

# **Assessing Habitat Use and Activity Pattern of Hoolock Gibbons (*Hoolock hoolock*) in the Mosaic Landscape of Garo Hills.**

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**in**  
**Wildlife Science**

Under the supervision of

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I hereby declare that the work conducted under the thesis entitled “Assessing Habitat Use and Activity Pattern of Hoolock Gibbons (*Hoolock hoolock*) in the Mosaic Landscape of Garo Hills”, is a record of original and independent research work done by me and subsequently submitted for the award of the degree of **Master’s in Wildlife Science** at the **Academy of Scientific and Innovative Research**. This research work has been carried out under the guidance and supervision of **Dr. Salvador Lyngdoh**, Scientist – E of Wildlife Institute of India, Dehradun, and **Dr. HN Kumara** Principal Scientist of SACON-WII. The work has not formed the basis for the award of any other degree, diploma, or any other qualification. I also declare that the thesis embodies my own work, analysis, observation, understanding and the particulars given in it are true to the best of my knowledge.

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## CERTIFICATE

This is to certify that the thesis by **Mr. Betwonsaoo Passah** entitled “**Assessing Habitat Use and Activity Pattern of Hoolock Gibbons (*Hoolock hoolock*) in the Mosaic Landscape of Garo Hills**” is an original and independent research work submitted to the **Academy of Scientific and Innovative Research**, for the award of the degree of **Master’s in Wildlife Science**.

**Mr. Betwonsaoo Passah** has put one semester of research work embodied in this thesis under my guidance and supervision. The work presented in this thesis has not been submitted to any other University or Institute for the award of any degree, diploma or distinction.

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## Summary

Primates react to environmental disruption in a variety of ways. Their home range and activity pattern are often linked with anthropogenic disturbance of the landscape. This study focuses on Hoolock Gibbons (*Hoolock hoolock*) in Garo Hills, Meghalaya, which is a highly arboreal primate and the only ape in India. Hoolock gibbon's habitat in the Garo hills is being degraded due to the increase in the conversion of forest land into plantations. As most of these forests where the gibbons are located are managed by the community, these forests face overexploitation, which threatens the endangered Hoolock Gibbons habitat. This study aims to establish a baseline Hoolock Gibbon Ecology in the community-managed forest and protected area in the mosaic landscape of Garo Hills, Meghalaya, by examining their habitat use and activity pattern. The main objective is to determine the Gibbon's habitat use within its home range and examine their activity patterns in different forest types. The study is conducted in Daribokgre CR (a continuous forest patch adjoining Nokrek National Park), Dura Kalakgre CR (a small strip of CR which is surrounded by abandoned jhum and active jhum), and an Areca nut plantation which is located in Rensengre close to Selbalgre CR. In each area, one group is chosen and tracked for 20 days. Geo-coordinates and behavioural data were collected, with vegetation sampling and disturbances within a 1 ha cell size grid, which was overlaid on the location points. QGIS was used to map habitat use based on the geospatial data, and the Generalised Linear Model (GLM) was used to check the influencing factors. The activity budget was calculated to understand the behaviour patterns.

Across the three studied groups, the habitat types were different group in Daribokgre (Forest group) is dominated by forest patches, the group in Dura Kalkgre (Jhum group) was dominated by abandoned jhum, and the group in Rensengre (Plantation group) was dominated by plantation, and their home range size were 24 hectares, 30 hectares, and 23

hectares, respectively. GLM reveals a significant effect only for the group in the disturbed habitat on the intensity of use. Overall, habitat use patterns and activity patterns varied across the groups, reflecting in behavioural and habitat preference.

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# 1. INTRODUCTION

## 1.1. Background

Primates show variable and multiple responses to environmental disturbances (Bryson-Morisson et. al, 2017). Their habitat uses, activity patterns, and range are often associated with anthropogenic disturbing environments (Bryson-Morisson et. al, 2017). In a landscape where there is a limited area for gibbons, understanding the individual-based approach is important to characterise the habitat requirement within the home range of a species (Akers et. al, 2013).

Hoolock Gibbon, being the only ape found in India (Kumar et. al, 2013), is listed as ‘Endangered by the IUCN Red List of Threatened Taxa (Brokelman et. al, 2019), with the current population trend declining from 100,000 to 5000 (Kumar et. al, 2010). It is also listed in Appendix 1 of CITES and protected as a Schedule 1 species in The Wild Life (Protection) Act, 1972. The species is found all over the northeastern state of India- Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Tripura, and Nagaland, and also in Myanmar, Bangladesh, and, Southern China (Choudry, 1991; Kumar et. al, 2013). Previously, the genus Hoolock is divided into species Western Hoolock Gibbon (*Hoolock hoolock*) and Eastern Hoolock Gibbon (*Hoolock leuconedys*) (Grooves, 1972). The distribution of Western Hoolock Gibbons is South of Brahmaputra, Dibang, and Lohit Rivers; its southern limit is the Chin Hills, the western limit is the Garo Hills, and the eastern limit is the Chindwin River. For eastern Hoolock Gibbons, is known to be found between the Chindwin and Salween Rivers in Myanmar, but this species is also recorded in the Lohit District of Arunachal Pradesh (Kumar et. al, 2013). In 2021, the two species of Hoolock (Grooves, 1972) are clubbed together into one species and it is now known as *Hoolock hoolock* (Trivedi et. al, 2021).

Hoolock Gibbons are known to occupy dense canopy areas with canopy heights of 15-20 m and also play a vital role in seed dispersal. It is recorded as the flagship, keystone, and indicator species for the good and healthy forest ecosystem (Kumar et. al, 2013). In West Garo Hills, the Hoolock Gibbons population trend decreased in all age categories between 1987 and 2007 (Sati, 2011). Most of the localities that were surveyed in 1987 were found to be degraded by the early 2000s and from the 32 localities where Gibbons was located in 1987 only 15 localities were observed in 2007 and also these localities were surrounded by either barren land or plantation (Sati, 2011). These gibbon's habitat is degraded due to the upcoming tea farm, Citrus orchards, betel-nut plantations, cashew-nut plantations, and jhum cultivation (Sati, 2011). Apart from the change in land use, other major reasons that led to the decrease in the number of gibbons in Garo Hills are anthropogenic disturbances, hunting, and poaching, canopy gap, livelihood issues, livestock grazing, predation (by dogs or big cats) during ground movement between forest patches (Sati, 2011).

Most of the societies in the northeastern region of India are predominantly agrarian and heavily reliant on forests for their livelihood and subsistence (Menon et. al, 2019). Opportunities for alternative livelihoods are scarce because the area is underdeveloped as compared to the other parts of the country (Menon et. al, 2019). In Meghalaya, the forests are highly threatened, especially in the Garo Hills due to the age-old practices of slash and cultivation (Poffenberger et.al, 2007), where the cycle of this cultivation has been reduced to 3-5 years from 20 years in the western and in the eastern part it has been reducing to 1-3 years (Kaul et.al, 2010). The degradation and fragmentation mostly happen in the unclassified forests, which also include the Community Forest land because of the nature of the management of these forests, which involves village-level decision-making (Menon et. al, 2019). Being part of the Indo-Burma biodiversity hotspot, most of the species are still being

threatened because of anthropogenic pressure as most of the forest are under the control of the local tribal community (Menon et. al, 2019).

Only 5% of Meghalaya's total geographical area is controlled by the State Forest Department, these forests are in the form of Reserved Forests, Wildlife Sanctuaries, National Parks, or Gardens. The remaining forested area is under the management of individuals, clans, or a community (Meghalaya Forest and Environment Department). Some of these non-government forested areas are managed and protected by the community, clan, or villages by keeping in mind safeguarding the interest of the poor and the landless (Tiwari et. al, 2010). Thus, to increase the number of protected areas, Community Reserve or, Community Conservation Reserves are promoted especially in the North-eastern state of India (Lyngdoh et. al, 2023). In Meghalaya, there are different ways of forest management by the communities- some are protected for the use of the poorest of the poor in the village where the forest is located, some forests are protected for several years to allow regeneration, some forests are used only if any casualties are happening in that particular village, some of the forests are fully protected and these are known sacred grove (Tiwari. et al, 2010). These forests which are managed by the community or the village are mainly used by the community or the local people for the collection of NTFPs, and timber extraction which will support their health and their livelihood (Tiwari et. al, 2010).

In Meghalaya, there are 74 notified Community Reserves Forests (Meghalaya Forest and Environment Department), and overexploitation of natural resources still occurs in these CRs (Lyngdoh et. al, 2023). Many of these CRs are secondary forests of 20 years of age of which they had experienced logging or cultivation in the past (Sarkar et. al, 2023). In West Garo Hills these CRs are surrounded by jhum cultivation, orange plantation, cash crop plantation, or settlements (Sailas et. al, 2021). Even though Community Reserves are facing

major problems like exploitation of natural resources they still have most of the endangered species, and one of them is Hoolock gibbons (*Hoolock hoolock*) (Lyngdoh et. al, 2023).

## 1.2. Literature Review

Most studies on the impact of human disturbance on terrestrial mammals have neglected the arboreal communities. A recent study found that arboreal mammal species show a stronger negative response to forest disturbance than terrestrial species. The occupancy rate of arboreal species, especially the large-bodied mammals reduced with the increase in forest degradation. Their presence is influenced by the habitat structure such as canopy connectivity and cover, which is crucial for survival. But, the response to disturbance is species-specific as the hunted primates are greatly reduced compared to the non-hunted species (Whitworth et al, 2019). These responses can be expressed through demography, use of space, activity budget, health status, and body condition (de Almeida-Rocha et. al, 2017). In tropical forests, human-induced habitat has negatively affected local primate's richness and abundance (de Almeida-Rocha et. al, 2017), and the continuous expansion of human footprint especially in places with higher biodiversity (Venter et. al, 2016), has left the primates to be one the world's most threatened mammals. 87% of Asia's 97 primate species are in danger of going extinct, with logging, hunting, agriculture, and wood harvesting being the main contributing factors (Fernandez et al., 2021). These Asian primate species are also becoming more and more isolated in the fragmented forest (Boonratana, 2019). Therefore, this will force the species to move out of its habitat and interact with humans which will lead to the transmission of infectious diseases, physical harm, and an increase in tension between humans and primates (Bloomfield, 2020). Fragmentation should be treated both as a stressor and a threat, and a better understanding of how primates use the fragmented habitat is crucial for developing effective conservation strategies (Boonratana, 2019).

Primates react to environmental disruptions in a variety of ways. In ecosystems that have been altered by humans, their resource consumption, activity patterns, diets, and habitat utilisation frequently alter (Bryson-Morrison, 2017). Given that an animal's fitness is largely reliant on its ability to obtain resources, it is imperative to take into account resource requirements in a fragmented landscape with patchy resources. To determine what is available, it is crucial to assess how the species uses its habitat. Intraspecific interactions pertaining to habitat usage in fragmented landscapes include home range size, ranging distance, matrix use, and activity pattern (Gabriel, 2013). The spatial distribution of species at the national or regional level, as revealed by numerous studies on macroscale habitat use, indicates that primates primarily inhabit areas with minimal disturbance in fragmented landscapes. The ability of the species to survive in such a fragmented setting, however, depends on scale. To better understand how anthropogenic disturbances affect a species' habitat utilization and behavior, it is crucial to take a finer-scale approach (Bryson-Morrison, 2017).

Several researchers have considered a macro-scale approach for understanding the habitat requirement of species, but this works only for a species whose population is spread across an area by correlating habitat attributes and species abundance across different regimes of disturbances (Worman and Chapman 2006; Hamard et al. 2010). Some studies that considered macroscale for understanding the habitat requirement of Hoolock Gibbons, show that its presence and absence do not correlate with human disturbance and distance to settlement (Pacchua et. al, 2013). Where studies on western black crested gibbons found that their habitat use is mostly influenced by food resource distribution, human disturbance, and canopy structure (Ni et. al, 2017). Another study on Hoolock Gibbons using an individual-based approach (microscale) rather than a population-based approach to characterize the habitat requirement shows that gibbons use the interior of the forest more frequently and avoid the edge area near a settlement or agricultural land (Akers et. al, 2013). Thus, in a fragmented

landscape considering multiscale in characterizing the use of habitat is crucial as it helps in determining what a species needs to thrive (Bryson-Morisson et. al, 2017).

Hoolock Gibbons in Garo Hills are known to have disappeared from several localities due to the conversion of forest land to a plantation, degradation of forest, poaching and hunting, and unplanned developmental activities (Sati, 2011). The forest where the gibbons are known to be present outside the protected area in Garo Hills is mostly Village Forest or the Songachan (abandoned jhum plot) (Gupta and Sharma, 2005). Garo Hills landscape is a mosaic landscape with dense forest, moderately dense forest, old growth fallow, new growth fallow, active jhum cultivation, monoculture, mixed plantation, tea plantation, areca plantation, orchards, settlements, etc., (Kurien et. al, 2019) and in most places where Gibbons is located in Community Forest (Sati, 2011), it is found that these forests are fragmented and surrounded by jhum cultivation, orchard, or cash crop fields (Sailas et. al, 2021). For the past few decades, a survey of Hoolock gibbons in Garo Hills shows that the population has declined in Community forests and other non-protected forests (Alfred et. al, 1990; Gupta and Sharma, 2005; Sati, 2011). As a flagship species and habitat specialist, Hoolock gibbons require an understanding of their ecology in such a landscape to ensure their protection, which in turn helps to conserve other endangered species (Gupta and Sharma, 2005).

### **1.3. AIM**

The study aims to form a baseline for the ecology of Hoolock Gibbons in and around the Community-managed forests, and Protected Areas by characterizing the habitat use of Hoolock gibbons and understanding their activity pattern, as these Communities have their own way of managing the forest which helps in sustaining both human livelihood and wildlife. The study will help in identifying the differences in the nature of protection on Gibbons through their habitat use and activity pattern and also identifying tree species that the used by the gibbons as this will help further in conserving the species.

## 1.4. Objectives

1. To determine habitat use by Hoolock Gibbon within its home range in and around the community-managed forests and outside the Protected area.
2. To examine the activity patterns such as feeding, resting, sleeping, sociality, and movement of Hoolock Gibbons.

### 1.4.1. Justification

1. As the nature of the protection status in the Community Managed Forest is expected to be different from the Protected Area that is managed by the Forest Department, many of the Community-managed Forests have undergone drastic changes in their habitat condition and these forests are mostly secondary forest, even with protection that the community provided, still the community have the rights to use the forest for different purposes and changing the habitat condition. However, Government owned Protected areas are not expected to have many variations in the forest stand structure, thus understanding the Behavioural ecology of a species in such a landscape is crucial before going into conservation, as there is a need to fine-scale the factors influencing the species behaviour, Since, the community people in the Garo hills are highly dependent on the on these community reserves and its adjoining area, considering the impact of human activities can help further in minimizing disturbances and promoting conservation
2. A species within its home range will use the area disproportionately based on the availability of resources and pressures that impact its survival. Thus, determining the habitat use of the Hoolock Gibbon within its home range will help in identifying the areas that are highly used by the gibbons and the factors influencing their use in these areas, since the resources as not equally distributed and most of the Gibbon habitats in Garo

Hills which are in the Community Forest are surrounded by plantations which makes them fragmented

## **1.5. Hypothesis**

**Hypothesis 1:** As the forest stand structure and level of protection are different in the Community Managed Forest, and Protected Area, the disproportionate use of habitats by gibbons within its home range in these different forest types will be different. (Sarkar et. al, 2023; Ni et. al, 2018; Akers et. al, 2014).

**Hypothesis 2:** The differences in the patchy distribution of resources which is high in the Community Managed Forest and the level of disturbances will make the Gibbons' activity profile different between different habitats (Gupta and Sharma, 2005; Hasan et. al, 2021, Muzzafar et. al, 2007, Aker et. al 2013).

