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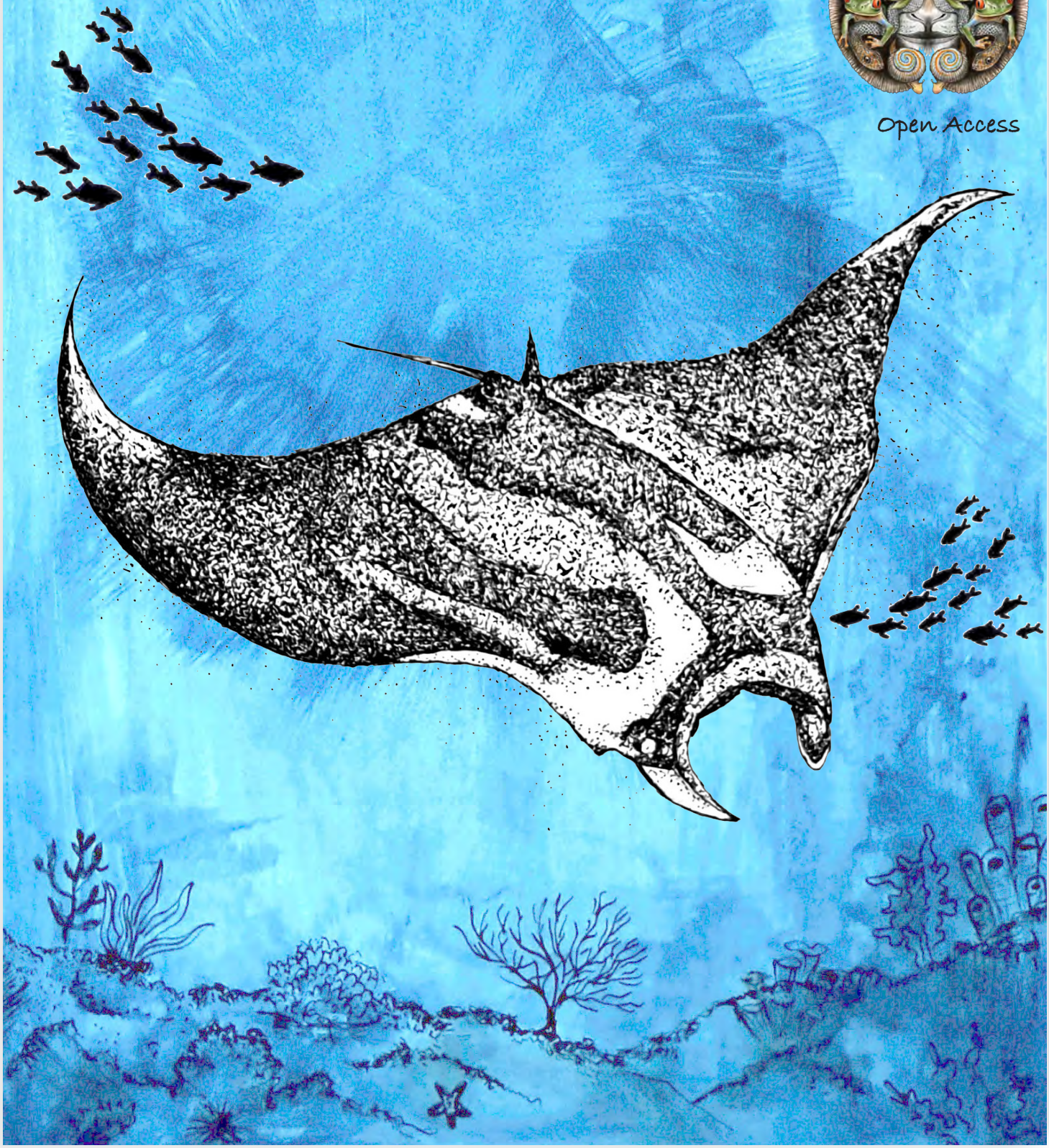

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Cover: Giant Oceanic Manta Ray *Mobula birostris* in ink on acrylic wash by Elakshi Mahika Molur adapted from scientific illustration by Roger Hall.

