Effect of land use change on the habitat and abundance of Grizzled giant squirrel in and around Srivilliputhur-Meghamalai Tiger reserve, Srivilliputhur Division, Tamil Nadu

by

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Enrolment no: 50BB22A73019

Dissertation Thesis

Submitted to Academy of Scientific and Innovative Research

For the partial fulfilment for the degree

Master of Science

in

Wildlife Science

Under the supervision of

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June 2024

DECLARATION

I, **Shilpa Bevoor**, hereby declare that the work conducted under the thesis entitled **"Effect of land use change on the habitat and abundance of Grizzled giant squirrel in and around Srivilliputhur- Meghamalai Tiger reserve, Srivilliputhur Division, Tamil Nadu",** 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. Gopi G V, Scientist-F**, and co-supervision of **Sh. Varun Kher**, **Designation and Dr. S P Goyal, Subject Matter specialist** of Wildlife Institute of India, Dehradun. 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 **Shilpa Bevoor** entitled "**Effect of land use change on the habitat and abundance of Grizzled giant squirrel in and around Srivilliputhur- Meghamalai Tiger reserve, Srivilliputhur Division, Tamil Nadu"** 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**.

Shilpa Bevoor 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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Acknowledgement

The successful completion of this thesis was made possible by the contributions of many individuals. Their readiness to share their expertise and offer timely assistance was invaluable. I sincerely thank everyone involved.

I am deeply thankful for my field assistant, Selva, who immensely helped throughout the fieldwork. From bargaining for vegetables and even getting some for free, to regularly entering data and assisting in cooking, her friendly conversations with the farmers helped build rapport and facilitated the collection of data for my questionnaire survey. In addition to her data collection skills, Selva drove me back to my room when I was too tired to ride the scooter. Her dedication extended to tirelessly searching Google for the scientific names of trees identified by forest guards, often given only in local names. She kept me energized throughout the day with her endless talks and even took the time to teach me how to speak Tamil. She was a wholesome and indispensable presence during my field days, and this work would not have been completed without her. I would like to express my special thanks to Peru from the junior batch for recommending Selva for my fieldwork.

I also extend my heartfelt thanks to my other field assistant who helped during Selva's absence. His assistance in exploring new areas within the Protected Area was crucial for my work. I wish to express my gratitude to all the EDC members and APWs: Perma, Dinesh, Renuka, Selvi Akka, Periyaswamy, Kumar, Johnson, Mariyappan, Selvaraj, Kumar, Kannan, Satheesh as well as the forest watchers and guards Samudravalli, Sudarasanadhi, Mahesh, Periyaswamy, Kalipandi, Laxmi, Boopathi, Shivaganesh, Vairamuttu, and Selvashakthi for their invaluable help in data collection within the protected area and for inviting me to share delicious meals during temple gatherings. I offer my sincerest gratitude to all of them for making this field experience unforgettable.

I extend my heartfelt gratitude to Ayyanarkovil, Rakashiammankovil, Shirdi Baba Temple, Valakattu Karupswamy Kovil, and Arvind Health Centre for their continuous support in providing nutritious meals. Their generous assistance significantly reduced the burden of cooking amidst my demanding fieldwork and kept me healthy throughout. The mutton and rasam from these temples were undoubtedly the best I have ever had in this country. Not to forget, Kabba hotel, which satisfied my cravings for chicken from time to time.

I am grateful to all my supervisors for their guidance in transforming my initial ideas into a real-world study. Special thanks to Gopi Sir for visiting my field study and making those days memorable, helping in study design and for assisting with logistical issues. Thanks to Varun for providing critical input that shaped the study's design and results. Lastly, Goyal Sir's expertise in rodents and experience in squirrel research helped me shape my proposal effectively.

My deepest gratitude goes to Navendu and Lallian, course directors, who supported us through thick and thin. The entire faculty at WII played an important role in successfully completing this course. Special thanks to Sutirtha and Qamar Sir for fostering my interest in statistics and assisting with study design and statistical analysis. I want to express my appreciation to Udayanna and Ankit for their help with GIS work amidst their busy schedules. Ashish Bhaiya was always available for a chat and to clarify doubts on almost everything. I am indebted to Negi Ji and Umesh Ji for their hard work over the past couple of years.

Words cannot express my gratitude to the XVIII MSc batch for being there for me over the past two years. I thank Arnab for his unwavering support, for being there in times of need, and for teaching me the basics of genetics and statistics, which significantly strengthened my academic journey. Adi for brainstorming ideas and editing drafts with his exceptional English skills, Bindu for her unwavering support since undergraduate days, and Abhishek, Rakshith, Prakruthi, Dave, Ashik, Abhimanyu, Sanjana, Niyaz, Shashank, Rishi, Abhinav, and others for making my MSc journey enriching and enjoyable. Special thanks to the four little kittens who brought us joy in the last few months.

I am thankful to the Director and Dean of WII for their logistical support and assistance with permissions. I am grateful to the Tamil Nadu Forest Department for permissions, logistical help, and support. Special thanks to Deputy Director Deeplip Kumar Sir, Devraj Sir, RFOs Sharanya Mam and Karthik Sir, and biologist Suresh Kumar for their constant support in the field.

Lastly, I am deeply thankful to my family, who are the pillars of my strength, for supporting my pursuit of my academic interest despite being far from home. Special thanks to my mother, Renu, for sending snacks and sweets timely, and to my father for arranging all necessary things, including the scooter for my fieldwork.

Thank you:)

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Summary

Human activities, especially energy extraction and food production, have drastically altered the global environment, impacting many wild species. Since 1990, around 420 million hectares of forests have been lost mainly due to agricultural conversion, significantly affecting biodiversity. In biodiversity hotspots like India's Western Ghats, agricultural expansion, monoculture plantations (tea, coffee, rubber), and non-timber forest product harvesting have fragmented protected areas, altered plant communities, disrupted nutrient cycles, and reduced carbon sequestration. While monoculture plantations reduce biodiversity, they can still provide habitats for some threatened species. Wildlife such as nilgai, blackbuck, elephants, and giant squirrels in India have adapted to these altered landscapes for food, water, and shelter, demonstrating resilience amidst habitat changes.

This study focuses on the impact of converting barren lands into mango and coconut plantations around the Srivilliputhur-Megamalai Tiger Reserve in southern India on the grizzled giant squirrel population and habitat. Over the past three decades, these changes have enhanced connectivity between natural forests and agricultural areas, offering energy-rich fruits that attract wildlife, including GGS. This shift has altered ecological dynamics, making wildlife more reliant on cultivated foods and affecting their movement patterns.

Density estimates reveal higher concentrations of GGS and nesting sites (dreys) in plantations compared to protected areas, with mixed plantations showing the highest densities due to the availability of nesting sites and year-round fruiting trees. Seasonal variations in GGS distribution highlight preferences for specific tree species based on fruit availability and habitat characteristics.

The study also examines drey site preferences, noting GGS preference for mango trees in plantations over coconut trees due to structural attributes that provide better support and protection.

These findings underscore the species' adaptation to plantation environments while emphasizing the critical role of specific habitat features for nesting and overall habitat suitability.

Local farmers report conflicts with GGS due to crop damage, particularly affecting coconut, mango, tamarind, and other fruit-bearing trees. Perceived economic losses from GGS feeding habits often exceed actual damage levels, emphasizing the need for accurate assessment and targeted mitigation strategies to reduce conflict.

Conservation implications stress the importance of maintaining critical habitats within protected areas, establishing buffer zones between plantations and natural forests, and promoting biodiversity-friendly practices in monoculture plantations. Community-based conservation efforts and adaptive management strategies are essential for mitigating human-wildlife conflicts and ensuring the sustainable coexistence of GGS and agricultural livelihoods in this biodiversity hotspot.

1. Introduction

1.1 Human Modification of the Global Environment

During the past few centuries, humans have drastically modified the global environment to meet their requirements and have consequently caused changes in the ecology of many wild animals (Ojima *et al*. 1994; Mannion, 2014). The major cause of such changes has been the increasing need for energy extraction and food production (Turner & Meyer, 1994). Higher food production can be achieved in two ways - either by intensifying cultivation on existing agricultural land or by expanding into new areas (Tilman *et al*., 2011). The later has been much more prevalent till recently and has caused major losses of natural habitats all across the globe (Laurance *et al*., 2014). The most prevalent method of agricultural expansion involves converting forests into agricultural land, which is regarded as the primary driver of global forest loss and degradation (Kissinger *et al*.,2012). Since 1990, it is estimated that approximately 420 million hectares of forest have been lost globally, primarily due to conversion to agricultural lands and other land uses (FAO, 2020). Such changes in land use can lead to significant environmental impacts, especially affecting biodiversity. (Alroy, 2017)

1.2 Land-Use Changes in Biodiversity Hotspots

Land-use change in biodiversity hotspots has generally occurred at a slower rate compared to other diverse regions (Kong *et al.*, 2021). However, the Western Ghats (WG) of India, one of the most significant biodiversity hotspots globally, has experienced substantial land-use and land-cover (LULC) changes in recent years (Kale *et al*., 2016). Historical developments, such as the construction of railways, roads, and dams during the British colonial period, facilitated resource exploitation and triggered rapid changes in LULC. This trend has persisted into contemporary times (Paranjpye, 2011; Kale *et al.*, 2016). Land-use changes driven by agricultural expansion, conversion to monoculture plantations, and non-timber forest product harvest have resulted in significant forest loss, posing a major threat to the biodiversity of the Western Ghats (Shahabuddin and Prasad, 2004). Land-use changes frequently result in the transformation of plant community compositions over wider areas. The removal and introduction of new plant species can disrupt nutrient cycles, leading to reduced carbon sequestration and intensified release of greenhouse gasses into the environment (Ojima *et al.*, 1994). The conversion of land to monoculture plantations, typically involving exotic or native plant species grown for timber or as cash crops, has substantial impacts on wildlife habitats and ecosystem services (Brockerhoff *et al.*, 2008). The Western Ghats have witnessed a significant increase in tea, coffee, cardamom, rubber, and teak plantations over the past few decades, leading to ecological disruption and biodiversity loss. (Menon and Bawa, 1997).

1.3 Forest Fragmentation and Monoculture Plantation

The protected area network in the Western Ghats has become highly fragmented due to the expansion of these aforementioned plantations and is now embedded in a heterogeneous matrix of human land uses (Anand *et al.*, 2012). Natural forests, with their complex vegetation structure and high plant diversity, support a rich functional diversity of species, contributing to ecosystem stability and resilience. In contrast, monoculture plantations, characterized by less understory vegetation, uniformity and lower diversity, ultimately result in reduced ecosystem services provided, including pollination, nutrient cycling, and seed dispersal (Ruiz-Jaen & Potvin 2011). Natural forests typically offer more suitable habitat for a broader array of native forest species compared to plantation forests. However, there is substantial evidence suggesting that plantations can still serve as important habitats, thus supporting certain threatened and endangered species

(McKinney & lockhood, 1999). Moreover, plantations might contribute to biodiversity conservation through various mechanisms by providing food resources, shelter, and refuge from predators. This homogenization threatens the ecological balance and reduces overall biodiversity in the region (McKinney, 2006).

1.4 Benefits and Drawbacks of Monoculture Plantations

Even though it is known that monoculture plantations reduce biodiversity, some species benefit from increased food availability and refuge from natural predators (Brockerhoff *et al*., 2008). For instance, a study conducted by Bali *et al*., (2007) in the Western Ghats reported the presence of 28 species of non-volant mammals, including a few endemic species, utilizing coffee estates. Similarly, Nogeire *et al*., (2013) study on avocado plantations in California found that carnivores such as bobcats, coyotes, and grey foxes frequently utilize these plantations. Research by Pardo *et al*. (2019) on oil palm plantations demonstrated that while these plantations negatively affect certain species like the capybara (*Hydrochoerus hydrochaeris*) and Naked-tailed armadillo: (Cabassous centralis), generalists such as the white-tailed deer (*Odocoileus virginianus)* and Giant anteater (*Myrmecophaga tridactyla*) were more likely to use these habitats. In the Indian context, several species, including Nilgai (*Boselaphus tragocamelus*), Blackbuck (*Antilope cervicapra*), Elephants (*Elephas maximus*), Chital (*Axis axis*), Primates, and Wild pigs (*Sus scrofa*), utilize agricultural lands for food, water, and shelter. This results in significant damage to farms and exacerbates human-wildlife conflict (Karanth *et al.,* 2012). In recent years, even giant squirrels such as the Malabar Giant squirrel (*Ratufa indica*) and Grizzled giant squirrels (*Ratufa macroura*) are utilizing agricultural lands for food resources (Govind & Jayson, 2018; Kumara, 2023).

1.5 Impact of Land Use Changes on Grizzled Giant Squirrel (GGS)

In recent years, a similar trend has been observed with the grizzled giant squirrel (hereafter referred as GGS) in southern India. GGS is a riparian forest-dwelling species, found in isolated populations in Kerala, Karnataka, and Tamil Nadu, is increasingly affected by land use changes and fragmentaion (Joshwa, 1992; Harlekar, 2010; Thomas, 2014). The habitat selection of giant squirrels is influenced by several critical habitat attributes, including canopy connectivity, tree density, and the availability of food trees (Sengupta et al 2023). Notably, the land around the protected areas, especially around the Srivilliputhur region of Srivilliputhur-Megamalai Tiger Reserve (SMTR), has significantly transformed into farmlands. The increased connectivity provided by these plantations is leading squirrels to venture into farmlands, causing substantial damage to crops and resulting in significant losses for farm owners (Rao *et al.,* 2015).

To date, all studies on the GGS have focused exclusively on its population, behavior and ecology within protected areas (Joshwa, 1992; Thomas, 2014). In contrast, this study examines how land use changes around these protected areas impact GGS density and habitat. To understand these effects, I compared the density of squirrels across different habitats both inside and outside the protected areas. Additionally, my research assesses habitat use by GGS and explores farmers' perceptions regarding crop damage caused by these squirrels. By expanding the scope of research to include zones surrounding Srivilliputhur-Megamalai Tiger Reserve, Srivilliputhr Division, this study aims to provide a comprehensive understanding of how GGS populations interact with human-modified landscapes. The findings will offer valuable insights into the impact of land use changes on wildlife and inform strategies for mitigating human-wildlife conflicts.

1.6 Objectives and questions

1.6.1 Objective I: Compare the population density of the GGS and its nest/ dreys in relation to habitat types (forests within protected area and plantations outside protected area) across winter and summer seasons

A. Research Question

a. What is the population density of GGS and its nests/ dreys across different habitat types?

b. Do the population densities of GGS vary across two seasons in different habitats?

B. Hypothesis

a. Higher food availability in the plantations leads to spillover and persistence of GGS from natural forests to plantations.

b. GGS from forests move to plantations during the fruiting season and return back after the fruiting season is over.

C. Prediction

a. Population density of GGS and their nests/dreys will be comparable/higher in plantations outside the protected area compared to forests within the protected area.

b. I anticipate that the densities will show variations across seasons, with higher densities in plantations during fruiting season.

1.6.2 Objective II: To understand the habitat (drey site) selection of GGS in natural and modified landscapes

A. Research Question

a. What factors influence drey site selection by GGS in natural and modified landscapes?

B. Hypothesis

a. Tall mature tree with greater girth at breast height (GBH) and canopy cover provides protection from the aerial predators and have abundant resources, and are thus used for creating dreys.

C. Prediction

a. Regardless of habitat types, the GGS exhibits a preference for mature trees characterized by substantial height, girth, canopy connectivity and crown width. Additionally, the species tends to favor specific tree species abundant in food resources for constructing its dreys to minimize the travel distance.

1.6.3 Objective III: To quantify the extent of GGS driven crop depredation in plantations and consequent perceptions of farmers/planters

A. Research Question

a. Does the GGSs cause crop damage, and if it does, to what extent?

B. Hypothesis

a. Increased food resources in plantations attracts GGS from neighbouring natural forests.

C. Prediction

a. Probability and extent of damage can be linked to the distance of the plantation to the forest patch.

2. Literature review

2.1 Distribution and status of GGS

The GGS is endemic to southern India and Sri Lanka. Distribution of GGS is mostly restricted to patchy riverine habitats in the rain shadow region of southern India. It is found as an isolated population in the Western and Eastern Ghats (Joshua, 1992; Thomas *et al.,* 2018). In India it is known to occur in Srivilliputhur GGS Sanctuary, Tamil Nadu (Joshua, 1992), Chinnar Wildlife Sanctuary, Kerala (Ramachandran, 1993; kumar *et al.*, 2007, Thomas & Nameer, 2018), Anamalai Tiger Reserve, Tamil Nadu (kumar et al., 2007), Theni forest Division (Babu et al. 2013), Sirumalia (Sathasivam *et al.,* 2008), Tiruvannamalai forest division (Babu & Kalaimani, 2014), Pakkamalai Reserve forest, Gingee (Vilalraj *et al.*, 2018) Palani Hills (Davidar, 1989). Kanakapura Forest Division, in southern Karnataka (Kumara and Singh, 2006; Baskaran et al., 2011), which is considered as the northern-most population (Kumara and Singh, 2006). Jatbana *et al*. (2008) recorded the presence of this species in Hour forest division along the Cauvery riverine forest. Molur *et al*. (2005) reported that in the last 25 years the population size of the GGS has declined by about 30%.

The Srivilliputhur Grizzled Squirrel Sanctuary supports the largest population of Grizzled Squirrel Sanctuary followed by Chinnar Wildlife Sanctuary. The GGS is listed as the Near Threatened in the IUCN Red List (IUCN, 2018). This species is listed under the Schedule I (Part I) of the Indian Wildlife (Protection) Act (1972), and is listed on CITES Appendix II regulating international trade in this species. The following wildlife sanctuaries are known for protecting this species in India namely: Srivilliputhur Grizzled Squirrel Sanctuary, Tamil Nadu, Chinnar Wildlife Sanctuary in Kerala and Cauvery Wildlife Sanctuary in Karnataka.

