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Importance of Forests Outside Protected Area Networks for Large-seeded Tree Species and their Large-bodied Avian Frugivores--a Study in Vazhachal Reserve Forest, India

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Importance of Forests Outside Protected Area Networks for Large-seeded Tree Species and their Large-bodied Avian Frugivores--a Study in Vazhachal Reserve Forest, India

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Abstract

Western Ghats, the mountain chain running along the west coast of India, is one of eight global hotspots of biodiversity and is particularly notable for its endemic flora and fauna. Yet only 10% of this land enjoys the protected status. Vast forested lands exist outside the protected network of national parks and wildlife sanctuaries in the form of reserve forests, community forests, and private lands. The present study sought to understand the role of such forests in the context of ecological system involving large-seeded tree species that depend on large-bodied avian frugivores for seed dispersal. I conducted a study over two and half years in Vazhachal Reserve Forest to collect information on the fruiting phenology of large-seeded tree species consumed by sympatric hornbills, the role that hornbills play in transporting the seeds of these trees to their nest sites, and rates of encounters with the large-bodied avian frugivores in these forests: Great Hornbill (*Buceros bicornis*) Linnaeus, (1758), Malabar Grey Hornbills (*Ocyceros griseus*) Latham, (1790) and Mountain Imperial Pigeons (*Ducula badia*) Raffles (1822). The analysis of fruiting phenology showed that lipid-rich fruits are generally available during the peak hot and dry season that coincides with nesting period of the Great Hornbill and the Malabar Grey hornbill. A significantly higher number of seedlings-saplings belonging to large-seeded tree species were documented in front of the hornbill nests compared to behind the nests, indicating that hornbills may be helping these species by removing their seeds from host-specific seed predators and fierce resource competition beneath their parent trees. Both hornbill species showed higher encounter rates than those recorded in a 2008 survey from Vazhachal Reserve Forests. Vazhachal Reserve Forest juxtaposes with Parambikulam and Anamalai Tiger Reserves and potentially acts as a link between these habitats for long-ranging

species such as the Great Hornbill and also provides food resources outside the protected area network. The data on fruiting collected during this study can be added to that collected by the hornbill nest monitoring program currently run by Kerala Forest Department and tribal community members to inform the design and implementation of local conservation policies and lay the groundwork for future long-term studies.

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Dedication

This work is dedicated to my parents and tribal brothers, Suresh and Manoj for making me believe that all sweat, blood and emotions invested in this project would be worth one day.

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Introduction

Tropical forests, especially those in developing countries, are currently under immense pressure due to anthropogenic activities that directly or indirectly have caused forest loss and degradation. Vast tracts of formerly contiguous forests have become fragmented, damaging these ecosystems' capacity to function. These acute changes have disturbed innumerable plant-animal interactions. Some of these forests have become as "Empty Forests" as they have lost most of its ecological functions and biodiversity (Datta et al. 2008). Western Ghats, one of most diverse regions in the world, has experienced accelerated forest loss and destruction over the last century. This landscape is not only integral for the sustenance of biodiversity, it is also the sole source for most of the natural resources on which human populations in the area depend.

One widely implemented method protecting ecosystems and their resident flora and fauna has been to delineate areas to act as repositories of biodiversity. India has an immense network of national park and wildlife sanctuaries that, cover 4.69% of the country's land, encompassing terrestrial, aquatic, marine, and island habitats. However, research shows that protected areas alone is not enough to protect and conserve many types of flora and fauna. Still, in India ecological research has been conducted almost exclusively inside protected areas, with unprotected and semi-protected forests long being neglected. The forests in Western Ghats are divided among, wide variety of ownership regimes including protected areas managed by the central government management, reserve forests managed by the state governments, community-owned forests, private forests. Neither species-specific nor ecosystem-level conservation efforts can be limited exclusively to protected areas. These programs must take a holistic approach by including to include forested areas that fall outside the protected networks.

Mutualistic relationships between plants and animals in tropical ecosystems, where 90% plants depend on animals for pollination and seed dispersal, are of paramount importance (Howe and Smallwood 1982, Jordano 1995, Ollerton et al. 2011). In such tightly evolved systems, loss of single species can have devastating repercussions, affecting other species and the ecosystem as a whole. The present study focused on, an important plant-animal system in Vazhachal Reserve Forest, an area that does not enjoy the same level of protection as those inside the protected network in the country. Vazhachal Reserve Forest is located in-between a tiger reserve and several human modified landscapes dominated by tea and coffee plantations. Hornbills are among the very few large-bodied frugivores in this area that help disperse the seeds of rare tropical tree species in exchange for the nutrients they obtain by consuming its fruits, earning them the sobriquet “Farmers of the forest” (Kinnaird and O'Brien 2007). A large number of Great Hornbill nests has been documented in Vazhachal Reserve Forest, yet there remains a dearth of information on fruit availability, fruiting patterns, and abundance of hornbill species in the region. Previous hornbill surveys have revealed that Vazhachal is an important hornbill conservation habitat. The present study builds on these findings to generate data that may facilitate the design and implementation of conservation efforts in this region.

This study was carried out over a period of 29-months spanning from 2013 to 2015.and focused on documenting three main components. to understand importance of Vazhachal Reserve Forest for large-seeded evergreen tree species and large-bodied frugivores that include two species of sympatric hornbills and Mountain Imperial Pigeon. In the first chapter, the fruiting patterns and availability periods of large-seeded tree species belonging to six genera are discussed. In this chapter, I discuss variability in fruiting patterns mediated by years and species and identify the tree species that contribute the most fruit during this fruiting episode. The second chapter discusses evidence for seed dispersal at hornbill nest sites. In this chapter, seedling-sapling demography and the species composition among large-seeded trees under hornbill nest trees as well as survival rates are discussed. Given the unique nesting habits of hornbills, where the female and young ones are incarcerated inside the nest cavity for the duration of the nesting period and tend to drop seeds under the nest tree and their nests are considered important seed dispersal sites. In the third chapter, encounter rates of three species of large-bodied frugivores; namely Great Hornbill (*Buceros bicornis*), Malabar Grey Hornbill (*Ocyceros griseus*) and Mountain Imperial Pigeon (*Ducula badia*) are discusses. I discuss encounter rates recorded over the 27 months, spanning from 2013 to 2015, patterns of encounter rate and differences in encounter rates between species. The conclusion addresses ecological and socio-economic issues pertaining to future management and local conservation strategies, as well as ways to make the region more accessible to the scientific community and conducive to research.

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Chapter 1.

Fruiting phenology of hornbill preferred large-seeded tree species producing lipid-rich fruits in the Vazhachal Reserve Forests of the Annamalai hills in Western Ghats, India.

Abstract

Tree species from six genera that produce lipid- rich fruits with large seeds were monitored over period of a 29-months in the Vazhachal Reserve Forest between year 2013 and 2015. These species belonging to the Myristicaceae, Miliaceae, and Lauraceae families displayed a seasonal fruiting patterns, with fruits mainly available during hot and dry season of the year that coincides with the nesting period of both the Great Hornbill (*Buceros bicornis*) and the Malabar Grey Hornbill (*Ocyceros griseus*). Species of *Myristica dactyloides* and species of *Litsea* were the most abundant taxa found in the study sites and contributed the most to the fruiting episodes during the study period. *Canarium strictum*, an important hornbill diet species, completely failed to fruit in the study sites. The fruiting of different species showed staggered and displaced fruiting patterns and fruited such that at least one species was fruiting every month during the hot and dry season. The results also revealed differences in tree density, depending on whether the study sites were located closer to human settlements or in less disturbed parts of the forest. The findings of the present study are potentially important as species of hornbills inhabiting human modified habitats access this forest due to resource availability and hence help sustain populations of hornbill species This can have an impact hornbill's effort to locate fruits and indirectly affect the seed dispersal patterns throughout the forest. Finally, the study showed that, species of *C. strictum* was present at low density and failed to fruit, which can hamper seed dispersal for this species as hornbills being only avian

seed disperser. Even though large-seeded, lipid-rich fruits were available during this period of overall fruit scarcity, it should be noted that two genera largely contributed to fruiting. This study indicated the need to further investigate if populations of the least abundant species are on a decline and how this might affect dietary requirements of sympatric species of hornbill.

Introduction

Half of the world's biodiversity occurs in tropical forests, but accelerated forest loss and degradations of these forests is evident as they have been cleared to sustain ever increasing populations of the world (Dirzo and Raven 2003). Today, these tropical forests face immense threats from anthropogenic activities that cause forest fragmentation, forest conversion as a result of urban expansion, infrastructural development to name few that directly or indirectly act as drivers of climate change in a larger sense. Tropical forests of Asia and South East Asia regions are known as a global hotspot of biodiversity and endemism but are also biotically threatened region in the world today (Olson and Dinerstein 1998). India, like other tropical developing countries, is facing threats to its wildlife and forests from anthropogenic activities that are changing the forested landscapes at unprecedented rates.(Reddy et al. 2016) The Western Ghats of India is one such global biodiversity hotspot known for its endemism (Myers et al. 2000). Surprisingly, there has been increase in forested land in India since the 1990s, but careful observation indicates that this increase can be linked to agro-forestry plantations, social plantations and mass afforestation projects (Ravikanth et al. 2000). In reality, the natural vegetation of Western Ghats has declined by 40% just between the years 1920 and 1990, and more importantly, fragmentation has increased fourfold (Menon and Bawa 1997). Menon and

Bawa (1997) also estimated that surviving patches of forests have been reduced in size by up to 83%.

One of the crucial aspects of the biodiversity and endemism seen in tropical forests is variety of biotic interactions observed in wide array of plants, vertebrates and invertebrates. Community level plant-pollinator and plant-disperser interactions across pan tropical forests have been well documented (Howe and Smallwood 1982). Tropical forests, in particular exhibit a wide variety of interdependent relationships between fruit tree species and frugivores (Howe and Smallwood 1982, Turner 2001). The importance and diversity of these relationship has astonished not only evolutionary biologists but also field biologists who have spent decades seeking to understand how these interactions support the maintenance of floral and faunal communities. Developing a thorough understanding of these relationships and its importance at local and global level can only help identify species that are important for health of these ecosystems. Tropical tree species provide habitats and ecological niches to the hundreds of different species and monitoring the status of these trees is an important component of conservation biology. Role of particular taxa in plant-disperser interactions vary across tropical ecosystems found in the world. Studies in the Neo-tropics document dependence of plants on dispersers heavily rely on avian communities but in southeast Asian tropics does not exhibit particular pattern of adaptation for biotic dispersal agents (Ganesh and Davidar 2001). These interdependent relationships face biggest challenge as the contiguous forests continue to be depleted and effects of fragmentation on these relationships become clear in coming decades. Community level plant-disperser relationships in Indian tropics indicate that avian community increasingly plays an important role as mammalian taxa face hunting and fragmentation pressures (Ganesh and Davidar 2001). Importance of role of large-bodied avian frugivores in these ecosystems cannot be understated as they serve as the primary seed dispersers for rare evergreen tree species in tropical forests of India (Corlett 1998).

Hornbills are among the very few avian frugivores that are wide gaped, large bodied, and capable of roaming the evergreen, semi-evergreen, deciduous tropical forests of Asia, all of which enables them to consume diverse fruit diets and disperse seeds from a wide range of tree species. Unlike the ground hornbill species of the African Savanna, whose diets consist mainly of animal matter, Asian hornbills have evolved to take advantage of the vast array fruits available in the tropical forests of Asia. The Western Ghats is laced with national parks and wildlife sanctuaries, but vast areas of the landscapes remain outside of this network. The region is a mosaic of tracks of forests, various kinds of plantations, agricultural land, hydroelectric projects and community lands. The current area of the protected network, which includes 43 wildlife sanctuaries and 13 national parks, is only 10% of the total land area of Western Ghats (Mudappa and Raman 2008). A recent assessment of the tropical evergreen forests of the Western Ghats showed that only 25 % of the existing natural forest exists in un-fragmented form, and more importantly, 74% of these forests lie outside of the network of protected areas (CEPF 2007). Protected areas have been established across the globe to reduce the impact of forest loss and protect biodiversity. Unfortunately, however, research indicates that the network of protected areas in the Asian tropics cannot provide adequate protection to conserve the biodiversity of these regions (Rodrigues et al. 2004). Landscape level changes such as fragmentation can hamper and restrict processes such as pollen and seed dispersal due less abundance of frugivores in fragmented forest patches. However, it still needs to be seen how frugivores adapt to these landscape level changes. Recent study on Great Hornbills nesting habitat has shown the species to nest in such modified habitats too (Pawar 2016).

Most hornbill research throughout India, has been carried out in national parks and wildlife sanctuaries, but only recently has the scientific community started focusing on reserve forests and community forest that fall outside protected area network (Naniwadekar et al. 2015b). The pioneering hornbill research by Kannan in India yielded publications in 1990s showcasing important aspects of hornbill breeding biology with a focus on the Great Hornbill's nest habitat requirement and keystone fruit resources in Top slip area of Annamalai hills and Mudappa thus followed her research on the breeding biology of the Malabar Grey hornbill and its nest tree requirements (Kannan 1997, Mudappa and Kannan 1997, Kannan and James 1999, James and Kannan 2009, Bachan et al. 2011). Vazhachal Reserve Forest along the same Anamalai Hill Range has been identified as a key reserve forest adjoining Parambikulam Wildlife Sanctuary as critical conservation unit for sympatric species of hornbill (Mudappa and Raman 2008). However, nest monitoring program run by the Kerala Forest Department remains the only active effort to collect data on hornbill populations in this region since 2005, and it has barely managed to survive (pers. obs.). The present study is an attempt to initiate research to understand the status of important large-seeded tree species that are an integral part of the hornbill diet, and the availability of the fruits of these tree species for hornbills in the Vazhachal Reserve Forest.