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ARTICLE

Nesting habitat and nest directionality of the Indian Giant Squirrel *Ratufa indica maxima* (Schreber, 1784) (Mammalia: Rodentia: Sciuridae) in the Nelliyampathy Reserve Forest, Western Ghats, Kerala, India

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Abstract: The information on selection of nesting habitat and nest directionality for arboreal species is crucial in developing conservation and management plan for the species. We studied the factors which affect the nesting habitat selection and the nest orientation by using the quadrat sampling method in Nelliyampathy Reserve Forest, Kerala. A total of 119 nest sites were observed on 26 different tree species in four different habitat types. Around 56.30% and 36.13% of the nests were sighted in contiguous forests and plantation with native tree shade, respectively. Of the 119 nests, 112 were in trees of height up to 30 m. *Cullenia exarillata*, *Mesua ferrea*, *Actinodaphne malabarica*, and *Schleichera oleosa* accounted for 45.4% of the nest with 15.9%, 11.8%, 9.2% and 8.4% nests, respectively. About 24.4% of the nests were directed towards the north-east direction (n = 29) whereas least preferred direction was the south (n = 05). This shows that the nests are oriented towards sun rise and to avoid wind and rainfall of monsoon which is foreseen from the south-west direction.

Keywords: Arboreal, behavior, conservation, ecology, forest fragmentation, native tree plantation, nest orientation, nest tree selection, rain avoidance, sunlight preference.

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Author contributions: KM - conceived the idea and collected the data; KM, JJE, MS - analyzed the data; KM, JJE, MS - wrote the article.

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INTRODUCTION

An understanding of the costs and benefits of choosing a certain nest site and placing a nest entrance in a specific direction in arboreal mammals is still in its inception. Nest sites chosen based on specific criteria, most often improve concealment, which may increase nesting success by lowering the risk of predation (Pradhan et al. 2017). Young individuals are highly sensitive to environmental factors, and by reducing environmental extremes in the nest, adults are likely to improve the survival rate of their infants, and their own fitness (Murphy 1983; Webb & King 1983; Bekoff et al. 1987; Webb 1987; Martin 1988; Martin & Roper 1988). It is predicted that most nests are orientated in response to environmental conditions such as wind, precipitation, and in particular sun radiation (Haggerty 1995; Burton 2007).

Avian nesting sites have shown that there is a wide range of nest orientation and pattern among species and/or nesting guilds (e.g., open cup, domed nest, primary/secondary cavity nest). Although some studies have found little to no pattern in nest orientation (Albano 1992; Rendell & Robertson 1994; Tarvin & Smith 1995; Mennill & Ratcliffe 2004), many groups representing a variety of nest architectures do show considerable preferences in the orientation of their nests (Austin 1974; Walsberg 1981; Martin & Roper 1988; Bergin 1991; Hooge et al. 1999; Mezquida 2004). Most often, researchers have discovered that nest orientation is related to either prevailing winds (Norment 1993; Mezquida 2004) or sun exposure (Viñuela & Sunyer 1992; With & Webb 1993; Yanes et al. 1996; Rauter et al. 2002; Hartman & Oring 2003; Burton 2006), both of which may have an immediate impact on the microclimate of the nest (Hartman & Oring 2003; Ardia et al. 2006). In hot habitats near the equator, animals would be predicted to orient their nests to optimize shade during the day, when the sun and thus temperatures are at their maximum (Maclean 1984). Mid-latitude nests commonly face eastward since it may be less important to avoid the mid-day or afternoon sun there. Nests that face east rather than west may warm up more quickly in the morning (Nelson & Martin 1999), lessening the potential effects of low overnight temperatures on embryos and young. Nests may be pointed towards the equator at the highest latitudes to benefit from the greater insolation and warmth coming from that direction and lessen the consequences of a cold climate (Ojedat et al. 2021). But due to variations in nest-site parameters at any given latitude, there may be a significant difference in the preferred nest orientations within species. Hence, nest site and orientation are crucial elements of bird reproduction that may have an impact on embryonic development, hatching success, nestling growth (Austin 1974; Viñuela & Sunyer 1992; Lloyd & Martin 2004; Burton 2006) and overall nesting success (Martin & Roper 1988; Filliater et al. 1994; Rauter et al. 2002). With the context of avian nesting sites, we would like to investigate the nesting orientation of the Indian Giant Squirrel as well.

