1998; Teichroeb et al., 2012; J. Anderson & McGrew, 1984). Sleeping on cliff faces may stand to serve various purposes like deter the approach of the predator towards the troop while sleeping(Hamilton III, 1982), protection from cold winds and rainfall(Stoltz & Saayman, 1970).

During the study period, we observed langurs continuously changing their sleeping sites to rest for the night. Throughout the day the troop travelled together and entered into a sleeping site together. On most of the occasions the sleeping site for the troop consisted of multiple trees, though crevices in cliff faces also served as sleeping site. The langur troop was observed to defecate in the morning from their sleeping sites. The continuous usage of a sleeping site will therefore result in the building up of odor. Odor around the sleeping patch could indicate the presence of langurs to the predator. Thus the continuous shifting of sleeping site does not result in the building up of the odor around the sleeping site (Hrdy, 1980; Heymann, 1995). The most frequently used sleeping site, Forest Chowki (FC), is located near a very frequently used motorable road with vehicles passing regularly through that place. This sleeping site also lies near the central market place of the Mandal village and a well built trail passes along Forest Chowki leading towards Sanso Village. This was the site that was also used continuously for maximum number of nights(five).

On all except two nights when the troop was located in their sleeping site the following morning, did the troop slept split. On these two occasions, the troop was crossing through agricultural fields towards their sleeping site. Human interference during this critical period resulted in the split of troop. Sleeping in large group could be turned to advantage by mobbing the predator. It also increases the probability of observing the predator if it had come dangerously close to the troop in the night(Busse, 1980; Reichard, 1998; Ramakrishnan & Coss, 2001b).

5.3 Foraging Constraints

Sleeping Sites as central places have been studied to understand the travel costs originating from an optimal feeding strategy in relation to the location of a centrally located sleeping place (Schoener, 1979; Andersson, 1981). Such a strategy might affect the choice of feeding sites, extent of home range, depletion of the resources of a patch, as well as prey-predator dynamics. Given the leaf eating ecology of Central Himalayan Langur and the abundance of leaf in the mixed type of forest present at the study site, it could be possible that the langur troop might choose a nearby sleeping site from their last feeding patch on that evening. The continuous shifting between various sleeping sites in their home range, which stands to serves as multiple "central places", as a strategy can indeed be helpful for these primates. Multiple Central Place Foraging (MCPF) has been shown to be an effective way of reducing travel costs (McLaughlin & Montgomerie, 1989).

It could be noted from the results that langurs chose to slept in the nearby sleeping site from the last feeding patch in the evening. Similar choices have been observed in African apes (Goodall, 1962),*Colobus guereza*(Von Hippel, 1998), *Colobus vellerosus*(Teichroeb et al., 2012). The continuous changing of sleeping sites also means that the troop avoids depleting the resources of a patch completely. The observed distances travelled by the troop from their last feeding patch closely resembles those predicted by a multiple central place foraging strategy(Chapman et al., 1989). The absence of any significant difference between the distances travelled to and from the last feeding patch and the first feeding patch in the morning, respectively, indicates that the troop does not show preference for the first feeding bout of the day after a long fast in the night. Alternatively it might indicate that since the primary food for langurs was abundant, they might as well enter the sleeping site while

still foraging on the way. This effect needs to be tested. Choosing the nearest sleeping site to enter after the last feeding bout also entail low travel costs everyday(Goodall, 1962; Basabose & Yamagiwa, 2002). This type of foraging strategy aids in the effective usage of the home range (Rasmussen, 1979; González-Zamora et al., 2012) while minimizing travel costs of returning to a fixed place to sleep every night. This might also help the langurs reach a safe refuge before their predator become active in the night.

5.4 Weather constraints

During the night, langurs are completely exposed to rainfall or dropping temperatures. Thus sleeping site choice and the behavior around at the sleeping site are also dictated by the need to maintain a constant body temperature. Energy can also be conserved by exiting late from the sleeping site and entering early into the sleeping site before the sun sets, effectively increasing the sleeping hours as the surrounding temperature decreases.
Thermoregulation played an important role in governing the behavioral responses at sleeping sites. As the surrounding temperature decreased, the troop delayed their exit from the sleeping site and entered the sleeping site earlier. This effectively decreased the time available for daytime activities for the troop individuals. A strong correlation of the time of entry with the immediate temperature suggests that the troop likes to get comfortable in their sleeping site before the night time temperature drops too low. The correlation between the immediate temperature and the time of exit was observed to be not as strong when compared to entry time. The range of times used by the troop to exit was also lesser as compared to that used to enter the sleeping tree.

Cold winter mornings may as well require sunbathing before the individuals began to move in their home range(N. H. Bishop, 1979; Furuichi et al., 1982). Another reason for a small range of exit times might happen to be the need to start early and maximize the time spent in feeding and sunbathing, thus adjusting the time of entry and exit according to the same. Though a crucial factor could be the light intensity in the environment serving as a clue for exiting and entering the sleeping sites. This remains to be tested. It is of common knowledge that the sun sets early during the winters when the temperature is also low. It could be possible that these two factors have a collaborative effect on the entry and exit time of the troop, though which one has a stronger effect remains to be tested.