The effect of global climate change have become more evident in recent years and have forced various species to move to higher elevations and latitudes, altered phenological cycles, and negatively impacted the demography of species worldwide (Thackeray et al. 2016). In particular, changes in phenological cycles can alter interactions between species and hence can impact the populations but without a long-term phenological datasets such impacts are difficult to assess (Yang and Rudolf 2010, Burkle et al. 2013).Phenological patterns in the tropics are not only more complex than patterns in temperate regions but are also less understood due to the lack of long-term documentation (Pau et al. 2011). Understanding fruiting phenological patterns of species that are important food source, particularly for only few large-bodied avian frugivores is critical for conserving these plant -animal relationships in tropical forests. Early scientific studies on hornbills focused only hornbill natural history aspects such as breeding biology, diet requirement and general ecology (Kannan 1994, Mudappa and Kannan 1997, Datta 1998). Research on hornbill’s efficiency as seed disperser has begun to emerge only in last decade and these studies have been concentrated in northeastern India. Hornbill research in southern Western Ghats is rich with publications on the dietary needs and breeding biology of sympatric hornbill species, which involves documenting the fruiting patterns and phenological cycles of diet plants (Kannan 1994, Mudappa and Kannan 1997, Kannan and James 1999, Balasubramanian et al. 2007, Kannan and James 2007, Mudappa and Raman 2008).

The objective of the present study was to examine the seasonality, interannual patterns of fruiting and flowering and the overall availability of the fruits of large-seeded lipid-rich tree species for avian frugivores such as the species of hornbills. The present study was the first to document the phenological patterns of a subset of fruiting tree species that hornbills consume in this reserve forest, which doesn’t enjoy same levels of protection as national parks or wildlife sanctuaries. Phenological information was limited to six genera of large-seeded lipid-rich tree species consumed by hornbills and was collected over a period of 29 months between January

2013 and May 2015. The study focused on large-seeded fruit species preferred by the Great hornbill (*Buceros bicornis*) and the Malabar grey hornbill (*Ocyceros griseus*), which commonly occur in the Sholayar Range of Vazhachal Reserve Forest. Understanding the availability of fruiting resources is very critical as these patterns can be spatially and temporally patchy in tropical ecosystems and can be integral to various frugivore species (Naniwadekar et al. 2015a). Documenting fruiting phenology of hornbill diet tree species can help to understand keystone plant resources and pivotal species (Leighton and Leighton 1982, Kannan 1994). The female and chicks confined to the nest cavity during nesting period depend on the male to provide food over periods three to five months depending on hornbill species. Hence overall knowing fruit availability is essential for conservation and management strategies at local level to safe guard the future of the both, frugivore and tree species.

It is also important to note most of these large-seeded tree species, provide essential livelihood resources for one or more of the tribal communities indigenous to Western Ghats. Tribal community member's livelihood is thus closely linked to the availability of fruits in any given year. Lastly, Kerala's Forest Department recruited members of the "Kadar" tribal community to help monitor and protect hornbill nests in Vazhachal Reserve Forest but no effort has been made in the region to monitor the availability of fruit resources, whose harvesting is unregulated (Bachan et al. 2011). Finally, phenological documentation can provide crucial information about the impact that natural climatic events , such as the deluge that Kerala experienced during the southwest monsoon in 2018, may have on trees, frugivore and human populations in coming years (Faizi 2018). Documentation of phenology of fruiting patterns of these large-seeded tree species can be integrated into information utilized for designing local conservation strategies in the region where the study was conducted.

Study Area

The Anamalai Hills are surrounded by the Nilliampathy Hills on the western side, the Nilgiri Hills in the north, the Pallani Hills in the southeast, and High Ranges in the south. Vazhachal Reserve Forest is located in the Anamalai Hill Range between 76^0 09' 06" – 76^0 54'E and 10° 07' 08" - 10° 23'16"N. It was declared as reserve forest by the Government of India in 1981. Five forest ranges are distributed throughout Vazhachal: Athirappilly, Charpa, Vazhachal, Kollathirumedu, and Sholayar. Vazhachal Reserve Forest is bordered by Parambikulam Wildlife Sanctuary to the north, Chalakudy Reserve Forest on the west, Malayattur Forest Division to south and Valaparai Plateau to the east. Intense study sites were located in Sholayar Forest Range between 600 and 1,000 m elevation and encompasses 30 sq. km of area (Fig 1). The headquarters for the Vazhachal Reserve Forest Division are located at Malakkappara and Anakayam. Sholayar Forest Range is situated on the north-eastern side of the Vazhachal Forest Division. Anakayamthodu, Chandanthodu, and few other streams, originate in the Sholayar region, flow east through the forest division, and eventually join Chalakudy River, which flows into the Arabian Sea. The Sholayar forest range covers just under 140 of the total 413 sq. km covered by the Vazhachal Reserve Forest. Sholayar and Vazhachal Forest Ranges primarily harbor majority of wet-evergreen forests within Vazhachal Forest Division. Most of the land in this range still has natural vegetation, but some parts have been given to Kerala Electric Board for the Sholayar Hydro-Electric plant and tribal communities displaced by this have been given small parcels of the land near Malakkapara. Some of this land is also leased out for tea and coffee plantation. Table 1 shows the distribution of land (Table 1).

Table1. List of various land shares with Sholayar forest range in Vazhachal reserve forest

Land distribution in Sholayar range of Vazhachal forest division	Area (in ha)
Total forested area	13035
Sholayar Hydro Electric Project	29
Malakkapara tribal colony	50
Malakkapara plantations	739
Perumpara plantation	35
Total area under Sholayar range	13888

It should also be noted that Anamalai Road runs from Chalakudy in the west all the way to Malakkapara passing through the lush evergreen forest of Vazhachal. In recent years it has become a popular tourist destination especially during monsoon season. Kerala's Forest Department does keep entry records for tourists, but monitoring is strictly implemented only around the Athirappilly Waterfalls. Littering, reckless driving, and noise pollution are all common along the road, which passes through part of the Sholayar Forest Range. The study sites were spread over the Sholayar Forest Range, with four study plots closer to road and/or human settlement and the other five sites located in less accessible parts of the forest, and away from human settlements, and infrastructure.

Annual rainfall measurements for the years 2013 and 2014 and three months of 2015 were obtained from a rain station maintained by the Tata Tea and Coffee plantation Limited (Fig. 2). Western Ghats receives most of its precipitation during southwest monsoons which lasts from June until September, and the rest during northeast monsoon, from October to January. The average annual rainfall in the evergreen forests in the Western Ghats ranges from around 2,000 to 7,500 mm (Pascal 1988). But the distribution from south to north is variable and depends on locality. As seen in figure 1, the rainfall peaked during the southwest monsoons in both 2013 and 2014, but remained generally low during the northeast monsoon in 2014.

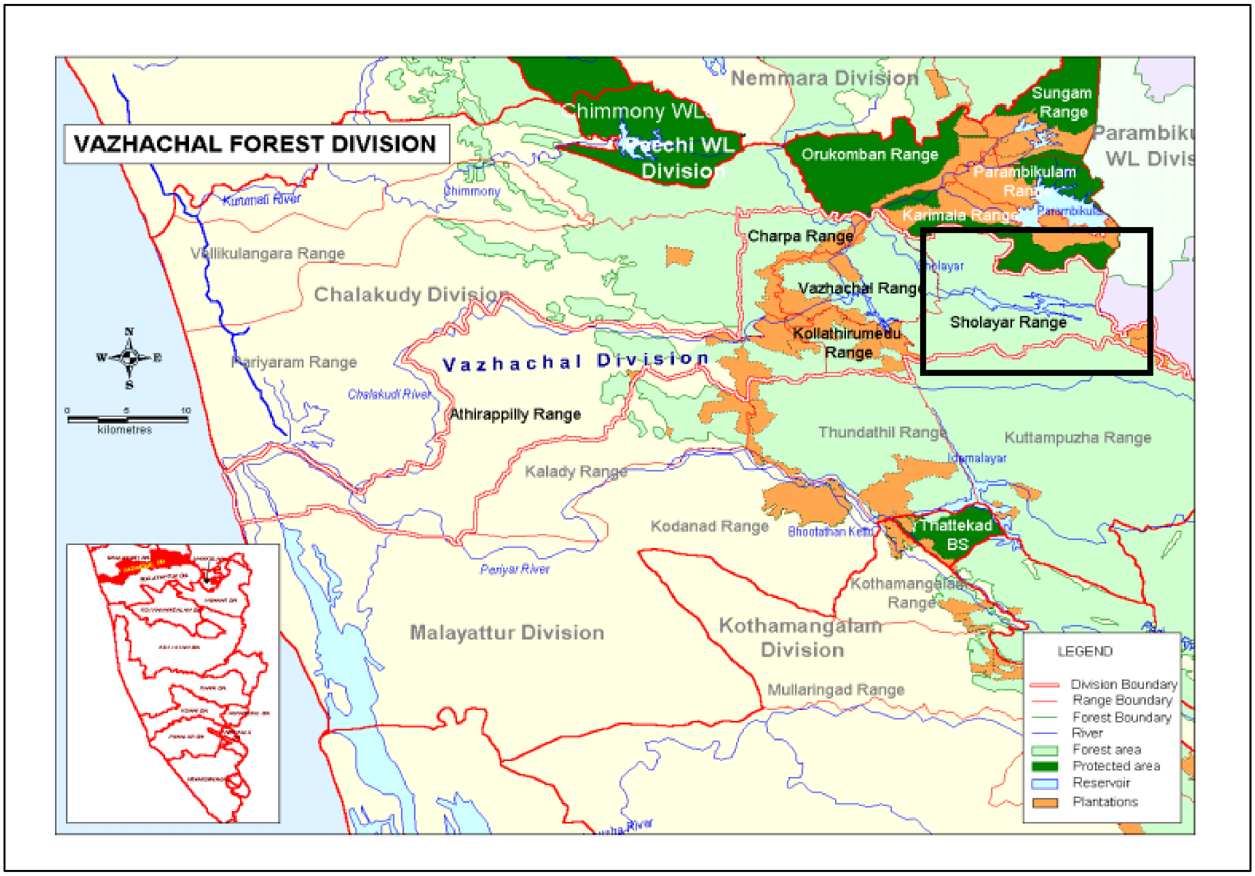

Figure 1. Map of the Vazhachal Reserve Forest Division showing all forest ranges, the Sholayar Forest Range with a box highlighted in the black, where the present study was conducted.

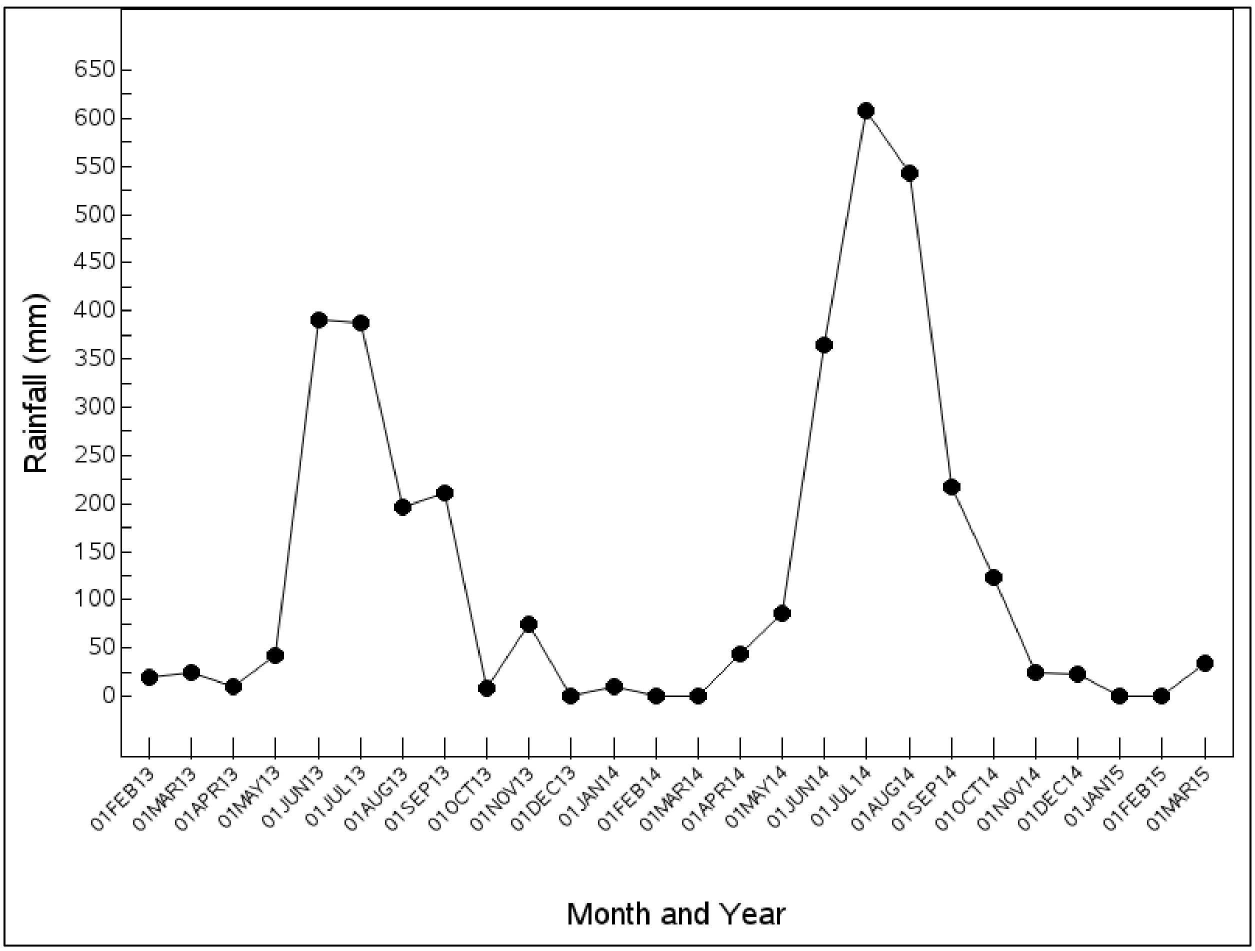

Figure 2. Monthly rainfall (mm) in Vazhachal Reserve Forest, Anamalai Hills, Kerala, from January 2013 to March 2015