The Indian Giant Squirrel (IGS; *Ratufa indica maxima*) is a diurnal and arboreal species which is found only in peninsular India (Agrawal & Chakraborty 1979; Corbet & Hill 1992). Despite being widely distributed within its range, it is found in severely fragmented populations (Molur et al. 2005). The ecology of squirrels in Asian countries has received less focus, and available research is scarce (Pradhan et al. 2012; Borges 2015). It is a solitary species that only appears in pairs during the breeding season. During a single breeding season, it usually builds more than one nest, or drey. Recent studies on nesting tree selection in the IGS have shown that the most common and abundantly available tree species in the forest were preferred for nesting over random tree species (Rathod et al. 2022). The nests made of leaves and twigs are large, globular in shape with a lateral opening which are built on tall, profusely branched trees in the higher canopy (Ramachandran 1988; Borges 1989; Datta & Goyal 1996; Kumara & Singh 2006; Pradhan et al. 2017). The nesting trees were comparably taller species with interlinking crowns which allowed easy access and movement in the canopy, probably to avoid predators (Ramachandran 1988; Datta

Image 1. The Indian Giant Squirrel *Ratufa indica maxima*

& Goyal 1996). At the landscape level, the nest trees were found predominantly in the contiguous forests of evergreen, moist-deciduous and deciduous forests with abundant availability of food resources, and away from the agricultural fields.

Factors that influence nest-site selection, nest design, nest orientation, and the inter- and intra-specific variation of these behaviours in IGS are scarce. As a result, we investigated nest-site selection and nest orientation patterns in the IGS. Our goals were to find out (1) the nesting preferences of IGS, and (2) whether there is any directionality to its nest entrance.

MATERIALS AND METHODS

Study area

We carried out this study in Nelliyampathy Range of Nelliyampathy Reserve Forest (10.41–10.30 N & 76.58–76.75 E), Nemmara Forest Division in the Western Ghats in Palakkad District of Kerala (Figure 1). It covers an area of about 157 km^2 (Erinjery et al. 2018) with a vegetation of evergreen, semi-evergreen and moist deciduous forests with interspersed tea, coffee and cardamom plantations (Ramachandran & Suganthasakthivel 2010). The altitude ranges 500–1,633 m. The average rainfall is about 3,378 mm over a period of 10 years. The forest mainly consists of *Cullenia*, *Mesua* and *Palaquim*s species (Pascal 1988; Ramachandran & Suganthasaktivel 2010; Erinjery et al. 2015). Some of the arboreal species which belong to family Sciuridae found here are the Western Ghats Striped Squirrel *Funambulus tristriatus* Waterhouse, 1837, the Dusky Striped Squirrel *Funambulus sublineatus* Waterhouse, 1838., the Indian Giant Flying Squirrel *Petaurista philippensis* Elliot, 1839, Travancore Flying Squirrel *Petinomys fuscocapillus*, and the Indian Giant Squirrel (Ramachandran & Suganthasakthivel 2010; Kumara & Suganthasakthivel 2011; Babu et al. 2015).

Data collection

The habitat of the IGS nests was broadly divided into four different types namely contiguous forest (45 km^2, >60% canopy cover, dominated by evergreen and dry deciduous forest trees), fragmented forest (8 km^2, evergreen/dry deciduous forest patches are divided between open plantation), plantation with native tree shade (25 km^2, 30–60% canopy cover, mainly included coffee, cardamom plantations with native trees) and plantation with monoculture tree shade (17 km^2, >30% canopy cover, dominated by monoculture Teak and Silver Oak). The categorization of the habitat was derived from the high-resolution vegetation type and land-use map with accuracy >85% developed from Sentinel2 MSI 10 m spectral bands and Sentinel1 SAR bands, NDVI and Textural layers (Erinjery et al. 2018). We obtained the data on IGS nesting by Quadrat sampling method (Heltshe & Forrester 1983). The study area was divided into quadrats of 0.5 x 0.5 km^2. Based on the average home range of the IGS, the observer walked randomly in each quadrat looking for the nests of the IGS, and made sure that 75% of the pre-defined habitat types in the quadrat was sampled without overlapping. We did not conduct surveys in habitats such as open plantations, rocky mountains and grasslands as these habitat structures did not consist of any tree species. Thus, a total of 95 km^2 was only sampled and considered for the analysis. Only active IGS nest was considered for the analysis. It is difficult to differentiate between active and non-active nests of the IGS unless an individual is sighted using the nest. Active nests are the ones which are freshly built nests of lush green in colour and are highly dense and compact in structure, which makes it difficult to sight as they camouflage with the tree canopy. Over a period as twigs of the nest dry, it becomes easier to identify due to variation in the nest and canopy colour. Non-active nest consists only of dry leaves and twigs and the walls of the nest are very loosely arranged and mostly worn out. Nest location was recorded by using handheld GPS (Montana 650). Data on nesting tree species (the trees in which nests are constructed), height of the tree and height of the nest from the ground was recorded by using the laser range finder (HAWKE LRF 900). We collected data on nesting direction for which nest orientation readings was recorded by holding a compass directly below the nest and orienting it with the nest entrance. A statistical test was performed to know the independent variable which is contributing to the habitat selection between the above mentioned habitat types by chi square test followed by Marascuilo's post hoc test. The alpha level for all statistical tests was kept at 0.05. The average was represented as mean±standard deviation (SD) to understand the true variation of the data using SPSS 20.