## 2. Materials and Methods

### 2.1. Study Area

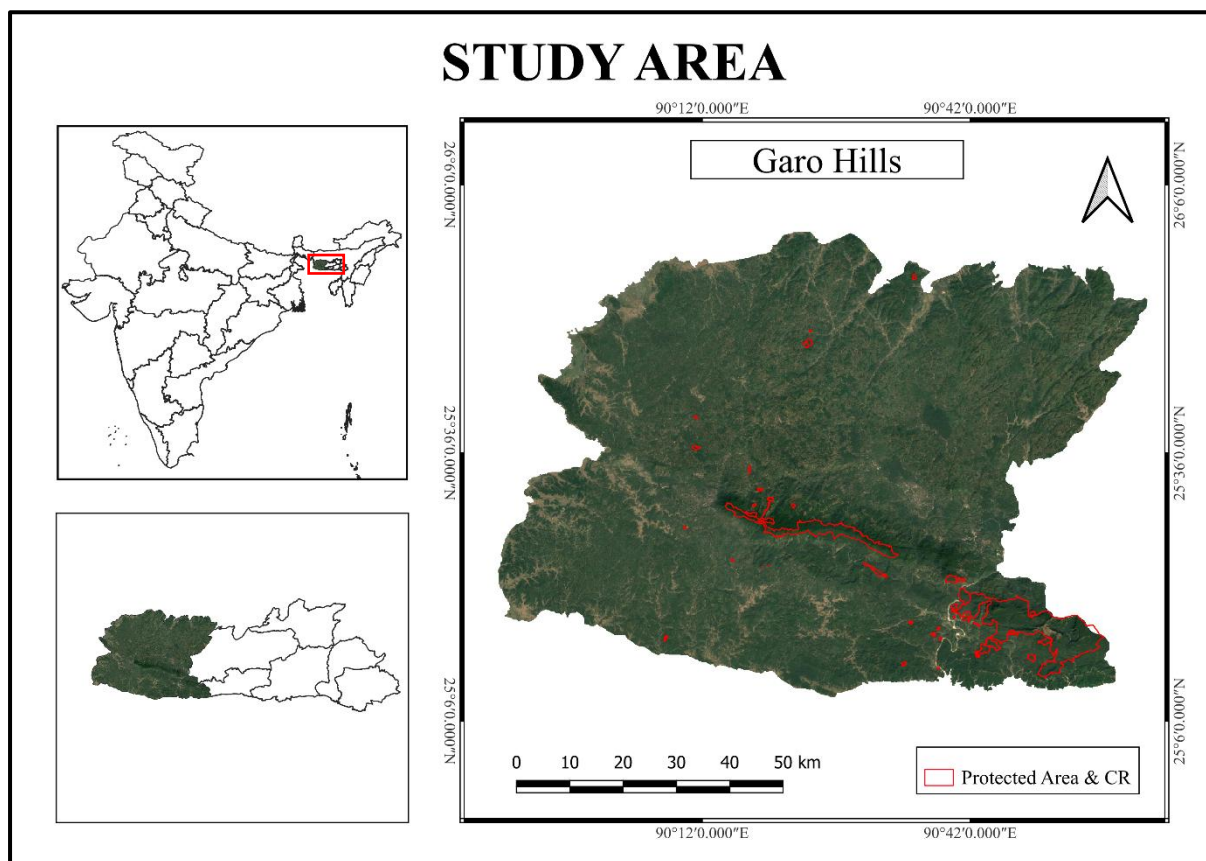


Figure 2.1. 1 Map showing the study area (Garro Hills).

Garro Hills is the westernmost of Meghalaya. It is bordered by Bangladesh to the south, Assam to the west and north, and to the east, it links to the Khasi Hills District. The old, native forests of the Garro Hills in western Meghalaya support diverse and dense tropical vegetation, which provides a good habitat for wildlife (Kumar et al., 2010). The Garro Hills are considered a part of the Meghalaya Subtropical Forests ecoregion, located within the Indian Subcontinent subrealm based on the Bioregions 2020 framework ([www.oneearth.org/bioregions-2020](http://www.oneearth.org/bioregions-2020)).

## **Vegetation**

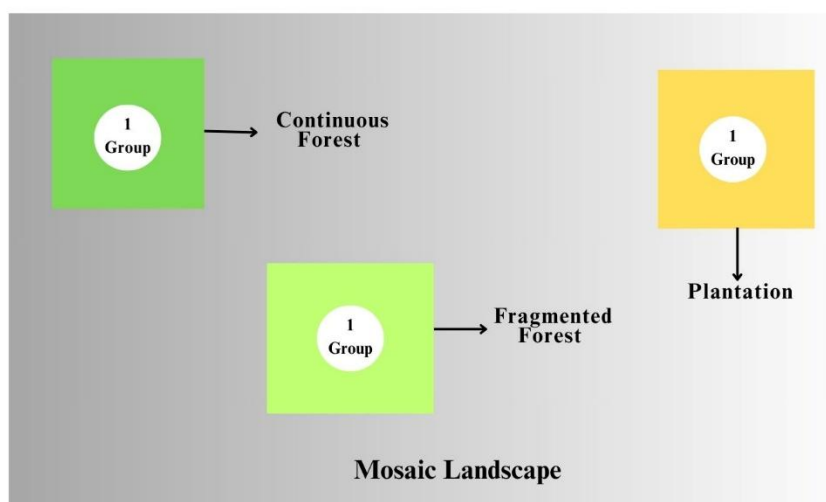
Vegetation of Garo Hills is broadly classified into those belonging to tropical and subtropical zones based on the altitude (Champion and Seth 1968). The tropical vegetation covers up to 1000 m in altitude. The subtropical vegetation occurs at 1200 m above sea level, and it is mostly found in Tura Peak and Nokrek Peak (Momin et al. 2016). Garo Hill embraces evergreen, semi-evergreen and deciduous forests, bamboo thickets, grasslands, riparian forest and swamps (Momin et al. 2016).

## **Agriculture**

People of Garo Hills rely heavily on agriculture for their livelihood, with shifting cultivation being the common practice ( Department of Management, North-Eastern Hill University, Tura Campus et al. 2019; Yadav et al. 2013). In most of the Jhum land, squash, pumpkin, rice, ginger, maize, and pulses such as pea are common grown. Other cash crops that were grown are betel nut, cashew nut, pineapple, and cinnamon. Poultry and pig rearing are the most common livestock in the area(Yadav et al. 2013). It has been determined that jhum or shifting cultivation has a detrimental effect on the region's forest cover (Kumar et al. 2008). In some areas, such as Daribokgre, Mandal Nokat, Chandigre, Baladingre, and Dura Kalakgre, which are in the buffer of Nokrek Biosphere Reserve, people have converted most of their jhum land into a permanent Orange plantation.

## 2.2. Study design

For this study, I have chosen three forest patches- one being a continuous forest patch, i.e., Daribokgre Community Reserve adjoining Nokrek National Park, a fragment forest (Disturbed), i.e., Dura Kalakgre Community Forest surrounded by Abandoned Jhum and Active Jhum, and Plantation (Human-dominated Landscape and high disturbance). Choosing these forests will give an idea of whether the habitat use and activity pattern are based on choice or resource availability. Additionally, it will illustrate how the gibbons' disproportionate usage of habitat varies between those three forest conditions.



*Figure 2.2.1 Study Design*

## 2.3. Field Methodology

**Selection of groups:** To achieve the objectives, three groups were chosen, one group in the Community Forest of Daribokgre adjoining Nokrek National Park, one group in Dura Kalakgre Community Reserve, which is surrounded by abandoned jhum, and one group in the Plantation area (Human-dominated Landscape).

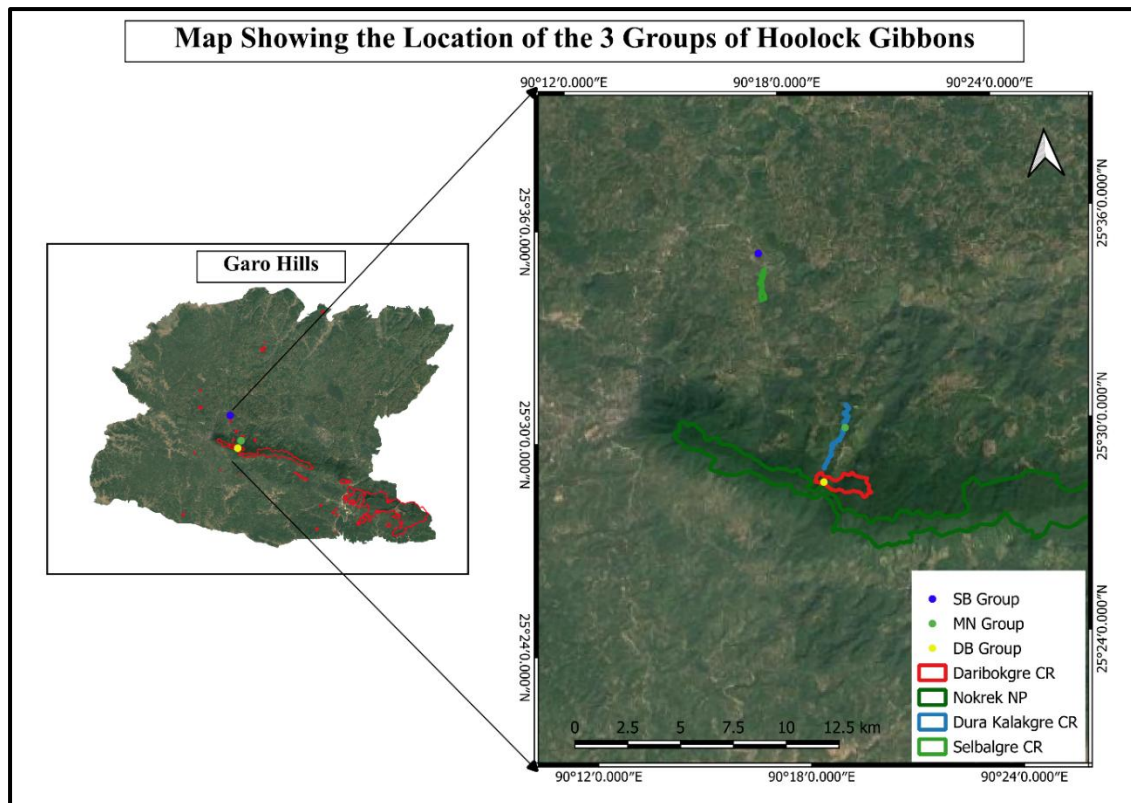


Figure 2.3. 1 Map showing the location of the chosen study group.

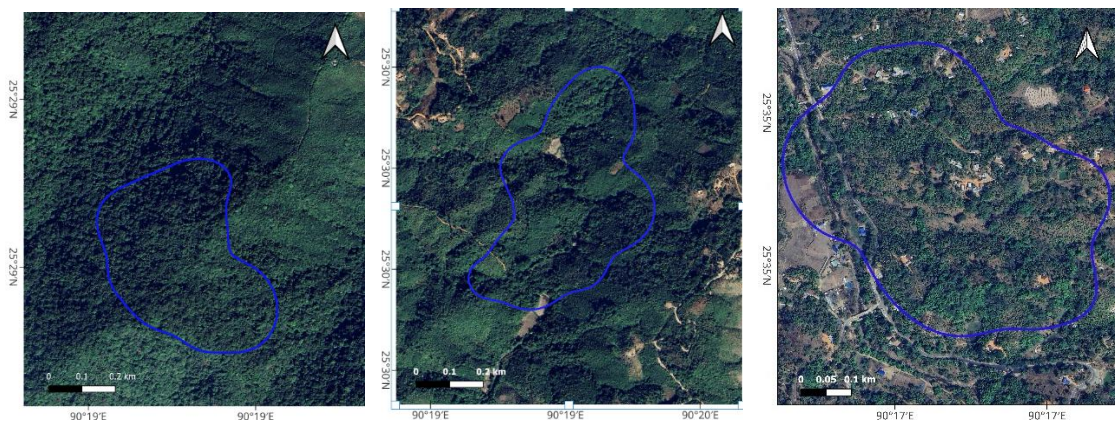


Figure: 2.3. 2 Expanded Map where the chosen group are located (Continuous Forest, Fragmented Forest, and Plantation respectively)

**Habituation of the selected groups:** Since most of the community-managed forests are adjoin to human settlements and people around the area use these forests, the Gibbons are habituated to human presence.

**Group Tracking:** To achieve objective 1, the selected groups were tracked from early morning to evening (until they went for roosting). Each group was tracked for 20 days. The Geo-coordinates location of the group was collected every 15 minutes.

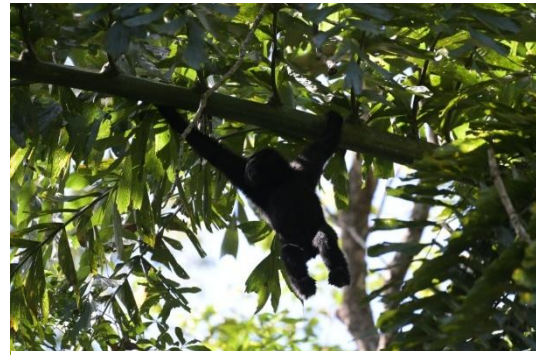
**Behavioural Sampling:** To achieve objective 2, focal sampling was conducted on each selected troop. The group was followed from early morning and late evening, and along with the collection of Geo-coordinates location after every 15 minutes. Major activities were recorded using instantaneous focal sampling (Altmann, 1974) for five minutes at intervals of 15 minutes as per the ethogram provided in Table 1. The sampling is alternating for each individual. In addition to the major activities, data on the strata used and resources that the animal will be feeding on were also collected.

*Table 2.3.1 Ethogram of major behaviour*

<b>Activity</b>	<b>Description</b>
Movement	Locomotion to spatially different locations, vertical movement on the same tree and movement within a group spread were not considered movements.
Feeding	Feeding on plant or animal resources.
Resting	This comprises states such as mastication, self-grooming, sleeping, or sitting.
Social	Behaviours comprise grooming, play, courtship, mating, and agonistic interactions with other group members.
Scouting	Individuals giving alarm calls to potential threats or being vigilant after noticing other groups in the vicinity, including behaviours directed towards other groups or organisms.



*Figure 2.3. 3 Socializing*



*Figure 2.3. 4 Moving*



*Figure 2.3. 5 Resting*



*Figure 2.3. 6 Scouting*



*Figure 2.3. 7 Feeding*

#### **Collection of Variables:**

At the end of the data collection on the location and behaviour, a grid of 100 ha x 100 ha cell size was overlaid on top of the geo-coordinates, which will be included within the home range of the gibbons. In the centre of each grid, a 10 m radius plot was laid for vegetation sampling. For vegetation sampling, tree densities, canopy height, canopy cover, and girth at breast height were measured. Signs of anthropogenic disturbances

such as NTFP collection, logging, and human trails were considered. Canopy height was classified into A (0-5m), B (6-10m), C (11-15m), D (16-20m), E (21-25m) and F (>26m). Same for disturbances, it was the class number of disturbance type, for example: if only one disturbance type is present, like the presence of a trail, then it is given a rank 1, but if two disturbance types are present, it is ranked as 2. For Disturbance area in each grid it was calculated from the percentage of non-forest area in each grid then it class into A (0-20%), B (21-40%), C (41-60%), D (61-80%), and E (81-100%).

## 2.4. Analytical Methodology

- Once the geo-coordinates locations of each group are recorded using GPS, using QGIS, the geo-coordinates points were converted to a shape file, and the points will be overlaid with a vector grid of 100 m x 100 m by using Joining attributes by location with intersection methods. Thus, by considering the home range of gibbons in Garo Hills as 36 hectares (Gupta et. al, 2005), a 1-hectare area is taken as an appropriate unit to understand habitat use. Based on the location, time spent on each grid, and the frequency of visiting the grid, analysis will further help in characterising which area within the home range is highly used by the gibbons.
- The Grid use pattern for each selected group of gibbons was divided into Very low (0-0.03), Low (0.04-0.06), Medium (0.07-0.09), and High (>0.1) based on the proportion of frequency of geo-coordinates on each grid.
- Distance to Jhum cultivation area, plantation, and settlements from each used grid was measured using the Shortest Line Between Features tool from QGIS once the overlaid grid was ready, and it was used as a variable.
- The aggregated activity budget method will be used to calculate the proportion of each activity (Marsh, 1981).