2.2 Habitat and Drey building

Arboreal dwellers, including the GGS, generally favor habitats with dense canopy cover and taller canopy heights (Baskaran *et al.*, 2011). The habitat of the GGS is narrow and located along major rivers and their tributaries, within mixed deciduous forests in distinct patches (Ramachandran, 1993). GGSs build their nests, known as dreys, using twigs and leaves in the upper canopy, specifically at the forked branches where the crowns of adjacent trees meet (Vanitharani and Bharathi, 2011). These squirrels prefer areas with abundant food and well-connected canopies for their nests. They typically select significantly larger trees with greater girth at breast height (GBH), taller heights, and numerous branches for nest building. According to Ramachandran (1992), this preference for mature trees with extensive canopy continuity facilitates easier movement to and from the nest in all directions, aiding in predator evasion and foraging. The composition of tree species and the structural attributes of forests play a crucial role in habitat utilization by the GGS (Ramachandran, 1993).

Vanitharani and Bharathi (2011) reported a total of 24 tree species used for building nests in the Srivilliputhur Wildlife Sanctuary, including *Lannea coromandelica, Mangifera indica, Sterculia chelonoides, Cullenia exarillata, Eriodendron pentandrum, Tamarindus indica, Terminalia arjuna, Terminalia bellirica, Terminalia chebula, Terminalia tomentosa, Azadirachta indica, Melia azadirachta, Albizia amara, Albizia lebbeck, Ficus benghalensis, Ficus racemosa, Ficus religiosa, Syzygium cumini, Dalbergia latifolia, Pterocarpus marsupium, Sapindus emarginatus, Schleichera oleosa, Grewia tiliaefolia, Gmelina arborea,* and *Tectona grandis.*

In Chinnar Wildlife Sanctuary, Veeramani et al. (2018) reported that GGS used 12 tree species for nest building, with nest heights varying from 2.5 to 35 meters. Subsequently, Thomas and Nameer (2021) identified 36 tree species for drey construction in Chinnar Wildlife Sanctuary, with most nests found in *Mangifera indica, Terminalia arjuna, Ficus microcarpa, Diospyros ebenum,* and *Pongamia pinnata.*

2.3 Foraging ecology of GGS

Seeds and fruits constitute the primary diet of the GGS. Vanitharani and Bharathi (2011) identified 15 tree species *Artocarpus heterophyllus*, *Artocarpus hirsutus, Ficus benghalensis, Ficus religiosa, Ficus, racemosa, Tamarindus indica, Mangifera indica, Lannea coromandelica, Morinda tinctoria, Syzygium cuminit, Eriodendrum pentadrum, Polyalthia suberosa, Aglaia elaeagnoidea, Chassalia curviflora and Sapindus emarginatus* are the main dependant tree species in the dry deciduous and reverine forests of Srivilliputhur Wildlife Sanctuary, with *Tamarindus indica* being a key food source (Joshua, 1992). During non-fruiting seasons or periods of fruit scarcity, the squirrels feed on the bark and leaves of these aforementioned tree species.

In the Chinnar Wildlife Sanctuary, a study revealed that GGS in the riverine forest feed on plant parts from 21 tree species (Senthilkumar *et al*., 2007). Rao *et al*., (2015) reported that GGS feed on 23 plant species in the Srivilliputhur Wildlife Sanctuary, including 11 tree species, 10 climbers, and 2 shrubs. Additionally, Thomas *et al*. (2023) found that GGS in the Chinnar Wildlife Sanctuary feed on 30 plant species belonging to 18 different families.

2.4 Time Activity budgeting

Like most other giant squirrels, GGS are diurnal and exhibit a bimodal activity pattern, influenced primarily by day length. The majority of daytime hours are dedicated to feeding, with resting typically occurring around midday, and approximately 10% of the day spent sleeping (Joshua, 1992). Rao *et al.* (2015) also documented eight distinct behaviors in GGS: feeding, moving, exploring, grooming, chasing, freezing, resting, and other activities, observing a similar behavioral pattern in their study.

2.5 Hybridization between GGS and Malabar Giant Squirrel

Interspecific hybridization between the Indian giant squirrel (*Ratufa indica*) and the GGS (*Ratufa macroura*) has been documented in several locations in South India, such as Srivilliputhur Wildlife Sanctuary, Tamil Nadu (Joshua, 1996), and Anjunad Valley, Kerala (Thomas *et al.*, 2018). This phenomenon often occurs when species that were previously geographically isolated (allopatric) are brought into contact (sympatry) due to human activities or natural events.

Despite their general non-overlapping distribution, these species coexist in forced sympatry in specific areas (Joshua, 1992; Thomas *et al.*, 2018). A recent study conducted in Chinnar Wildlife Sanctuary by Moti, (2023) reported 23 hybrids between these species and observed that these hybrids are reproductively viable. A detailed genetic study is required to understand the extent of hybridization.

2.6 GGS as a pest and human-wildlife conflict

One of the main reasons for the increased human-wildlife conflict in the modern world is the result of changes in land use (Fernando *et al.*, 2011; Bharathy *et al.*, 2022). Human-Wildlife conflict can often result in the disruption of the social, economic, or cultural lives of humans and wildlife and environmental conservation (Roy, 2017; Bharathy *et al.*, 2022). The movement and ranging patterns of wildlife are primarily influenced by the availability of food, water, and mates (Moorter *et al.*, 2013). Wallace and Hill (2012) explained that human–wildlife conflict frequently arises from crop-raiding, especially in Asian and African countries. Crop-raiding by wild animals close to the vicinity of protected areas is a serious threat to conservation efforts (Bayani *et al.*, 2016; Tekalign & Alemayehu, 2023). Pattern of crop damages caused by different herbivores varies depending on location and type of crop cultivated, estimating these damages using a single method may not be possible. For example, raiding by Asian elephants (*Elephas maximus*) results in visibly obvious damage over measurable areas. In contrast, smaller to medium-sized herbivores such as blackbuck (*Antilope cervicapra*), nilgai (*Boselaphus tragocamelus*), chital (*Axis axis*), wild pig (*Sus scrofa*), peafowl (*Pova cristatus*), rodents such as Malabar giant squirrel (*Ratufa indica*) may chew or nibble particular parts of plants, causing damage that is not immediately obvious (Woodroffe *et al.*, 2005; Bayani *et al*., 2016). However, despite the subtlety of the damage, these activities can still significantly affect crop yields (Naughton-Treves L, 1997). In African villages, African elephant (*Loxodonta africana*), Anubis Baboon (*Papio anubis*), Vervet Monkey (*Chlorocebus pygerythrus)*, and Grivet Monkey (*Chlorocebus aethiops*) as the major crop- raiding animals (Alemayehu & Tekalign, 2022), where as in Indian context the aforementioned species are major crop-raiders. Yet the damage caused by the small mammals goes unnoticed. In recent years, giant squirrels such as Malabar and grizzled squirrels are causing significant crop damage to coconut in southern India and Sri lankan villages (Govind & Jayson, 2018; Kumara *et al.*, 2023).

A study by (Kumara *et al.*, 2023) highlights that the GGS has become a significant issue for various crops in traditional home gardens in Sri Lanka. Their habit of chewing particular parts of plants has led to extensive damage to fruit crops, food crops, and spices. Reports indicate they have damaged over 30 different crop species in Sri Lanka, often destroying more than they consume by damaging fruits, seeds, leaves, and tree branches. Rural communities in Sri Lanka increasingly view the Giant Squirrel as a pest, exacerbated by their rapid population growth over the past two decades and the conversion of forested areas into mono-crop fields and other human activities.

A similar trend has been observed in the Alagarkovil Valley, Tamil Nadu, where the population of GGSs has increased (Ref.). They have begun encroaching into mango plantations and coconut plantations east of the valley, causing significant crop damage (Wildlife Association of Rajapalayam and Forest Department, cited in Mammals of South Asia).

2.7 Threats and conservation measures

Habitat loss continues to be a significant threat to the GGS throughout its range (Joshua, 1992; Joshua and Johnsingh, 1994; Molur *et al.*, 2005). The primary cause of this habitat loss is fragmentation due to the felling of forest trees to meet various human needs (Joshua and Johnsingh, 1994; Datta & Goyal, 2008; Harlekar, 2010). Therefore, protecting the habitats of the GGS is crucial for the conservation of this species.

Measures such as habitat restoration, maintaining canopy continuity, and halting large-scale auctions of Tamarindus indica fruits by the Forest Department for commercial purposes can significantly enhance the long-term survival of this habitat-specialist animal. These actions are essential for mitigating the ongoing threats posed by habitat loss and fragmentation, thereby ensuring the conservation of the GGS.

3. Study area

3.1 Location

The study was conducted in the Srivilliputhur Grizzled Squirrel Wildlife Sanctuary, spanning over 476.65 sq.km in the Southern Western Ghats of Tamil Nadu. The sanctuary's geographical coordinates range from 09° 23’ 38” N to 09° 49’ 51” N latitude and from 77° 21’ 51” E to 77° 47’ 20” E longitude. It predominantly lies within the Srivilliputtur and Rajapalayam taluks of Virudhunagar district and the Peraiyur taluk of Madurai district. This sanctuary is contiguous to the Periyar Tiger Reserve on the southwestern side and the Megamalai Reserve Forest on the western side. Its southern limit adjoins the Sivagiri Reserved Forest of Nellai Wildlife Sanctuary, and its northern limit borders the Sulapuram Reserved Forest of Megamalai Wildlife Sanctuary. In 2021, this sanctuary was designated as the 51st Tiger Reserve by combining it with the Megamalai Wildlife Sanctuary, forming the Srivilliputhur-Megamalai Tiger Reserve. This initiative aims to establish a continuous corridor for big cats by connecting adjacent protected areas. Additionally, this sanctuary is part of the Agasthiyarmalai landscape in the Western Ghats.

3.2 Vegetation and geographical features

The sanctuary encompasses a diverse forest habitat, including thorn forest, moist deciduous, dry deciduous, semi-evergreen, riverine forest, grassland, and evergreen forest ecosystems. A wide variety of habitats are observed across the sanctuary, from its western to eastern regions. The variation in vegetation is attributed to a rainfall gradient, with the eastern part situated in the rain shadow region of the Western Ghats, resulting in a transition from dry thorn forest to mixed moist forests. The area receives rainfall both from South West and North East monsoons and the bulk of which is from North East monsoon. The average annual rainfall in this area is 824 mm. Within the sanctuary, there are three ephemeral streams namely Arjuna nadhi, Mudangiar, and Sevalperiar, while perennial rivers are absent. The terrain varies from steep slopes to undulating areas, with elevations ranging from 200 meters in the plains to 2019 meters above sea level.

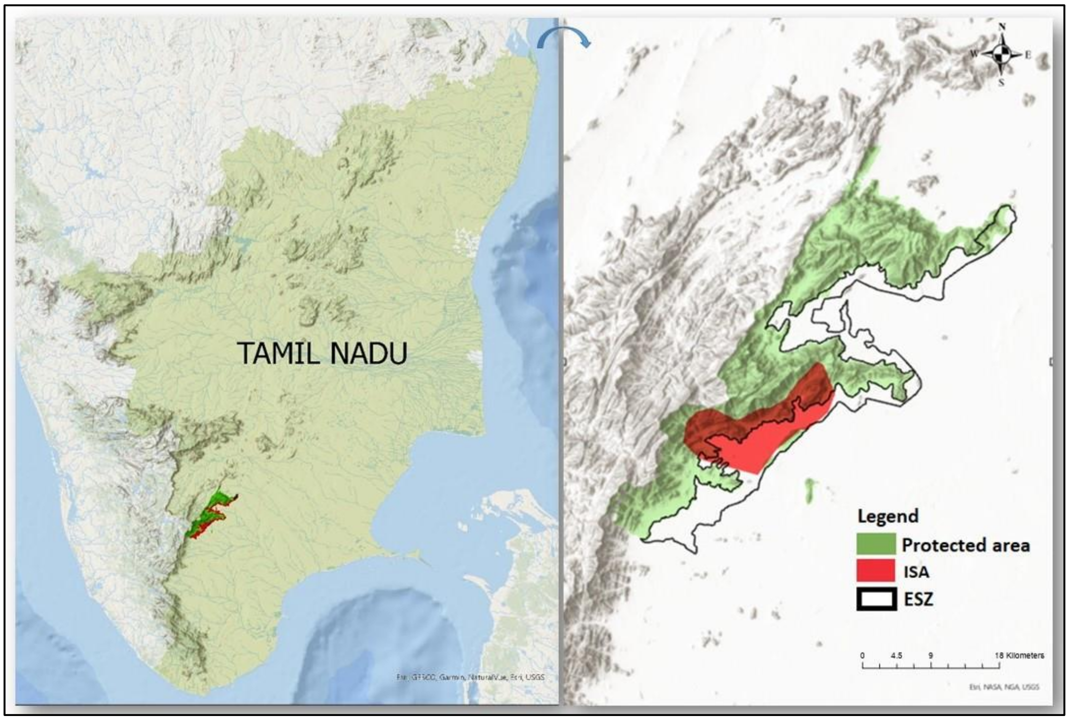


Figure1: Map of Study area in Virudhunagar district of Tamil Nadu, India showing Srivilliputhur Grizzled Squirrel Wildlife Sanctuary, Eco-Sensitive Zone and Intensive study area.

3.3 Wildlife

This sanctuary has wide varieties of endangered species such as Grizzled Squirrel, Elephant (*Elephas maximus*), Tiger (*Panthera tigris*), Leopard (*Panthera pardus*), Nilgiri tahr (*Nilgiritragus hylocrius*), Gaur (*Bos gaurus*), and Lion Tailed Macaque (*Macaca silenus*). In India, this Srivilliputhur Wildlife Sanctuary is the potential habitat for grizzled squirrels, followed by Chinnar wildlife sanctuary. Hence this species is identified as flagship species for this protected area. This sanctuary is also Part of elephant reserve and facilitates annual migration of elephants between Tamilnadu and Kerala in the Western Ghats. Furthermore, the sanctuary is also renowned for its rich and varied populations of mammals, avians, herpetofauna, and insects.

3.4 Administrative Structure and Geographic Divisions

The Srivilliputhur Wildlife Sanctuary is organized into four main ranges: Raja Palayam, Srivilliputhur, Watrap, and Saptur. Each range is further subdivided into ten sections: Seithur, Mudangiar, Rajapalayam, Srivilliputhur, Pudupatti, Khansapuram, Kodikulam, Watrap, Maharajapuram, and Saptur. These sections are then further divided into forty beats. The study focused on eight specific beats within the Raja Palayam and Srivilliputhur ranges: Ammankoil, Rajamparai, Neeravi, Ayyanarkoil, Viriyankoil, Athithundu, Alagerkoil, and Rengerkoil.

3.5 Anthropogenic pressure

The Srivilliputhur Wildlife Sanctuary is bordered by approximately 140 villages and hamlets, whose inhabitants heavily depend on the forest for livelihood activities such as collecting Non-Timber Forest Products (NTFPs) and grazing cattle. Additionally, within the Reserve Forests, there are several enclosures including temples and estates, which have contributed to the degradation of the forests. Notable among these enclosures are historical and sacred temples such as Sundara Mahalingham and Sandana Mahalingham temples in Saptur RF, Kattu Alagar Koil and Ayyanar Koil in Srivilliputhur RF, and Sasthakoil and Thavampetra Nayagi Ammankoil in Seithur RF. Moreover, numerous other temples are situated within the sanctuary. These religious sites attract thousands of pilgrims from various places every week, leading to disturbances to wildlife and environmental pollution.

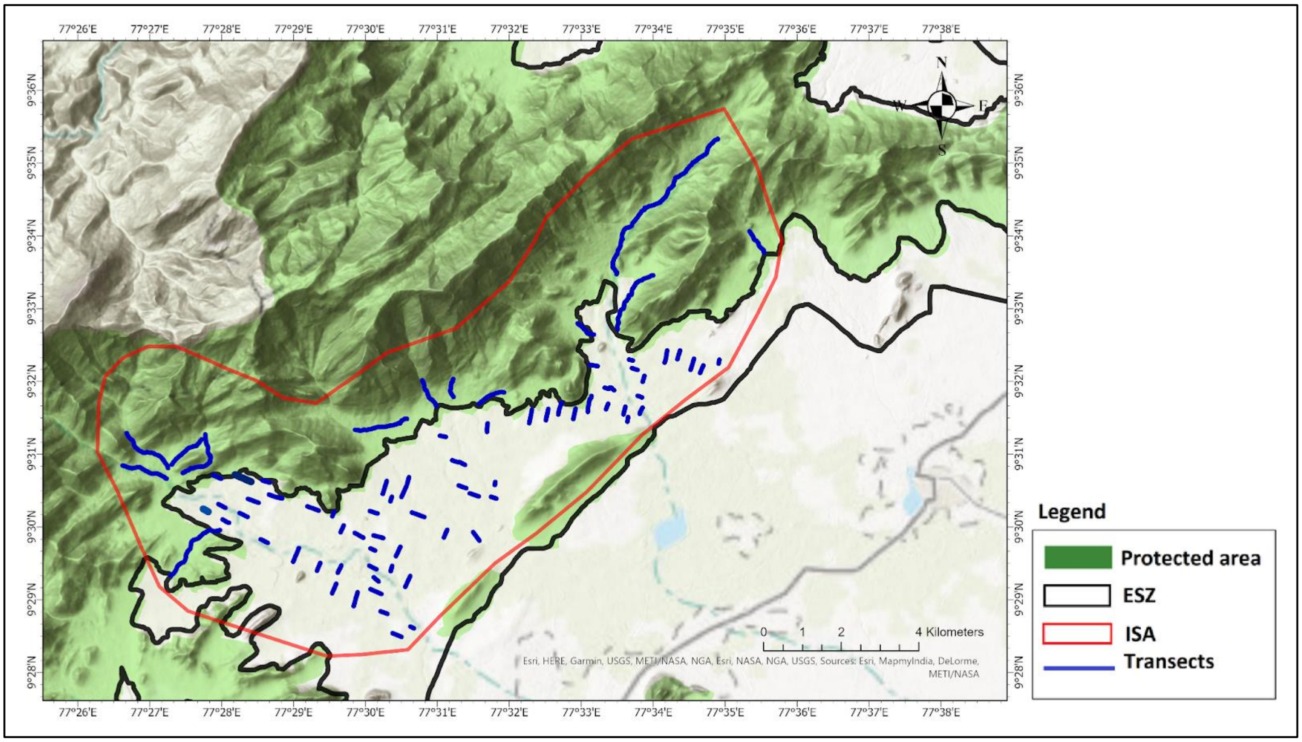


Figure 2: Map of study area showing Intensive Study area with varied length of transects falling in both protected area and Eco-Sensitive Zone

3.6 Eco-Sensitive Zone

The eco-sensitive zone (ESZ) for this wildlife sanctuary was officially designated in 2020. The extent of the ESZ ranges from zero kilometers, due to the inter-state boundary, to 6.2 kilometers around the perimeter of the protected area. The total area of the ESZ 208 sq km. The majority of the ESZ consists of private/patta lands that encompass mango and coconut plantations, teak plantations as well as agricultural land. The study within the ESZ was conducted on lands adjacent to the beats mentioned above.