RESULTS

Nest tree selection

A total of 119 nests (Table 1) of IGS were located on 26 tree species (Table 2). There were more than one or two nests in a single tree. The tree species with multiple nests were *Culenia exarillata, Artocarpus heterophyllus and Mesua ferrea.* The number of nests in contiguous

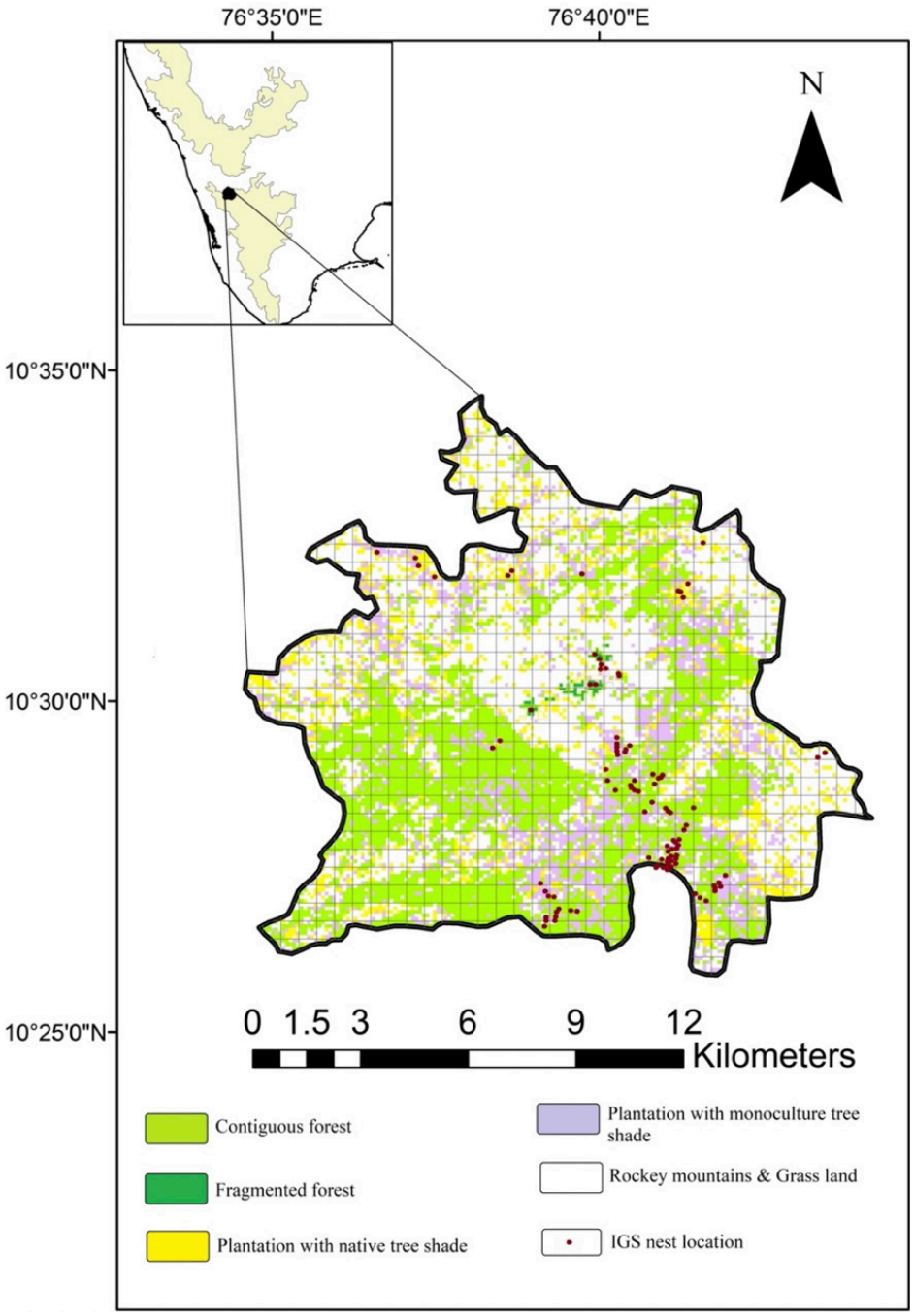

Figure 1. The study locality.