- RStudio (R version 4.3.3 (2024-02-29 ucrt) was used apart from QGIS for used in further analysis.
- One-way ANOVA is used to analyse the spatial variation of habitat type within each group.
- Pearson's correlation test is used to find out the association of the intensity of grid use by gibbons and the proportion of available habitat type.
- To understand what factors influence the Intensity of use within each grid across the home range, a Generalised Linear Model (GLM) with Quasibinomial family was used, keeping the Intensity of Use as the response variable.
- Chi-Square test of independence is used to find the difference in overall activity across the three groups of gibbons
- Kruskal Wallis Test was used to test the differences in each behavioural activity across the three groups.

### 3. Results

#### 3.1. Group Composition

The group composition of the three groups of *Hoolock hoolock* that were considered for this study ranged from 4-5. The Forest and Jhum groups contain one adult male, one adult female, two sub-adult and one juvenile. The Plantation group contains one adult male, one adult female, one sub-adult, and one juvenile.

*Table 3.1.1 Group Composition*

<i>Location</i>	<i>Group Name</i>	<i>Number of Individuals</i>			
		<i>Adult Male</i>	<i>Adult Female</i>	<i>Sub-adult</i>	<i>Juvenile</i>
<i>Daribokgre CR</i>	<i>Forest Group</i>	<i>1</i>	<i>1</i>	<i>2</i>	<i>1</i>
<i>Dura Kalakgre CR</i>	<i>Jhum Group</i>	<i>1</i>	<i>1</i>	<i>2</i>	<i>1</i>
<i>Rensengre</i>	<i>Plantation Group</i>	<i>1</i>	<i>1</i>	<i>1</i>	<i>1</i>



*Figure 3.1. 1 Forest Group*



*Figure 3.1. 1 Jhum Group*



*Figure 3.1. 3 Plantation Group*

### **3.2. Variation of Habitat Type**

In the Forest group, the Habitat type composition was relatively homogeneous. Of all the 24 grids that have been delineated by overlaying them on the geo-coordinates, only one grid contains both forest and abandoned Jhum Land. Thus, in this group, the habitat is mostly dominated by Forest patches. No tests were considered for the spatial variation of habitat type in this group.

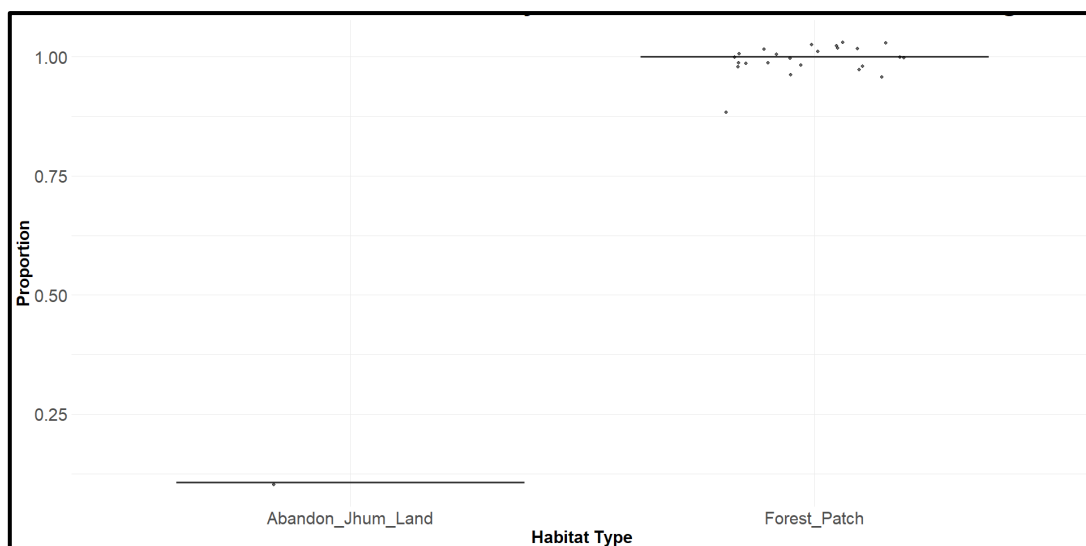


Figure 3.2.1 Graph showing the distribution of habitat type within the Forest Group

For the Jhum and the Plantation group, the spatial availability in habitat type differs significantly (F-value = 7.27, p-value <0.05 for Jhum Group, and F-value = 35, p-value < 0.05 for PLANTATION group). Tukey's post-hoc test of HSD for Jhum group shows that the proportion of Forest Patch (mean = 0.45, se = 0.054) and Abandon Jhum Land 10-20 Years (mean = 0.51, se = 0.082) were much higher than compared of other habitat types. In the Plantation group, Tukey's post-hoc test of HSD shows that the proportion of Plantation (mean = 0.71, se = 0.04) was higher than the other habitat types.

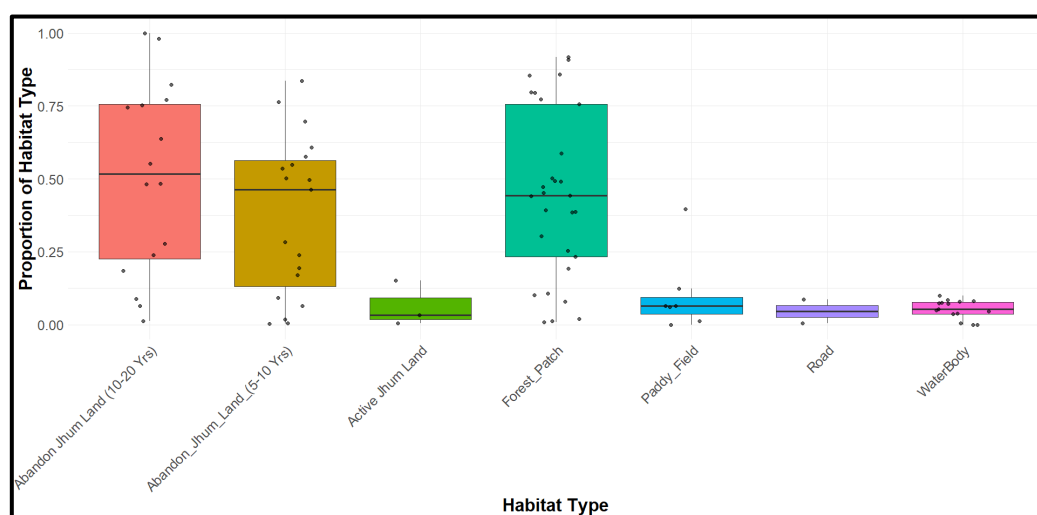


Figure 3.2. 2 Graph showing the distribution of habitat type within the Jhum group

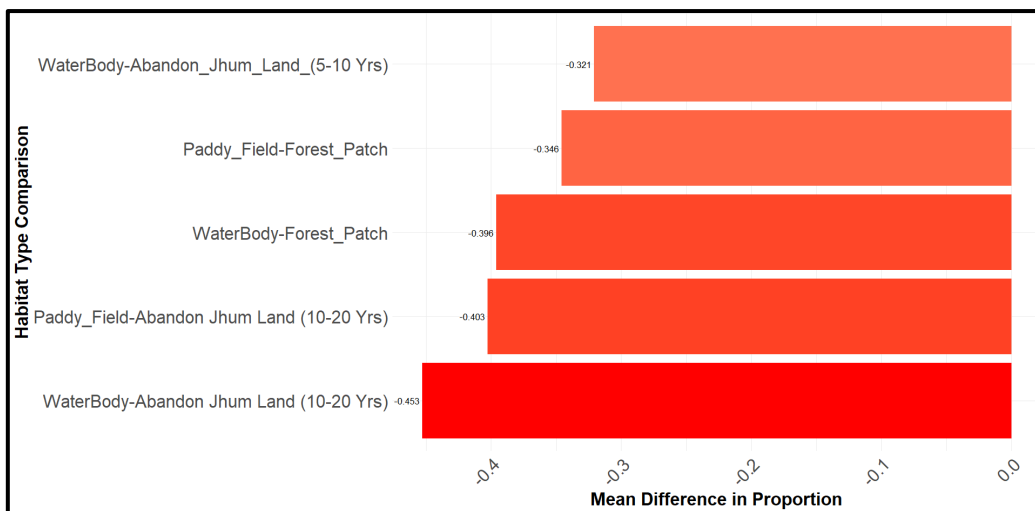


Figure 3.2. 3 Graph showing the significant habitat availability differences (Tukey's post-hoc test) for the Jhum group

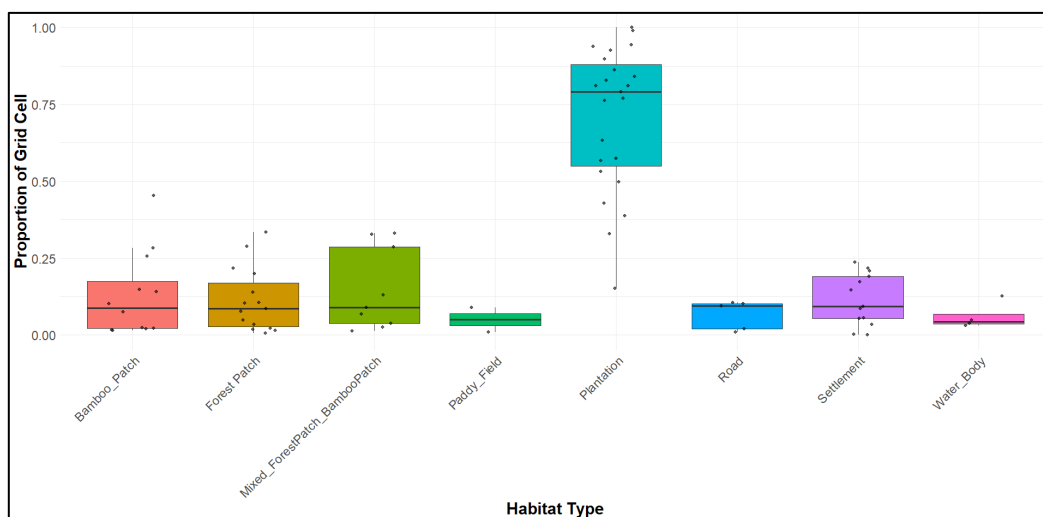


Figure 3.2. 4 Graph showing the distribution of habitat type within the Plantation group

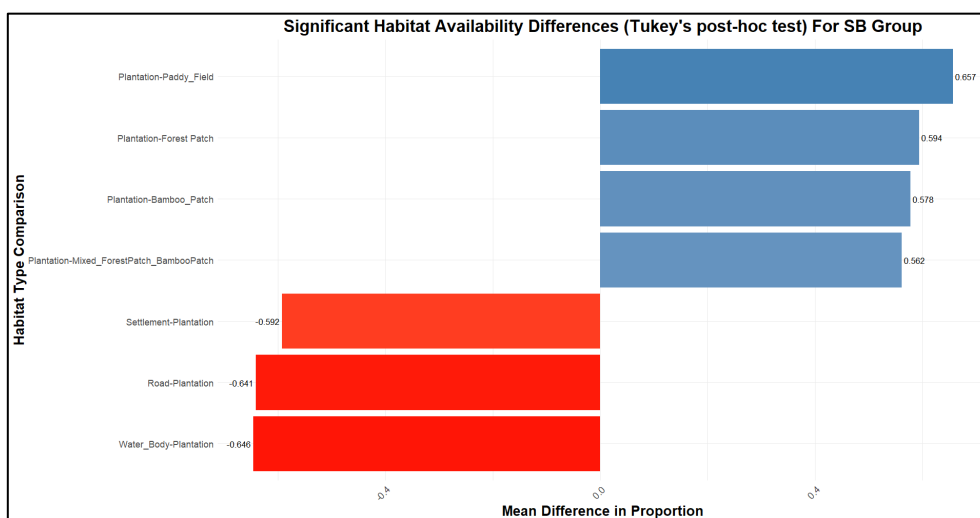


Figure: 3.3. 5 Graph showing the significant habitat availability differences (Tukey's post-hoc test) for Plantation group

### 3.3. Home range

Using Autocorrelation Kernel Density Estimate, the home range of each group was estimated. The Forest group home range was estimated to be 18.44 hectares with Confident Interval ranges from 22.94 hectares to 14.41 hectares (Figure: 3.3.1.), the Jhum group home range is 30 hectares (Figure: 3.3.2.), and the Plantation group home range is 23 hectares (Figure: 3.2.3.).

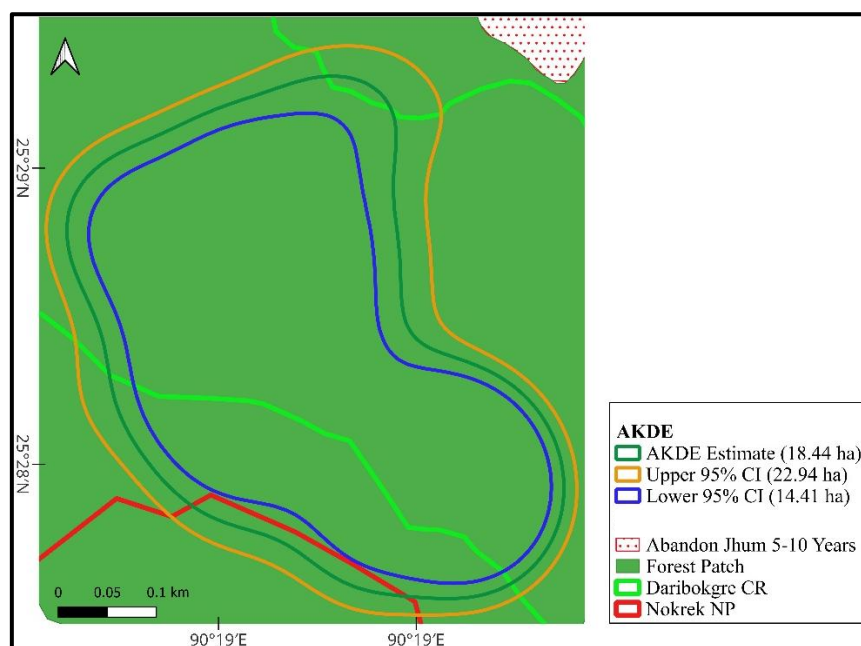


Figure: 3.3.1 Map showing the Home range estimated by using AKDE for the Forest Group

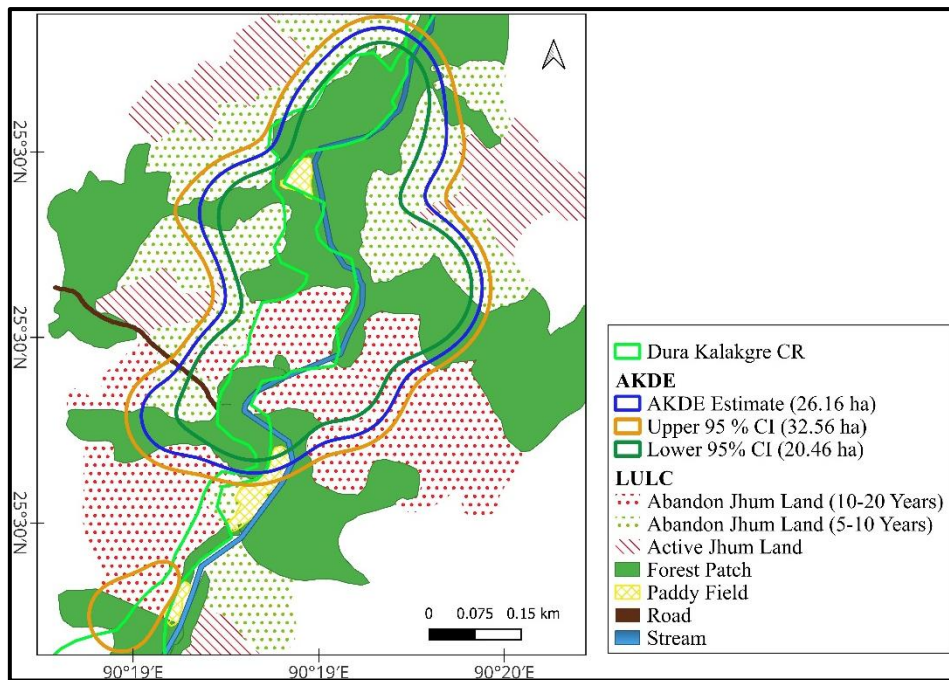


Figure 3.3. 2 Map showing the Home range estimated by using AKDE for the Jhum Group