Within the eco-sensitive zone, mainly 3 types of plantation are present, namely coconut plantation, mango plantation and coconut mix mango plantation. Along these plantations few people have also cultivated teak, jackfruit, guava, sapota and cotton tree interspersed with coconut and mango farms

3.6.1 Coconut plantation

A significant portion of the study area is dedicated to coconut plantations, where coconut trees typically begin yielding fruits three years after planting. For the survey, only farms that were actively yielding crops were selected. Farmers commonly cultivate two varieties of coconuts: Normal coconut, primarily for its pulp and King coconut for its tender water. The majority of the land is utilized for cultivating the pulp variety. Coconuts are harvested roughly every 45 days of interval.

3.6.2 Mango plantation

Most of the mango plantations are situated along the boundary of the protected area. For the survey, only plantations that had reached the fruiting stage were selected. Mango trees begin flowering around February and produce fruits from April to June. Farmers in the region apply pesticides and fertilizers before flower setting to enhance flowering. Mango trees often exhibit a natural phenomenon known as biennial bearing or alternate bearing, where they produce a heavy crop one year followed by a lighter crop or no crop the next year. This cycle is influenced by the depletion of the tree's resources during the heavy cropping year, which affects its ability to flower and fruit the following year. This year, inadequate flower setting resulted in sporadic fruit production.

3.6.3 Coconut mix mango plantation

In the study area, coconut mix mango plantation (hereafter referred as mix plantation) were also surveyed, provided both tree species had reached the fruiting stage. These mix plantations are less common compared to monoculture plantations. However, they represent a diversified agricultural practice that combines the benefits of both crops, potentially enhancing land use efficiency and economic stability for farmers.

4. Methods

This study aimed to understand the impact of land use change on the habitat and abundance of the GGS, with a particular focus on the effects of increasing land use change. To achieve this, an Intensive Study Area (ISA) was selected based on the dense cultivation of plantations in the ESZ and adjacent Protected Area using Google Earth Pro. A decadal Land Use Land Cover (LULC) analysis was conducted for the years 1993 and 2023 within the ESZ to assess the expansion of agricultural land. To evaluate the impact of land use change, the density of squirrels and dreys was estimated in both plantation and protected areas. Additionally, drey site selection was analyzed in both areas to understand habitat preferences in a changing landscape. Given that this species is known to cause crop depredation, structured questionnaire surveys were administered to gather relevant information from farmers.

4.1 Change detection Analysis for 1993 and 2023 Using Google Earth Engine and ArcGIS pro

4.1.1 Data Collection & Preprocessing

High-resolution satellite images from Landsat 5 TM for 1993 and Landsat 8 OLI/TIRS for 2023 were obtained from the Google Earth Engine (GEE) dataset repository. The images were preprocessed to ensure consistency and accuracy. Cloud-free images were filtered and selected using GEE, and a median composite was applied to reduce noise and cloud cover. Built-in cloud masking functions were used to remove clouds and shadows from the images. These steps ensured that the images were ready for accurate analysis and classification.

4.1.2 Classification

Training data were collected by creating polygons for four land use types directly in GEE. This involved manually laying polygons over the imagery to represent different land cover classes such as Water, Agriculture, Barren and Forest cover. A Random Forest classification algorithm was then used due to its robustness and accuracy. The training data from both years was used to train the classifier, which was subsequently applied to classify the images separately for 1993 and 2023. This resulted in two classified LULC maps, one for each year.

4.1.3 Accuracy Assessment

For accuracy assessment, the same polygons used for training were split into training and validation datasets, with 70% of the data used for training and 30% for validation. Metrics such as overall accuracy and the Kappa coefficient were calculated to assess the performance of the classification.

4.1.4 Change Detection

Classified images (GeoTIFF files) from 1993 and 2023 were imported into ArcGIS Pro and clipped to the study area boundary using the Clip Raster tool, ensuring consistent extents for accurate comparison. The Reclassify tool standardized land use classes for agriculture, water, barren land, and forest. A new field was added to each raster's attribute table to assign class values. The Change Detection Wizard in ArcGIS Pro was used with the 1993 raster as the initial state and the 2023 raster as the final state to generate a change detection raster highlighting land use transitions. The area for each land use class in 1993 and 2023 was calculated by multiplying pixel counts by 30m x 30m, followed by calculating the overall change and percentage change from 1993 to 2023.

4.2 Field survey

To conduct the survey in the protected area, existing beat transects, patrolling tracks, and fire lines were delineated as line transects to estimate the density of squirrels. A total of 17 line transects, varying in length from 450 meters to 2750 meters, were sampled, encompassing a total effort of 18 kilometers across Riparian Forest and deciduous forests within the specified beats of the protected area. Additionally, sixty-seven transects, ranging from 100 to 500 meters in length, were established in the eco-sensitive zone across different plantation types (mango, coconut, and mixed). The length of each transect depended on the length of the plantation, fencing, and crop type. Distances of approximately 250 meters were maintained between the each transects in the plantation to avoid the double counting of GGS. Twenty transects were sampled in mixed plantations with a total effort of 4.5 kilometers, twenty-five transects in coconut plantations with a total effort of 5.5 kilometers, and twenty transects in mango plantations with a total effort of 5.7 kilometers. The total survey effort in the plantations within the eco-sensitive zone amounted to 15.8 kilometers. All the transects were replicated four times during the study duration, which was divided into two distinct seasons. The first period, from December to February was designated as the winter season (hereafter referred as Season1) and from March to April was designated as the summer season (hereafter referred as Season2). Dreys were counted only once (in 1st replicate) during the entire study period.

4.2.1 Squirrel and drey survey

All sightings of squirrels and dreys along the transects were recorded, along with the following data: tree species, count of individuals, distance from the observer, and angle of sighting. The positions were determined using a handheld GPS device (Garmin eTrex 20X), while distances were measured using a laser rangefinder (Nikon Forestry Pro). Angles were recorded using a compass-enabled mobile handset. Surveys were conducted during the morning hours, between 0700 and 1200 hours, coinciding with peak squirrel activity (Joshwa, 1992). Predefined line transects were walked at a uniform speed, and the identification of dreys inside the protected area was confirmed by consulting two individuals.

4.2.2 Drey site selection

Only dreys encountered on the line transects were considered for site selection. Out of all encountered dreys, 50% were randomly selected to understand the drey site preference. Parameters such as tree species, tree height, GBH, drey height, canopy cover, crown width, number of main branches, and canopy connectivity were recorded for each selected drey. To assess drey site preferences, ten nearest trees were considered as control trees and with GBH ≥ 30 cm around each tree were sampled. Tree height, drey height, and canopy cover (low- 0 to 25%, medium- 25 to 50% and high- >50%) were estimated visually, while GBH, crown width, and distance from the drey tree to control trees were measured using a 15-meter measuring tape. Canopy connectivity was categorized as nil, low, medium, or high based on the percentage of tree connectivity with other trees. Nil- 0%, low- 1-25%, medium- 25-50%, high- >50%.

4.2.3 Questionnaire survey

To gauge farmers' perceptions of crop depredation, structured questionnaires were administered in different plantation types. A survey was conducted across 50 farms within the study area to assess the impact of GGS and other wildlife on farms. Data were collected on crop types, number of trees, farm size, and year of establishment. The survey investigated instances of crop depredation, focusing on coconuts and mangoes, and evaluated associated economic losses. It explored the frequency and nature of crop damage, identified wildlife species responsible for the damage, and assessed the effectiveness of protective measures employed by farmers. The survey also captured farmers' perceptions of crop depredation and its economic implications, inquiring about the frequency of GGS sightings and the presence of dreys in the plantations.

4.2.4 Crop depredation assessment by control plots

To quantify the extent of crop depredation, A total of 10 control plots of 50*50m were established, comprising three in mixed plantations, two in King Coconut plantations, and five in normal coconut plantations. Prior to setting up the plots, the sites were cleared of damaged coconuts, and farmers were advised not to remove any fallen and damaged coconuts during the study period. The number of coconut and mango trees in each plot was recorded. These plots were monitored throughout the entire study period to assess the presence and severity of crop damage. The number of coconuts damaged and the number of days monitored were recorded Additionally, factors influencing crop damage such as canopy connectivity, tree spacing, adjacent plantation types, and the presence of nests and GGS were documented for each area.

The predation rate on coconuts in each plot was calculated by dividing the number of coconuts damaged by the number of trees within the control plot, and then multiplying by the number of days monitored. This rate was then annualized by multiplying it by 365 days, yielding the number of coconuts damaged per tree per year by GGS.

4.3 Analytical Methods

4.3.1 Density estimation

Density of GGS and dreys were estimated using the distance package in software R (version 4.2.2). Primarily the distance sampling accounts for the proportion of animals that were missed during the survey by using a detection function generated from the records of the distances of those seen, and then estimates abundance. The different detection functions were fitted to the data using perpendicular distances, which was calculated from the formula D= sighting distance*Sin(θ). Multiple detection functions were modeled, incorporating different covariates and truncation distances, were tested to identify the best-fitting model. Model selection was based on Akaike Information Criterion values (AIC) and goodness-of-fit tests.

4.3.2 Drey site selection

Generalized Linear Models (GLM) with a binomial family were used for analyzing the relationship between the drey presence and predictor variables. Model selection was based on the AIC value. Before running the GLM model, correlation between the variables were checked through a correlation matrix. In case of variables having a high degree of correlation (55%), only one variable was chosen based on the ecological function of the variable. Having multiple correlated variables can create bias in the model and are thus removed to increase the accuracy of the model.

Utilization and availability for various variables were calculated to understand the species' selective use of resources relative to their availability. These methods statistically compare used and available resources to identify preferences and avoidance (Neu et al,. 1974). Preference value was calucated by dividing proportion of used divide by proportion of available (P = U/A). All statistical analyses were carried out using the statistical software R (version 4.2.2) and Microsoft Excel.

4.3.3 Other data analysis

Further analysis of change detection, farmers' perceptions, and crop depredation was conducted using Descriptive Statistics and Pivot Tables in Microsoft Excel. Descriptive Statistics were employed to calculate measures such as averages, counts, sums, and variability indicators (e.g., standard deviation) to assess variables related to crop damage severity, perceived impacts, and changes observed over time. Pivot Tables were utilized to summarize and aggregate data.

5. **Results**

5.1 Land-Use and Land-Cover Changes

The land-use land-cover change data from 1993 to 2023 reveals significant shifts in the landscape. However, plantation and agricultural areas were difficult to clearly discriminate from each other as they had similar spectral classes and were, therefore, recorded into one class i.e. agriculture. The area classified as water increased dramatically from 267.21 ha in 1993 to 365.4 hectares in 2023, a 136.75% rise. Plantation areas also saw substantial growth, expanding from 8837.71ha in 1993 to 4496.58 ha in 2023, which represents a 50.88% increase. Conversely, barren land experienced a considerable reduction., decreasing from 10467ha in 1993 to 7313 ha in 2023 with 30% loss. Similarly, forested area declined by 1101.78 ha, marking a 44.99% loss. The land use and land cover classification clearly discriminated between the two classes: plantation and barren. Majority of the Conversion was from barren land and forest to agriculture. The overall accuracy of the classification was 86.9 per cent, with a Kappa coefficient of 89.5 per cent.

Table 1: Changes in the major land-use and cover classes within Eco-Sensitive Zone between 1993 and 2023 with Absolut change and Percentage

		Area (ha)		Change	
Sl no	land-use land-cover type (class)	1993	2023	Absolute change (ha)	Percent
1	Water body	267.21	632.61	365.4	136.7464
2	Plantation & Agriculture	8837.73	13334.31	4496.58	50.87935
3	Barren land	10467.09	7313.22	-3153.87	30.1313
4	Forest cover	2449.17	1347.39	-1101.78	44.98585

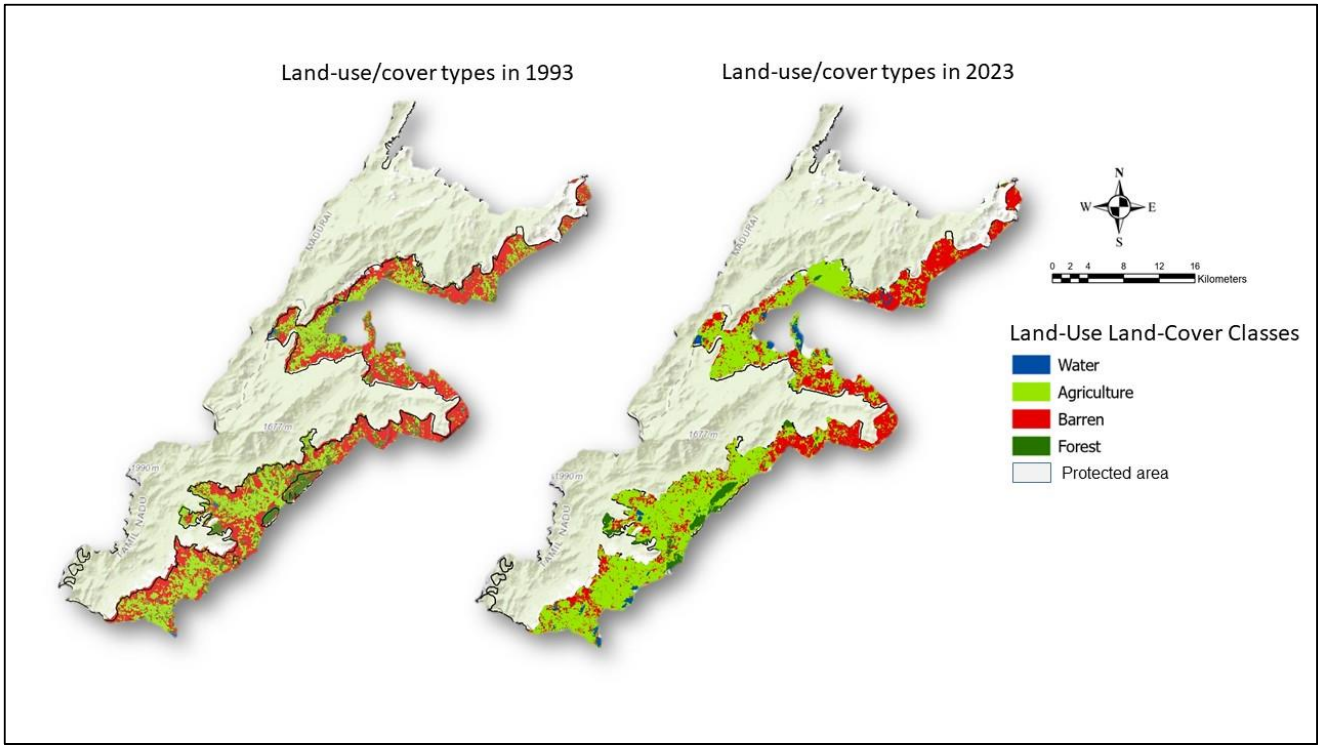


Figure 3: Extent of Land-Use Land-Cover change in the Eco-Sensitive Zone between 1993 to 2023 with major land- use classes as Water, Agriculture, Barren and Forest

5.2 Density estimation

5.2.1 Comparison of GGS densities in different land-uses

In the protected area, during the study period a total of 15 transects were walked four times and 2 transects were walked two times resulting in the total effort of 67.9 km. Out of this 40.5 km was covered in deciduous areas and 27.4 km was covered in Riparian Forest forest. In the deciduous 11 squirrels and 51 dreys were recorded. In the Riparian Forest forest, 8 squirrels and 2 dreys were recorded.