Study Species

Seasonal climatic changes in tropical forests play an important role in unevenness of fruit production of fruits (Leighton and Leighton 1983). Fruiting and flowering phenology patterns documented by Kannan (1994) included extensive research of many Great hornbill diet species in the Top Slip area of the Anamalai Hills, which is along the same hill range where the present study was conducted. The area-based sampling method was modified from (Leighton and Leighton 1983) study of fruiting phenology among evergreen species in the tropical forests of Borneo. The present study targeted only species that were documented as important hornbill diet species and provide lipid-rich nutritious fruits unlike the fruits produced by *Ficus species*. Unlike 0.25-hectare study plots used by Leighton, present study utilized 1.0-hectare plots for monitoring of phenology. Past and present hornbill research has shown the importance of lipid-rich fruits in hornbill diets (Kannan and James 1999, Datta and Rawat 2003, Kitamura 2011). The large-seeded, lipid-rich fruit-producing tree species were selected based on the results of Kannan's dissertation work in 1994, and the list was modified based on the local abundance and availability of species in the present study area. The species selected belonged to genera: *Litsea, Canarium, Knema, Myristica, Dysoxylum*, and *Persea*. These genera constitute important part of hornbill diet, especially during the nesting period helping meet high metabolic energy demands.

The present study targeted large-seeded trees belonging to six different genera belonging to four families. The families were Burseraceae, Lauraceae, Meliaceae, and Myristicaseae. *Dysoxylum malabaricum* Bedd. belongs to Meliaceae family. This large canopy tree species occurs in evergreen and semi-evergreen forests in Western Ghats between 200 and 1200 m elevation and grows to a height of 30-40 m or more (Bodare et al. 2013). *Dysoxylum malabaricum*, commonly called "Vellakil" in the local language (Malayalam), produces a capsular fruit that varies in size from 5 to 7.5 cm and, once ripe expose 3-4 seeds along its furrows (Ved et al. 2015). Commonly known as white cedar, this species has economic value for its sweet-scented wood, the medicinal properties of its fruit, and its cultural important to tribal communities. The wood and the fruits of *D. malabaricum* have been used by tribal communities across its distribution range, and its the populations have declined over the years due to unregulated harvesting (Kumar 2009). Regeneration studies have shown very poor regeneration in certain populations of *D. malabaricum* and have also documented notable loss of juveniles in fragmented forest patches (Shivanna et al. 2003b). The same study implicates over harvesting of wood and fruits in the decline juveniles, but other factors, especially landscape-level changes, may also be in the play. The IUCN Red List, has classified *D. malabaricum* as endangered (EN) with declining populations (Ved et al. 2015). As per state law in Kerala, the felling of *D. malabaricum* is currently prohibited, though trees located in private or community owned forests can be cut after they attain a certain girth (ca. 180 cm) (Menon and Balasubramanyan 2006). The economic value of this species has led to heavy forest fragmentation throughout its natural range (Shivanna et al. 2003a).

Canarium strictum Roxb., known as "Thalli" by tribal communities in Kerala, belongs to family Burseraceae, and its non-timber products are harvested in several South and Southeast Asian countries (Varghese and Ticktin 2008). A canopy tree, with buttressed bark, *C. strictum* can grow to 30m tall and produces drupes that can be up to 3.5cm and produce 1-3 seeds. Black damar is the resin extracted from *C. strictum* and has long used for medicinal and spiritual purposes by many tribal communities along Western Ghats (Ravikumar and Ved 2000). It is also commercially harvested for making incense and matchsticks (Augustine and Krishnan 2006). Burned marks and machete marks on the specimens of *C. strictum* in the Vazhachal Reserve Forest indicate ongoing harvesting (pers. obs.). Concerns over the survival of this species in the face of over harvesting and tapping practices has been well documented (Kannan 1992, Varghese and Ticktin 2008). Being one of the large-seeded tree species, *C. strictum* has only few dependable seed dispersers.

The Myristicaceae family, commonly known as nutmeg tree enjoys pan-tropical distribution. A diverse 20 genera and with 500 species, has been listed as one of the most important tropical tree families (Kitamura and Poonswad 2013). The genera *Knema* and *Myristica* have been thoroughly studied across the Asia-Pacific region, but none of these studies have been carried in southern Western Ghats where these trees appear to represent an important source of nutrition for hornbills. The only studies looking at the role of hornbill species in dispersal and recruitment were carried out in North East India (Datta and Rane 2013).

The species *Myristica dactyloides* Gaertn. is endemic to southern India and Sri Lanka, where it occupies mid - high elevational ranges (840 – 1400 m) in evergreen forests and grow to 20-35 m tall (Sharma and Shivanna 2011). This species produces dehiscent capsular fruits that grow up to 6 cm in length and, when ripe, which showcase bright orange-red arils to attract frugivores species such as pigeon and hornbills. One way to identify this species in the field, commonly called as “Pathiri” by tribal communities in the region, is to make a small cut on the bark to see if it released reddish sap. This species is frequently over-harvested for its seeds and arils, both of which are used as spices across the globe, and particularly in the study area the harvest is unregulated and unchecked. *Myristica dactyloides* has recently been categorized as a vulnerable species (Haridasan et al. 2015). Haridasan et al ‘s study also reveals that in India, *Myristica dactyloides* Gaertn populations have been reduced by 40% over the last 90 years due to fragmentation, repurposing of the forest land for agriculture, and hydroelectric projects, and other anthropogenic activities across south India.

Unlike *M*. *dactyloides*, *Knema attenuata* (Hook.f. & Th.) Warb., another large-seeded evergreen species of the family Myristicaceae commonly found in the Western Ghats, does not appear to be vulnerable in status. The IUCN Red List has classified this species as low risk, but it should be noted that this is based on records from 1998 and has not been updated since. *Knema attenuata* has been identified as an important large-seeded diet species for animals including hornbills, large-bodied pigeons, and even for the palm civet (Mudappa et al. 2010). These species known as “Chrapathiri” by local tribal communities, grow up to 20 m tall and produce bright red capsular arillate fruits, which, at 2 – 4 cm, are smaller than M. dactyloides but very noticeable in their natural habitats because of the bright color of the arils (pers. obs.).

The genus *Litsea* belongs to the family Lauraceae, one of the most diverse tropical tree families with 52 genera and about 2,550 species (Singh 2015). *Litsea* includes both tree and shrub forms distributed across tropical and subtropical Asia, and North and South America. This genus has been extensively utilized in traditional medicine across its distributional range to treat ailments including influenza, stomach ache, inflammations, and illnesses related to the central nervous system (Wang et al. 2016). 44 species of the genus *Litsea* are distributed across India from the north-east to peninsula. India is a global leader in scientific publications on the genus *Litsea*, especially ethnobotanical studies and pharmacological research, and many communities in India harvest these tree’s bark, stem and leaves for medicinal purposes (Bhuniya et al. 2009) In the area of the present study, species belonging to this genus commonly occur in the forests near human habitation (pers. obs.). Communities in the Western Ghats of Kerala generally use the vernacular name “Chovukudi” to refer to all Litsea species (pers. obs.).

The species of *Persea macrantha* (Nees) Kosterm. belongs to the family Lauraceae and its fruit has been documented as an important component of the hornbill diet. This large evergreen species occurs in low densities in the evergreen forests of Western Ghats and grows as tall as 30 m. Its large, aromatic berries can be up to 2 cm wide and, when ripe display red coloration with whitish dots.

Methods

Anamalai Road cuts through the Sholayar Forest Range from the town of Malakkapara on the eastern side of the range to the town of Chalakuddy on the western border of the forest range and runs almost 80 km in length. Study plots were located in forested areas on either side of this road. Four of these 1-ha plots were either close to the tribal settlement on the southern side of the road (Fig 3). The closer plots were no more than 1 km from the road or the settlements. The other five plots were on the northern side of the road beyond the Sholayar Reservoir and hence less accessible to the tribal communities and were at least 5 km away from tribal settlements or the road. The plots near the road or tribal settlements will be referred to as the “Close” study plots, and those located in less disturbed areas will be called “Far” study plots. The forests where the “Close” plots were located are more accessible to tribal members, who often go there to collect firewood and harvest non-timber forest products.

Individual 1-hectare plots were located randomly using random data table and off from forest trails used by either wildlife or tribal communities. The study plots were distributed across a 30 km^2 area of the Sholayar Forest Range. Only individuals greater than or equal to 30 cm of girth at breast height (GBH) known to produce fruits were recorded and monitored (Naniwadekar et al. 2015a). In each study plot, all plant individuals belonging to the targeted large-seeded tree species were identified, marked with paint, assigned a number, tagged, and height and girth at breast height was recorded. Tree identification were made with the help of a botanist and local collaborator on the project who has actively worked in the present study area for over a decade (Bachan et al. 2011b). Vernacular names were documented with the help of tribal assistants. Samples were collected when possible for identification using the flora of Pascal and Ramesh 1997, whereupon, some previously misidentified species had to be eliminated. Species level identification was not possible for the genus of *Litsea*, and analysis of these samples was limited to the genus level.

Each 1.0 ha study plot was visited once a month and tagged trees were monitored for 29 months from January 2013 to May 2015, during which time each tree's flower and fruit production was recorded. Rain-forest trees are known to produce small quantities of ripe fruit during each fruiting episode over the fruiting season, hence, fruiting was recorded every time signs of ripe fruits were observed (Leighton and Leighton 1983). Quantification of individual fruiting individual was not recorded as it is not as important as documenting number of fruiting trees (Kannan 1994). Signs of fruiting were identified by scanning forest canopy with binoculars, recording animal activity, and examining the forest floor. The individual trees that died during the study period were not included in the analysis of the data. It should be noted that the data was collected during all 12 months of 2013 and 2014, but for only 5 months during 2015, when the project ended. The analysis and comparisons are made at species level, between “Close” and “Far” study plots, and overall fruiting phenology in all plots combined. Analysis was carried out in R (version 3.4.3 (2017-11-30)). Packages ‘ggplot2’ (Wickham 2009), ‘dplyr’ (Wickham et al. 2017), ‘tidyrr’ (Wickham and Henry 2018) and SAS 13. 1 (SAS Institute Inc. 2013).

Figure 3. Locations of 1-hectare plots (white solid dots) used for monitoring of large-seeded tree species in Vazhachal Reserve Forest, Anamalai Hills, Kerala, India.

Results

The large-seeded, lipid-rich fruit-producing tree species considered in the present study produced three types of fruits; capsular and dehiscent fruits of the genera *Myristica*, *Knema* and *Dysoxylum*, berries of the genera *Litsea* and *Persea* and drupaceous fruits of the genus *Canarium*. Across nine hectares, 317 trees belonging to families the Myristicaceae (*Myristica dactyloides* and *Knema attenuata*), Burseracea (*Canarium strictum*), Meliaceae (*Dysoxylum malabaricum*), Lauraceae (*Lisea species and Persea macrantha*) were tagged and monitored. Mature tree densities ranged from 1.3 trees/ha (*Persea macrantha*) to 14.4 trees/ha (*Myristica dactyloides*). Only members of the genera *Myristica* and *Litsea* had more than 10 tress/ha and the other four genera had fewer than three trees/ha. As seen in (Fig. 4) species composition differed from each one-hectare plot to the next, and the “Close” study plots (C1, C2, C3 and C4) contained more trees belonging to genus the *Litsea* than to any other genera. The “Far” study plots (F1, F2, F3, F4, F5) on the other hand, “Far” sites were dominated by trees of genus *Myristica*. The fruiting patterns of the trees in the “Close” and “Far” plots are shown below in Figure 6.