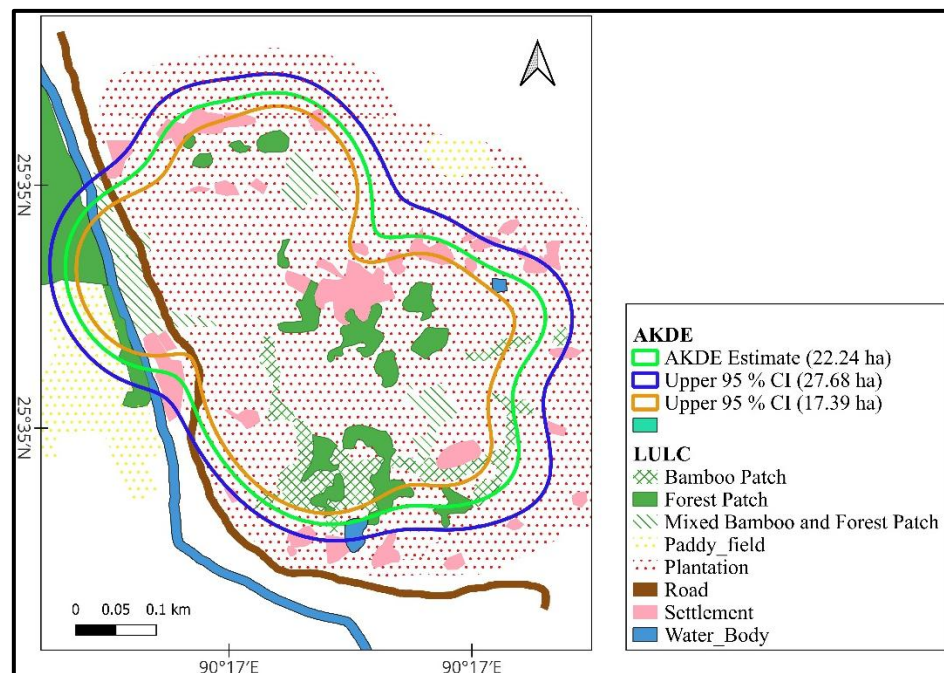


Figure 3.3. 3 Map showing the Home range estimated by using AKDE for the Plantation Group

Adding to AKDE, a grid-based method was also used to estimate the home range, as it was used in checking the covariates that influence the habitat use within the home range. In the grid-based method, a 1 hectare grid size was overlaid on the geo-coordinates, and the intensity of use on each grid was measured by the frequency of geo-coordinates on each grid and divided by the total number of geo-coordinates for each group. Using the grid-based method, the home range of the Forest Group was 24 hectares (Figure 3.2.4), for the Jhum Group it was 30 hectares (Figure 3.2.5), and for the Plantation Group it was 23 hectares (Figure 3.2.6). The home range estimation using both AKDE and GBM gave almost similar results.

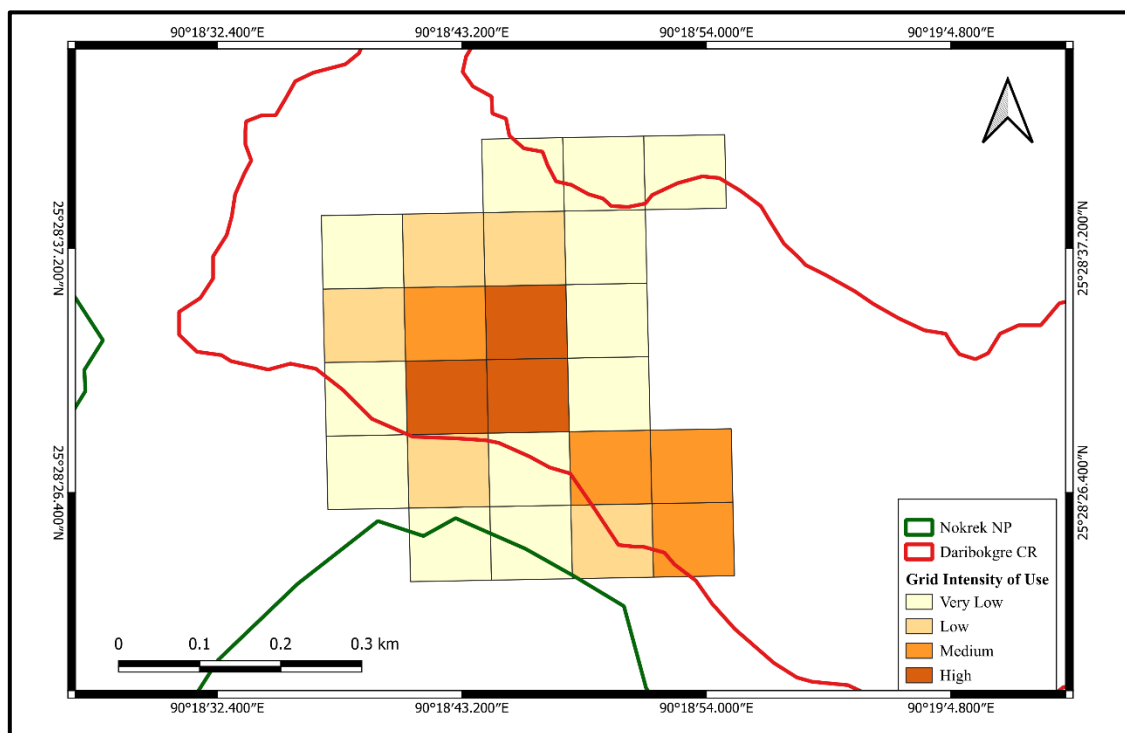


Figure 3.3. 4 Map showing the Home range of Forest Group using GBM with the intensity of use classified into Very low (0-0.03), Low (0.04-0.06), Medium (0.07-0.09), and High (>0.1)

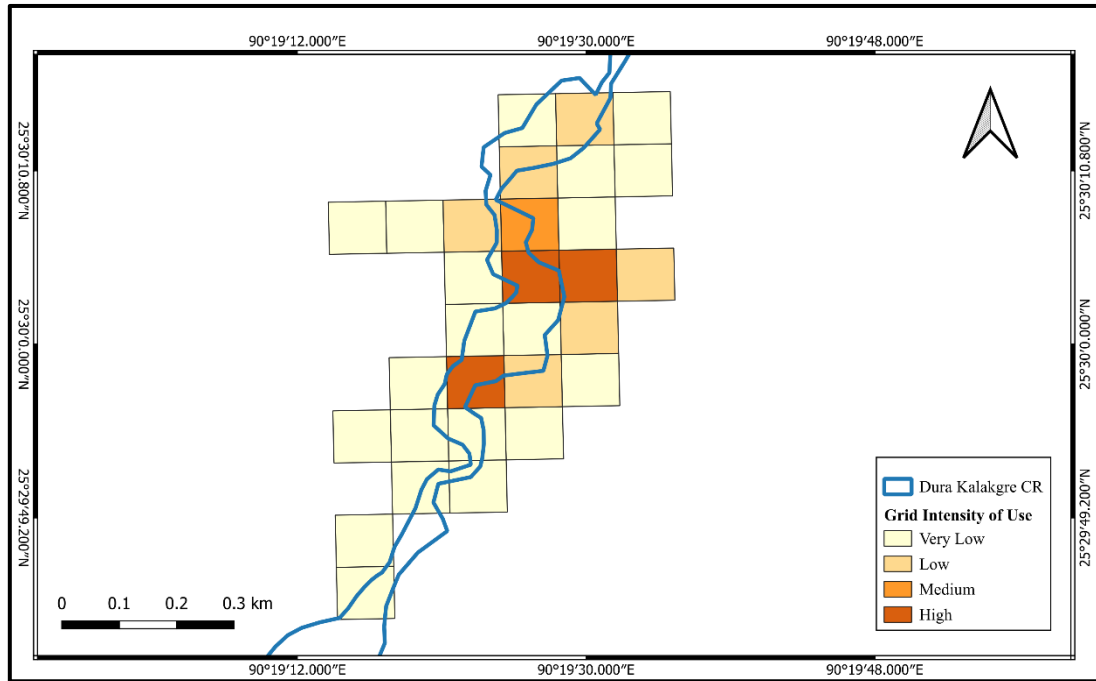


Figure 3.3. 5 Map showing the Home range of Jhum Group using GBM with the intensity of use classified into Very low (0-0.03), Low (0.04-0.06), Medium (0.07-0.09), and High (>0.1)

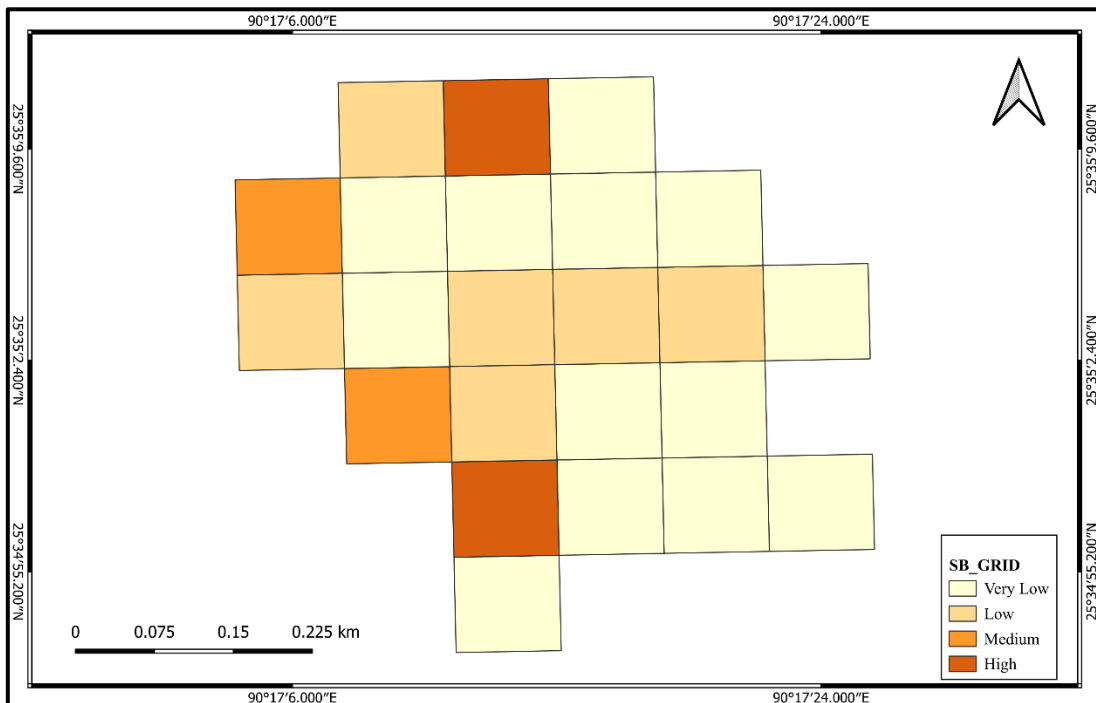


Figure 3.3. 6 Map showing the Home range of the Plantation Group using GBM with the Intensity of use is classified into Very low (0-0.03), Low (0.04-0.06), Medium (0.07-0.09), and High (>0.1)

### 3.4. Association of Habitat Type and Intensity of Grid Use

To check for correlation between the habitat type and intensity of grid use, Pearson's correlation test is used. The test is only used for the Jhum and Plantation groups, since the Forest group habitat is highly dominated by the Forest patch (Figure 3.2.1). For the Jhum group, the test shows that none of the Habitat types have any significant relation with the Intensity of grid use (Table 3.4.1). For Plantation, the test shows that Bamboo patch, Mixed Forest and Bamboo Patch show a positive significant relationship with intensity of use, whereas plantation shows a negative relationship with intensity of use (Table 3.4.2).

**Table 3.4.1 Association of Habitat Type with Intensity of Grid Use (Jhum Group)**

<i>Habitat Type</i>	<i>Estimate</i>	<i>p</i>
Abandon Jhum Land (10-20 Years)	-0.194	0.472
Abandon Jhum Land (5-10 Years)	-0.0346	0.888
Active Jhum Land	0.0003	0.1
Forest Patch	0.299	0.115
Paddy Field	-0.351	0.441
Water Body	0.288	0.298

**Table 3.4.2. Association of Habitat Type with Intensity of Grid Use (Plantation Group)**

<i>Habitat Type</i>	<i>Estimate</i>	<i>P</i>
Bamboo Patch	0.595	<b>0.041</b>
Forest Patch	0.244	0.380
Mixed Forest and Bamboo Patch	0.860	<b>0.003</b>
Plantation	-0.576	<b>0.004</b>
Road	0.954	0.012
Settlement	-0.420	0.153
Water Body	0.219	0.781

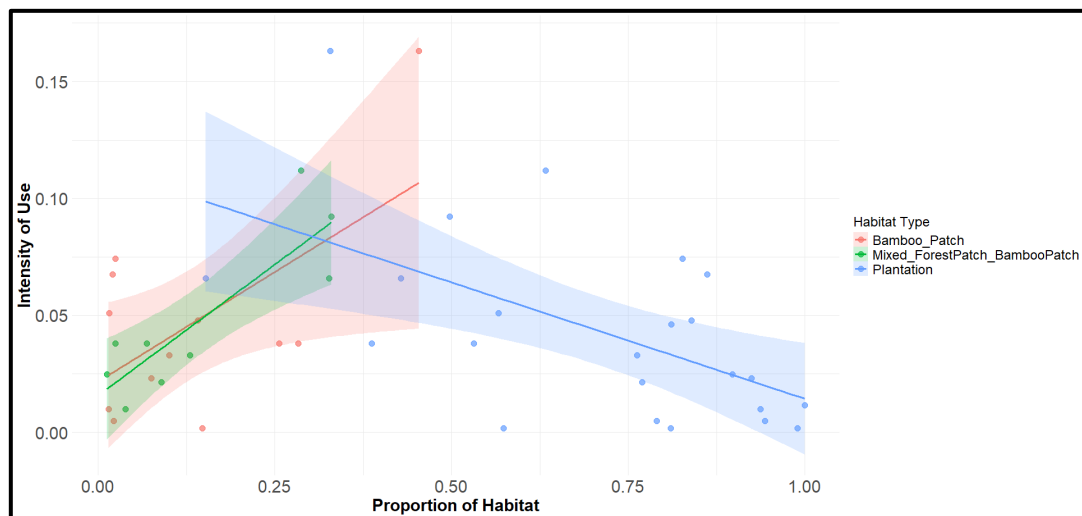


Figure 3.4. 1 Graph showing the significant correlation of different habitat types with the Intensity of use (Plantation Group)

### 3.5. Differences in the Grid Use Pattern across the Three Groups

The Intensity of use (proportion) is divided into four Use classes: 0-0.03(Very Low), 0.04-0.06(Low), 0.07-0.09(Medium), and above 0.1(High). Using the Fisher test for testing if the differences in the Grid Use pattern within the Home range across the groups give the p-value (0.534), which is  $> 0.05$ , this shows that there is no difference in the pattern of grid use within the home range across the three groups. But, standardised residuals (Figure 3.5.1) show some trend at the group level. Where in the Forest Group, slightly underused the low use class and slightly overused the medium use class, and the Jhum Group slightly overused the low use class and slightly underused the medium use class. These may reflect on the patterns of habitat quality differences across the three Groups.