Table 2: Transect wise effort and sighting data in Deciduous and Riparian Forest in Protected area (SQS1- Squirrels in Season 1& SQS2- Squirrels in Season 2)

Sl no	Location	Habitat Type	No of replica	Effort (Km)	total effort (Km)	Drey	SQS1	SQS2
1	Alagarkovil BT PA	Deciduous Forest	4	2	8	14	1	1
2	Alagarkovil temple	Deciduous Forest	4	1	4	2	0	0
3	Ammankovil BT PA	Deciduous Forest	4	1.98	7.92	0	0	0
4	Attithundu PA	Deciduous Forest	4	0.515	2.04	12	4	2
5	Neeravi PA2	Deciduous Forest	4	0.76	3.04	1	0	0
6	Neeravi PA1	Deciduous Forest	4	0.78	3.12	1	0	0
7	Rengarkovil PA	Deciduous Forest	4	0.75	3	11	0	0
8	Viriyankovil BT PA1	Deciduous Forest	4	1.5	6	4	1	2
9	Viriyankovil main falls	Deciduous Forest	4	0.525	2.1	2	0	0
10	Viriyankovil Thataparai	Deciduous Forest	2	0.75	1.34	4	0	NA
11	Alagarkovil valley	Riparian Forest	2	2.75	5.5	NA	NA	2
12	Ayynarkovil PA1	Riparian Forest	4	0.45	1.8	0	0	0
13	Ayynarkovil PA2	Riparian Forest	4	1	4	1	0	0
14	Ayynarkovil PA3	Riparian Forest	4	1.23	4.92	0	0	0
15	Neeravi PA3	Riparian Forest	4	1	4	0	0	0
16	senghakatoppu falls PA	Riparian Forest	4	1	4	1	2	3
17	Viriyankovil Pallar falls	Riparian Forest	4	0.8	3.2	0	1	0
	Total			18.79	67.98	53	9	10

In the plantation, a total of 67 transects were walked four times, resulting in a total effort of 60.9 km. This effort was distributed as follows: 17.7 km in mixed plantations, 20.2 km in coconut plantations, and 22.9 km in plantation plantations. In the mixed plantations, a total of 55 squirrels and 47 dreys were recorded. In the coconut plantations, 29 squirrels and 23 dreys were observed. In contrast, the mango plantations had significantly fewer sightings, with only 6 squirrels and 2 dreys recorded. Additionally, there was a significant seasonal variation in squirrel numbers. During the winter season, a total of 52 squirrels were encountered, whereas in the summer season, the number decreased to 38 squirrels.

Table 3: Treatment wise effort and sighting data in Mix plantations, Coconut plantation and Mango plantation in Eco-Sensitive Zone in 2 Seasons (SQS1- Squirrels in Season 1& SQS2- Squirrels in Season 2)

Habitat types	No of transects	Effort	Total effort	SQS1	SQS2	drey sightings	Total GGS sightings
Mix Plantation	20	4.42	17.71	36	19	57	55
Coconut Plantation	25	5.05	20.21	15	14	17	29
Mango Plantation	22	5.74	22.96	1	5	3	6
Total	67	15.22	60.9	52	38	77	90

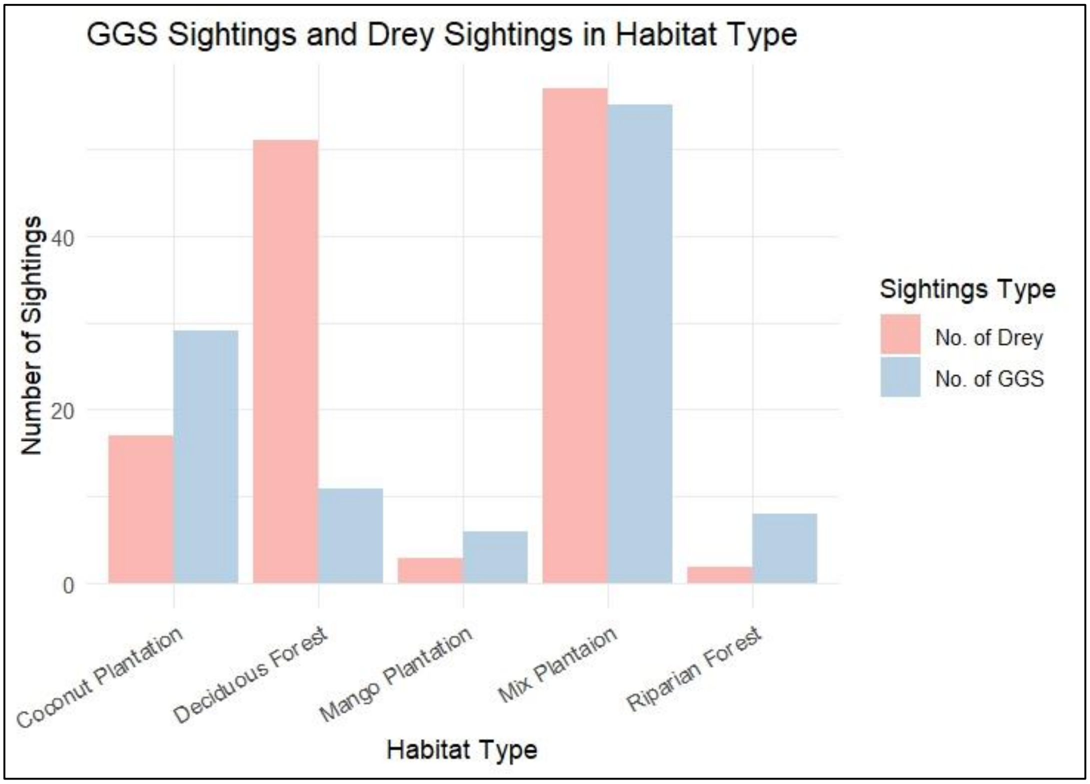


Figure 4: Variation in the Number of sightings of GGS and Drey in different Habitat types

To run the detection function in the R program, only sightings within 35 m were considered to achieve a better fit of the model. The half normal model with null adjustment was deemed to be the best model based on lower AIC value (660.4) and a higher GOF P value (P = 0.21191). The density estimate varied considerably between the different habitat types. In general, densities were higher in the plantations when compared to the protected area. In the plantations, mix plantations had the highest density with 72.95 ± 22 squirrels per sq. km, followed by coconut plantations with 57.28±19 squirrels per sq. km. Mango plantations had very less density with an estimated 5.21± 6 squirrels per sq. km. In case of the protected area deciduous forests had an estimated density of 14.31 ± 9 squirrels per sq. km, which slightly reduced to 10.59 ± 6 squirrels per sq. km in case of Riparian Forest forests. Due to less sampling effort, the CV for the density estimates of the protected area was relatively higher. Thus, the estimate for the protected area should be considered as a conservative estimate.

Table 4: Overall density estimate of GGS in different habitat types

Sl no	Habitat types	Density estimate	Standard Error	Encounter rate	CV(%)	95% CI
1	Mix Plantation	72.95	22.65	2.8	31	39.1-136.1
2	Coconut Plantation	57.28	19.51	1	34	29.3-111.9
3	Mango Plantation	5.21	6.41	0.2	123	0.75-36.2
4	Deciduous Forest	14.31	9.52	0.2	66	3.8-52.9
5	Riparian Forest	10.59	6.73	0.2	63	2.7-41.3

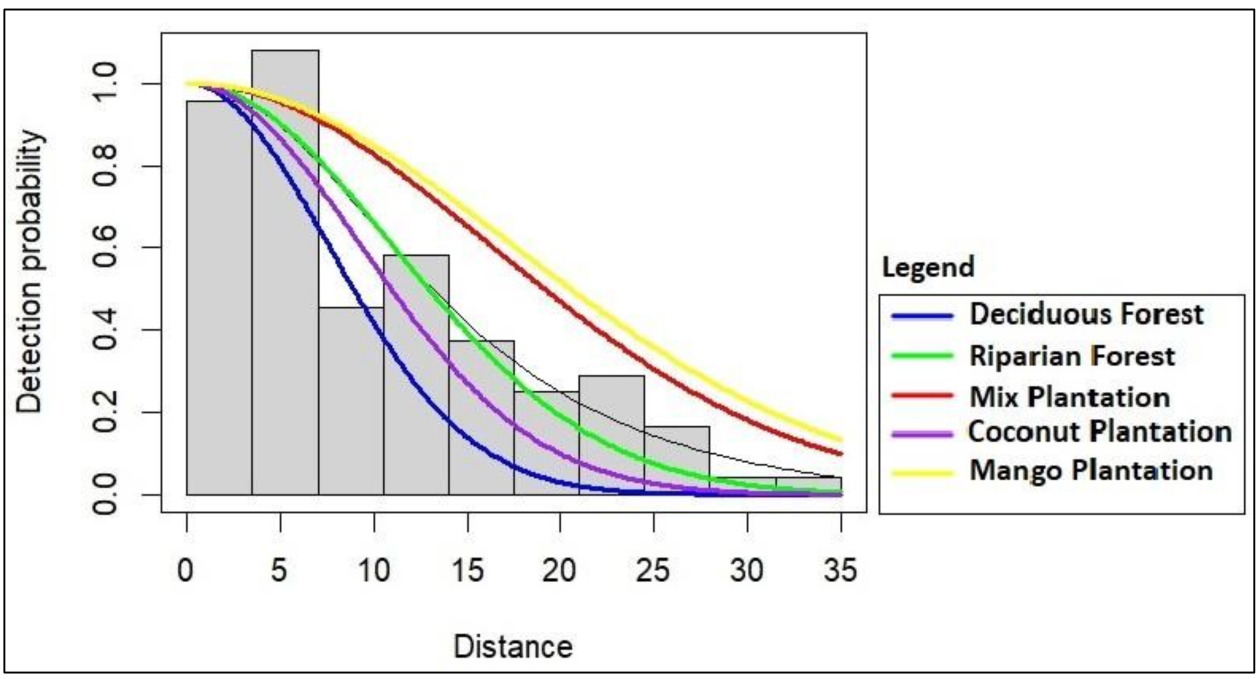


Figure 5: Detection probability of GGS in different habitat types

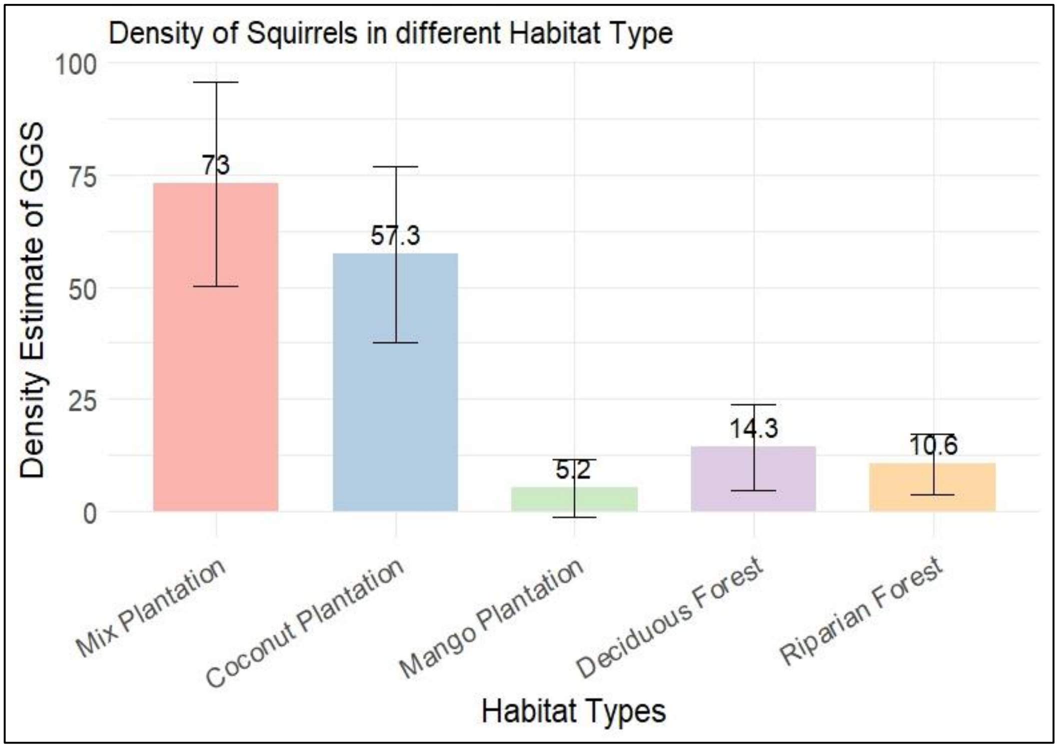


Figure 6: Density of GGS in different habitat types with Standard Error

5.2.2 Squirrel density across two seasons in plantations

There was a significant difference in the number of GGS sightings between the two seasons. In season 1, there were 52 GGS sightings, whereas in season 2, the sightings were reduced to 38. Consequently, separate distance sampling analyses were conducted for each season and the half-normal detection function with 30m right truncation adjustments provided the best fit. For season 1, overall density estimates of 48.5 squirrels per sq.km, with an AIC value of 277.62 and a GOF p-value of 0.559. In contrast, for season 2, the half-normal detection function was the best fit, with an AIC value of 249.55, a GOF p-value of 0.277, and an overall density estimate of 39.99 squirrels per sq.km.

In season 1, only a single squirrel sighting occurred in the mango plantation, so it was omitted to ensure data reliability. The density of GGS in the mixed plantation was estimated at 93.50 ± 29 squirrels per sq.km, which decreased to 50.49 ± 21 squirrels per sq.km in season 2. Conversely, the density in the coconut plantations increased from 52.14 ± 20 to 62.23 ± 28 squirrels per sq.km. Additionally, the density in mango plantations in the second season was 7.25 ± 7 squirrels per sq.km.

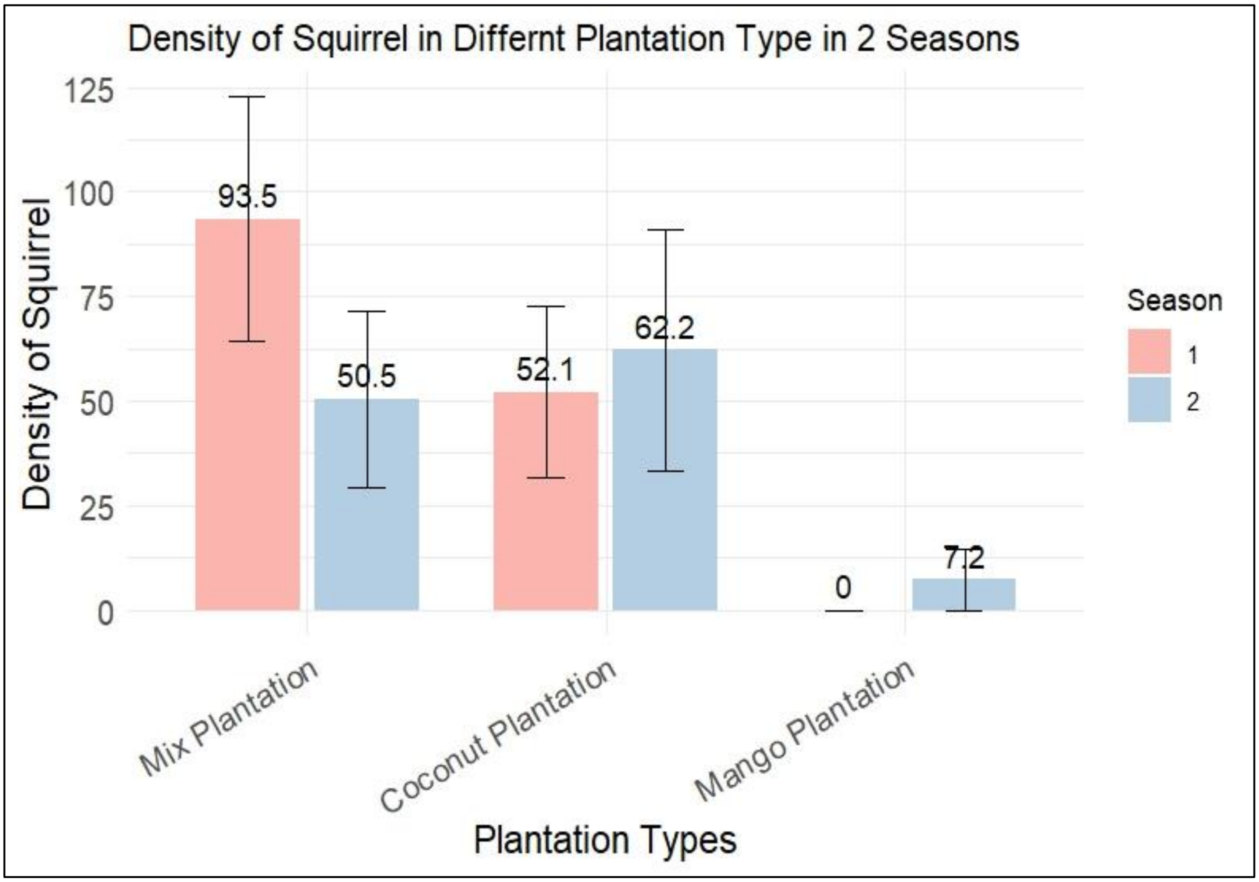
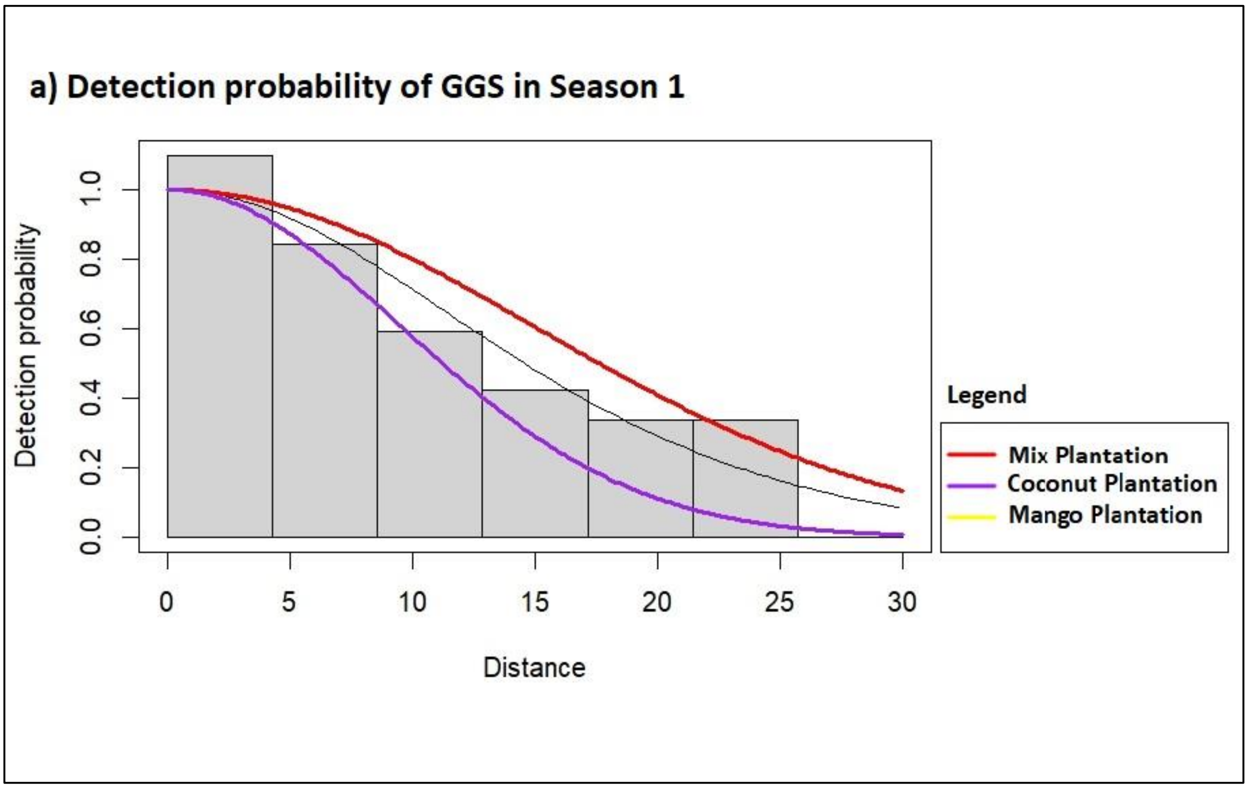