The increase in sleeping duration showed a strong correlation with the decreasing average temperature across the period of observation. Increased sleeping time during winters help in conserving energy and maintain a constant body temperature (Aquino & Encarnación, 1986; Chivers, 1974; Liu & Zhao, 2004; Xiang et al., 2010; J. Anderson & McGrew, 1984). Like other primates that sleep on trees,langurs sleep sitting up on the tree branches, with their limbs tucked inside, and the body constricted forward, so as to conserve body heat. Primates that sleep upright possess a patch of ischial callosites under their hindquarters to assist in making a good grip on the branch and might serve the function to prevent abrasion of the skin from the surface of the tree branches. The presence of ischial callosites provide additional stability while sleeping (Washburn, 1957; Vilensky, 1978).

Chapter 6

Summary

Sleep as a behavioral and physiological state has been studied to understand its importance and prevalence across invertebrates and vertebrates alike. While sleeping, an individual misses on various general activities like grooming, feeding, interaction with its surroundings, and mating. It also makes the individual vulnerable to attack due to the effective suppression of the physiological and neuromuscular machinery. Thus sleeping behavior and the choice of sleeping at a selected place reflects upon the trade-offs made by a certain species. The study of sleep behavior in non-human primates living in the wild stands to reflect upon the sleeping behavior of the earliest hominids which used to sleep on trees and use also used to descend to ground for daily activities.

This study presents the qualitative and quantitative characteristics of the sleeping site ecology of a troop of Central Himalayan Langur (*Semnopithecus schistaceus*. This data collection was done from August 2018 to mid December 2018 at the field site at the outer fringes of Kedarnath Wildlife Sanctuary in the Garhwal Himalayas. This study was able to conclude and show that the studied troop chose trees to sleep-in every night in a manner so as to avoid the risk and disturbances arising from various factors. The results showed that the sleeping site choice of this troop was governed by the following mutually exclusive factors - avoiding the risk of a predator attack while sleeping, optimal foraging strategy, and thermoregulatory aspects.

The choice of trees to sleep in the night was expected such as to minimize the risk of attack of a predator. Towards this expectation, the troop showed a preference to sleep on trees whose average Diameter at Breast Height, average Basal Diameter, and average Height was greater than the non-sleeping trees. Sleeping trees consisted of a larger proportion of

trees with exposed crowns as compared to that present in the non-sleeping trees. The troop showed a cryptic behavior while entering in to the sleeping sites in the evening which might be in order to not cue the predator about their location. The species in the pool of trees used for sleeping were represented according to their frequency in the composition of the forest at the study site. Such a usage might have direct consequences on the sleeping behavior and ecology of the species. A decrease in the density of the dominant species might mean reduction in the number of suitable trees to sleep in and hence will effect the survival of the species. Thus, the study of the sleeping sites also forms part of a conservation strategy especially for such species living at the fringes of protected areas. The troop continuously changed its sleeping site and chose 14 different sleeping sites in their home range and chose 306 unique trees to sleep in. The observed usage frequency of the sleeping sites differed significantly from the expected frequency indicating preference for sleeping sites as well. The preference for a sleeping site was found to depend upto a limit on the density of trees at the site. A reduction in density of trees will also threaten the existence of multiple sleeping sites having its adverse effects on population density and spatial distribution of this species.

The troop tend to choose sleeping sites which were closest to the last feeding patch closely following a multiple central place foraging approach. Such an approach is advantageous for it helps in reducing travel costs while promoting the efficient usage of the home range. Reduced travel costs entails reduced energy expenditure which will be desired during low temperatures so as to maintain internal body temperature.

The need to conserve energy during harsh environmental conditions and low temperatures could be achieved by increasing the resting time in the sleeping trees. The langur troop entered the sleeping tree earlier and delayed its exit from the sleeping tree in the morning as the temperature decreased towards December. This effectively increased the sleeping duration of the langurs thus aiding in body heat conservation.

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(a) Adult Male

(b) Adult Female with her Infant

(c) Juvenile

(d) Sub Adult

(e) Study troop

(f) Study troop huddling in winters

Plate 1: Study Troop

(a) Study area (General landscape)

(d) Cliff face used as sleeping site

(b) Study area (Monsoon)

(e) Moving towards sleeping site

(c) Study area (Winter)

(f) Rhesus Macaques share the home range

Plate 2: Study Area and Habitat

(a) Sleeping perched on a tree

(c) Long branches facilitate lateral movement

(b) Sleeping posture and huddles

(d) Fecal patch under a sleeping tree

(e) Taking measurements

(f) Taking measurements

Plate 3: Observations at Sleeping Site