forests, fragmented forests, plantation with native tree shade and plantation with monoculture tree shade was 67, 4, 43, and 5, respectively, and the density of 1.48 nests/km^2, 0.5 nests/km^2, 1.72 nests/km^2, and 0.29 nests/km^2, respectively in these habitat types varied significantly ($\chi^2 = 45.9$ df = 3 $p < .01$). Plantation with native tree shade and contiguous forest accounted for 81% of the nests. IGS were observed to nest on 26 tree species (Table 2) and the number of nests per tree species varied

Table 1. Preferred habitat types of the Indian Giant Squirrel for nesting.

Habitat type	Number of nests	Density of the nest per sq. km.	Percentage (%)
Contiguous forest	67	1.48	56.30
Fragmented forest	04	0.5	3.36
Plantation with native tree shade	43	1.72	36.13
Plantation with monoculture tree shade	05	0.29	4.20

Table 2. Tree species and nesting height preference by Indian Giant Squirrel.

	Tree species	Tree height (m ± SD)	Nest height (m ± SD)	Percentage (%)
1	*Actinodaphne malabarica*	25 ± 9.98	24 ± 9.45	9.24
2	*Aglaia bourdillonii*	40 ± 0	38 ± 0	0.84
3	*Aglaia malabarica*	24.66 ± 1.52	22.33 ± 1.52	2.52
4	*Artocarpus heterophyllus*	18 ± 3.03	17.5 ± 2.42	5.04
5	*Cedrela toona*	25.5 ± 4.24	22.12 ± 2.69	6.72
6	*Cinnamomum malabatrum*	18 ± 0	17 ± 0	0.84
7	*Cordia gharaf*	22 ± 0	21 ± 0	0.84
8	*Cullenia exarillata*	23.12 ± 4.96	21.73 ± 5.69	15.96
9	*Drypetes malabarica*	16 ± 3.46	13.66 ± 4.93	2.52
10	*Dysoxylum malabaricum*	15 ± 4.24	13.5 ± 4.94	1.68
11	*Ficus beddomei*	16 ± 0	13.5 ± 0.70	1.68
12	*Ficus racemosa*	20.66 ± 4.61	19.66 ± 3.78	2.52
13	*Ficus talbotii*	25.33 ± 4.61	23.66 ± 4.16	2.52
14	*Garcinia gummi-gutta*	18 ± 0	18 ± 0	0.84
15	*Holoptelea integrifolia*	17 ± 4.24	15.5 ± 3.53	1.68
16	*Macaranga peltata*	16 ± 3.46	14.33 ± 3.05	2.52
17	*Mangifera indica*	18 ± 0	16 ± 1.41	1.68
18	*Mesua ferrea*	22.57 ± 7.77	21 ± 7.22	11.76
19	*Myristica dactyloides*	20.5 ± 5	19 ± 4.83	3.36
20	*Neolitsea scrobiculata*	23 ± 0	21 ± 0	0.84
21	*Palaquium ellipticum*	23 ± 10.39	20 ± 8.12	3.36
22	*Persea macrantha*	22.6 ± 3.43	21.6 ± 2.88	4.20
23	*Pleurostylia opposita*	20.8 ± 4.60	19.6 ± 4.03	4.20
24	*Polyalthia longifolia*	23.75 ± 6.13	21.25 ± 6.13	3.36
25	*Schleichera oleosa*	21.3 ± 5.33	19.2 ± 5.63	8.40
26	*Vernonia monosis*	21 ± 7.81	18.33 ± 7.23	2.52