Figure: 3.5.1 Variation in Grid Use pattern across the three groups (DB= Forest group, MN=Jhum Group, and SB=Plantation Group)

### 3.6. Response of intensity of use to habitat covariates

The effect of covariates was analysed for each group using Generalised Linear Model (GLM) with Quasibinomial distribution to account for overdispersion, and keeping the Intensity of use on each grid as response variables for all three groups. For each group, both interactive and additive models were run, and based on pseudo  $R^2$  and Variance Inflation Factor (VIF), a model was chosen to explain the effect of covariates on the intensity of use.

#### 3.6.1. Forest Group

Covariates such as Canopy cover, Canopy Height, Average Girth at Breast Height, Tree density, Distance to Abandoned Jhum Land, and Disturbances are used to check if any of these affect the Intensity of Use. A GLM with quasibinomial family was run, keeping Intensity of Use at each grid as a response variable. Both interactive and additive models were run, and using pseudo  $R^2$  value and Variance Inflation Factor (VIF), a model was chosen with a High pseudo  $R^2$  value and vif value of less than 2. The model shows that none of the predictor variables shows any significant effect on the Intensity of use. The detailed result of the model is given in Table 3.6.1.1.

**Table 3.6.1. 1. GLM-Response of the Intensity of Use on habitat covariates**

<i>Predictors</i>	<i>Estimate</i>	<i>SE</i>	<i>t</i>	<i>p</i>
(Intercept)	-4.151	0.676	-6.138	<0.05
Average GBH	0.093	0.281	0.330	0.746
Canopy cover	0.580	0.304	1.907	0.075
Mean NDVI	0.585	0.279	2.097	0.052
Disturbances.1	0.690	0.439	1.573	0.135
Disturbances.2	0.395	1.082	0.365	0.720
Canopy Height. E	0.359	0.604	0.594	0.561
Canopy cover $\times$ Mean NDVI	0.364	0.383	0.949	0.357

Null deviance: 1.01  
Residual deviance: 0.523  
Pseudo-R<sup>2</sup>: 0.482

### 3.6.2. Jhum Group

In Jhum Group, the model explained 73% of the deviance (residual deviance = 0.294, null deviance = 1.097). The predictors that were used in modelling for the JHUM group are: Average GBH, Tree density, Canopy cover, Canopy Height, Disturbances, Distance to abandoned jhum land, Distance to active jhum land, Disturbances area, mean NDVI, and mean elevation, and keeping Intensity of Use as response variables. Among these predictors, only canopy height with class E ( $\beta=2.342$ ;  $SE=1.068$ ;  $p=0.042$ ) and F ( $\beta=2.580$ ;  $SE=1.201$ ;  $p=0.046$ ) show a significant positive effect ( $p$ -value < 0.05) on the Intensity of use by JHUM Gibbons Group (Table 3.6.2.1). This suggests that areas with tall canopies are intensively used by the gibbons.

**Table 3.6.2.1 GLM (Quasibinomial) results for Intensity of Use**

<i>Predictors</i>	<i>Estimate</i>	<i>SE</i>	<i>t</i>	<i>p</i>
(Intercept)	-5.196	1.046	-4.969	<0.001
Tree Density	-0.102	0.270	-0.377	0.711
Average GBH	-0.187	0.178	-1.049	0.308
Mean elevation	-0.230	0.187	-1.231	0.234
Mean NDVI	0.054	0.171	0.317	0.755
Distance to Active Jhum Land	-0.170	0.208	-0.816	0.425
Canopy Height. C	1.027	1.130	0.909	0.375
Canopy Height.D	1.351	1.055	1.281	0.217
Canopy Height. E	2.342	1.068	2.193	<b>0.042</b>
Canopy Height. F	2.580	1.201	2.148	<b>0.046</b>
Disturbances.1	0.452	0.457	0.989	0.336
Disturbances.2	-0.740	0.553	-1.337	0.198

Null deviance: 1.097

Residual deviance: 0.294

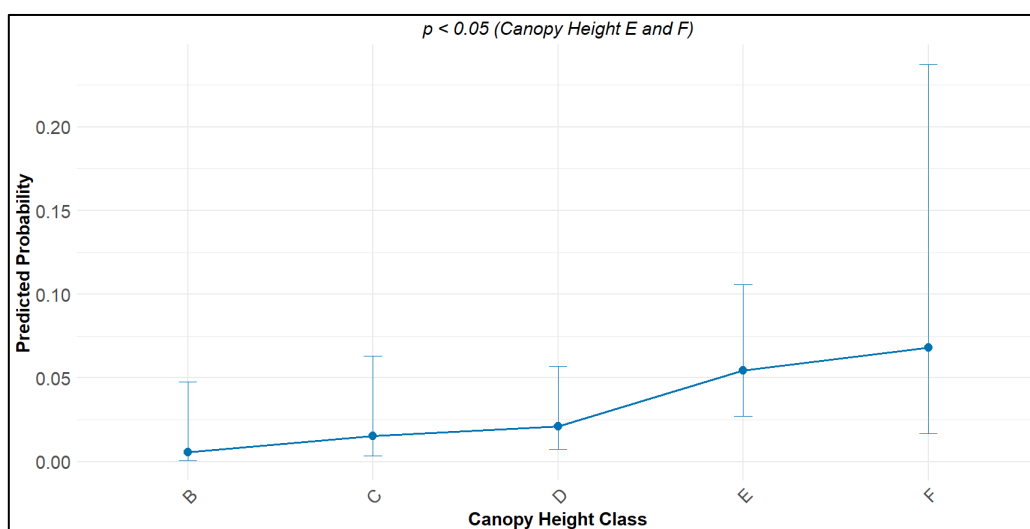
Pseudo R<sup>2</sup>: 0.732

Figure 3.6.2.1 Response of the Intensity of on Canopy height for Jhum group (B=6-10 m, C = 11-15 m, D=16-20m, E=21-25m, F=>25m)

### 3.6.3. Plantation Group

In the Plantation gibbon Group, the model explained 62% of the deviance (null deviance = 0.837, residual deviance = 0.313). The predictors that were used in the models are: Average GBH, Tree density, Canopy Cover, Canopy Height, Distance to Settlement, Distance to Plantation, and Distance to road, mean NDVI, and mean elevation, keeping Intensity of Use as a response variable. Among these predictors, Distance to plantation ( $\beta = 0.501$ ;  $SE = 0.208$ ;  $p = 0.029$  and Canopy cover ( $\beta=0.839$ ;  $SE=0.275$ ;  $p=0.008$ ) show a significant positive effect on the Intensity of use of gibbons on each grid in the PLANTATION group (Table 3.6.3.1). At a high distance from the plantation, the prediction of intensity of use is uncertain, as this is due to the area being largely dominated by the areca plantation.

**Table 3.6.3.1 GLM-Response of the Intensity of Use on habitat covariates (Jhum Group)**

<i>Predictors</i>	<i>Estimate</i>	<i>SE</i>	<i>t</i>	<i>p</i>
(Intercept)	-3.397	0.196	-17.319	<b>&lt;0.001</b>
Canopy cover	0.839	0.275	3.051	<b>0.008</b>
Tree density	0.125	0.320	0.391	0.702
Average GBH	0.293	0.233	1.258	0.228
Distance to Plantation	0.501	0.208	2.408	<b>0.029</b>
Distance to Settlement	0.351	0.235	1.496	0.155
Mean Elevation	0.107	0.264	0.405	0.691
Mean NDVI	0.303	0.242	1.249	0.231

Null deviance: 0.837  
Residual deviance: 0.313  
Pseudo R<sup>2</sup>: 0.626

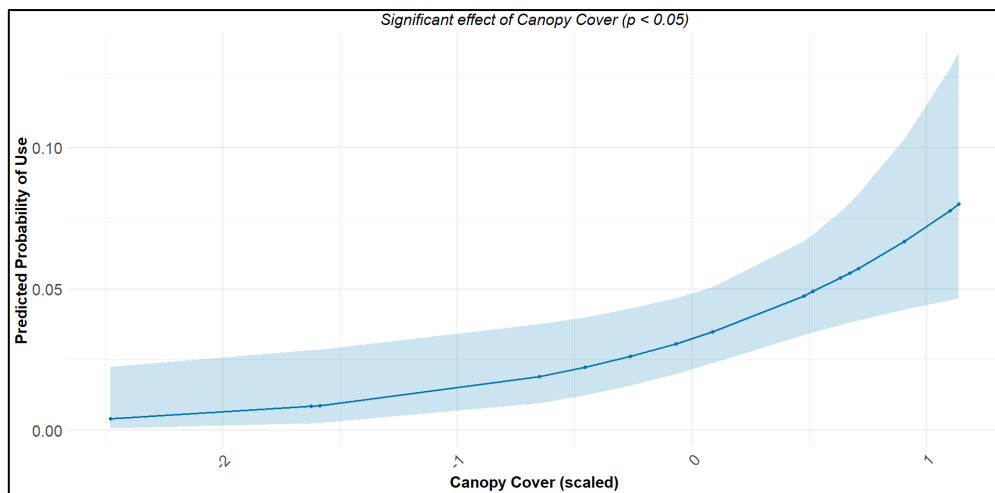


Figure 3.6.3 1 Response of the Intensity of Use on Canopy Cover for Plantation Group

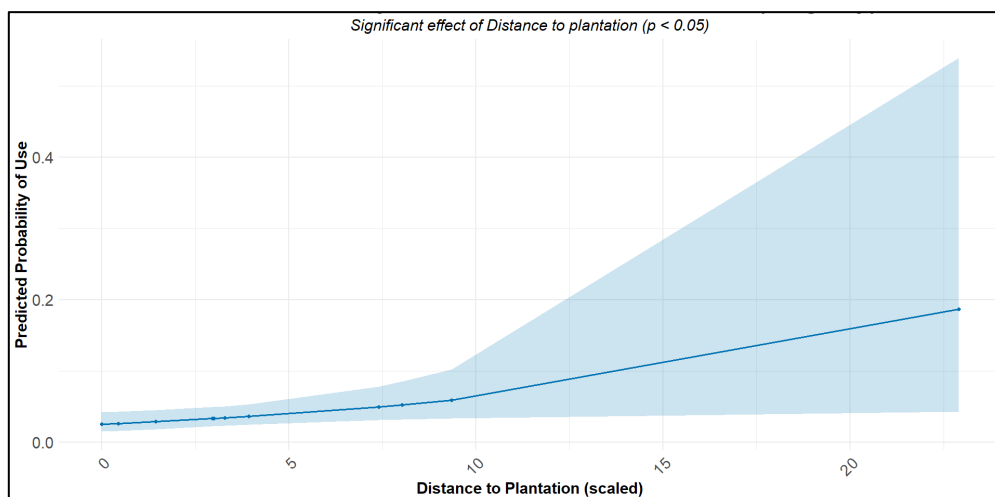


Figure 3.6.3 2 Response of the Intensity of Use on the Distance to Plantation for Plantation Group

### 3.7. Activity Budget

A total of 29 hours 06 minutes of focal sampling was collected for the Jhum group, 31 hours 95 minutes of focal sampling for the Forest group, and 46 hours 16 minutes for the Plantation group. The focal sampling observations were recorded for a period of 20 days for each group.

For the Forest group, out of the total observation, it was found that the group spent 41.8% on resting, 25.9% on feeding, 13.6% on Scouting, 9.06% on socialising, 7.95% on calling, and 1.63% on moving. It was found that there is a significant difference when these various activities are compared (Chi sq = 75029, df = 5,  $p < 0.00$ ). The total time spent on various activities across different use classes (Very low, Low, Medium, and High) shows a significant difference (Chi sq = 6587.9, df = 15,  $p < 0.00$ ). Standardized residuals (Figure 3.7.1) shows that calling is significant low in Very low and High use class, feeding is significantly high in Very Low Use Class and it is significant low in Medium and High use class, Moving is significantly high in Very Low Use Class, resting is significantly low in Very Low use class and Low use class, scouting is significantly high in Very low use class and low in medium use class, and socializing is significantly high in High use class and low in Medium use class. The total time spent across time class (7:00 -9:00, 9:00-11:00, 11:00-13:00, 13:00-15:00, >15:00) also shows a significant difference (Chi sq = 32027, df = 20,  $p < 0.00$ ). Standardised residuals (Figure 3.7.3) reveal that calling and feeding are prominent during the early hours (7:00-11:00), but resting is comparatively low. During the early hours, scouting is also pronounced. But around 11:00-13:00, socialising and moving were common during this period. As the day progressed, resting became a predominant behaviour, with all other behaviours becoming low.

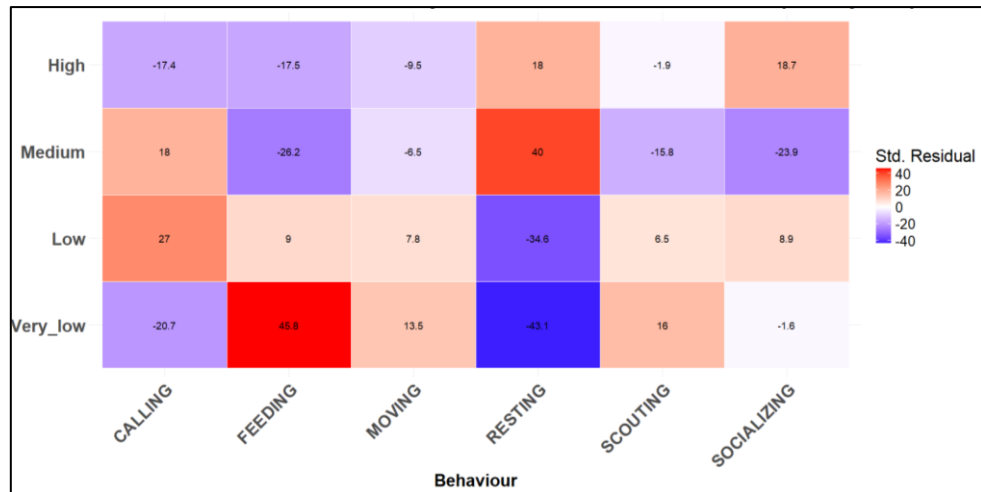


Figure 3.7. 1 Standardized Residuals Heatmap for Behaviours across Intensity use Class (Forest Group)

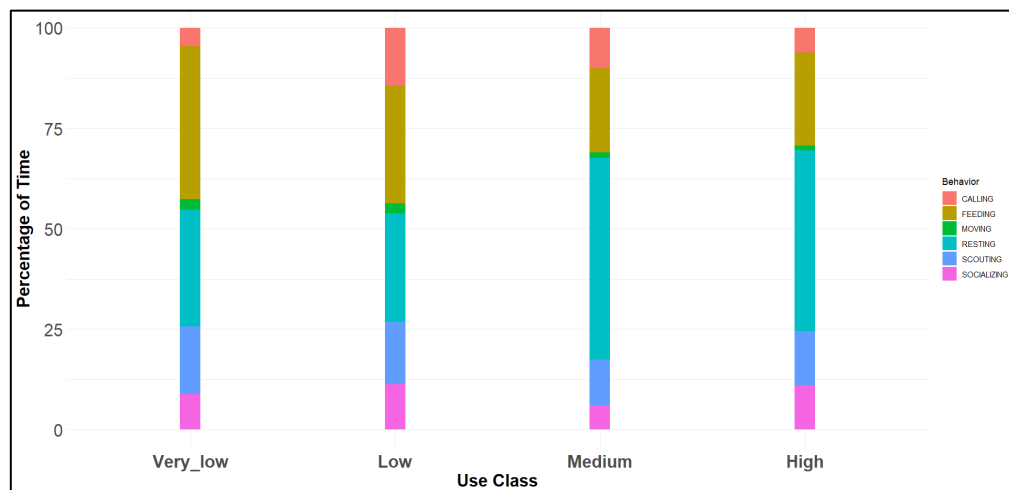


Figure 3.7. 2 Graph showing the proportion of time spent on each behaviour across the Intensity of use class (Forest Group)