Height and girth at breast height of all tagged individual trees were recorded for all species across all sites, and the height and girth distribution plotted (Fig. 3 and 4). Except for *Litsea species* all other species are canopy species and distribution of height and girth show the presence of old growth trees. Among the six species average individuals of *Dysoxylum malabaricum* were tallest and largest in girth indicating old growth form of deep forest evergreen species with average height of 22 m and girth of 155 cm. Individuals of *Dysoxylum malabaricum* ranged in height from 7-45 m and 30-300 cm in girth, indicating a mix of both young and old adult trees. *Myristica*. *dactyloides* was one of the species more commonly present in both “Close” and “Far” sites and the height of the individuals ranged from 7 to 40 m and girth between 30.5 to 390 cm. But average height of *Myristica*. *dactyloides* was around 16 m and girth 98 cm. *Persea*. *macrantha* had lowest density per hectare and the height ranged from 7 to 30 m with girth ranged between 39 to 318 cm. Individuals of *P*. *macrantha* averaged between 16 m tall and 98 cm in girth. Majority of *Knema attenuata* individuals were found in “Far” sites and average height was 20 m and 133 cm in girth indicating more old adult trees in the study region. With only 17 individuals of *Knema attenuate*, heights ranged between 7 and 36 m and 51 to 272 cm in girth. Height of 14 *Canarium*. *strictum* individuals ranged between 6 to 25 m and girth between 38 to 300 cm. But the average height was 13 m and 85 cm in girth indicating presence of younger trees. *Litsea species* are known to grow up to 20 m and the present study recorded average height of 9 m and 51 cm in girth indicating young fruiting trees. Species of *Litsea* were second most common species found in the study area after *Myristica*. *Dactyloides.* The heights ranged between 5 to 20 m and girth between 30 to 150 cm.

The results indicated that the fruiting of the large-seeded tree species included in this study generally peaked during the hot and dry months of the year, from February to May, when rainfall is lowest (Fig 7). In 29-month period of the study, the percentage of trees fruiting peaked in March and declined gradually until July. For study sites, located both in "Close" and "Far", locations indicated similar fruiting patterns, though percent of trees fruiting within these sites showed differences and some sites had more fruiting compared to others. Statistical analysis comparing differences in percent fruiting between "Close" and "Far" did not reveal any significant differences over period of 29-months of monitoring period (t-values= 0.448, SE= 0.098, p value= 0.660).

Figures 8 and 9 show total number of trees fruiting in individual "Close" site and "Far" sites. During 2013 more fruiting trees were recorded in the "Far" sites compared to the "Close" sites. This pattern changed during 2014 and early 2015, when more trees of species of *Litsea*, heavily concentrated in the "Close" sites were recorded fruiting. For comparing interannual fruiting pattern only data from 2013 and 2014 were used as both included all 12 months. Percent fruiting between "Close" and "Far" sites between year 2013 and 2014 did not differ significantly from each other though species of *Litsea* showed heavy fruiting in 2014 (t-values= -0.379, SE= 0.10, p values= 0.710). Due to staggered fruiting patterns among different species, lipid-rich fruits remained available in the study area during post hatching period for species of hornbills. Great Hornbills and the Malabar Grey Hornbills nest during this time of year and require nutrient-rich food resources. The fruiting pattern seen in Figure 7 does not reveal which species of fruit are available during the hornbill's nesting seasons, but does shows overall availability of lipid-rich fruits over the 29-months study period. One species, *Canarium strictum*, failed to fruit throughout the entire period of monitoring, and very few trees of *Persea macrantha* fruited during the study period. The species of *Myristica* and *Litsea* produced the majority of the fruit recorded in the study.

Three species tagged in this study that produce arillate and/or capsular lipid-rich fruits: *M*. *dactyloides*, *K*. *attenuata*, and *D*. *malabaricum*. The average density of *M*. *dactyloides* was recorded 14.4 trees/ha, *K*. *attanuata's* was 1.8 trees/ha, *D*. *malabaricum's* was 2.3 trees/ha, P. macrantha was 1.3 trees/ha, and Litsea species were 13.5 trees/ha. *Myristica*. *dactyloides* and *Litsea species* were the only two species that showed variation in density of trees found in "Close" and "Far" study sites. Trees of *Myristica*. *dactyloides* were recorded highest in the "Far" study sites. *Myristica*. *dactyloides*, an important hornbill diet species, was found at the highest density in all study sites. All three species fruited in the hot and dry season, when Great Hornbills and the Malabar Hornbills are known to nest in this part of Western Ghats. *M*. *dactyloides* represented 36% of the trees recorded in the "Close" sites and 46% of those recorded in the "Far" sites. During the first year of the study, the percentage of fruiting *M* *dactyloides* declined sharply from about 17% to 5 %, and no more than 18% of all *M*. *dactyloides* trees were recorded to fruit at peak fruiting season during any given year (Fig 9). *M*. *dactyloides* began fruiting as early as September in 2014 and as late as December in 2015.

Great Hornbill were observed to anywhere from 10 minutes to an hour per visitation feeding on the fruit of *M*. *dactyloides* between January and May (pers. obs.).

Knema. *attanuata* is even though commonly seen tree species (pers. obs.), but was found to have low density in the study sites. Only 1.2% of trees in 'Close' sites belonged to *K*. *attenuata* and about 9.3 % in "Far" sites. *Knema attenuata* began fruiting in January in both 2013 and 2014, but was delayed until February in 2015 (Fig. 10). The percent of trees that fruited increased gradually every year. Though *K*. *attanuata* occurred at a lower density than *M*. *dactyoides*, between 52% - 71% of the *K*. *attenauta* trees recorded in the study fruited during the peak fruiting months of the study period. Hornbills and Mountain Imperial Pigeons which were commonly seen feeding on these fruits (pers. obs.).

The average density of *Dysoxylum*. *malabaricum* was 2.3 trees/ha and a total 21 trees were tagged across all sites. *Dysoxylum malabaricum* fruited slightly later than the other species mentioned above, starting around February and peaking during April and May for first two years and in the month of May during the last year of the study (Fig 11). No more than 25% of tagged *D*. *malabaricum* individuals fruited in any given year.

Persea macrantha and the *Litsea species* both produce berry-like, lipid-rich fruits with fleshy pulp. The species of *Litsea* were the second most abundant trees in the study area, with an average density of 13.5/ha across all study sites. 69% of all trees belonging to this species were found at the "Close" sites. Site C1 had more trees of *Litsea species* than other sites and was the closest to a human settlement. This can have implication on resource availability for species of hornbill species near human modified lands. Species of *Litsea* were also the only tagged species that showed fruiting for a prolonged period of time between September and June/July (Fig 12).

The number of trees fruiting during peak months showed little variation, but peak fruiting times did vary substantially from year to year. During 2014, *Litsea* species showed a sharp increase in fruiting, from only four individuals fruiting in September to 29 fruiting in t November (Fig. 7). Conversely, a 50% decline in percentage of fruiting trees was observed in 2013, with 28 trees fruiting at the peak in April and only 14 trees fruiting in May. Fruiting peaked in March and April in 2013 and 2015, and in December 2014.Species of *Litsea* were the only tree species observed to show an inconsistent pattern of peak fruiting times, but *Litsea* fruits also remained available over a longer period. Encounter rates of the Malabar Grey Hornbills and the Mountain Imperial Pigeons near this Site C1 also began increasing in December of 2014 (Chapter 3) indicating that these frugivores were tracking fruit patches. *Persea macrnatha* had the lowest density among all tagged trees, averaging only 1.3 trees/ha across all sites. At least one tree of this species was found in each “Close” site, but among the “Far” sites, it occurred only at F5. None of these trees fruited during 2014, and the maximum number of fruiting trees was two in 2013 and three in 2015 (Fig 13). The last species, *C. strictum*, had an average density of 1.6/ha across all sites. None of the tagged trees ever showed fruiting during study period of 29 months. Individuals of *C. strictum* were commonly seen growing along the edge of the road in this region (pers. obs.).

Fruiting patterns varied depending on site, year and the species. For the purpose of this analysis, percentage of trees fruiting will be used instead of integers. Figures 14 through 22 show variations in fruiting at individual sites for all large-seeded tree species considered in this study. Site C1 was located near a tribal settlement called Malakkapara, where the forest department headquarters are located, and tribal members frequently visited the site to collect firewood and other non-timber products. It also had more paths connecting it to other forested areas, and cattle were sometimes observed grazing in the vicinity. Among all "Close" sites, Site C1 showed the highest rate of fruiting, largely due to high concentration of *Litsea* trees (Fig. 14). At this site 59 adult trees representing all species except *K. attenuata* were tagged, and almost 75% belonged to the genus of *Litsea*, which occurred at a higher density here than at any other site. Trees belonging to *Litsea species* showed an inconsistent pattern of fruiting, and variations in fruiting from year to year were more pronounced compared to other fruiting species at Site C1 site. Two *D. binecteriferum* trees, one *C. strictum* tree, and one *P. macrantha* tree were tagged and monitored at this site, none fruited during the study period. Site C1 displayed low fruiting in 2013 with less than 10 % of the trees in fruiting, compared to 33% in 2014 and almost 25% in 2015.

Site C2 was located near a tribal settlement called Pathadipalam and tribal community members visited the site to harvest non-timber forest products such as honey. The total density of trees tagged and monitored here was 30/ha. 16 trees belonged to *M. dactyloides* (about 53%), 11 to the species of *Litsea* (37%). *C. strictum*, *P. macrantha*, and *K. attenuata* all had one tagged individual respectively, and *D. malabaricum* was not found at this site. *Canarium strictum* never fruited during 29-months of monitoring. With low fruiting tree density this site recorded fruiting of 30% in year 2015 from months January to May and lowest 17% in year 2014 (Fig. 15).

Site C3 was located about 1,000 m away from the Malakkapara-Chalakuddy road, which is the only motorable road in this region. Site C3 showed the lowest density of trees belonging to the large-seeded species of interest among all sites, with only 22/ha. 46% of the trees at this site belonged to the species of *Litsea*. Although it also was the only site among "Close" sites where all species of interest occurred. Among all "Close", Sites C3 had highest number of *C. strictum* but none of these fruited during the 29-months (Fig. 16).

Site C4 was located about 1500 m from the Malakkapara-Chalakuddy road and the terrain was very uneven. Tribal members used this part of the forest frequently for honey collection (pers. obs.). A total of 45 trees were tagged and monitored. Over 50% of the trees belonged to *M. dactyloides* and 23% belonged to species of *Litsea*. *C. strictum* and *D. binecteriferum* trees did not fruit at all at this site and one tree of *P macrantha* fruited only during first year of the study. No trees belonging to *K*. attenuata were recorded at this site. The trees of *M. dactyloides* and *Litsea species* dominated the fruiting episodes at this site, and the lowest fruiting rates occurred during the last five months of 2015 (Fig. 17).

At Site F1, 28 trees were tagged and monitored. The same pattern of species dominance as Site C4 was observed here with 43% *M. dactyloides* trees and 39% of species of *Litsea* of all tagged individuals. Except for *P. macrantha*, all other species were observed at this site. The percentage of fruiting trees declined over time, with 40% trees fruiting in 2013 and only 20% fruiting at the beginning of 2015 (Fig 18). As seen at the "Close" sites, none of the *C. strictum* trees fruited during the study period, but the other four species each fruited during at least one year of the study period. When all species were accounted for, the fruits were available from December to June of each year. 2013 showed a sharp drop in the percentage of fruiting trees from April to May. For the rest of the study period, the number of fruiting trees was observed to increase and decrease gradually. In September 2014, a single *Litsea* tree fruited. Adult *Litsea* trees at other sites were also recorded to fruit around this time. *Litsea* berries became available to frugivores earlier than the arillate fruits of *M*. *dactyloides*, *K*. *attenuata* or *D*. *malabaricum*, all of which fruit during the hot and dry season.

Site F2 was one of the two sites where trees of the species of interest occurred at the lowest density. Only 24 were tagged and monitored, and F2 yielded the lowest percentage of fruiting trees among all sites, "Close" and "Far". Only 7% fruited during 2014 and the percentage of trees fruiting during 2013 and the initial period of 2015 remained around 17% (Fig 19). All species of interest were recorded at this site except for *P. macrantha* but only *M. dactyloides*, *Litsea species* and *K. attenuata* were observed to fruit during the study period, and of these species, only a few individuals of *M. dactyloides* and *Litsea species* fruited.

Only 25 trees of the species of interest were recorded and monitored at Site F3, but higher percentage of fruited than any other site, with almost 47% fruiting during both 2013 and the initial 5 months of 2015 (Fig 20). Almost 50% of the trees at Site F3 belonged to species of *Litsea*, 28% to *M. dactyloides*, and almost 20% to *K. attenuata*. The density of *K*. *attenuata* trees was higher compared to the site's average of 1.8 trees/ha. Sharp increases in were observed in both 2013 and 2015.

At Site F4 33 trees were tagged and monitored. This site had the low density of *Litsea* trees among all sites, with only 3 individuals tagged, and the highest density with six individuals tagged. of *K*. *attenuate*. Of all the *C*. *strictum* trees that were monitored in "Far" sites, 45% were tagged at Site F4. none fruited during the study period. Overall fruiting trees at F4 increased gradually over time, with 20% fruiting in 2013 and 2014, and 25% fruiting during year 2015 (Fig. 21). Almost 50% of the trees at Site F4 belonged to *M*. *dactyloides,* and the percentage of fruiting individuals increased and decreased gradually. Fruiting among all species occurred during the and dry time of the year between from February to May. During both 2013 and 2014, fruiting peaks were observed during March-April, but in 2015, the fruiting peak was delayed by a month in 2015. No fruiting was observed in October or November during 2013 or 2014.