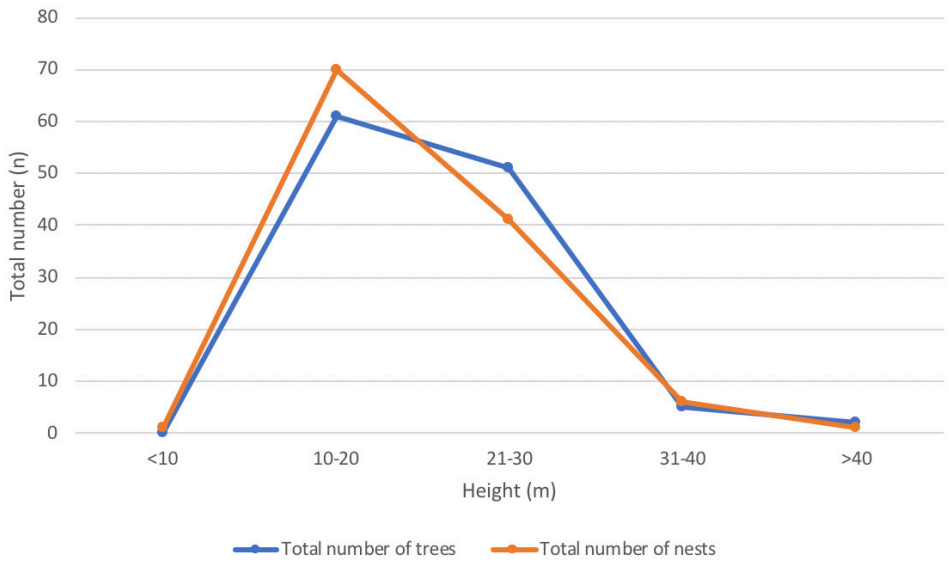

Figure 2. Different height class of nesting trees and Indian Giant Squirrel nests.

significantly (χ^2 = 95.07 df = 25 p <.01). However, only four tree species including *Culenia exarillata, Mesua ferrea*, *Actinodaphne malabarica*, and *Schleichera oleosa* accounted for 45.36% of the nests with 15.96%, 11.76%, 9.24%, and 8.40% nests, respectively (Table 2). Table 2 shows the frequency in various class height on which nests were observed. The squirrels made nests in trees of height classes of <10 m, 10–20 m, 21–30 m, 31–40 m, and >40 m with a frequency of 0, 61, 51, 5, and 2, respectively, which differed significantly (χ^2 = 117.89 df = 3 p <.01). Likewise, the number of nests in nest height categories of <10 m, 11–20 m, 21–30 m, 31–40 m, and >40 m was 1, 70, 41, 6, and 1, respectively, which significantly varied (χ^2 = 121.71 df = 4 p <.01). The tree height and the nest height correlated significantly (Pearson r = 0.96 N = 5 p <.01) (Figure 2) showing that most nests were in trees of height up to 30 m with similar nest height numbers indicating that the nests were towards the tree canopies.

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Nest characteristics

The IGS builds globular nests out of green leaves, twigs, and branches. The nests were either round or oval in shape with a lateral opening. The nests were usually constructed away from the tree trunk where the canopies were interlocked with the neighboring tree canopies. The entry of the nest was placed horizontal to the ground. Most of the nests were constructed by using the tender leaves of the nesting trees itself. However, squirrels also used the leaves of other plant species such as *Mallotus tetracoccus* and *Pouteria campechiana* in the construction of the nests. The number of nests in different directions (Figure 3) varied significantly (χ^2 = 27.06 df = 7 p <.01). Most of the nests sighted in the study area were observed facing towards the north-east direction (n = 29) followed by east (n = 23), and south-west (n = 17) whereas least preferred direction was towards the south (n = 05) (Figure 3). Nests were very often found at the highest point on the tree (Table 2).

DISCUSSION

Preference for nesting habitat could depend on factors such as access to nesting material, nest safety, branching pattern of the tree species, and availability