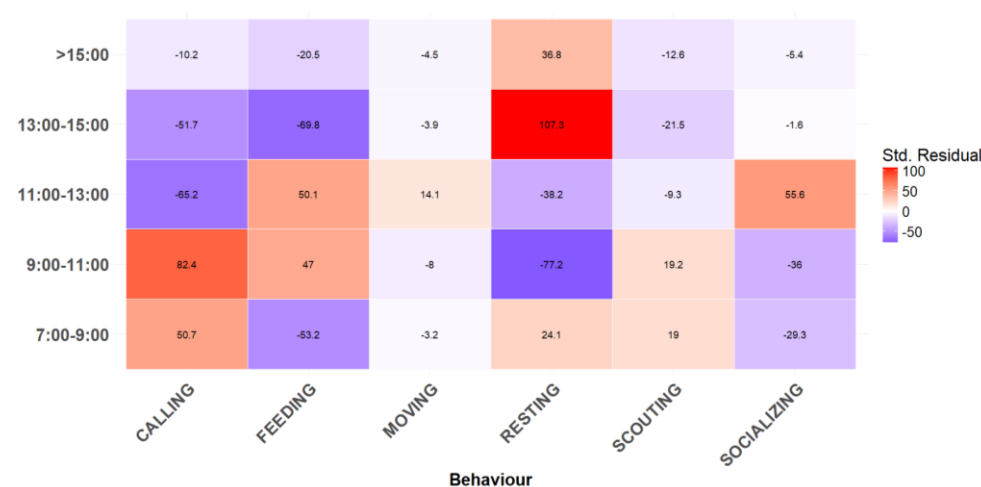


Figure 3.7. 3 Standardised Residuals Heatmap for Behaviours across Time Class (Forest Group)

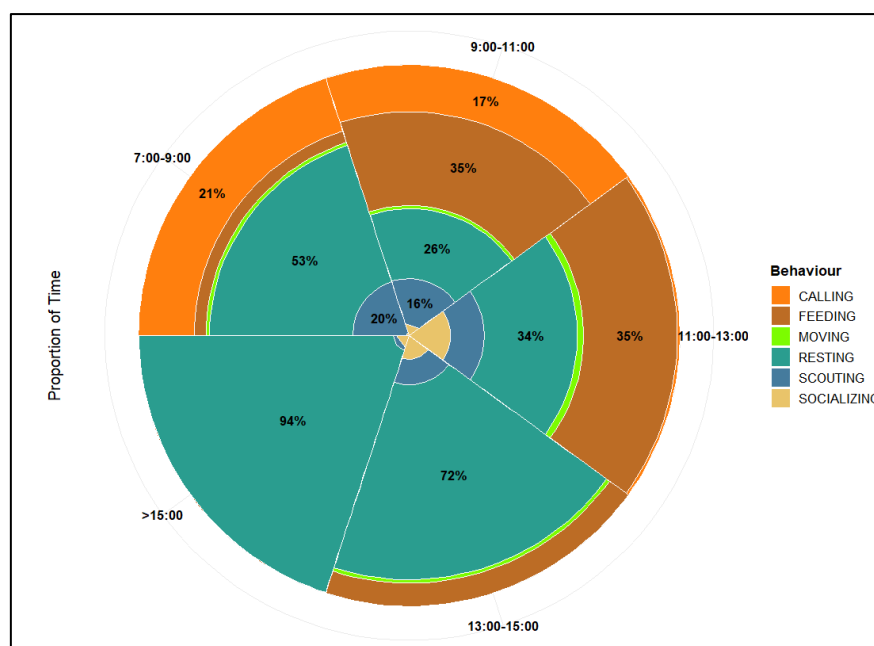


Figure 3.7. 4 Graph showing the proportion of time spent on each behaviour across the Time class (Forest Group)

For the Jhum group, out of the total observation, it was found that the group spent 29.9% on resting, 25.3% on feeding, 24.5% on Scouting, 9.49% on socialising, 8.07% on calling, and 2.77% on moving. It was found that there is a significant difference when these various activities are compared (Chi sq = 40797, df = 5,  $p < 0.00$ ). The total time spent on various activities across different grid use classes (Very low, Low, Medium, and High) shows a significant difference (Chi sq = 9924.2, df = 15,  $p < 0.00$ ). Standardised residuals (Figure 3.7.5) from a chi-squared test examining the association of behaviour and grid use class show that in a Very Low use class calling, scouting and feeding are high compared to other behaviours, as indicated a high positive residuals, whereas socialising and resting are significantly less. In low-use areas, moving, scouting, and socialising the residuals is moderately positive, but it is not as extreme as in other classes. In the Medium use area, resting is significantly higher than expected, while feeding and socialising are negatively significant. This could indicate that the Medium use area is preferred as a resting zone. In high-use areas, resting and socialising, the residuals are positively high, while other behaviours are underrepresented. This could suggest

that a high-use area acts as a core activity for resting and socialising. The total time spent across time classes (7:00 -9:00, 9:00-11:00, 11:00-13:00, 13:00-15:00, >15:00) also shows a significant difference (Chi sq = 30233, df = 20,  $p < 0.00$ ). Standardised residuals from the chi-squared test reveal significant temporal variation (Figure 3.7.7) in the behavioural patterns. Calling shows high positive residual during the morning hours (7:00-11:00), whereas resting is more frequent around mid and late afternoon (13:00-15:00 and >15:00). The peaked period of feeding is around 11:00-13:00, and during this period, socialising is more frequent. Meanwhile, resting and socialising show negative residuals during the early morning, especially around 9:00-11:00.

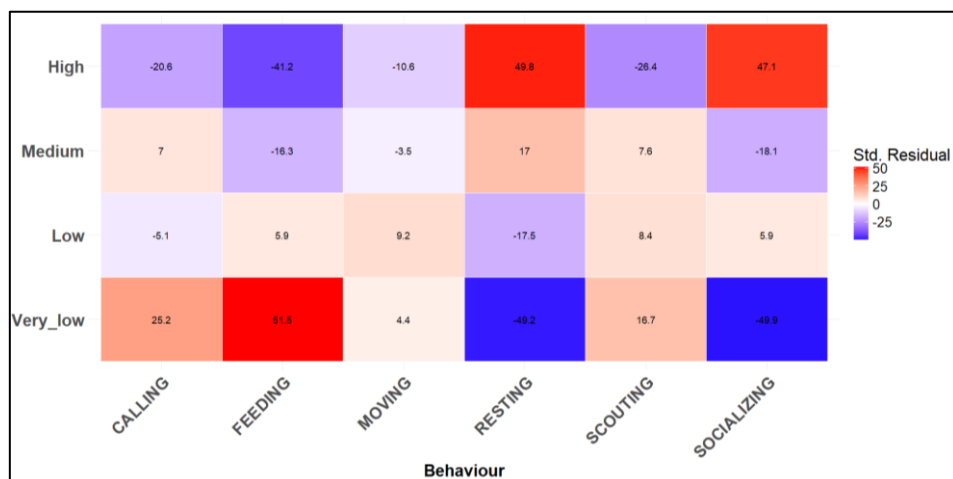


Figure 3.7. 5 Standardized Residuals Heatmap for Behaviours across Intensity use Class (Jhum Group)

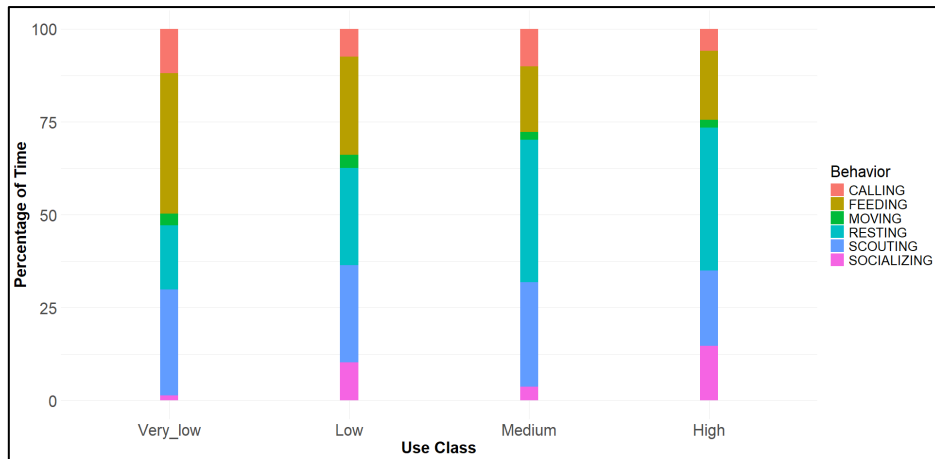


Figure 3.7. 6 Graph showing the proportion of time spent on each behaviour across the Intensity of use class (Jhum Group)

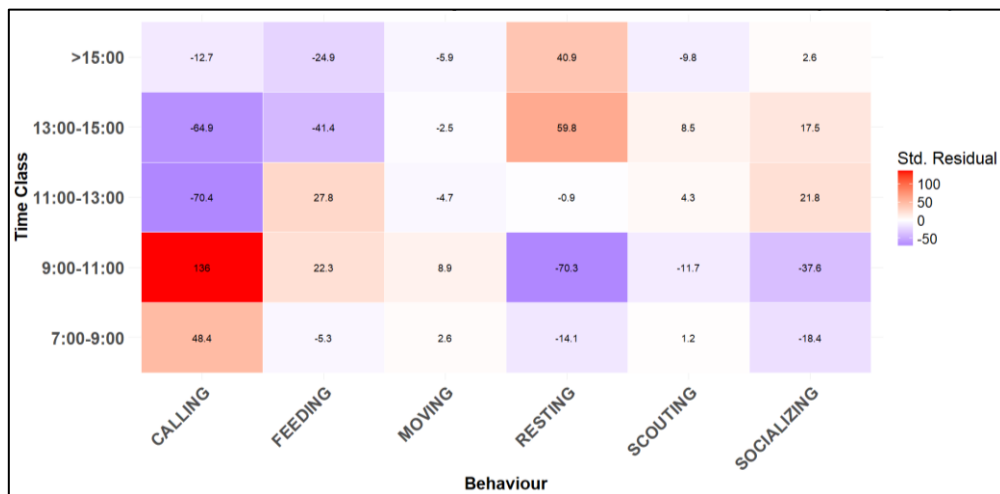


Figure 3.7. 7 Standardised Residuals Heatmap for Behaviours across Time Class (Jhum Group)

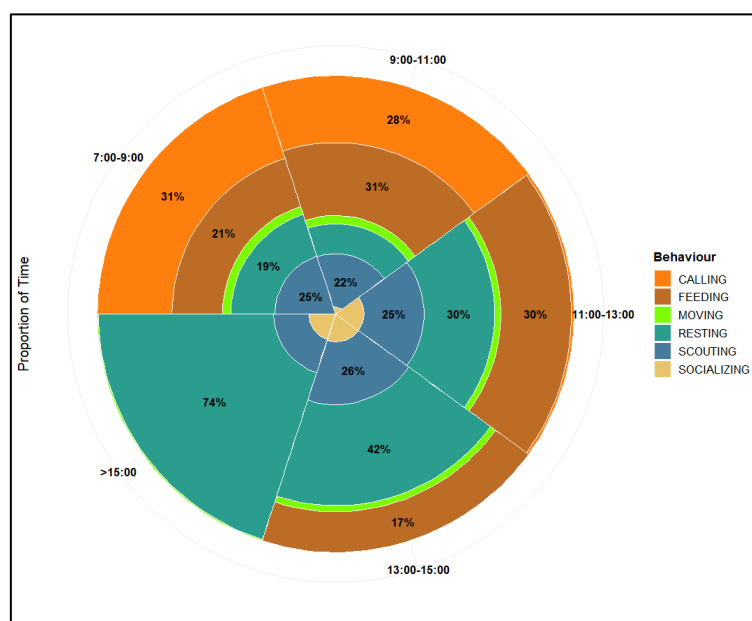


Figure 3.7. 8 Graph showing the proportion of time spent on each behaviour across the Time class (Jhum Group)

For the Plantation group, out of the total observation, it was found that the group spent 41.8% on resting, 25.9% on feeding, 13.6% on Scouting, 9.06% on socialising, 7.95% on calling, and 1.63% on moving. It was found that there is a significant difference when these various activities are compared (Chi sq = 111393, df = 5,  $p < 0.00$ ). Chi-squared test for spatial variation and behaviour shows that there are significant differences (chi sq = 4079.7, df=15,  $p < 0.00$ ). The standardised residuals (Figure 3.7. 9) show that there is distinct behaviour across different use intensities. Socialising and calling show large positive residuals in the High-use area, which suggests these behaviours are more common than expected. Whereas, scouting shows strong negative residuals in high-use areas, implying that this behaviour is less frequent than expected. Conversely, scouting is more frequent than expected in the Very Low use area, while socialising, resting, and calling are strongly underrepresented, suggesting that gibbons scout more in the very low use area and prefer to socialise and vocalise more in the high use area. For the association of behaviour and the temporal variation, the chi-squared test shows that there are significant differences (chi-sq = 9249.1, df = 20,  $p < 0.00$ ). A clear temporal pattern is revealed when analysing the standardised residuals (Figure 3.7. 11) from the chi-squared test assessing the association between behaviour and time of the day. In the early morning, calling shows a strong positive residuals, indicating that this period is used for vocalisation. Socialisation also becomes significantly more frequent during the early morning and elevated from 9:00-11:00. In contrast, feeding becomes more frequent from 13:00-15:00, with a large positive residual, indicating that early afternoon is a primary feeding period. The overrepresentation of resting during the late afternoon marks it as a key time for inactivity, while the same is being underrepresented during the midday time (13:00-15:00). Scouting is peaking modestly during 11:00-13:00 but becoming less frequent in the late afternoon. The

results indicate that morning time is dominated by communication and socialisation, afternoon is focused on feeding and late afternoon is spent on resting.