At Site F5, 51 trees were tagged, more than at any other "Far" sites. All six species of interest were observed at this site. Almost 47% of the trees tagged belonged to M*. dactyloides*, 28% of *Litsea species*, and 14% of *P*. *macrantha*, and the rest belonged to *K*. *attenuata* and *C*. *strictum*. At this site, the number of trees that fruited during peak season increased gradually from 2013 to 2015 (Fig. 22). Fruiting among all species peaked during the hot and dry season, around March-April and then gradually decreased by June or July during first two years of the study. A very small low percentage of species of *Litsea* trees fruited between October and November in 2014 but fruiting did not start around the same time in year 2013. Of the total trees present, a maximum 22% were recorded fruiting

Discussion

Documentation of recurring biological events such as fruiting and flowering phenological cycles can provide insights into ecosystem functioning such as fruit-frugivore and flower-pollinator interactions as well as effect of climate change on these phenological cycles, and its implications. Understanding and documenting phenological patterns can reveal range of individual species responses at local and global level can help us understand the ecosystem health (Abernethy et al. 2018). To detect any changes in flowering and fruiting phenologies, in response to environmental factors such as anthropogenic activities, landscape level changes or climate change, research must first establish the baseline behavior of the organisms in the system, from which future deviations can be quantified. Long-term phenological records from tropical areas, especially in Asia, are still rare. Tropical environments have long been considered aseasonal, discouraging the long-term collection of long-term phenological data, but studies such as this one clearly shows seasonality among fruiting cycles for large-seeded tree species. Most of the tropical records on phenology that do exist emerged from ecological studies of food availability for birds and primates, whose dependency on critical foo resources such as lipid-rich fruits has been well documented through studies in neotropical and Asian tropical forests (Couralet et al. 2013). In one of the few neotropical phenological datasets spanning over 30 years, (Wright et al. 1999) were able to show that climatic drivers do impact the flowering phenology of some species on Barro Colorado Island, Panama.

The present study is the first to document the phenology of large-seeded tree species that produce lipid-rich fruits in forests outside of protected area network. The large-seeded tree species considered in the present study are an important part of hornbill diet, especially during nesting periods of species of sympatric hornbills, post hatching period in particular (Kannan 1994, Kitamura 2011, Kitamura et al. 2011). The present study builds on previous hornbill research in two major ways: 1) the results reveal for the first time the phenological patterns of fruiting in reserve forest of Vazhachal, that doesn't enjoy the same level protection as National Parks and Wildlife sanctuaries, 2) phenological patterns of large-seeded tree species, some of which exists in very low densities but are important part of hornbill diets, and

3) importance of regions such as Vazhachal Reserve Forest that sits among mosaic of protected areas, human modified landscapes such as commercial plantations and can potentially play as an important repository of fruit resources for large-bodied frugivores. During their nesting and post-nesting period, hornbills experience increased metabolic energy requirement, and even a small number of lipid-rich fruits can provide this energy as well as high quality. This study added support to the findings of studies by Kannan (1994) and Datta (1998) that have documented seasonality and the synchronous fruiting pattern of large-seeded tree species in the tropical evergreen forests of India. Findings of hornbill breeding biology has shown that percent of lipid-rich fruits increases during post-hatching period when these trees are in fruiting. A recent study carried out in adjacent region (Valparai plateau) to present study area has revealed, that Great Hornbills nesting in coffee plantations are potentially utilizing adjoining contiguous forests to find lipid-rich fruit resources which occur in low densities or are absent in these human modified regions (Pawar 2016). These findings are extremely important as Vazhachal Reserve Forest is one of the only contiguous forested landscape that links adjacent Parambikulam and Anamalai Tiger Reserves and vast commercial plantations that lies along this landscape. Even though recent findings have shown hornbills. Recent studies have also shown the species of hornbills are adapting to changing landscapes, but still prefer modified locations that are closer to contiguous forests and have access to important fruit resources belonging to native tree species. Hornbill foraging studies have documented that species such as Sulawesi red-knobbed and Great Hornbills that inhabit degraded forests and varying sized fragmented forests forage long distances to contiguous forests in search of patchily available fruit resources as human modified landscapes don’t support such high fruit tree densities (Kinnaird et al. 1996,

Naniwadekar et al. 2015a). Similar patterns have been recorded in study of three hornbill species that inhabit secondary forest in Central Africa were documented to access high resource areas in the primary forests (Whitney and Smith 1998).

Studies of the characteristics of seeds dispersed by hornbills have revealed, that among non-fig fruits, hornbills prefer large dehiscent or indehiscent fruits with thin husks that grow in the canopies of tall trees, and become red, black, or purple as they ripe (Suryadi et al. 1994, Datta 1998, Kitamura et al. 2011). The tree species that were the focus of the present study satisfy all of these criteria. Such species are shown to display seasonal fruiting and are available only during certain periods, unlike the fig species, which are available year round across the pantropical region (Datta 1998, Kannan and James 1999). The observations from the present study showed that the percentage of fruit producing lipid-rich tree species varied among tree species and species contributing to fruiting varied from site to site within the region. These findings are similar to other studies' which have documented the seasonal fruiting patterns of such lipid-rich fruit tree species (Leighton and Leighton 1983, Kannan and James 1999, Datta 1998). In the tropical forests of India, the evidence suggested that certain tree species depend more on birds for seed dispersal than on primates, and hence understanding fruit-frugivore interactions and fruit availability is important(Ganesh and Davidar 2001). The results of the present study showed that fruiting patterns between years was generally similar, with peak fruiting typically coinciding with the periods of lowest rainfall. Analysis at the species level displayed staggered and displaced fruiting patterns that enabled fruit availability over the entire hot and little over into pre-monsoon period so that there was at least one species fruiting during the post hatching period when energy demands are highest. Similar fruiting patterns have been described by others researchers who have studied hornbill diet species (Kannan and James 2007).

The small *Litsea* berries and the medium sized *P*. *macrantha* berries fruited first, starting in September, and ending during the southwest monsoon period. Most of the capsular and arillate fruits produced by members of families Myristicaceae and Meliaceae were available during the hottest months of April and May, a crucial period during which hornbill parents' and young ones' metabolic needs increase substantially. The average densities of the trees species considered here was similar to those recorded by (Kannan 1994) in the same Anamalai Hill Range, his study sites were located inside Anamalai Tiger Reserve, protected area unlike the present study area which is a reserve forest. Another study from the national park in southern Western Ghats showed that these large-seeded tree species occurred at similar or lower densities, and that most trees in these wet evergreen forests depended on their avian frugivores for dispersal of seeds (Ganesh and Davidar 2001). This implies that the forests in Vazhachal region are providing fruit resources to the frugivores that inhabit these forests and also to frugivores that utilize adjoining commercial plantations landscapes at similar or higher rates than the forested lands inside the protected area network.

This study also revealed the differences in fruiting patterns across different location. Generally, a higher percentage of trees at the "Far" sites fruited than at the "Close" sites, with an exception during 2014 when heavy fruiting occurred among species of *Litsea* This can have implications for further research on fruit patch foraging by sympatric hornbill species and their role in dispersing seeds to different germinating sites. Among the six large-seeded tree species considered in this study, of *M*. *dactyloides* and the species *Litsea* produced most fruit across all the sites. Kannan (1994) showed that, the species of *Myristica* contributed heavily to fruiting but the present study indicated that apart from *M*. *dactyloides*, *Litsea* species are equally important in terms of fruit availability in this region, especially in areas closer to human habitations. Sites closer to roads, and/or settlements and more accessible to tribal communities were dominated by the species of *Litsea*, a member of family of Lauraceae but more species research is needed to how, why and whether species of *Litsea* is thriving near human habitats and whether acting as an important food source for the sympatric hornbill species

Three species out of the six considered in the study displayed low densities, but these species nevertheless appear to be important components of the hornbill diet, as indicated by seedlings-saplings growing under hornbill nest trees (Chapter 2). Though present in low densities, most *K*. *attenuata* trees fruited during the study period, *P*. *macrantha*, on the other hand, completely failed to fruit in 2014. This indicates fruits of certain species possibly are disproportionately available, which can affect not only fruit availability for frugivores, but also the process of seed dispersal. Recent research in fruit tracking by hornbills in north eastern India has shown that fruit tracking varies depending on the hornbill species and the scale at which hornbills look for fruits. (Naniwadekar et al. 2015a). Fruits of fig species dominate diets of Great Hornbills comprising up to 70% of all fruits consumed but proportion of lipid-rich fruits increases during post hatch period. The Great Hornbills that nest in human modified landscapes have shown to have significantly higher proportion of lipid-rich fruits than the ones nesting in the contiguous forests (Pawar 2016). This can have long-term impacts on seed dispersal and regeneration of these large-seeded and lipid-rich tress species in the future.

Large-seeded tree species in particular rely on small coterie of dependable seed dispersers and hornbills are among the very few frugivores that can consume large-seeded fruits without damaging seeds, and their wide-ranging habits ensure the transportation of seeds to different parts of the forest. The phenological patterns documented in the present study indicate that the of *M*. *dactyloides*, with its capsular and arillate fruits, are important resource for hornbills, and that hornbills in turn capable of dispersing this species' seeds without any damage as they carefully consume only the outer oily aril. This tree species also provides important resources to the tribal communities in this region, and the human harvesting practices can interfere with seed dispersal by hornbills. *Myristica dactyloides* trees contributed majorly to the fruiting peaks, but not all of these fruits were available to frugivores. Members of the tribal community frequently collect fruits and separate the aril and discard the seeds on the forest floor, where they usually rot due to fungal infections (pers. obs.). This harvesting of aril is unchecked and unregulated and can negatively impact fruit availability and seed dispersal. Another species, *C*. *strictum*, which also represents an important resource for both hornbills and tribal communities, completely failed to fruit during the 29-month study period. Its resin is harvested by means of burning or slicing the bark, which over time can kill the tree or affect its flowering and fruiting patterns. The finding of the study suggest that a thorough investigation needs to be carried out to understand the population ecology of *C*. *strictum* and its current status.

Finally, the information gathered in the present study has made available phenological data that was absent from Vazhachal Reserve Forest, an important hornbill conservation region. The exact role of members of genera of *Myristica* and *Litsea* needs to be explored more at a species level to understand their importance in diets of both Great Hornbills and Malabar Grey Hornbills. Other species that such as *C. strictum*, that were seen fruiting in the region, but none fruited in the study sites, require population studies along with documentation of methods of resin harvest and its quantification. Lastly, Kerala Forest Department needs to make this region conducive for research by providing logistic and infrastructural support so interior portions can become accessible for researchers. The existing hornbill nest monitoring program needs to be extended to also document fruit diversity in hornbill diet in Vazhachal Reserve Forest in continuation with monitoring fruit availability. This will enable species focused conservation efforts for species that might need urgent attention including species of hornbills and large-seeded tree species that are rare.

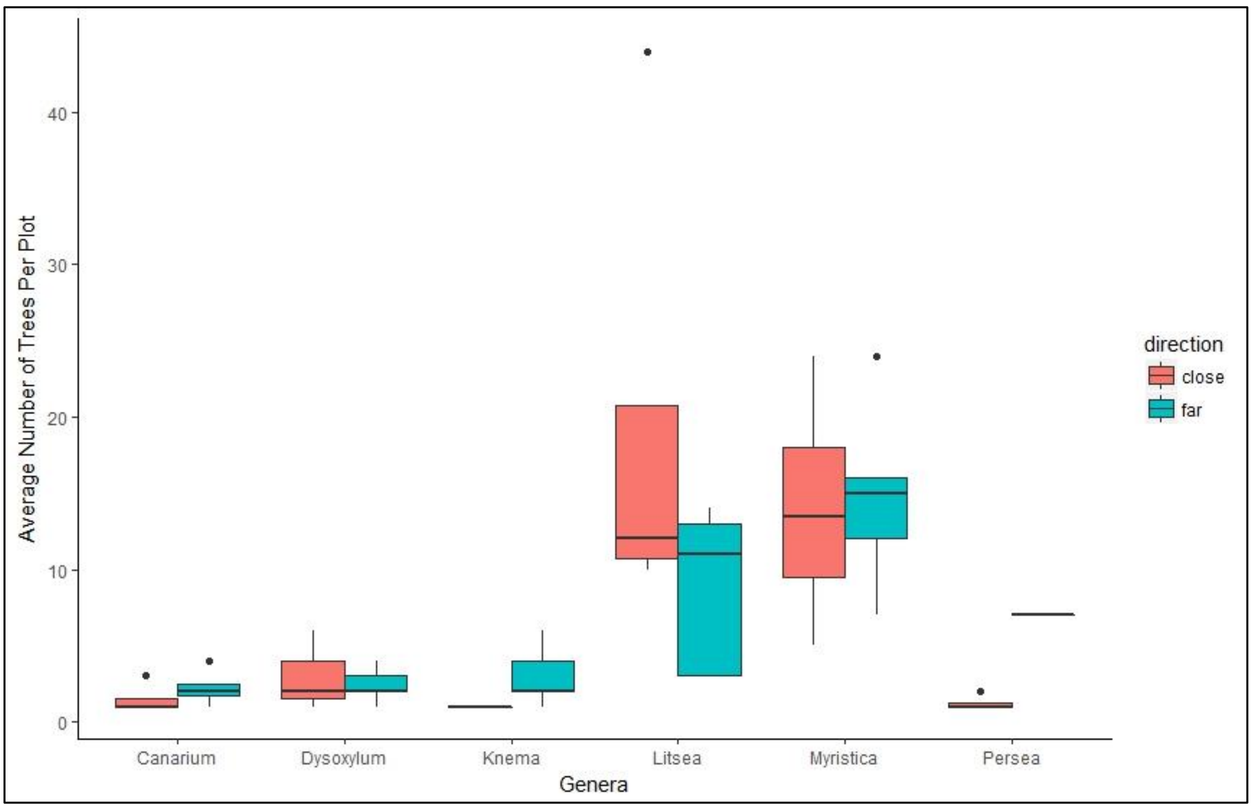

Figure 4. Average tree density for each species per hectare in “Close” and “Far” sites in Vazhachal Reserve Forest, Western Ghats, India.