Figure 7: Density estimate of GGS across two season (Season 1-Winter, Season 2-Summer) in Different plantations types with Standard Error

Table 5: Density estimate of GGS across two season (Season 1-Winter, Season 2-Summer) in Different plantations types

Season	Habitat types	Density estimate	Standard Error	Encounter rate	CV(%)	95% CI
Season1	Mix Plantation	93.50	29.28	3.3	31	50.16-174.30
Season1	Coconut Plantation	52.14	20.37	1.2	39	24.39-11.43
Season1	Mango Plantation	0.0	0	0	0	0
Season2	Coconut & mango	50.49	21.00	2.1	41	22.36-114.01
Season2	Coconut Plantation	62.23	28.87	1.4	46	25.52-151.74
Season2	Mango Plantation	7.25	7.35	0.4	101	1.32-39.70



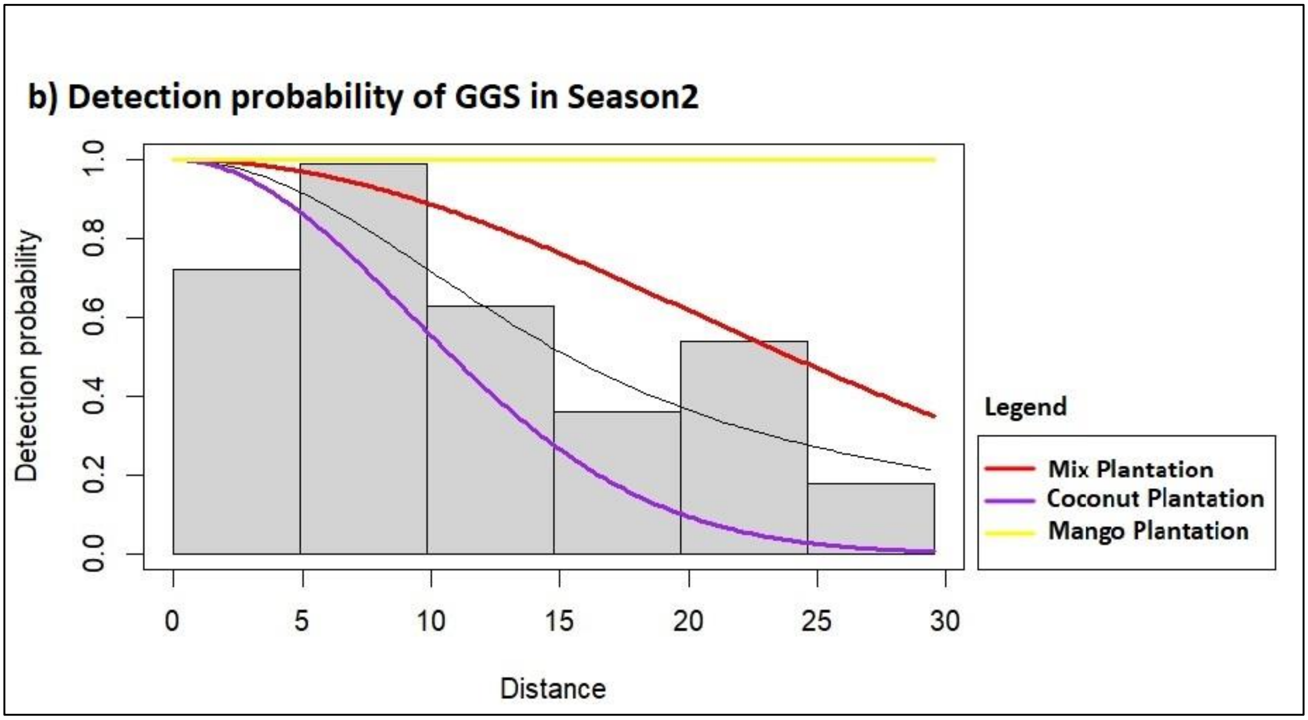


Figure 8: a) Detection probability of GGS in different habitat types in Season 1, b) Detection probability of GGS in different habitat types in Season 2

5.2.3 Drey density across different habitat types

To run the detection function in the R program, only sightings within 30 m were considered to achieve a better fit of the model. The hazard-rate model with null adjustment was deemed to be the best model based on lower AIC value (783.5) and a higher GOF P value (P = 0.05121). The density estimate of dreys varied considerably between the different habitat types. In general, densities were higher in the plantations when compared to the protected area. In the plantations, mix plantations had the highest density with 400.62 ± 93 dreys per sq. km, followed by coconut plantations with 68.92 ± 28 dreys per sq. km. Mango plantations had very less density with an estimated 18.12 ± 23 dreys per sq. km. In case of the protected area deciduous forests had an estimated density of 289.70 ± 110 dreys per sq. km, which slightly reduced to 7.26 ± 6 dreys per sq. km in case of Riparian Forest forests. Due to less number of sightings, the CV for the density estimates of the protected area and mango plantations was relatively higher.

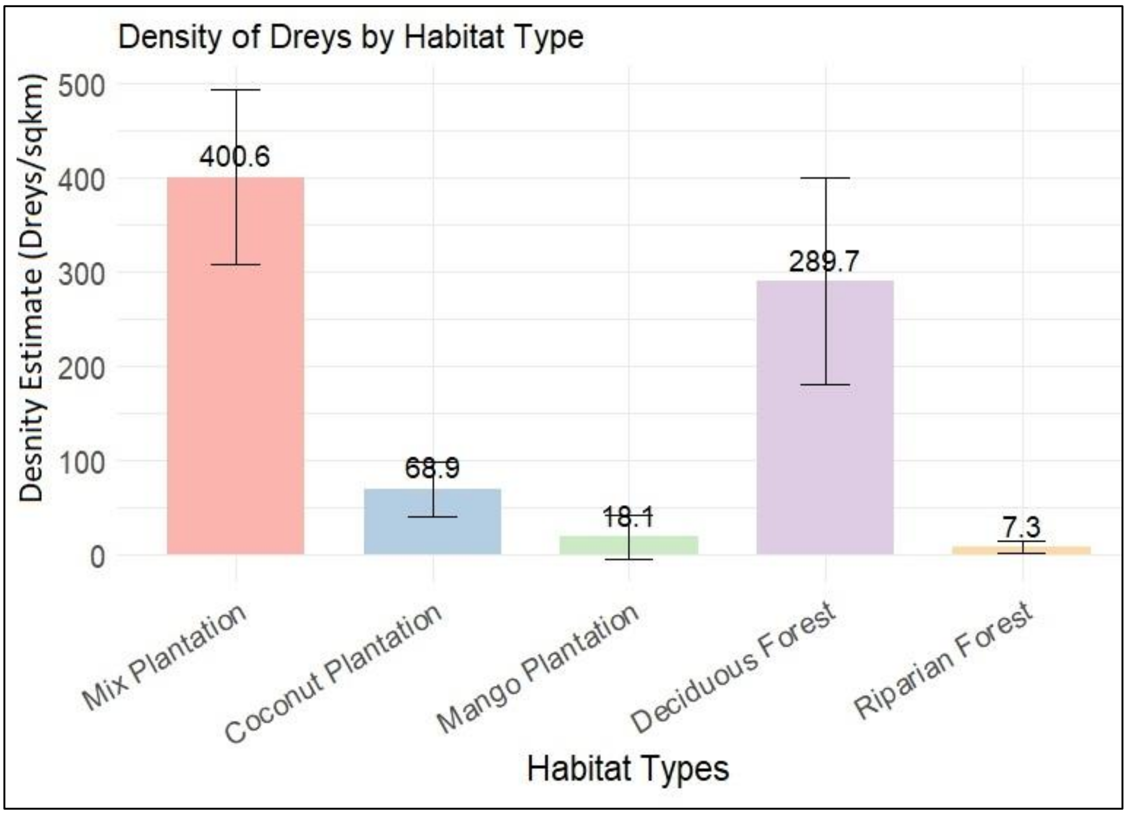


Figure 9: Density of Dreys in different habitat types with Standard Error

Table 6: Density estimate of Dreys across different habitat types

Sl no	Habitat types	Density estimate	Standard Error	Encounter rate	CV(%)	95% CI for Density Estimate
1	Mix Plantation	400.62	93.06	12	23%	251.6-637.7
2	Coconut Plantation	68.92	28.73	3	41%	30.92-153.61
3	Mango Plantation	18.12	23.33	0.5	128%	2.48-132.0
4	Deciduous Forest	289.70	110.10	4	38%	130.1-644.65
5	Riparian Forest	7.26	6.81	0.3	93%	1.42-37.20

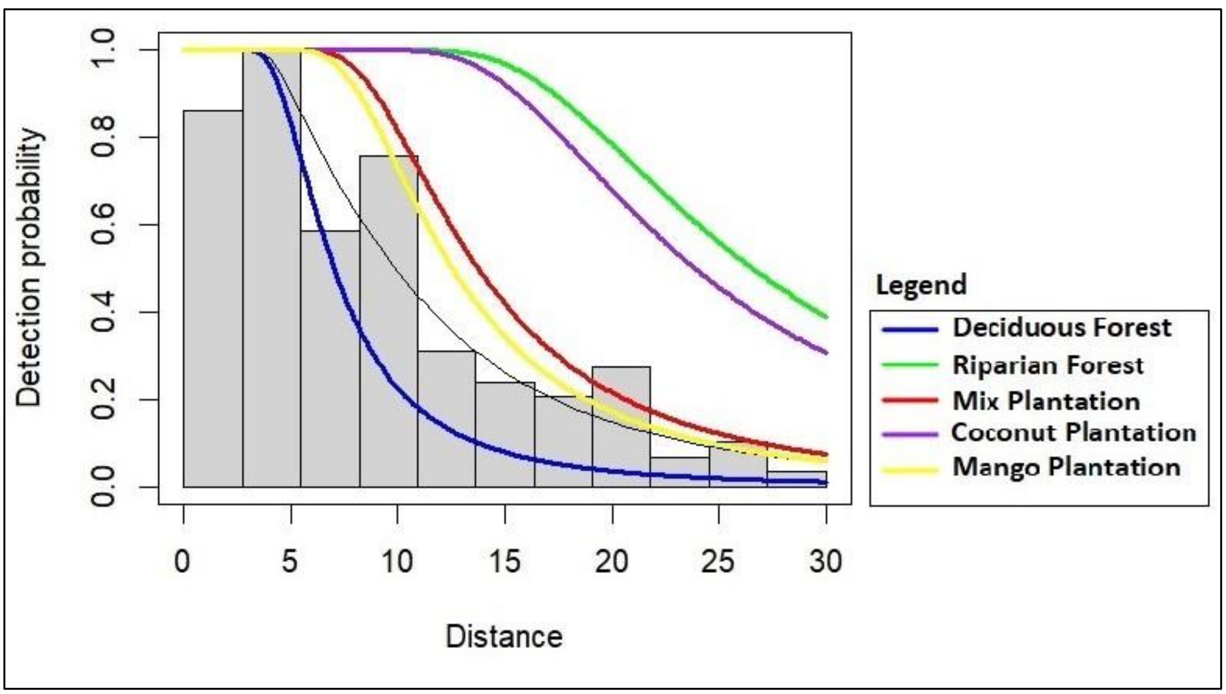


Figure 10: Detection probability of Dreys in different habitat types

5.3 Drey Site selection Resourse Utilization

5.3.1 Drey selection in protected area

Out of the 53 dreys encountered on the line transects in the protected area, a subset of 29 dreys was randomly sampled to assess drey site selection and habitat preference by GGS. Among these 29 sampled dreys, 13 were found on *Tamarindus indica*, 3 on *Albizia amara*, and 3 on *Holoptelea integrifolia*, indicating a high affinity towards these tree species.

To analyze the relationship between drey presence and various predictor variables, Generalized Linear Models (GLM) were employed. Prior to running the GLM, the correlation between the variables was examined using a correlation matrix. The variables girth at breast height (GBH) of trees, tree height, and crown width were found to be highly correlated (>50%). Consequently, only tree height was chosen for the model to avoid multicollinearity. The GLMs were run using a binomial distribution with an additive function, appropriate for the presence-absence data of dreys. The model selection was guided by the Akaike Information Criterion (AIC), with the final model having an AIC value of 138.77. The results from the summary statistics indicated that tree height and canopy connectivity significantly influenced drey site selection. In contrast, other parameters such as canopy cover and the number of branches did not have a significant effect on the selection of drey sites.

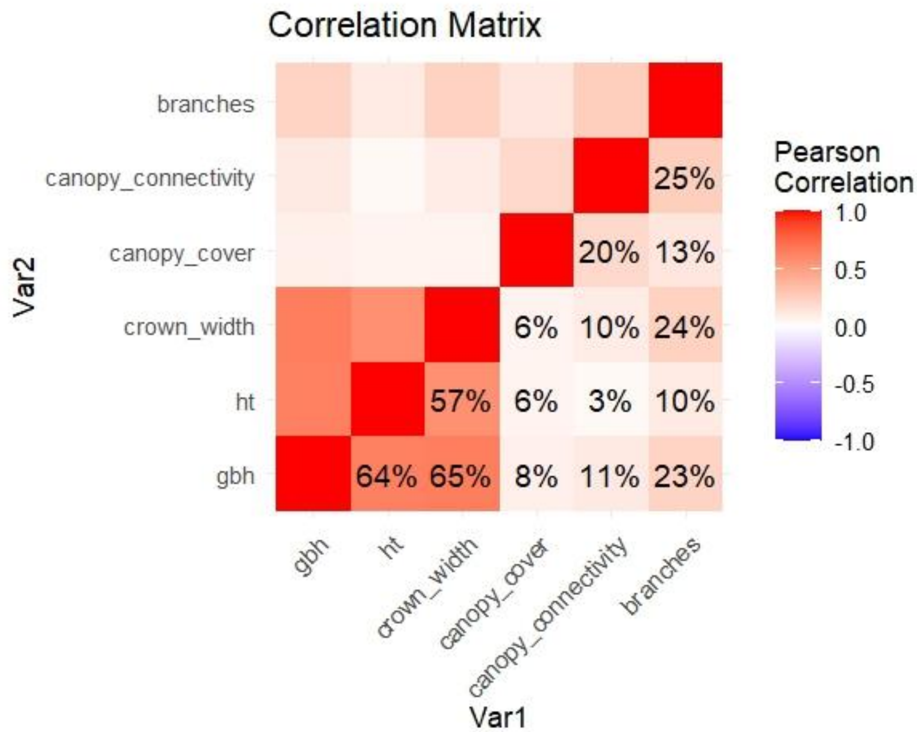
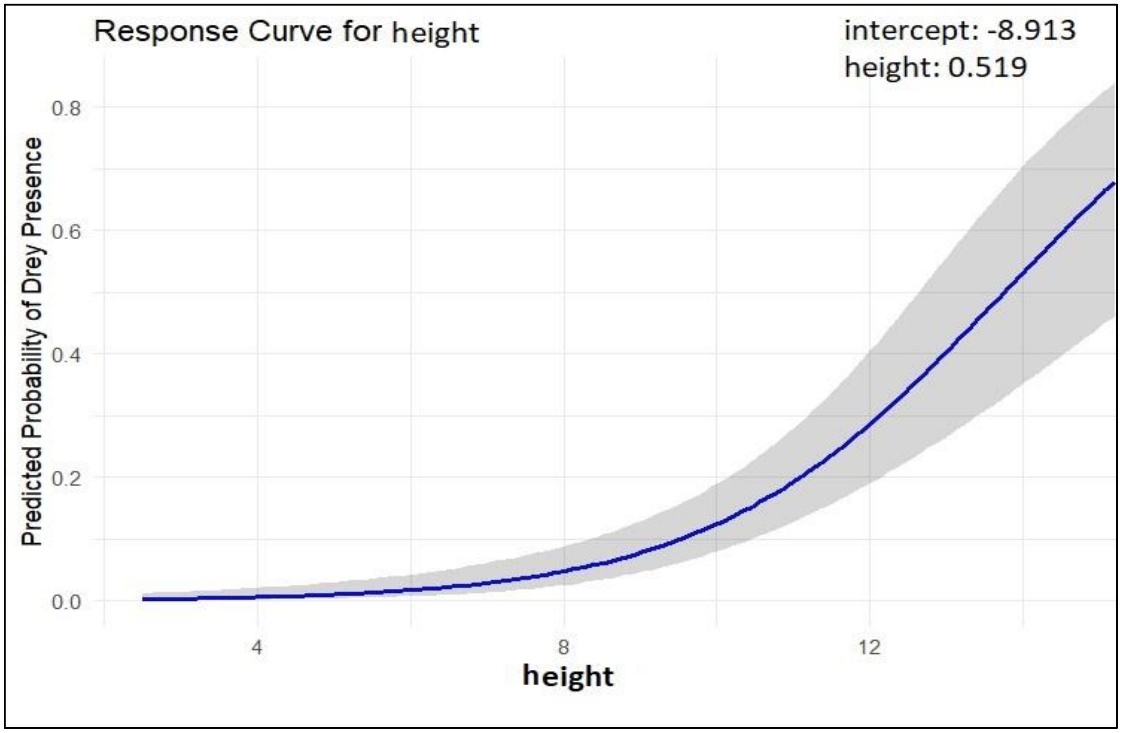


Figure 11: Correlation matrix of drey Variables in protected area

Table 7: Result of GLM for Drey site selection for drey in Protected area

Formula = glm(formula = drey ~ height+ canopy_connectivity) Family = Binomial				
	Estimate	Std.Error	z-value	Pr(>|z|)
(Intercept)	-8.91281	1.35064	-6.599	**4.14E-11**
height	0.51931	0.08603	6.036	**<0.001**
canopy_connectivity	0.0306	0.01318	2.321	**<0.001**

a.)



b.)