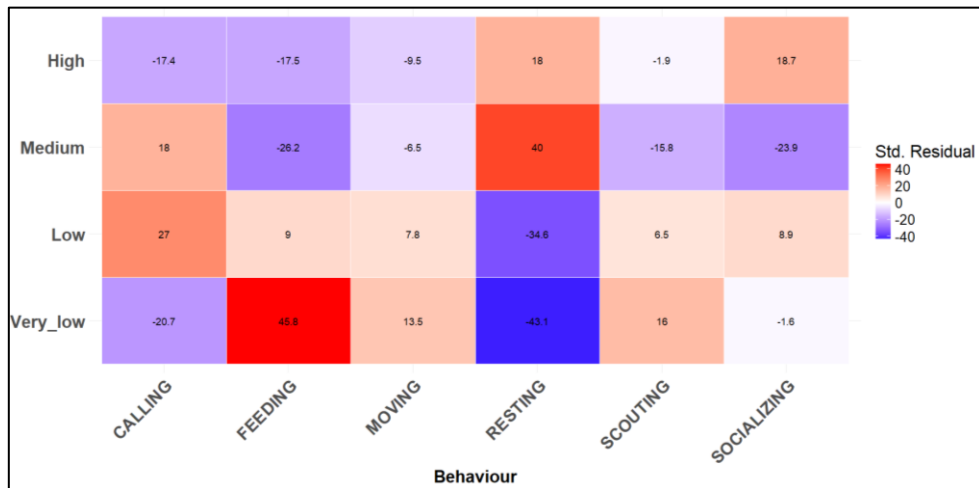


Figure 3.7. 9 Standardized Residuals Heatmap for Behaviours across Intensity use Class (Plantation Group)

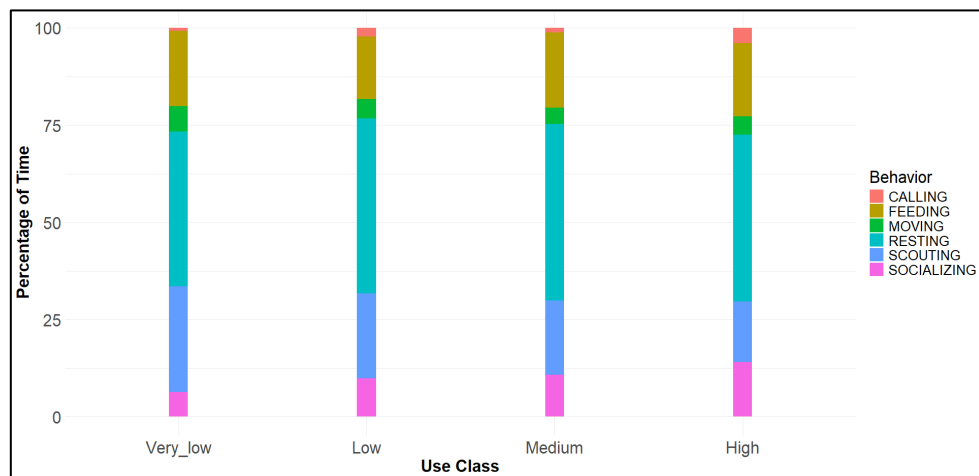


Figure 3.7. 10 Graph showing the proportion of time spent on each behaviour across the Intensity of use class (Plantation Group)

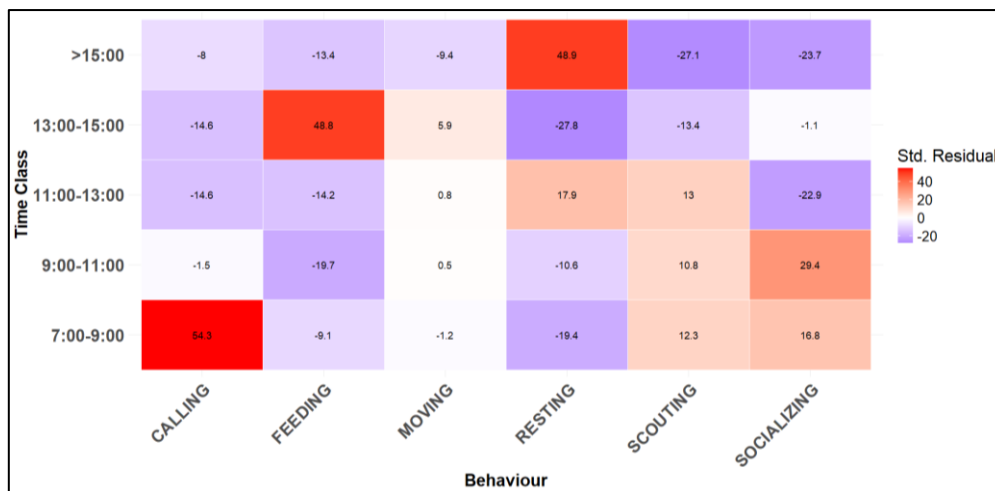


Figure 3.7. 11 Standardised Residuals Heatmap for Behaviours across Time Class (Plantation Group)

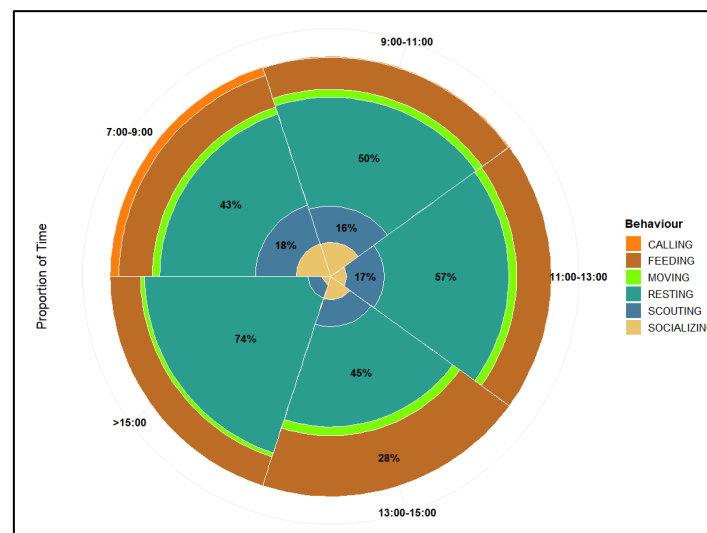


Figure 3.7. 12 Graph showing the proportion of time spent on each behaviour across the Time class (Plantation Group)

Using Kruskal-Wallis' test to compare group behaviour differences reveals that there are significant differences in time allocation for moving, resting, and scouting across the three groups ( $p < 0.05$ ). From the standardised residual (Figure 3.7. 14), it reveals that there a distinct behavioural patterns among the three gibbon groups (Forest, Jhum, and Plantation). Forest Group exhibited significantly higher than expected levels of calling, feeding, and resting, while showing strong avoidance of moving and scouting behaviours. Similarly, group Jhum showed a strong positive deviation in calling and scouting but rested far less than expected. In contrast, the Plantation group displayed a markedly different behavioural profile, engaging significantly

more in moving, resting, scouting, and socialising, while showing substantial underrepresentation in calling and feeding. These results suggest clear intergroup differences in behavioural time allocation.

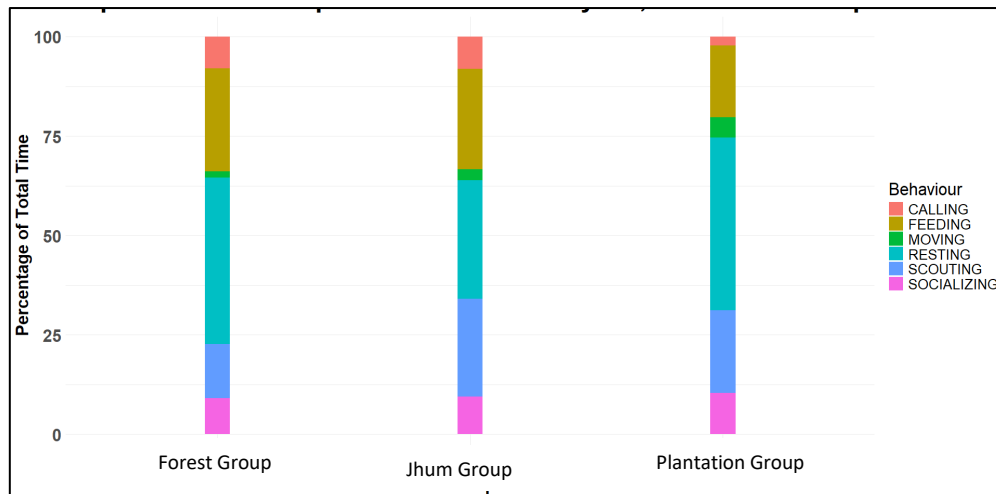


Figure 3.7. 13 Graph showing the total proportion of time spent on each behaviour across The three groups.

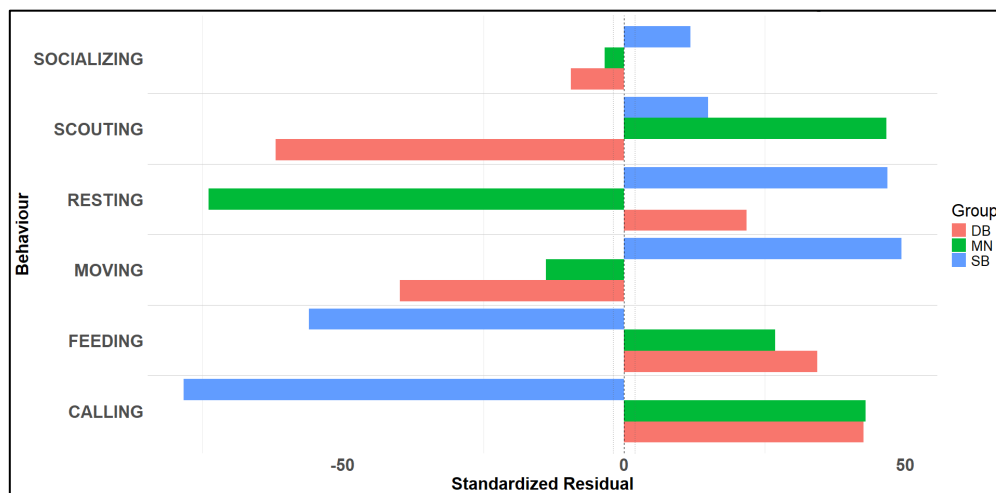


Figure 3.7. 3 Standardised residuals for each behaviour across the three groups (DB=Forest Group, MN=Jhum Group, SB Plantation group)

### 3.7.1 Daily Path Length

Daily path length is measured as the shortest distance between the points for the day. The average daily path length for the forest group is  $0.87 \text{ km} \pm 0.06 \text{ km}$ , for the jhum group it was  $0.74 \text{ km} \pm 0.05 \text{ km}$ , and plantation group it was  $0.93 \text{ km} \pm 0.08 \text{ km}$ . There is not much of a difference in the path length between groups.

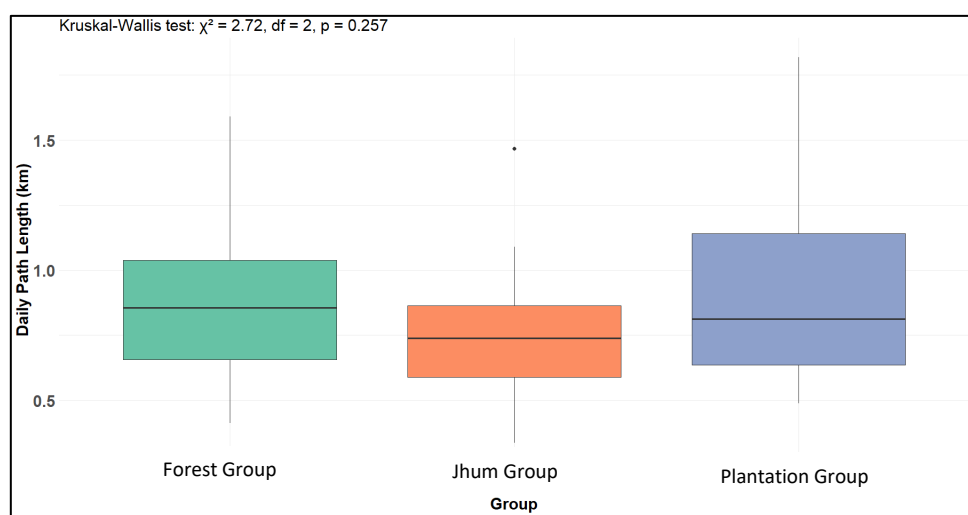


Figure 3.7.1. 1 Graph showing the daily path length of each group

### 3.7.2 Feeding Frequency on Different Food Resources

The feeding frequency reveals a clear pattern where *Ficus sp.* Emerges as a dominant food resource across all three groups, with which it was recorded 120 times in the Forest groups, 70 times in the Jhum group, and 90 times in the Plantation group. Despite this dominance, the differences in habitat types show that secondary feeding preferences vary significantly among the groups. Apart from *Ficus sp.* The forest group also shows strong preferences for *Saurauria sp.*, the Jhum group shows strong use of *Ehretia acuminata* (Agilda in Garo), *Saurauria sp.*, and *Eurya japonica*, while the Plantation group relies heavily on *Ipomoea sp.* and *Alnus nepalensis*. Additionally, apart from the plant species, the gibbons in all three groups were also seen feeding on Insects with relatively low and sporadic usage.

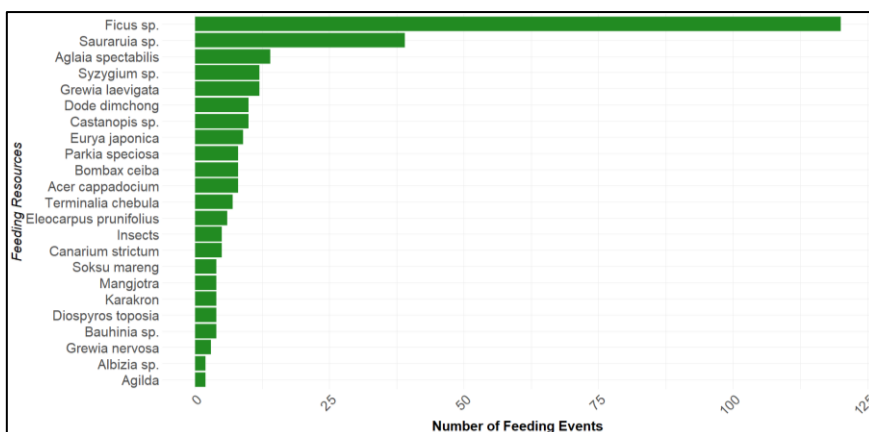


Figure 3.7.2. 1 Feeding frequency on different food resources (Forest Group)

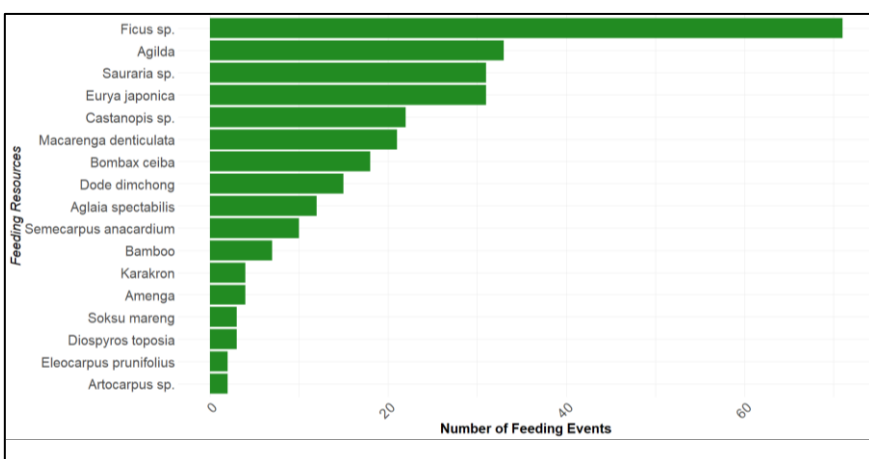


Figure 3.7.2. 2 Feeding frequency on different food resources (Jhum Group)

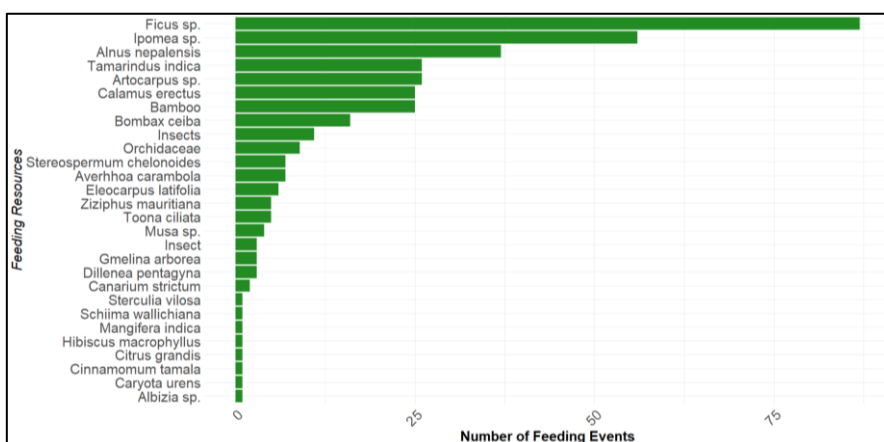


Figure 3.7.2. 3 Feeding frequency on different food resources (Plantation Group)

## 4. Discussion

Gibbons, being highly arboreal primates, are threatened due to forest fragmentation as they use continuous tree canopies for dispersal (Ray et al. 2015). Correlation between gibbons' habitat use and forest condition is quite ambiguous (Ray et al. 2015), as some studies reveal that the presence of gibbons does not correlate with forest condition or vegetation type (Pachau et al. 2013; Ray et al. 2015). Hoolock gibbons' presence has also been recorded where human disturbances are high (Pachau et al. 2013; Yuan et al., 2013), and in northeast India, most of the Hoolock gibbons' habitats are highly disturbed by humans (Ray et al. 2015). Thus, for species to be able to survive in such a disturbed habitat diversity of edible tree species play a major role (Muzaffar et al. 2007), but the overall adaptation of a species to survive depends on the allocation of time on different activities and the pattern of habitat use (Velankar et al. 2024). So, this study helps in understanding the habitat use and activity pattern of three groups of Hoolock gibbons, where their habitat type significantly differs from each other. It was expected that the three groups, being located in three different habitat types, their habitat use within the home range and their activity patterns would differ. The study also helps in understanding the adaptability of the gibbons in human human-dominated landscape in terms of their behaviour.