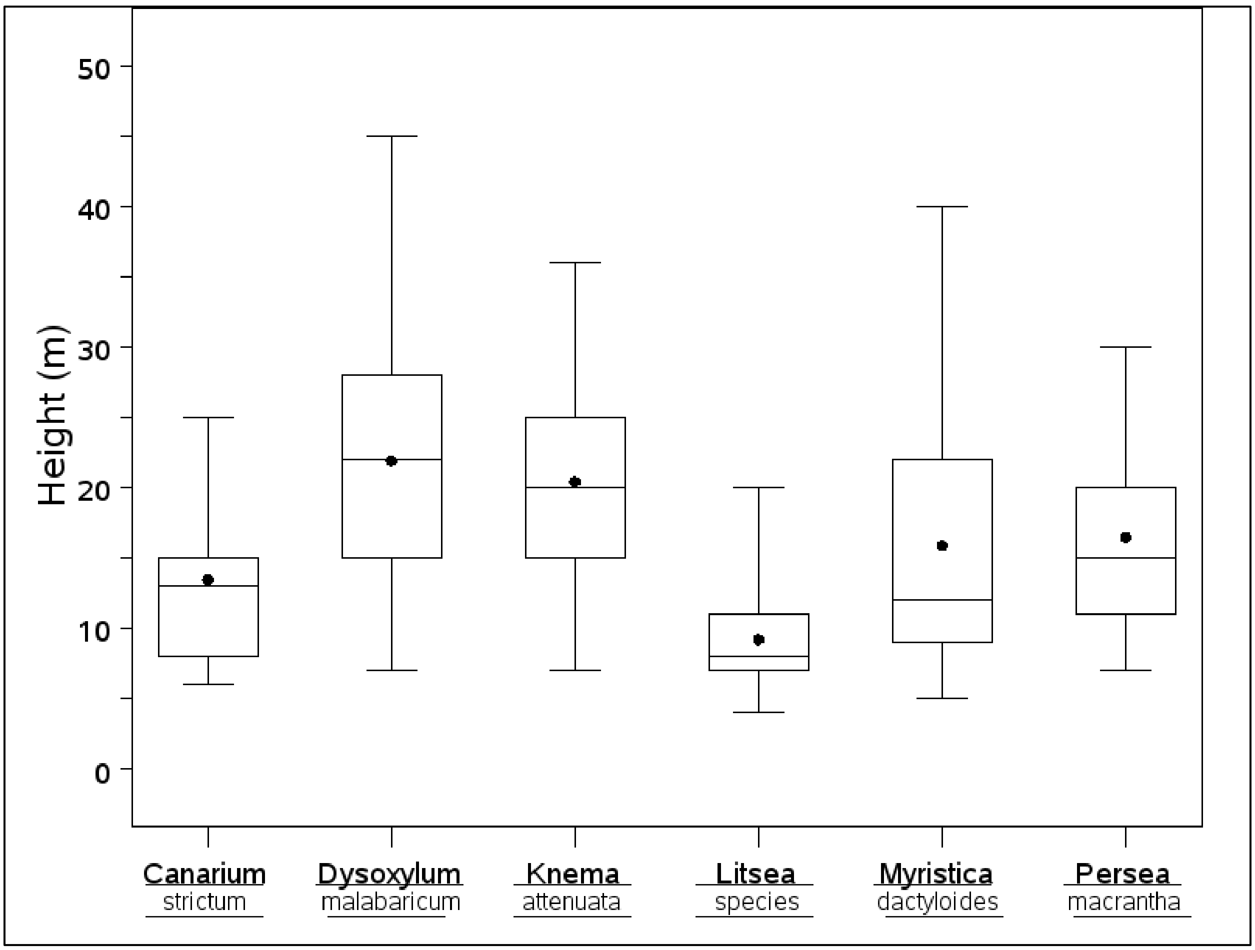

Figure 5. Distribution of the heights of all tagged trees across all species during monitoring period, from January 2013 to May 2015.

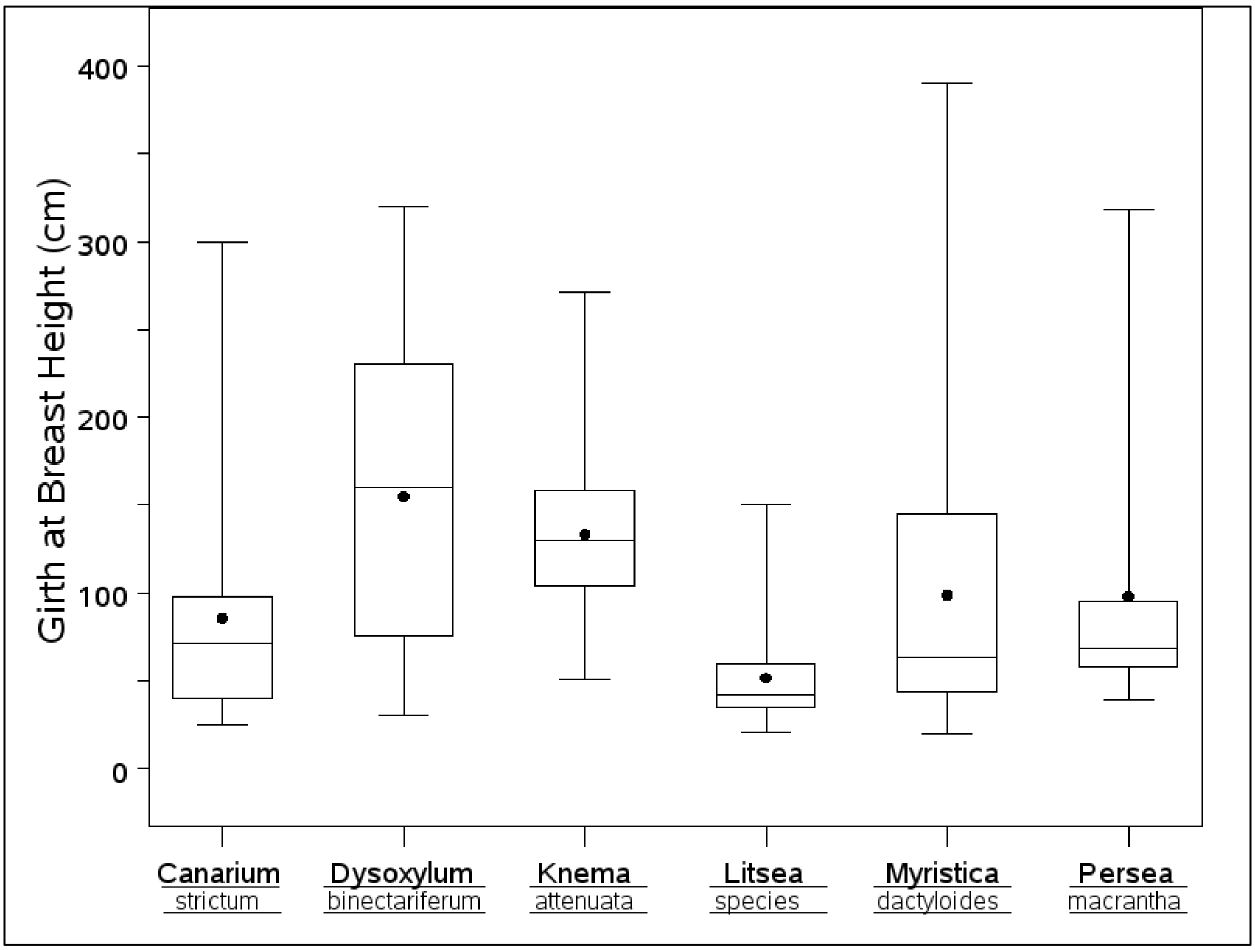

Figure 6. Girth at breast height of all six large-seeded tree species in the Vazhachal Reserve Forest, from January 2013 to May 2015.

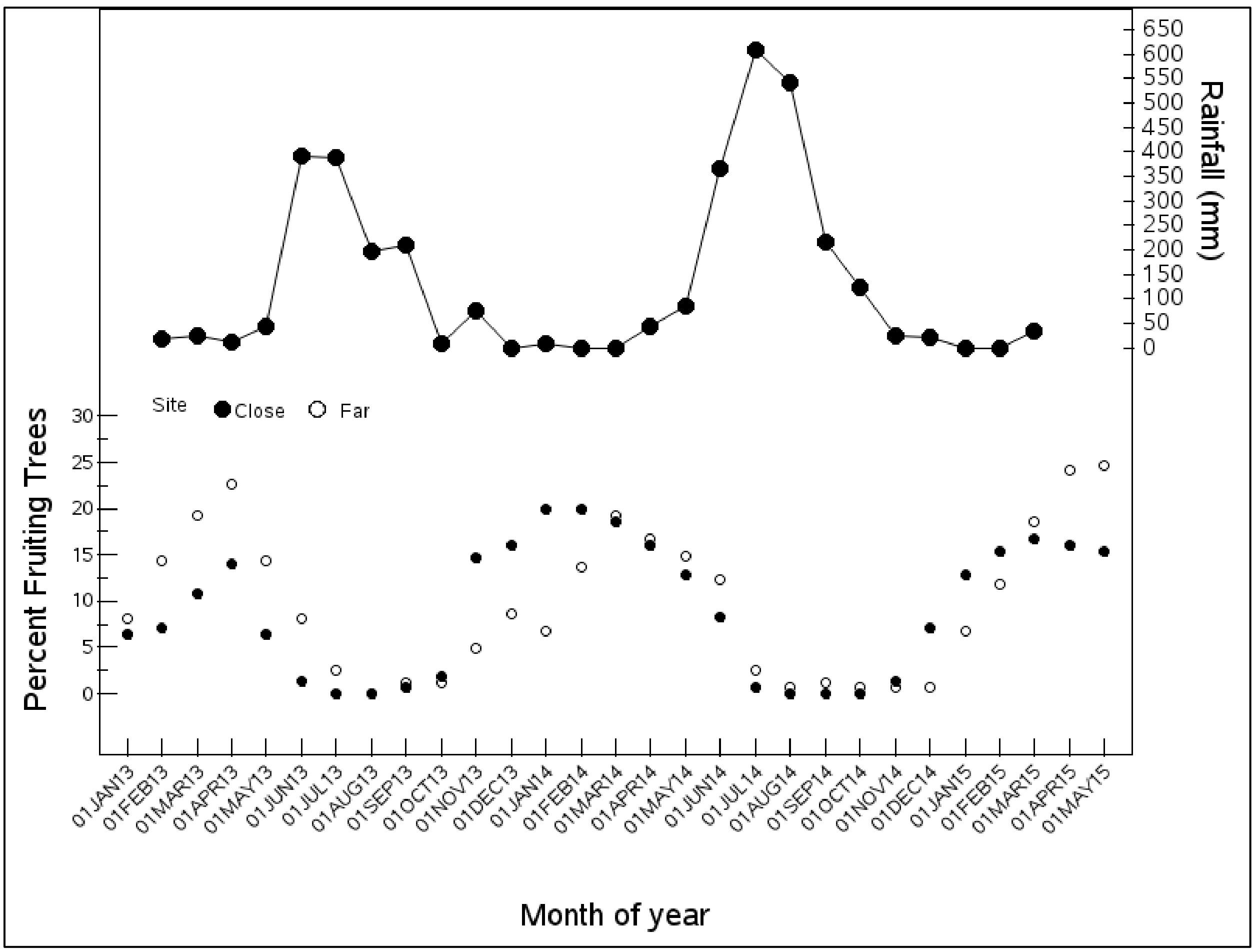

Figure 7. Fruiting phenology of all six large-seeded tree species in both “Close” (empty circles) and “Far” (solid black circles) sites with monthly rainfall in the Vazhachal Reserve Forest, from January 2013 to May 2015.