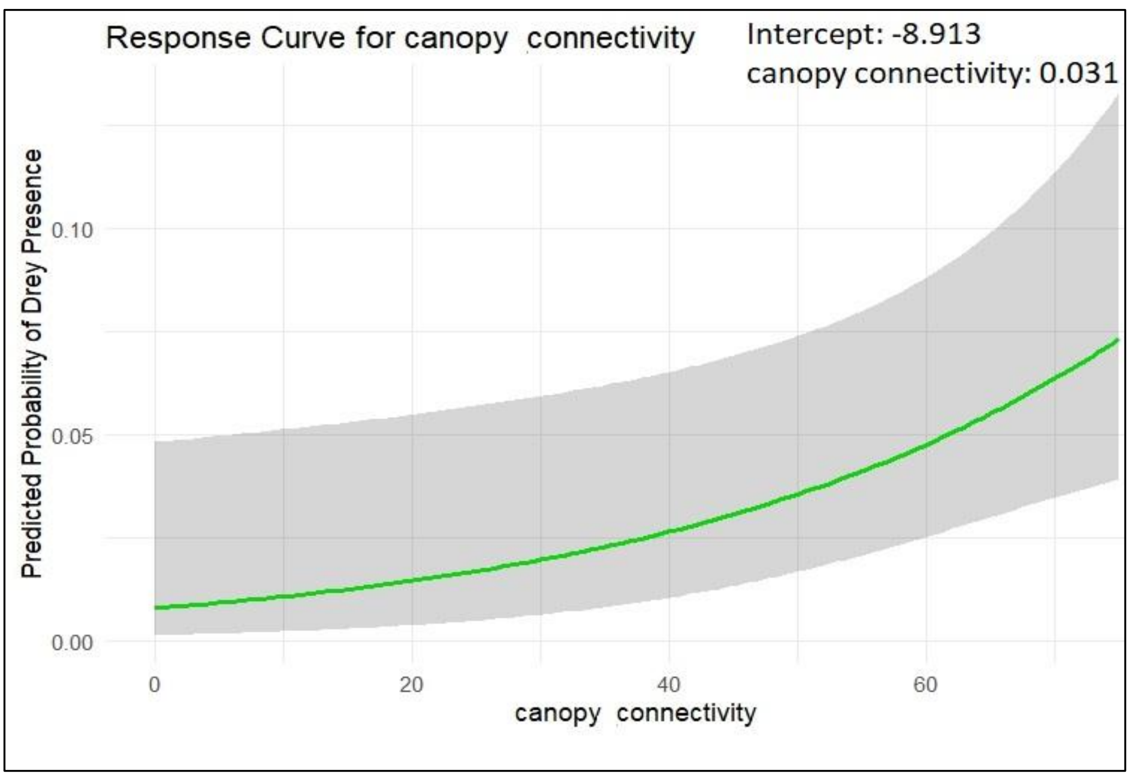


Figure 12: Effect of Predicted variables on Drey Site Selection in Protected area a.) height b.) Canopy connectivity

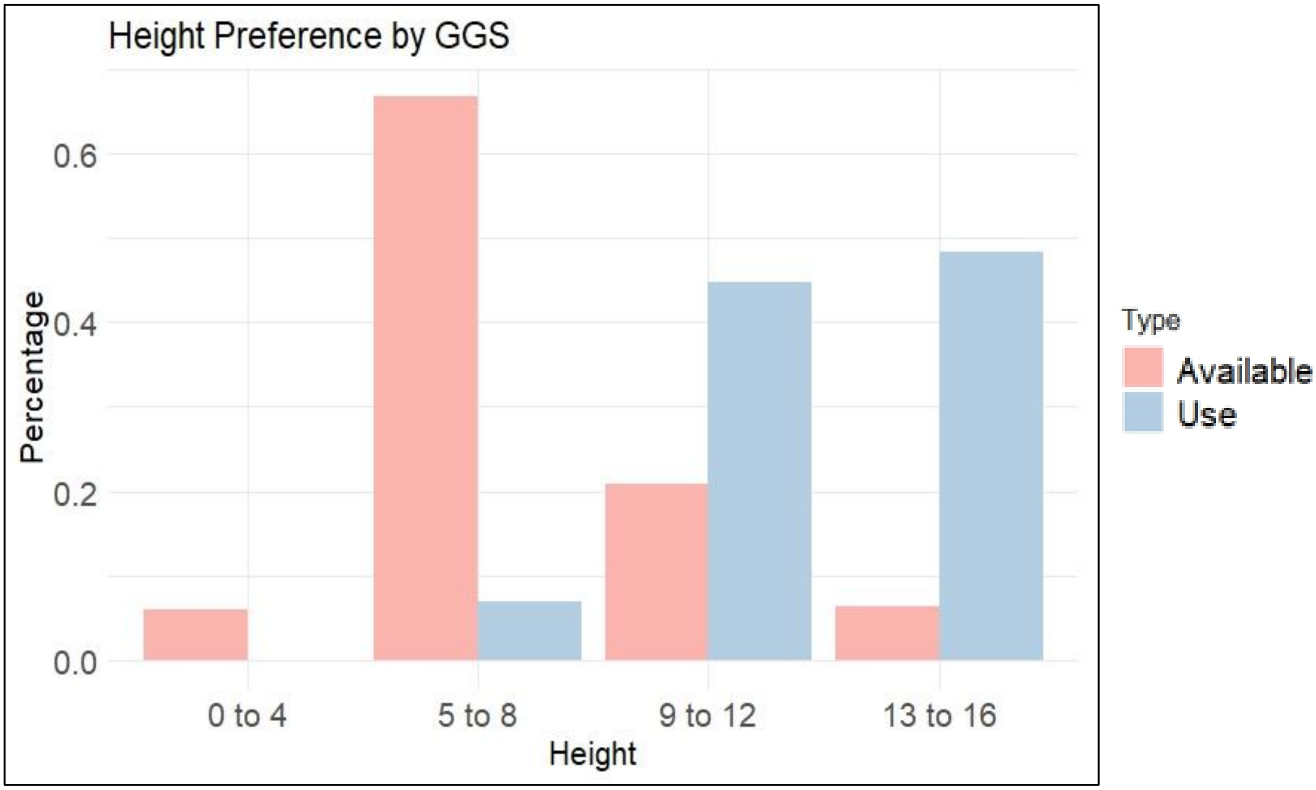
5.3.2 Utilization- Availability of different variables on drey site selection in Protected area

A preference value greater than 1 indicates high preference (Appendix: Table 1). The graph was plotted only for the variables that were significant in the GLM analysis. The results showed that GBH greater than 150 cm, height greater than 9 m, canopy cover greater than 75%, crown width greater than 9 m, canopy connectivity greater than 45%, and more than 3 branches had high preference values.

Table 8: Preference value of each variable for drey site selection in protected area

Variables	Bin	Expected use	Preference value
GBH (cm)	50 ot 99	12.18	0
	100 to 149	10.44	0.478927
	150 to 199	**3.712**	**1.346983**
	200 to 249	**1.508**	**1.98939**
	250 to 299	**0.812**	**8.62069**
	>300	**0.348**	**25.86207**
Height (m)	0 to 4	1.74	0
	5 to 8	19.372	0.103242
	9 to 12	**6.032**	**2.155172**
	13 to 16	**1.856**	**7.543103**
Canopy cover (%)	25 to 50	5.684	0.879662
	50 to 75	13.224	0.983061
	>75	**10.092**	**1.089972**
Crown width (m)	0-4	7.888	0.25355
	5 to 8	19.256	0.467387
	9 to 12	**1.392**	**7.902299**
	13 to 16	**0.464**	**15.08621**
Canopy connectivity (%)	0 to 25	1.276	0
	25 to 50	5.22	0.383142
	50 to 75	6.844	0.87668
	>75	**15.66**	**1.340996**
No of Main branches	1 to 2	13.804	0.362214
	3 to 4	**11.484**	**1.044932**
	5 to 6	**2.9**	**2.758621**
	7 to 8	**0.812**	**3.694581**
	>9	0	0

a.)



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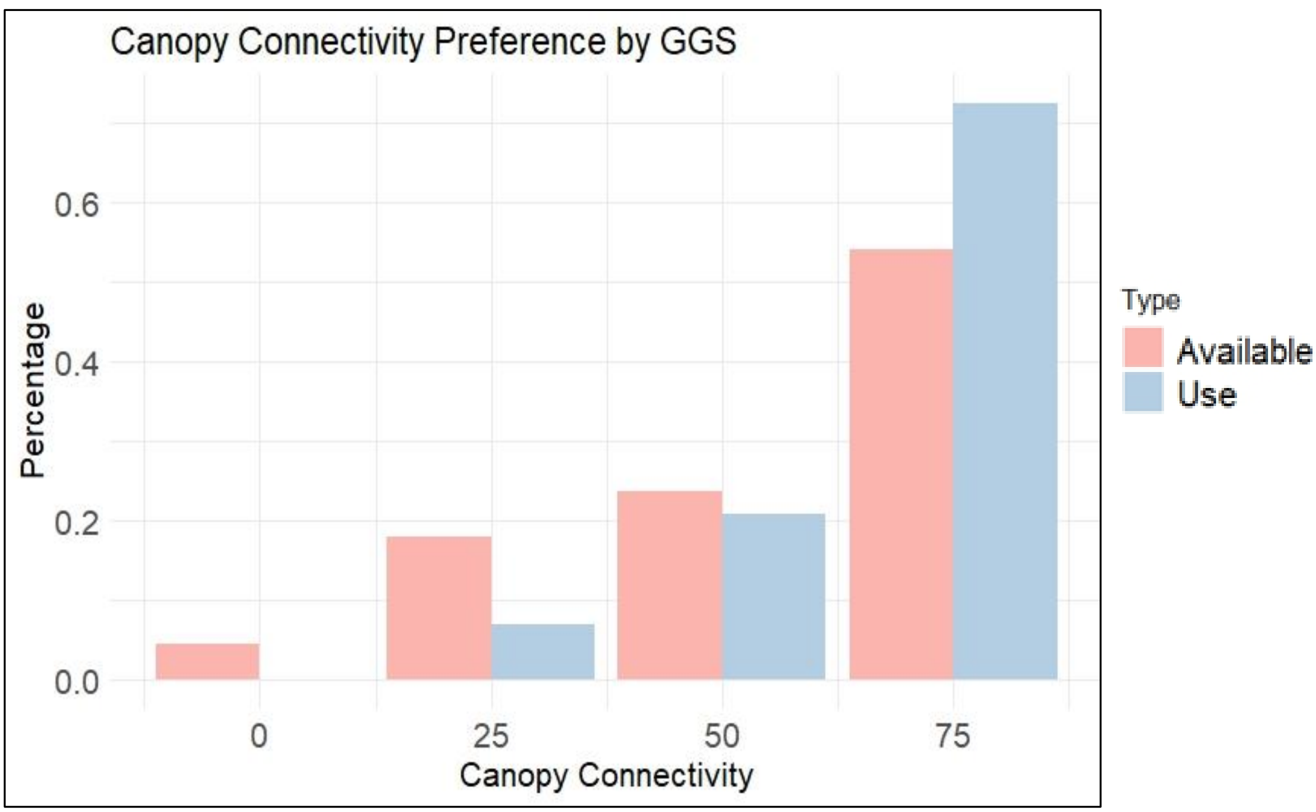


Figure 13: Available v/s use a.) Height b.) Canopy connectivity

5.3.3 Drey site selection plantations

Out of the 77 dreys encountered on the transects in the plantations, 34 were sampled. Most of these dreys (23) were found on *Mangifera indica* trees, with 4 on *Artocarpus heterophyllus* and 2 on *Ceiba pentandra*. A correlation matrix revealed high correlations among GBH, crown width, and canopy cover, leading to the selection of crown width for further analysis to avoid multicollinearity.

GLM with a binomial additive function was used to analyze drey site selection. The best model was chosen based on the AIC value (163.89), indicating that crown width and the number of branches significantly influenced drey site selection. Other parameters did not show a significant effect.

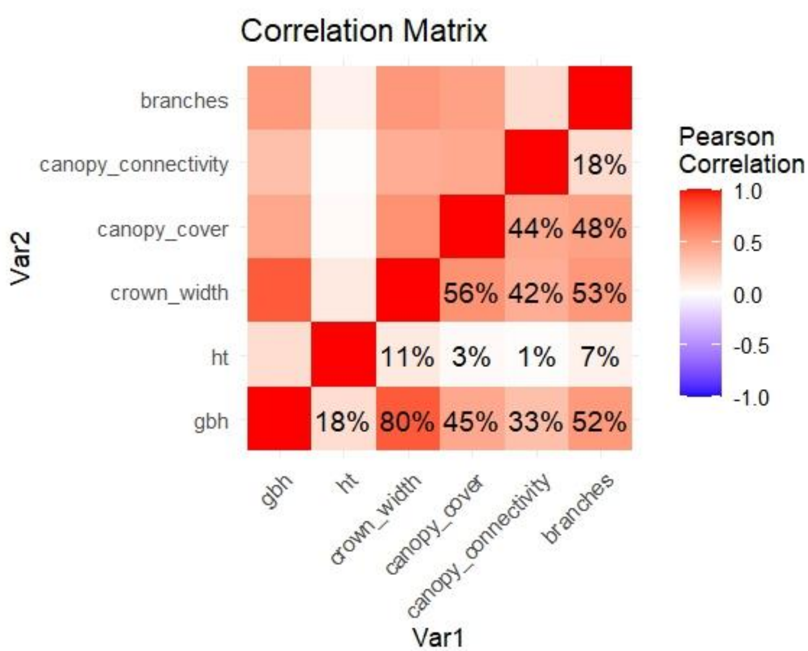
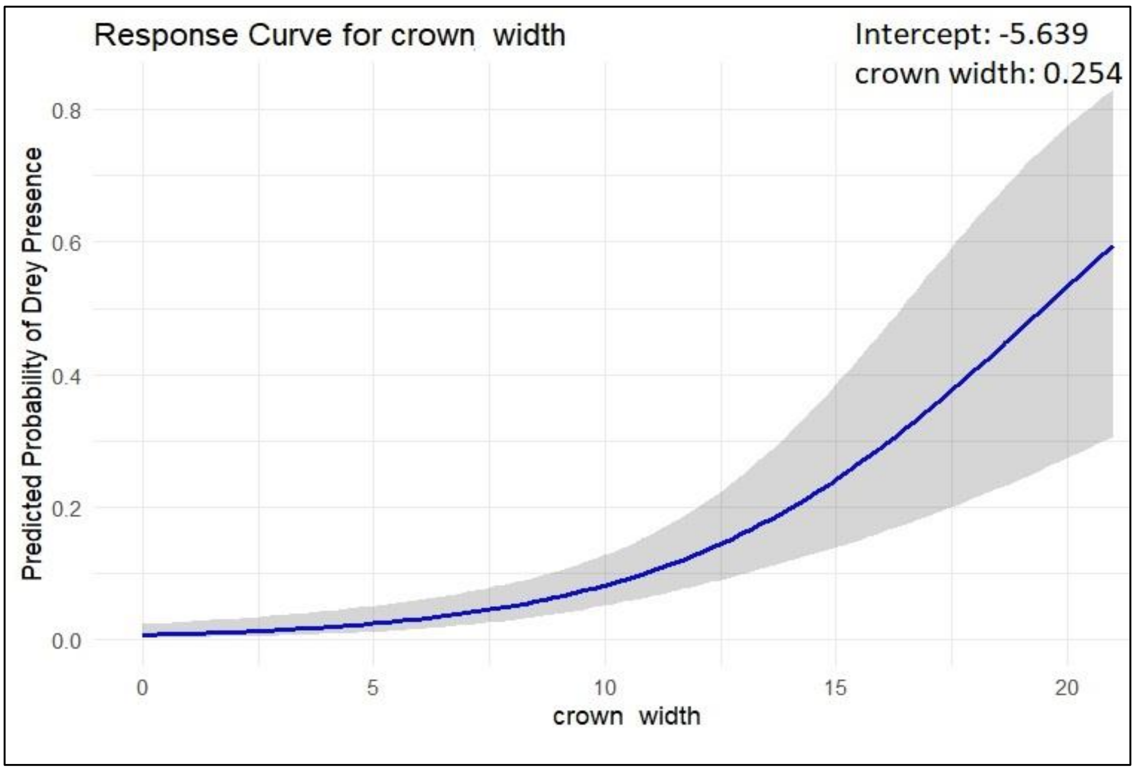


Figure 14: correlation matrix for drey variables in plantation

Table 9: Result of GLM for Drey site selection of GGS in Plantation

Formula = glm(formula = drey ~ crown_width + Branches) Family = Binomial				
	Estimate	Std.Error	z-value	Pr(>|z|)
(Intercept)	-5.8715	0.842134	-6.972	< 2e-16
crown_width	0.240161	0.062592	3.837	**<0.001**
Branches	0.3408	0.098832	3.448	**<0.001**

a.)



b.)