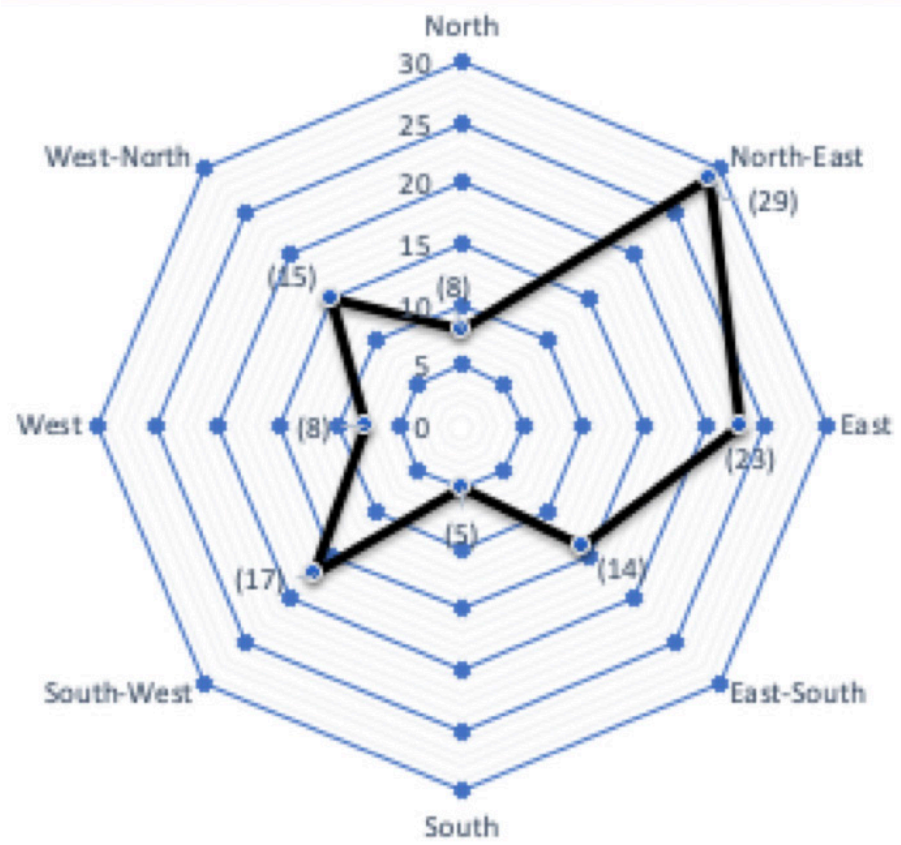

Figure 3. Directionality of the Indian Giant Squirrel nests in the Nelliyampathy Reserve Forest.

of food. A total of 26 tree species were recognized as nesting trees of the IGS in Nelliyampathy Reserve Forest of which *Culenia exarillata, Mesua ferrea*, *Actinodaphne malabarica*, and *Schleichera oleosa* were highly preferred for nesting. The high preference of these species maybe because of the dense canopy and higher canopy height which facilitates the IGS for easy movement from the nest in all directions (Ramachandran & Suganthasakthivel 2010). There is also the major advantage to escape from predators and to move to other parts of the home range for foraging and other activities through the canopy (Datta & Goyal 1996; Arockianathan 2020). In addition to that, most of the species of trees which is preferred for nesting accounts for the major diet of the IGS as well. Given the fact that the IGS prefers to feed as soon as they get out of the nests in the dawn and to feed before entering the nests in the dusk (Ramachandran 1988), they prefer mostly to build nests in the same trees which they feed on frequently. This helps them to reduce the time and energy spent on locomotion and foraging activities and in turn helps in conserving energy for other activities.

Most of the nests were sighted in the plantation with native tree shade and contiguous forest, maybe because of the availability and more abundance of the preferred nesting trees with highest parts of canopies and canopy contiguity, and the presence of food throughout the year in these habitat structures. Fragmented forests and plantation with monoculture tree shade were less preferred because they are more open and exposed habitat types where the probability of encountering predators is more, and as they consist less diverse tree species composition, the food choices are also limited. We observed that the nests were built towards the tree tops, but these were not built on the extreme top of the canopy, as the squirrels sought cover above the nest. Such cover might help to avoid direct heat from the sun and serve as hiding from birds of prey (Datta 1998; Pradhan et al. 2012). We observed that majority of the nests were built by using the same foliage of the tree in which the nests were built but, in some instances, they were using different foliage than the nesting tree species. We could not comprehend the reason behind this kind of behavior and hence, more specific study is required for knowing as to why some trees are used for nesting but its leaves are not used for nest building.

We found evidence to support the hypothesis that the nest orientation is mostly towards the north-east and east directions. This shows that the species has the cognitive ability to identify different directions and they preferred to orient most of the nests towards the sun rise. As the temperature in these forests becomes low in the nights, the animal receives the early morning sun light from the easterly direction for the warmth. Further, this region gets its rains primarily from the south-west monsoons in which the heavy winds and the rains are received from the west. The easterly direction of the nests therefore helps avoid direct exposures to winds and heavy monsoon rains.

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