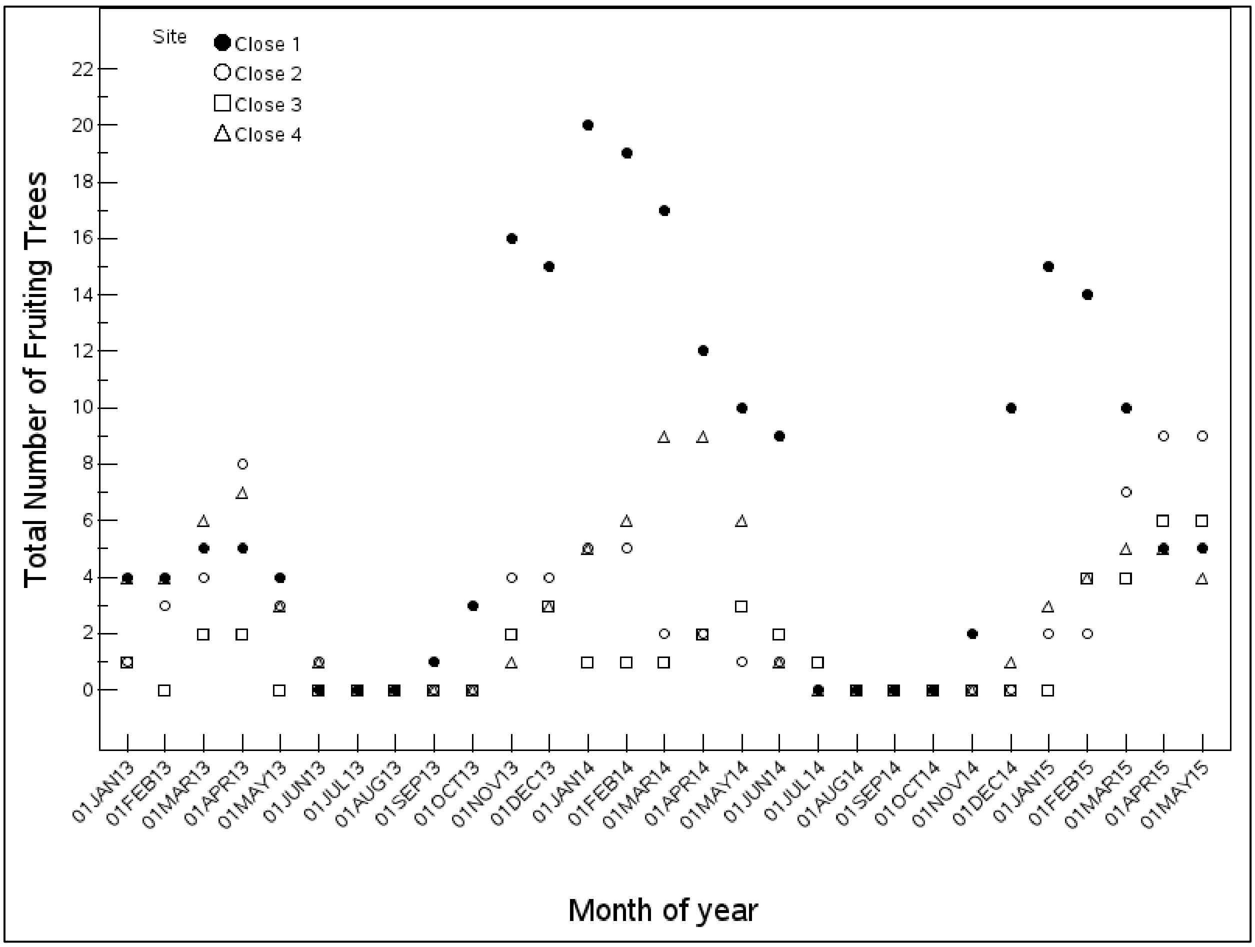

Figure 8. Total number of fruiting trees combining all targeted species across individual “Close” sites (C1, C2, C3, and C4) in Vazhachal Reserve Forest, from January to May 2015.

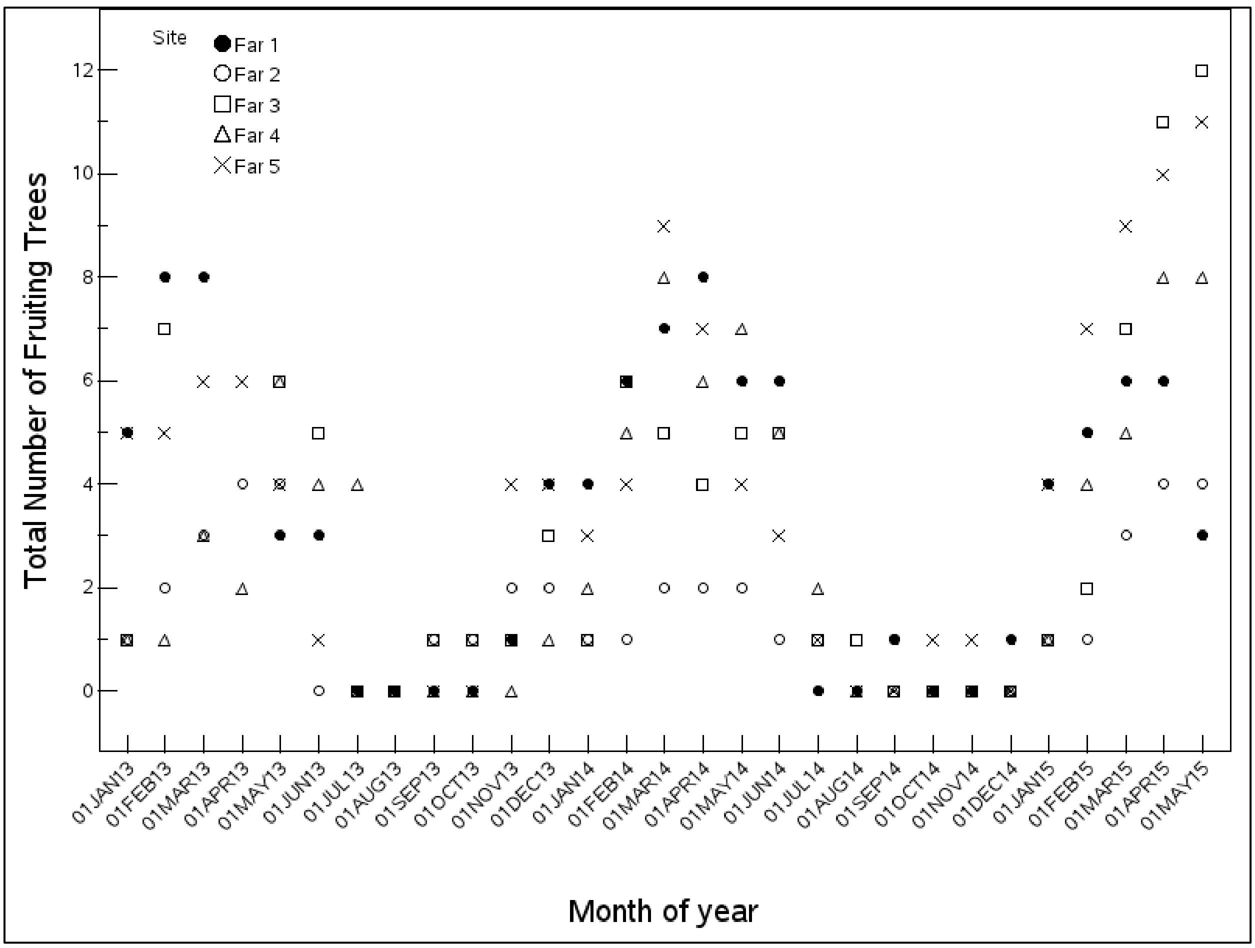

Figure 9. Total number of fruiting trees combining all targeted species across individual "Far" sites (F1, F2, F3, and F4) in Vazhachal Reserve Forest, from January to May 2015.

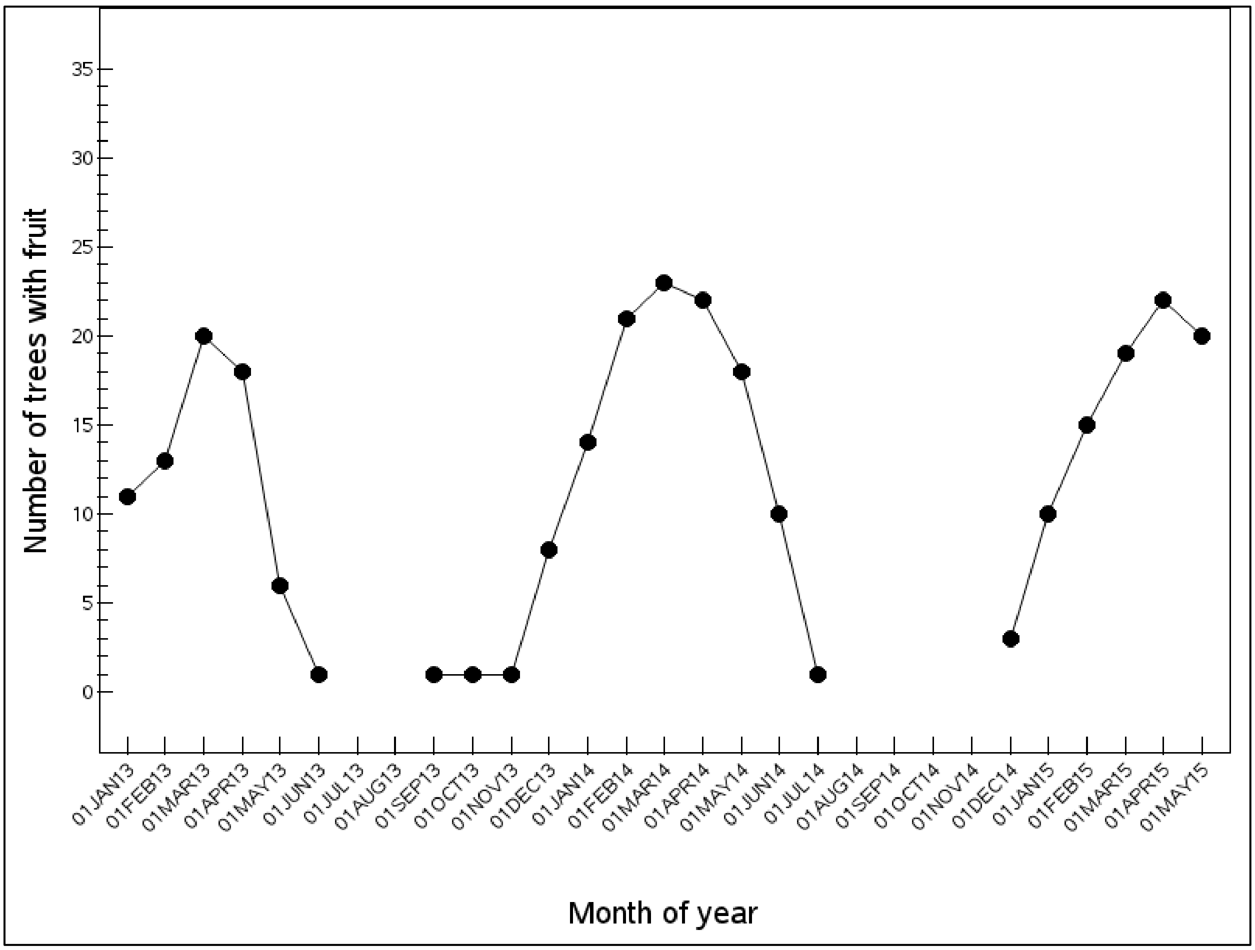

Figure 10. Fruiting phenology of *Myristica dactyloides* in the Vazhachal Reserve Forest from January 2013 to May 2015. (Gaps indicates no fruiting during a particular month)

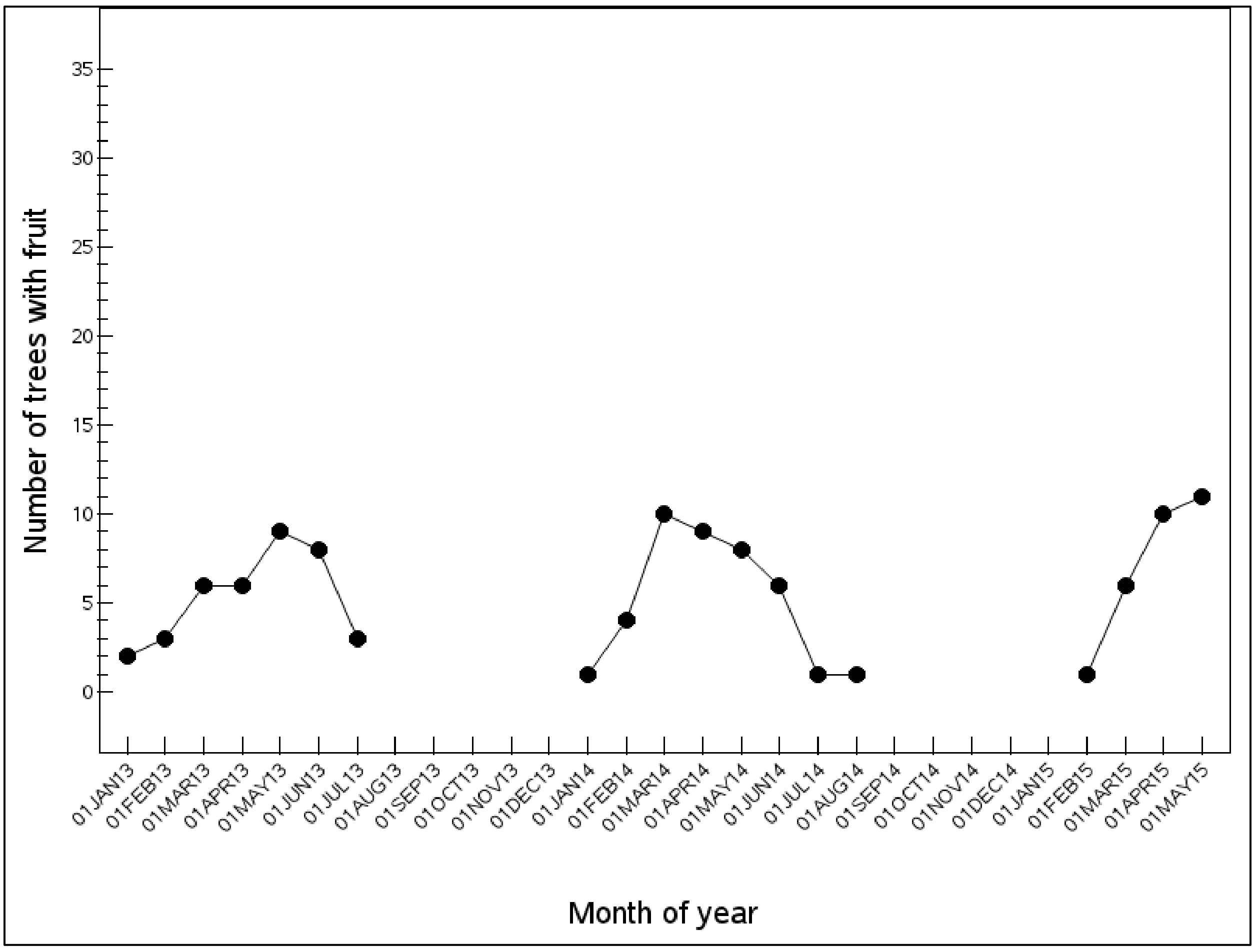

Figure 11. Fruiting phenology of *Knema attenuata* in the Vazhachal Reserve Forest from January 2013 to May 2015. (Gaps indicates no fruiting during a particular month)