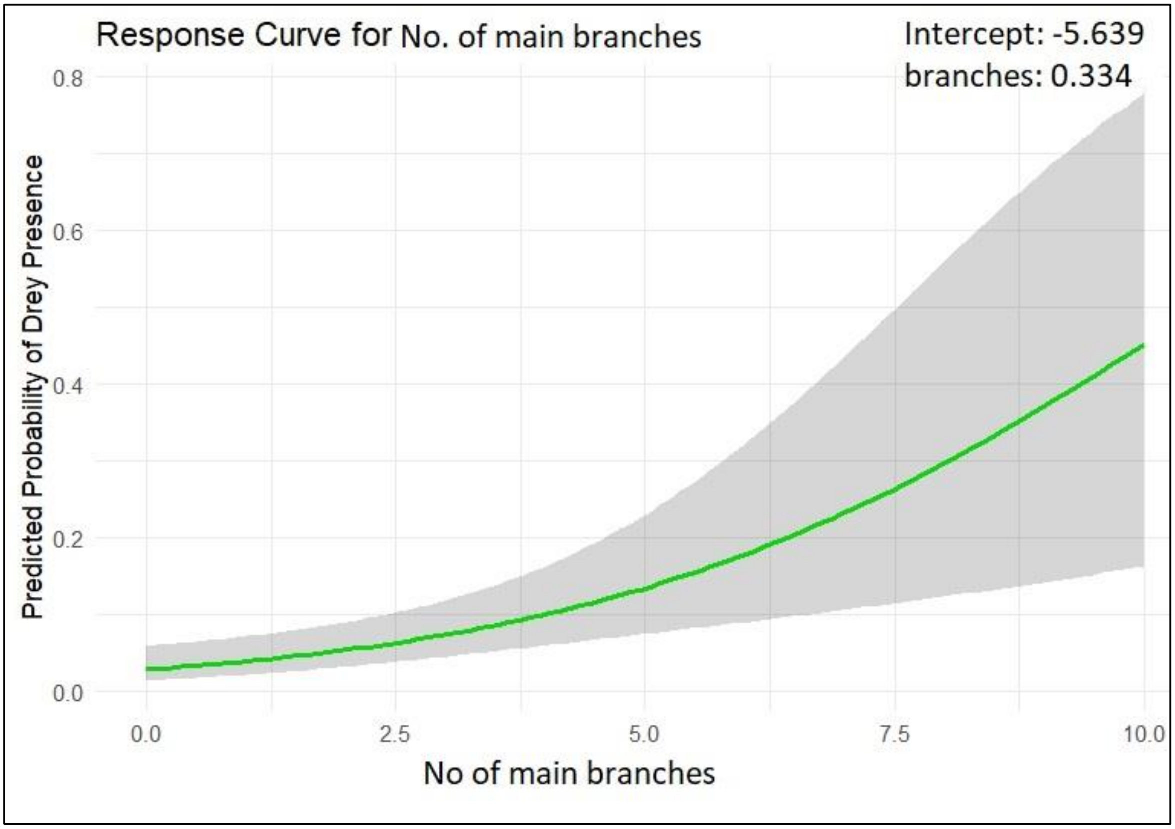


Figure 15: Effect of Predicted variables on Drey Site Selection in Protected area a.) Crown width b.) No. of branches

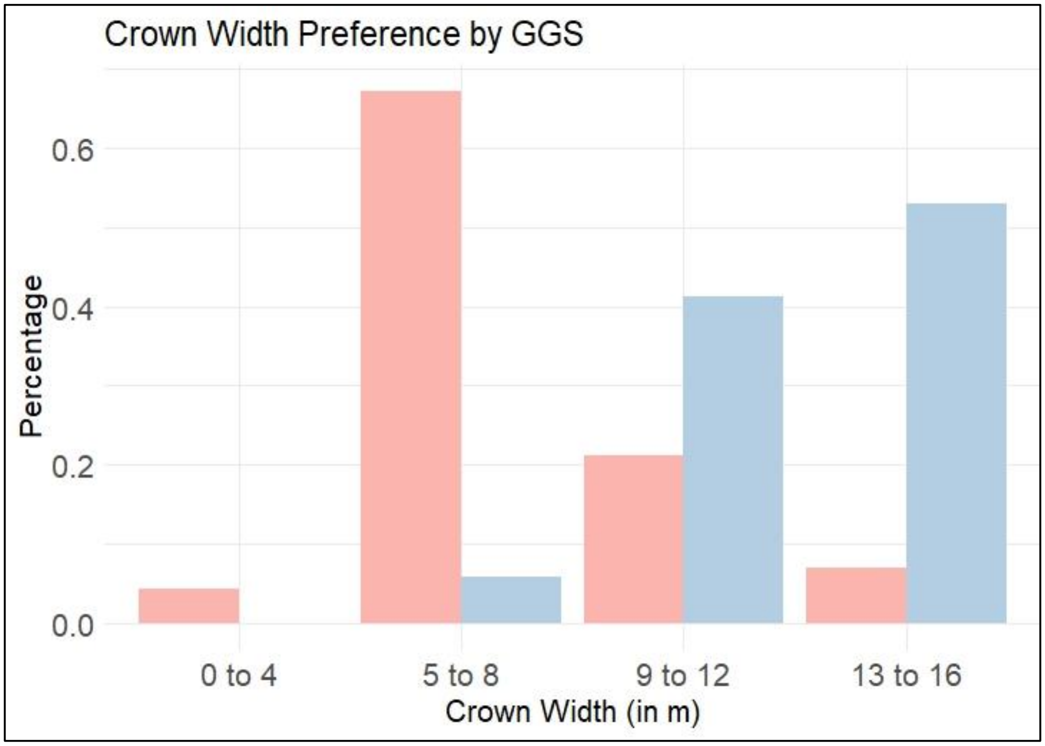
3.4.4 Utilization- Availability of different variables on drey site selection in Plantation

A preference value greater than 1 indicates high preference (Appendix: Table 1). The graph was plotted only for the variables that were significant in the GLM analysis. The results showed that GBH greater than 150 cm, height greater than 9 m, canopy cover greater than 75%, crown width greater than 9 m, canopy connectivity greater than 75%, and more than 3 branches had high preference values.

Table 10: Preference value of each variable for drey site selection in Plantation

Variables	Bin limit	Expected use	Preference value
GBH (cm)	50 to 99	2.067568	0
	100 to 149	23.08784	0.086626
	150 to 199	4.47973	2.678733
	200 to 249	1.952703	3.584775
	250 to 299	1.493243	2.678733
	>300	**0.918919**	**9.794118**
Height (m)	0 to 4	0.459459	0
	5 to 8	8.72973	0.343653
	9 to 12	**20.67568**	**1.064052**
	13 to 16	**4.135135**	**2.176471**
canopy cover (%)	25 to 50	13.20946	0.22711
	50 to 75	9.418919	0.212339
	>75	**11.37162**	**2.550208**
crown width (m)	0-4	1.493243	0
	5 to 8	22.85811	0.087496
	9 to 12	**7.236486**	**1.934641**
	13 to 16	**2.412162**	**7.462185**
canopy connectivity (%)	0 to 25	2.412162	0
	25 to 50	7.006757	0.713597
	50 to 75	11.48649	0.348235
	>75	**13.09459**	**1.909185**
No of branches	1 to 2	27.33784	0.256055
	3 to 4	**4.364865**	**3.436533**
	5 to 6	**1.722973**	**4.062745**
	7 to 8	**0.22973**	**13.05882**
	>9	**0.344595**	**5.803922**

a.)



b.)

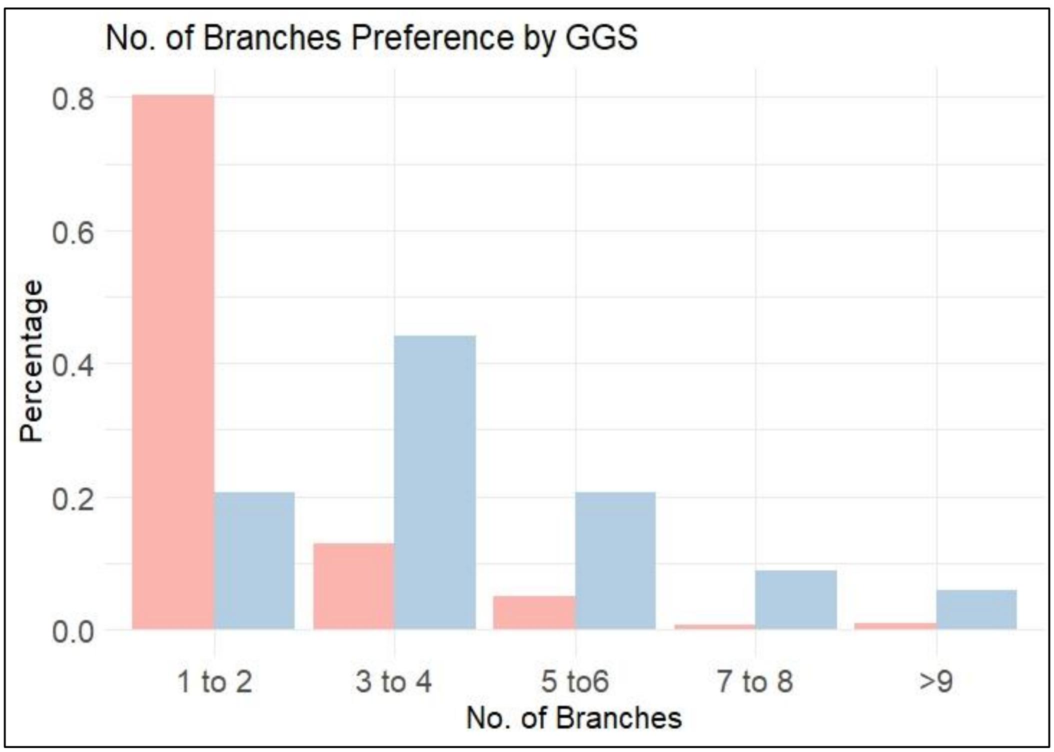


Figure 16: Available v/s use a.) Crown Width b.) No. of main branches

5.4 Farmers perception

To understand farmers' perceptions of crop depredation, 50 farms were surveyed. A significant majority, 98% of the farmers, reported the presence of GGS on their farms. Additionally, 90% of the farms were under lease, with the majority cultivating coconut and mango plantations. Farmers also reported crop damage caused by other animals, including bats, elephants, gaur, monkeys, and wild pigs.

Regarding the frequency of GGS sightings, 93% of farmers reported frequent encounters, while 4% reported occasional sightings, and 2% reported rare sightings. In terms of crop damage frequency, 86% of farmers experienced frequent damage, 6% encountered occasional damage, and 4% faced rare damage from GGS. Specifically related to coconut damage, 64.6% of farmers reported damage exceeding 50 coconuts per day, 13.2% reported damage ranging from 50 to 100 coconuts daily, and 8.3% reported damage exceeding 100 coconuts per day. Considering economics, 30% of farmers reported annual losses exceeding Rs. 25,000 due to GGS, while 12% reported losses ranging between Rs. 25,000 and Rs. 50,000, and another 12% reported losses exceeding Rs. 50,000 annually.

In terms of the duration of GGS presence on their farms, 10% of farmers reported sightings for less than 5 years, 51% reported sightings between 5 to 15 years, and 4% reported sightings for more than 15 years.

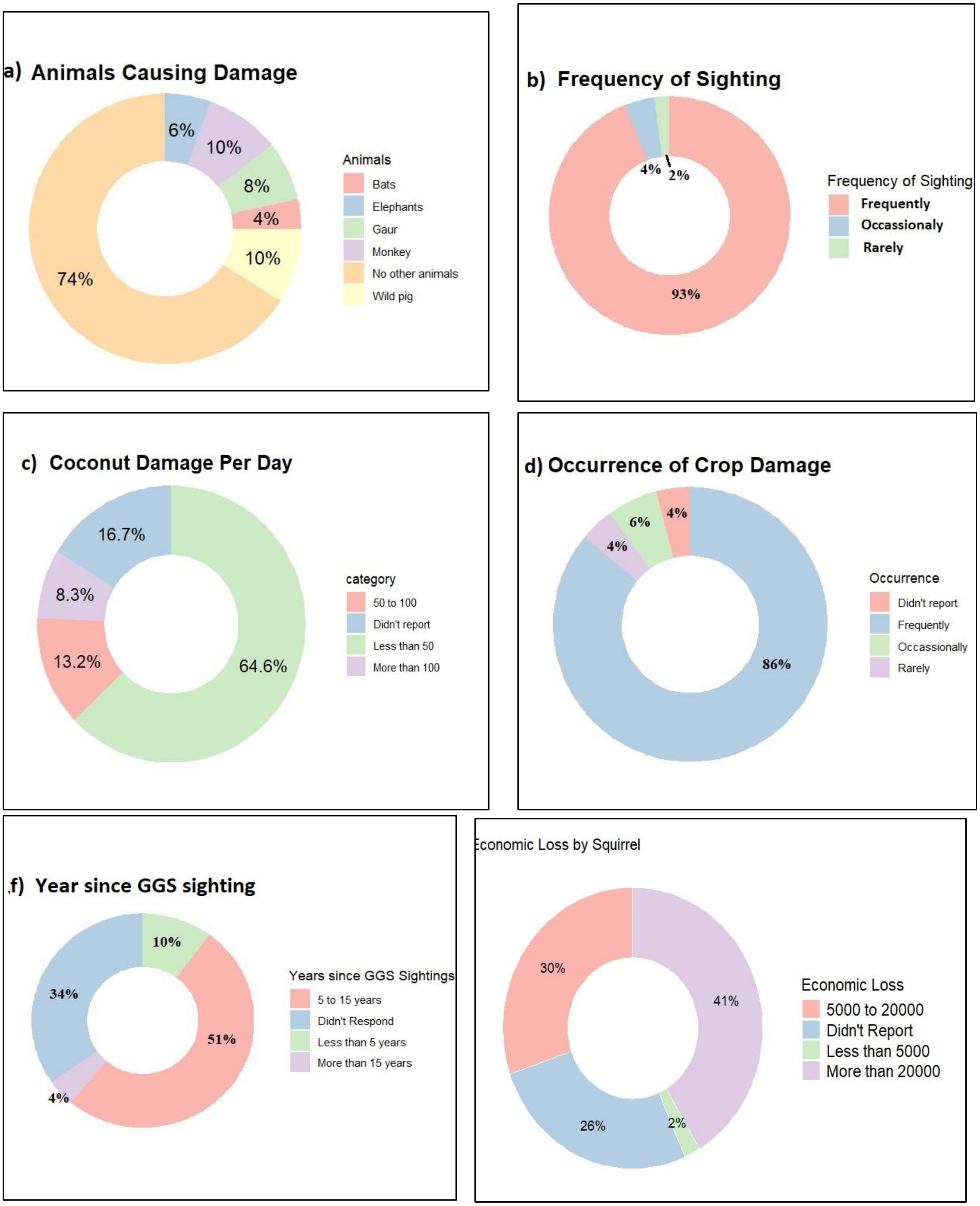


Figure17: a) Other animals causing crop damage to the framers, b) Frequency of Sightings of GGS in their farms, c) coconut damage caused by GGS as per reported by Farmers, d) Occurrence of crop damage, e) Economic loss reported by farmers, f) Year since the farmers started to see GGS in their farmer

5.5 Crop depredation assessment

The total no of coconut damages varied between the plots. In mix plantation the mean predation rate was 3.84 per year per tree, in normal coconut plantation the mean predation rate was 0.62 and in King coconut plantation was 5.48 per year per tree. It was observed that mixed plantations and King Coconut plantations experienced higher damage compared to normal coconut plantations. The overall mean predation rate across all control sites was found to be 3.3 ± 2 coconuts damaged per tree per year. (Appendix: Table - Site wise mean crop depredation rate)

A landowner with one acre of land planted with coconut trees at a spacing of 6x6 meters can have approximately 112 trees. If each tree produces 100 to 300 coconuts, on average 3 damaged coconuts per year, this results in a total of 336 damaged coconuts annually. With the market price of each coconut being Rs. 8, the economic loss due to crop depredation by grizzled giant squirrels (GGS) would be approximately Rs. 3000 per year.