### 4.1. Home range

The home ranges of the three groups of gibbons were 24 hectares, 30 hectares, and 23 hectares using the grid-based method. Similar results were also produced using the Autocorrelation Kernel Density Estimate. The home range that was estimated for these three groups was similar to what had been predicted by Alfred and Sati in 1990. The group that is located in a continuous forest patch and in the plantation have a similar home range, whereas

the group that is located in an area where it is dominated by abandoned jhum land shows a higher home range size pattern. Several factors, such as group size, population density, interspecific competitors, tree diversity, and physical size constraints of the area, determined the home range of a species (Marsh 1981). The group with 24 hectares is in Daribokgre Community Reserve, which is adjacent to Nokrek National Park; this group contains a continuous patch of forest. Whereas the group with a 30-hectare home range is located in Dura Kalakgre Community reserve, which is a thin strip of forest surrounded by abandoned Jhum land and Active Jhum Land. The group with 23 hectares of home range is located in Rensengre, which is purely an areca plantation habitat. In each group, different factors might have influenced the size of the home range. As in the Daribokgre community reserve, even though there is a continuous forest patch presence of neighbouring gibbon groups might influence the size of the Home range. In Dura Kalakgre, since the CR is surrounded by abandoned jhum land, which is mostly dominated by two or three species, causing the resource to be scattered, which increases the size of the home range as compared to the group found in Daribokgre CR. Another group with 23 hectares of Home range is found to be isolated in a plantation, but the presence of local edible fruiting trees might have influenced the size of the home range to be similar to the one found in Daribokgre CR.

## **4.2. Habitat use**

Since the spatial variation in habitat type across the three groups is different from each other, there are differences in habitat use patterns. For a Forest group where the habitat type is mainly dominated by the forest patch, the pattern of use in this group is more consistent compared to the other groups. In the Jhum group, where the habitat type is mainly dominated by the abandoned jhum, the habitat preference of the group is different from what was observed in the Forest group. In the Jhum group, the proportion of the low-use area Jhum group is

comparatively high compared to other groups. Since the home range of the Jhum Group is surrounded by active jhum land or abandoned jhum, most of the low-use areas are found at the edge of the home range, and high-use areas are in the core of the home range. The low-use area in the Jhum group is mostly abandoned jhum or active jhum. Previous studies have reported that the movement of gibbons from the interior of the forest patch to the edge allows the species to maximise the resources available in such a fragmented forest (Akers et al. 2013). The limitation of good habitat type in the Jhum group, which is only present on the thin strip of the Dura Kalakgre CR, forces the gibbons to expand their home range into the abandoned jhum to maximise the resources available. Even though evidence for the presence of other groups was not recorded, based on the field observation, there are three groups which is present around the Jhum group: one on the north side, one on the southern side, and another one on the western side. The presence of these groups surrounding the JHUM group might also push the home range of the Jhum group into the abandoned jhum land. In another group, i.e., the Plantation group, this group habitat type is totally different from the other two groups because the group are known to be using the areca nut plantation. Human settlement, roads and streams causes the group to be isolated. Within the home range of this group, human settlements were also found, and a small patch of bamboo and a forest patch were also present. But these patches of bamboo and forest were mostly located at the edge of the home range. Limiting the study to only one group can make the findings site or group-specific (Akers et al. 2013). The differences in spatial variations of habitat type across the three groups make the group more site-specific. Thus, the same covariates cannot influence the ranging pattern of the three studied groups.

When testing the correlation of the intensity of use from each and the variation of habitat type, only the Plantation group shows a significant correlation. The gibbons of the Plantation group increase their intensity of use when the proportion of bamboo patch and mixed forest and bamboo patch increases, but with the plantation, the intensity of use decreases. Also,

distance to plantation and canopy cover were the most influential factors when modelling covariates for the Plantation group. Gibbons of the Plantation group show a high preference for areas which have high canopy cover, which is mostly found in forest, bamboo and mixed forest and bamboo patches, and these areas are mostly found at the edge of the home range. Thus, high intensity of use of the home range is mostly found at the edge. This reflects an adaptive response to the quality of the habitat or avoidance of the plantation, which has high disturbances that dominate the interior part of the home range. Such edge-based use may also indicate the flexibility in selecting the habitat in response to anthropogenic landscape features.

For the Forest group, no statistical test was run for the correlation of intensity of use and variation of habitat use since the home range of this group is covered with only a single habitat, i.e., a continuous forest patch. A continuous forest patch is an ideal habitat for gibbons as it provides consistent canopy connectivity for movement (Alfred and Sati 1990). Despite the Forest group home range being located in a continuous forest patch, none of the environmental variables and disturbances show a significant effect on the intensity of grid use. This may be attributed to the homogeneity of habitat condition within the Forest group's home range, where minimal variables exist to drive spatial differences in intensity of use. However, one possible unmeasured factor that may influence the intensity in this area is the intergroup dynamic. Since Hoolock gibbons show high territoriality (Kumar et al. 2013), the presence of neighbouring groups around the Forest home range sites could have influenced the shift in activity zones within the home range.

Jhum group show a high preference for areas with high canopy height, and none of the habitat types shows any correlation with the intensity of use. This shows that considering the structural characteristics of habitat type rather than just the categorical labels alone can explain the intensity of grid use by the gibbons. The key structural features of the habitat type, such as tall canopy height, which are biologically relevant for arboreal primates like gibbons and are

more concentrated within forest patch habitat. This forest patch, which is in the Jhum group, is primarily located within the Community Reserve, a protected area that contains primary forest with taller canopies. The alignment between tall canopies and forest patches suggests that gibbons may be responding more strongly to habitat quality and vertical structure than to a broad land-cover classification.

### **4.3. Activity Pattern**

Hoolock gibbons, being diurnal primates, rest will be their predominant activity, followed by feeding (Kumar et al. 2013). The Forest group, which is located in the continuous forest patch of the Daribokgre Community reserve, shows a different pattern from what has been recorded in Bangladesh (M. A. Islam and Feeroz 1992). The Forest group spend most of their time resting, followed by feeding, scouting, socialising, calling, and moving. This finding is similar to what it has been recorded by Fan in 2013 (Fan et al. 2013; D. M. Islam and Choudhury 2018). The reason for being low is that behaviour sampling was stopped when they moved to another geolocation; only a proportion of the moving behaviour was captured at a particular time. When behaviour was examined across the intensity of use classes, it was observed that feeding and moving were high in the very low use area, suggesting that this area may contain transient food resources which the gibbons exploit opportunistically. They mostly use the high-use area, which is mostly in the interior of their home range, for socialising, suggesting that they use this zone to interact within the group or rest. Gibbons are also to defend their territory by giving loud calls (Kumar et al. 2013), since the neighbouring groups (8 groups was once heard calling) was observed and heard from all aside of the Forest home range, calling when combine in low and very low use area is the highest and both the use classes are at the edge of the home range. Temporal pattern in behaviour also reveals a strong diurnal structuring, with feeding, calling and moving were dominant in the morning, and as days progressed, scouting and resting became more common.

The Jhum group, which is located in Dura Kalakgre Community Reserve, shows a balanced allocation of time in feeding. Spatial variation in activity patterns shows how space is used differently in the home range. Behaviour such as feeding, calling, and scouting is higher in a very low use area, which likely reflects defending the home range and availability of edible plant parts in this zone, which is located at the edge of the home range. Since the very low use class is mostly abandoned jhum, and it is highly dominated by *Macaranga denticulate*, *Eurya* sp., *Callicarpa* sp., *Saurauia* sp., which is preferred by gibbons in this site, thus pushing the feeding to be high in the very low use area. And the high-use area, which is mostly located in CR, which is a primary forest, thus this area is mostly preferred for resting and socialising. With gibbons showing plasticity in response to the spatial context, the distribution of behaviours across these spatial classes determined that different zones within the home range have their own function, with gibbons showing plasticity in response to the spatial context.

The Plantation group, which is located in the plantation area, a human-dominated landscape, also shows a clear variation in activity budget, where resting is heavily dominated, followed by feeding, with lesser time in scouting, socialising, calling and moving. The same has been observed in other primate species, where resting behaviour is dominant in highly disturbed areas (Velankar et al. 2024). Spatially, the Plantation group's behaviour varied significantly across the grid use intensities. Since high-use area in this group is mostly forest patch or bamboo patches or a mix of both, these areas were preferred by the gibbons for socialising and resting, and since it is at the edge of the home range, calling in these high-use areas was also high. Since calling in gibbons is used in communicating between the groups for territoriality (D. M. Islam and Choudhury 2018), the Plantation group used this high-use edge area for vocalisation, as there are three neighbouring groups around it. In contrast, scouting is more prevalent in very low-use area, which is mostly plantation or human settlements, this reflected by the group using these areas for movement. Temporally, feeding in this group peaks

in the early afternoon, while resting increases towards late afternoon. The early hours were mainly dominated by calling, which links to group bonding or territory defence, as gibbon groups do now behave independently (Nijman, 2001).

Overall group behaviour reveals significant differences in allocation time for each behaviour. These distinctions highlight how social, ecological or environmental factors shape group-specific activity patterns. Calling time in gibbons has been recorded as high in undisturbed forest as compared to disturbed forest, but calling is also group dependent, the more number of neighbouring group calling will be more prevalent (Nijman, 2001). The same have been observed in this study where calling is more prevalent in the Forest and Jhum groups as compare to the Plantation group, which is located in human human-dominated landscape. The availability of local edible fruiting trees in the plantation provides easily accessible and nutrient-rich food (fruits), causing the Plantation group to spend less time in feeding and more time resting. This type of behaviour, where feeding on nutritious food allows the animal to spend more time on behaviour such as resting and socialising in a disturbed habitat, has been recorded in different primate species (Velankar et al. 2024; Bryson-Morrison et al. 2017). The Forest group which is in the continuous forest patch (less disturbed area compared to the location of the other two studied groups), exhibited high calling, feeding, and resting, which reflects the group occupying a stable and resource-rich habitat. In contrast, the Jhum group locating in an area surrounds by abandoned jhum and active jhum spends more time in feeding and scouting, alongside reduced resting time, which may indicate a disturbed environment requiring increased vigilance and movement. Plantation groups which is located in the plantation area spend more time in scouting in comparison to other groups. this type of pattern reflects a more socially dynamic habitat where individuals invest more in maintaining cohesion and spatial navigation. Overall, behavioural activity differs from habitat to habitat and it is the

response of both physical and habitat conditions of the species (D. M. Islam and Choudhury 2018).

## 5. Conclusion

Primates' habitat use, ranging, and activity budget are frequently linked to an anthropogenically disturbed environment (Bryson-Morrison et al. 2017). This study provides a comprehensive comparison of the habitat use and activity pattern of three groups of Hoolock gibbons at three different distinct habitat types – continuous forest (Forest group), abandoned jhum landscape (Jhum group), and plantation dominated area (Plantation group). The findings reveal how spatial and ecological heterogeneity influences gibbons' behaviour, home range and adaptability to varying levels of anthropogenic disturbances. Ranging pattern in a group which is in plantation plantation-dominated area shows how the availability of local edible fruiting trees compensates for habitat fragmentation, and this also reflects on the behaviour where the group exhibit high resting, likely due to easy access to energy-rich foods in the plantation, with behavioural peaks adapting to disturbance pattern. Overall, the study highlights that gibbons' behaviour and habitat use within the home range are shaped not only by the habitat type but also by the structural factors. These findings emphasise the adaptability of Hoolock gibbons in response to habitat degradation and underscore the importance of maintaining structurally diverse habitat, especially the presence of a sacred forest patch (Kosi in Garo language) in such a human-dominated landscape, such as the areca plantation, supports their conservation.

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## Appendix

Table: Hoolock Gibbons feeding trees from all the three Groups

Garó Name	Scientific name
Agong	<i>Eleocarpus prunifolius</i>
Adambak	<i>Sauraria sp.</i>
Adambak	<i>Sauraruia sp.</i>
Agatchi	<i>Dillenea pentagyna</i>
Agilda	<i>Ehretia acuminata</i>
Amelwa	<i>Parkia speciosa</i>
Amenga	<i>Amenga</i>
Aminsep	<i>Ficus sp.</i>
Amlenga	<i>Averrhoa carambola</i>
Angkhil	<i>Ziziphus mauritiana</i>
Arimmo	<i>Artocarpus laccucha</i>
Aritak	<i>Terminalia chebula</i>
Babari	<i>Semecarpus anacardium</i>
Babari	<i>Castanopsis</i>
Bol bret	<i>Toona ciliata</i>
Bol gipok	<i>Gmelina arborea</i>
Bolchu	<i>Bombax ceiba</i>
Bolchu	<i>Albizia sp.</i>
Bolchu prite	<i>Grewia nervosa</i>
Boldak	<i>Schiima wallichiana</i>
Bolgisim	<i>Diospyros toposia</i>
Bollumak	<i>Acer cappadocium</i>
Bolmengo	<i>Grewia laevigata</i>
Bolphu	<i>Albizia</i>
Bolsel	<i>Stereospermum chelonoides</i>
Chagru	<i>Macarenga denticulata</i>
Chaku	<i>Castanopsis sp.</i>
Chaku	<i>Syzygium sp.</i>
Chaku domok	<i>Syzygium sp.</i>
Chamishi	<i>Eurya japonica</i>
Cheng	<i>Tamarindus indica</i>
Chikamba	<i>Alnus nepalensis</i>
Citrus grandis	<i>Citrus grandis</i>
Darichik acisa	<i>Bauhinia</i>
Dode dimchong	
Dongkrenng	<i>Canarium strictum</i>
Eleocarpus	<i>Eleocarpus latifolia</i>
Ginsning	<i>Saurauia sp.</i>
Karakron	
Mangjotra	

Moa	<i>Hibiscus macrophyllus</i>
Phrap	<i>Ficus sp.</i>
Rangol	
Samphal	<i>Aglaia spectabilis</i>
Samphal khadari	<i>Aglaia spectabilis</i>
Sawi	<i>Caryota urens</i>
Shitri	<i>Ipomea sp.</i>
Sokmil	<i>Calamus erectus</i>
Soksu mareng	<i>Soksu mareng</i>
Te.bil	<i>Ficus sp.</i>
Te.brong	<i>Artocarpus heterophyllus</i>
Te.rik	<i>Musa sp.</i>
Tej pata	<i>Cinnamomum tamala</i>
Tekbil	<i>Ficus sp.</i>
Ti ga.chu	<i>Mangifera indica</i>
Umak	<i>Sterculia vilosa</i>
Wa.a	<i>Bamboo</i>

*Thank You*