Table 11: Mean crop Depredation rate of coconut by GGS in different Plantation types

Plantation Types	Mean Depredation Rate	Standard error
King coconut	5.48	2.01
Normal coconut	0.61	0.73
Mix Plantation	3.840	3.33

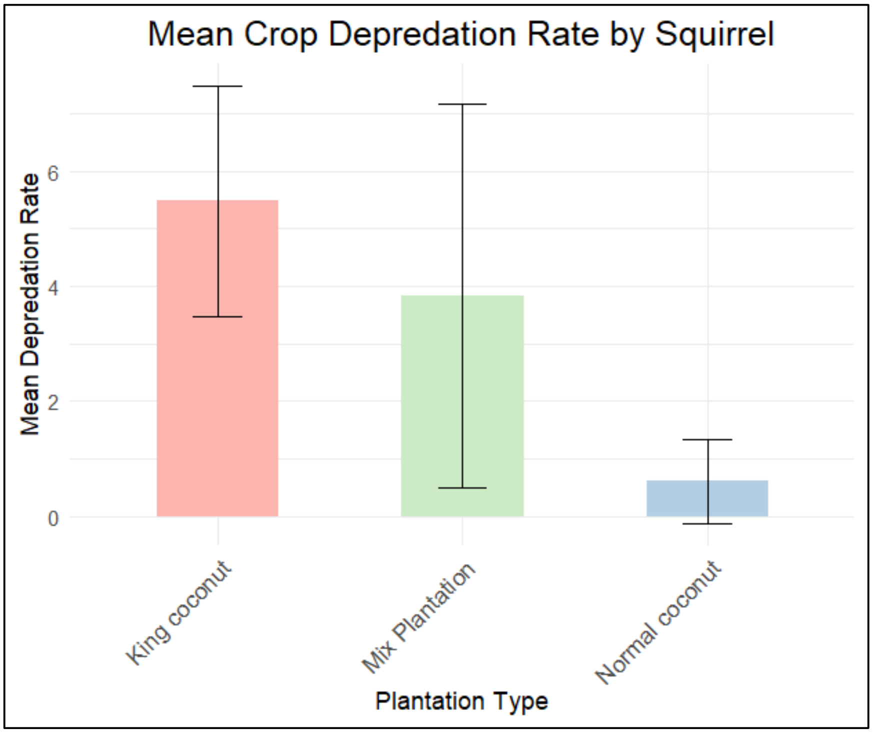


Figure 18: Predation rate of Coconut done by GGS per year per tree in different plantation type

5 Discussion

6.1 Effect of Land-Use change around Protected area

Over the past 30 years, the land around the Srivilliputhur region of Srivilliputhur-Megamalai Tiger Reserve (SMTR) has undergone significant conversion from barren land to mango and coconut plantations. This change has increased connectivity between natural and human-modified landscapes, encouraging wildlife species to venture into farms. The fruits from these farms are energy-rich, easily digestible, and often clumped in plantations, offering substantial energetic advantages over natural foods for wildlife in the agriculture-forest ecotones (Sukumar, 1990). Studies have shown that increasing conversion of natural habitats to alternative land uses, particularly around protected areas (PAs), causes wildlife residing within these PAs to become increasingly dependent on cultivated foods (Paterson & Wallis, 2005; Hockings & McLennan, 2012). The movement and ranging patterns of wildlife are primarily influenced by the availability of food, water, and mates (Mace *et al.,* 1996). The same holds true for GGS, which have adapted their feeding ecology to exploit these plantations.

6.2 Density estimate of GGS and Dreys in different habitat types

The density estimate obtained from this study should be considered a conservative estimate due to several factors such as variations in the detectability of GGS across different habitats, influenced by vertical stratification, canopy cover, and the squirrels' shyness within protected areas. Additionally, the difficulty in distinguishing active from abandoned dreys further impacts the accuracy of the density estimate.

The result of this study indicates that density of GGS and its dreys was higher in plantations compared to the protected area, which might be due to increased amount of food resources available throughout the year. Furthermore, the density of GGS and dreys was higher in mixed plantations, followed by coconut plantations and mango plantations. This could be attributed to the presence of both nesting and fruiting trees in mixed plantations (Table 8), providing a more favorable habitat in terms of increased canopy connectivity, canopy cover, which helps GGS to move easily and escape from aerial predators (Joshua & Johnsingh, 1994). A previous study undertaken by Joshua (1992), estimated the density of GGS in the same area. That study reported the density to be 150 squirrels per sq.km in Ayyankovil (total count was 9 squirrels in 0.06 Sq.km), 117 squirrels per sq.km in Viriyankovil (total count was 7 Squirrels in 3km effort) and 9 squirrels per sq.km in Alagarkovil (total count was 115 squirrels in 10.2km effort). The variation in density estimates can be attributed to very less squirrel sighting (<10) in the former two areas, suggesting that only the density estimate for the Alagarkovil area is reliable. In this study the same areas were also covered along with a few other areas and the GGS density is estimated to be 14.31 squirrels per sq.km in deciduous forests and 10.59 squirrels per sq.km in Riparian Forest forests.

Additionally, the distribution of GGS in the plantations varied seasonally, with higher densities observed in winter compared to the summer season. Although GGS densities were expected to be higher in the summer due to the fruiting season, this discrepancy may be attributed to the placement of transects primarily in coconut and mango plantations. In 2024, mango fruiting was sporadic, possibly due to the biennial fruiting nature of mango trees and climatic conditions. Conversely, other fruiting trees such as jackfruit, sapota, and guava which were available in other areas were fruiting during the summer season may have significantly influenced GGS movements, as these provided easier accessibility to food resources. As a result, the squirrel density in the mango and coconut plantation reduced substantially.

6.3 Drey site selection of GGS across different habitat types

Dreys provide indirect evidence of the presence of GGS and reflect the degree of habitat usage. Therefore, studying drey site selection by GGS was essential to understand their habitat preferences. Squirrels typically choose trees with overall height, and the number of branches, all of which are crucial for nest building. (Thomas & Nameer 2021). In the protected area, certain tree species such as *Tamarindus indica*, *Holoptelea integrifolia*, and *Albizia amara* were predominantly selected for drey construction (Table 7). Additionally, the results of the GLM showed that tree height and good canopy connectivity were essential for drey site selection. As the tree height is important parameter for all the arboreal animals as it provide safety and canopy connectivity will facilitate the easy movement of GGS from tree to tree. GGS are known to prefer areas with abundant food availability and high canopy connectivity for living and nesting (Vanitharani and Bharathi, 2011). They are also known to build multiple dreys (3-4) within their home range, which may be used for nesting, resting, or as a refuge from predators (Joshua, 1992).

In contrast, in the plantations, mango trees with substantial crown width and more branches were preferred for drey construction (Table 8). As large crown width connects the canopy of one tree to another tree and helps GGS to move easily, No. of branches was shown significant due to large no of coconut tree as control tree. However, coconut trees were found to be unsuitable for drey building primarily due to the regular shedding of fronds (branches) and the disturbances caused by frequent harvesting of coconuts. These factors make coconut trees less secure and stable for drey construction. In contrast, mango trees in plantations are preferred due to their structural attributes, which provide a more suitable environment for the construction and stability of dreys. The wider crowns, multiple branches, and greater stability of mango trees offer better support and protection for GGS.

6.4 Farmers-Squirrel conflict

Recent changes in land use around protected areas have been beneficial for GGS, as it provides increased access to food resources. However, this has led to unintended consequences. These squirrels now venture into farmlands, causing significant damage to crops. Particularly in Sri Lanka, GGS has emerged as a serious threat to various crops traditionally grown in home gardens. These squirrels exhibit a behavior where they particularly chew on specific parts of plants, often causing more destruction than consumption (Govind & Jayson, 2018). To assess the perception of farmers regarding this issue, a structured questionnaire survey was conducted. The results revealed an overall negative perception among farmers, primarily due to economic losses incurred as a result of GGS damage. The extent of the damage reported was substantial, and farmers expressed dissatisfaction with the lack of compensation or support from relevant agricultural and forest departments.

GGS have been observed feeding on a variety of crops including coconut, mango, tamarind, jackfruit, sapota, and guava. The economic losses suffered by farmers due to these feeding habits are further exacerbated by the lack of adequate compensation. Before the sanctuary was designated as a tiger reserve, the Forest Department provided incentives of Rs. 2000 per nest in plantations affected by GGS. However, farmers have reported that these incentives ceased following the sanctuary's change in status.

While GGS exhibit feeding patterns similar to other small mammals such as rats and palm squirrels, the nocturnal activity and small size of these species often lead to the misattribution of damage solely to GGS.

To compare perceived damage versus actual damage, control plots were established in king coconut, normal coconut plantations, and mixed plantations. The predation rate on coconuts in the control plots were influenced by several factors, including coconut variety, canopy connectivity within and around the plantation, coconut harvesting, and the presence of nesting trees. King coconuts were preferred over normal coconuts due to their easier husking, thinner shells, and higher water and pulp content. In areas without king coconuts, normal coconuts were also damaged, but the predation rate was higher in mixed plantations. This increased predation rate was attributed to the availability of both fruiting and nesting trees, high canopy connectivity within the plantation, and the presence of other food resources.

The distance from protected areas had no effect on predation rates, as GGS have been established in the plantations for 15-20 years. However, farmer perceptions of crop damage were clearly exaggerated. Control plots showed significantly lower damage levels compared to farmer perception.

6.5 Conservation Implications

The significant presence of GGS in plantations outside protected areas underscores the necessity for community-based engagement in their long-term conservation. Effective conservation can be achieved through outreach programs, financial incentives for farmers and local communities, and compensation for crop damage. Given the higher density of GGS and crop damage in mixed plantations, implementing monoculture plantations with adequate spacing to reduce the canopy connectivity within the plantation is required. Maintaining and restoring Riparian Forest zones and other critical habitats within protected areas is essential for supporting the current population of GGS. Once these habitats are restored and deemed suitable for GGS, the potential relocation of individuals from plantations to these restored areas can be considered.

The recent conversion of barren lands to plantations has posed significant challenges for the conservation of GGS. To address this issue, it is vital to protect remaining grasslands and prevent their future conversion into plantations. Designating plantations as Other Effective Area-Based Conservation Measures (OECMs) or as community reserves can provide substantial conservation benefits for GGS and other species. Establishing and maintaining buffer zones between protected areas and plantations is a critical strategy for reducing the incursion of GGS and other wildlife from protected areas into agricultural lands. Buffer zones act as transitional areas that mitigate human-wildlife conflicts by providing additional habitat and resources for wildlife, reducing their need to venture into farmlands. Additionally, planting of fruiting trees that are preferred by GGS along the road side can minimize the effect of crop damage in the farms.

Advanced studies on the GGS are essential for conducting long-term ecological research using tracking technologies to monitor their behavior and habitat preferences across different seasons. More intensive studies should be carried out in plantations by establishing control plots and conducting long-term monitoring to accurately estimate the economic losses incurred by GGS. Additionally, deploying camera traps to identify other animals responsible for crop damage and recognizing clear feeding signs from these animals will help to develop more robust measures to mitigate the problem with respect to each species.

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Appendix

Table 1: Tree species preferred by GGS to build Dreys in Protected area

Protected area		
Sl no	Tree species Preferred	No of dreys
1	*Tamarindus indica*	13
2	*Albizia amara*	3
3	*Holoptelea integrifolia*	3
4	*Stereospermum suaveolens*	1
5	*Acacia leucophloea*	1
6	*Albizia lebbeck*	1
7	*Anogesis latifolia*	1
8	*Bauhinia racemosa*	1
9	*Gyrocarpus jaquini*	1
10	*Mangifera indica*	1
11	*Pterocarpus marsupium*	1
12	*Streblus asper*	1
13	*Terminalia bellarica*	1
	Grand Total	29

Table 2: Tree species preferred by GGS to build Dreys in plantations

plantation		
Sl no	Tree species	No o dreys
1	*Mangifera indica*	23
2	*Artocarpus heterophyllus*	4
3	*Ceiba pentandra*	2
4	*Azadirachta indica*	1
5	*Tamarindus indica*	1
6	*Tectona grandis*	1
7	*UN1*	1
8	*Limonia acidissima*	1
	Grand Total	34

Table 3: Proportion of Available-Used with Expected Use and Preference value for each variable in Protected area

Tree Species						
Species Ava	count_avaliable	Proportion avaliable	count_used	Proportion_used	Expected use	Prefernce
Stereospermum suaveolens	2	0.013158	1	0.034483	0.381579	2.62069
Acacia leucophloea	1	0.006579	1	0.034483	0.190789	5.241379
Albizia amara	28	0.184211	3	0.103448	5.342105	0.561576
Albizia lebbeck	16	0.105263	1	0.034483	3.052632	0.327586
Anogesis latifolia	0	0	1	0.034483	0	0
Bauhinia racemosa	7	0.046053	1	0.034483	1.335526	0.748768
Gyrocarpus jaquini	10	0.065789	1	0.034483	1.907895	0.524138
Holoptelea integrifolia	12	0.078947	3	0.103448	2.289474	1.310345
Mangifera indica	0	0	1	0.034483	0	0
Pterocarpus marsupium	0	0	1	0.034483	0	0
streblus asper	48	0.315789	1	0.034483	9.157895	0.109195
Tamarindus indica	28	0.184211	13	0.448276	5.342105	2.433498
Tarminlai bellarica	0	0	1	0.034483	0	0

GBH (cm)						
Bin limit	count_avaliable	Proportion avaliable	count_used	Proportion_used	Expected use	Prefernce
50 ot 99	105	0	0.42	0	12.18	0
100 to 149	90	5	0.36	0.172414	10.44	0.478927203
150 to 199	32	5	0.128	0.172414	3.712	1.346982759
200 to 249	13	3	0.052	0.103448	1.508	1.98938992
250 to 299	7	7	0.028	0.241379	0.812	8.620689655
>300	3	9	0.012	0.310345	0.348	25.86206897

Height (m)						
Height Bin limit	count_avaliable	Proportion avaliable	count_used	Proportion_used	Expected use	Prefernce
0 to 4	15	0	0.06	0	1.74	0
5 to 8	167	2	0.668	0.068965517	19.372	0.103241792
9 to 12	**52**	**13**	**0.208**	**0.448275862**	6.032	**2.155172414**
13 to 16	16	14	0.064	0.482758621	1.856	7.543103448

Canopy cover (%)						
Canopy cover	count_avaliable	Proportion avaliable	count_used	Proportion_used	Expected use	Prefernce
25	49	0.196	5	0.172413793	5.684	0.87966221
50	**114**	**0.456**	**13**	**0.448275862**	13.224	**0.983061101**
75	**87**	**0.348**	**11**	**0.379310345**	10.092	**1.089972255**

Canopy width (m)						
Canopy width binBin	count_avaliable	Proportion avaliable	count_used	Proportion_used	Expected use	Prefernce
0-4	68	0.272	2	0.068966	7.888	0.253549696
5 to 8	**166**	**0.664**	**9**	**0.310345**	19.256	**0.467386789**
9 to 12	12	0.048	11	0.37931	1.392	7.902298851
13 to 16	4	0.016	7	0.241379	0.464	15.0862069

canopy connectivity						
Canopy con_bin	count_avaliable	Proportion avaliable	count_used	Proportion_used	Expected use	Prefernce
0	11	0.044	0	0	1.276	0
25	45	0.18	2	0.068966	5.22	0.383141762
50	**59**	**0.236**	**6**	**0.206897**	6.844	**0.876680304**
75	**135**	**0.54**	**21**	**0.724138**	15.66	**1.340996169**

Branches						
No of branches	count_avaliable	Proportion avaliable	count_used	Proportion_used	Expected use	Prefernce
1 to 2	119	0.476	2	0.068965517	13.804	0.14488554
3 to 4	99	0.396	3	0.103448276	11.484	0.26123302
5 to6	**25**	**0.1**	**7**	**0.24137931**	**2.900**	**2.413793103**
7 to 8	**7**	**0.028**	**5**	**0.172413793**	**0.812**	**6.157635468**
>9	**0**	**0**	**6**	**0.206896552**	**0.000**	**0**

Table 4: Proportion of Available-Used with Expected Use and Preference value for each variable in Plantation

Tree species						
	Count of ava species	Count of use species	prop of ava	prop of use	Expected use	Preference
Cebia pentandra	17	2	0.150442	0.058824	5.115044	0.391003
Jack fruit	4	4	0.035398	0.117647	1.20354	3.323529
Mango	73	23	0.646018	0.676471	21.9646	1.047139
neem	2	1	0.017699	0.029412	0.60177	1.661765
Tamarind	1	1	0.00885	0.029412	0.300885	3.323529
teak	16	1	0.141593	0.029412	4.814159	0.207721
UN1	0	1	0	0.029412	0	0
wood apple	0	1	0	0.029412	0	0

Height						
Bin limit	av count	use count	proportion av	proportion use	Expected use	Preference value
4	4	0	0.013514	0	0.459459	0
8	76	3	0.256757	0.088235	8.72973	0.343653251
12	180	22	0.608108	0.647059	20.67568	1.064052288
16	36	9	0.121622	0.264706	4.135135	2.176470588

GBH						
Bin limit	av count	use count	proportion av	proportion use	Expected use	Preference value
50	18	0	0.060811	0	2	0.00
100	201	2	0.679054	0.058824	23	0.09
150	39	12	0.131757	0.352941	4	2.68
200	17	7	0.057432	0.205882	2	3.58
250	13	4	0.043919	0.117647	1	2.68
>300	8	9	0.027027	0.264706	1	9.79

Crown width						
Bin	av count	use count	proportion av	proportion use	Expected use	Preference value
4	13	0	0.043919	0	1	0
8	199	2	0.672297	0.058824	23	0.087496
12	63	14	0.212838	0.411765	7	1.934641
16	21	18	0.070946	0.529412	2	7.462185

Canopy connectivity						
Canopy con_bin	Count of ava	Count of use	Proportion ava	proprotion_used	Expected use	Preference value
0	21	0	0.070946	0	2.412162	0
25	61	5	0.206081	0.147059	7.006757	0.713597
50	100	4	0.337838	0.117647	11.48649	0.348235
75	114	25	0.385135	0.735294	13.09459	1.909185

canopy cover						
Bin	Count of ava	Count of use	Proportion_ava	proprotion_used	Expected use	Preference value
25	115	3	0.388514	0.088235	13.20946	0.227109974
50	82	2	0.277027	0.058824	9.418919	0.212338594
75	99	29	0.334459	0.852941	11.37162	2.550207962

No of branches	Count of Ava	Count of use	Proportion_ava	proprotion_used	Expected use	Preference value
1 to 2	238	7	0.804054	0.205882	27.33784	0.256055363
3 to 4	38	15	0.128378	0.441176	4.364865	3.436532508
5 to6	15	7	0.050676	0.205882	1.722973	4.062745098
7 to 8	2	3	0.006757	0.088235	0.22973	13.05882353
>9	3	2	0.010135	0.058824	0.344595	5.803921569

Table 5: Site wise mean crop depredation rate in different plantation types

Site_ID	**Predation rate**	**plantation Type**
CS1	8.31	Mix plantation
CS2	7.49	King Coconut
CS3	0.30	Normal Coconut
CS4	0.29	Mix plantation
CS5	0.08	Normal Coconut
CS6	0.70	Normal Coconut
CS7	2.92	Mix plantation
CS8	1.99	Normal Coconut
CS9	3.46	King Coconut
CS10	0	Normal Coconut

Plate 1

Plate 2