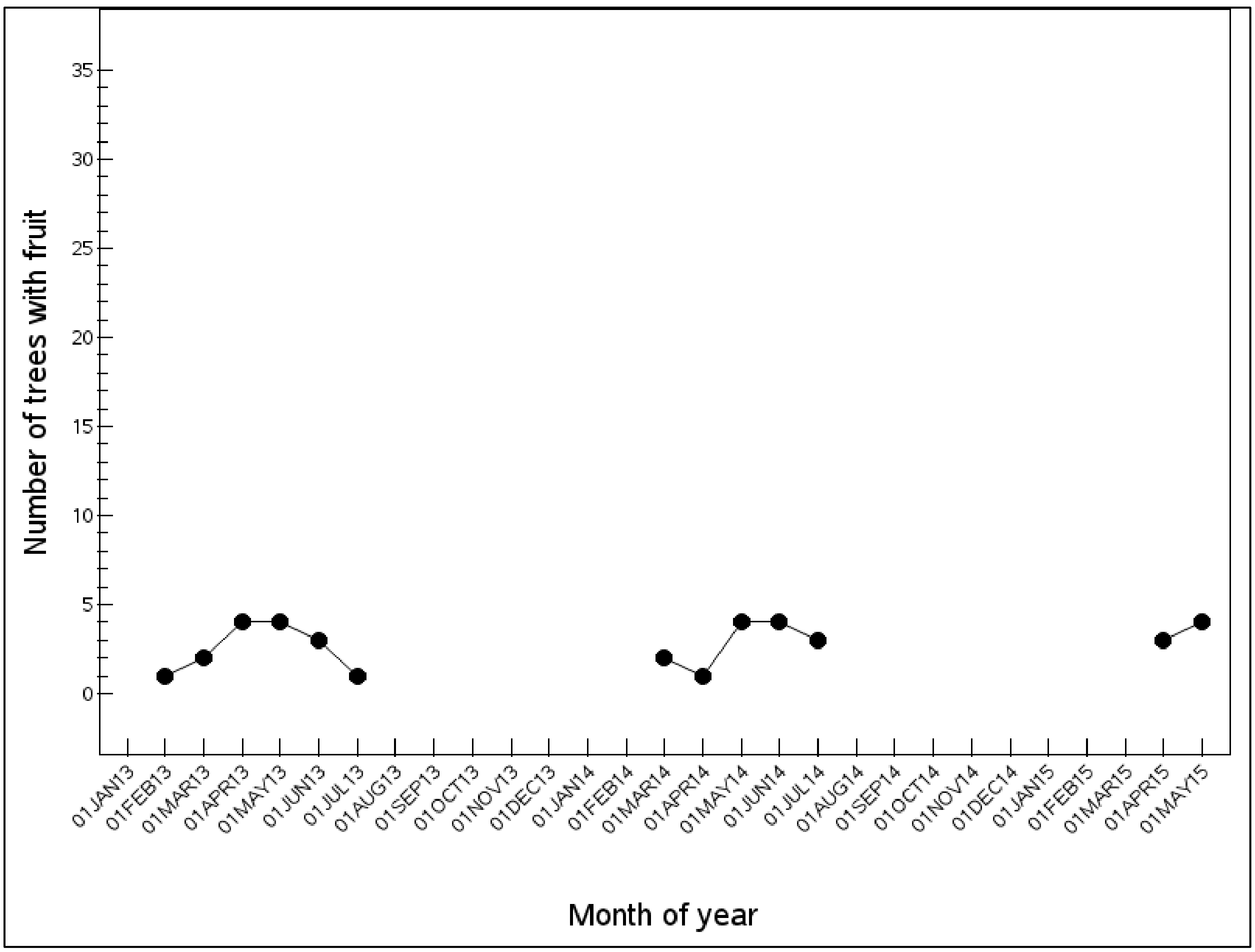

Figure 12. Fruiting phenology of *Dysoxylum malabaricum* in the Vazhachal Reserve Forest from January 2013 to May 2015. (Gaps indicates no fruiting during a particular month)

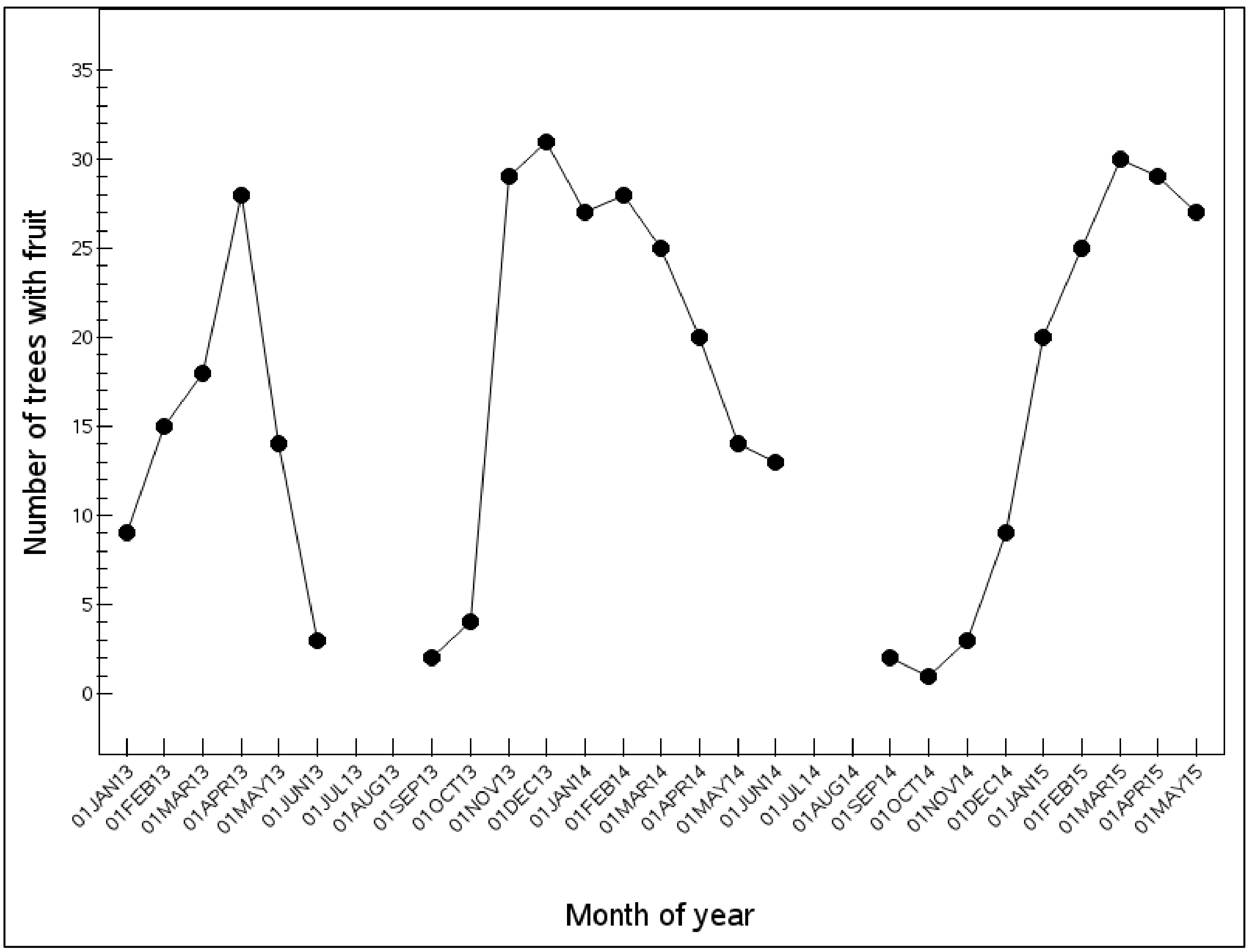

Figure 13. Fruiting phenology of the species of *Litsea* in the Vazhachal Reserve Forest from January 2013 to May 2015. (Gaps indicates no fruiting during a particular month)

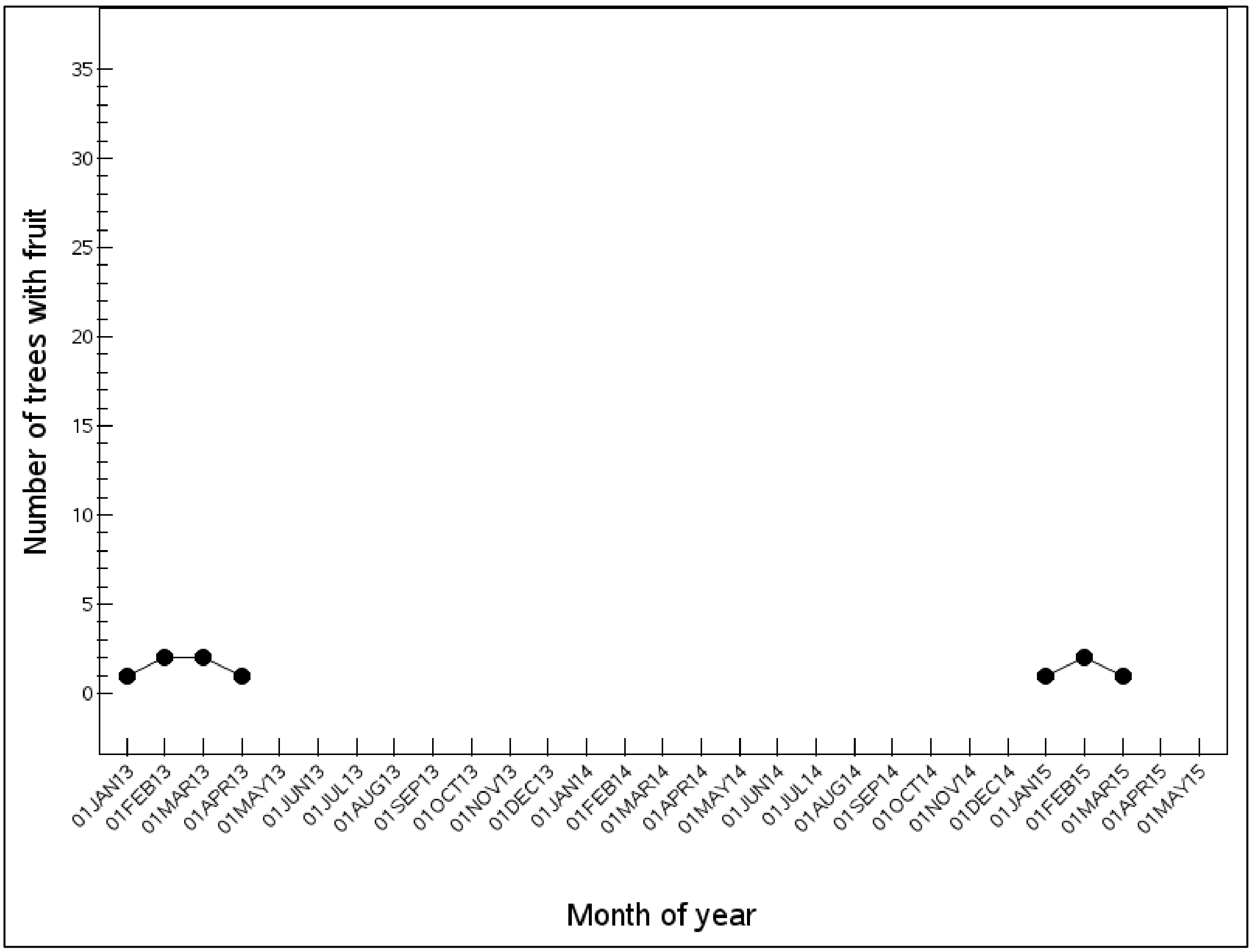

Figure 14. Fruiting phenology of *Persea macrantha* in the Vazhachal Reserve Forest from January 2013 to May 2015. (Gaps indicates no fruiting during a particular month)

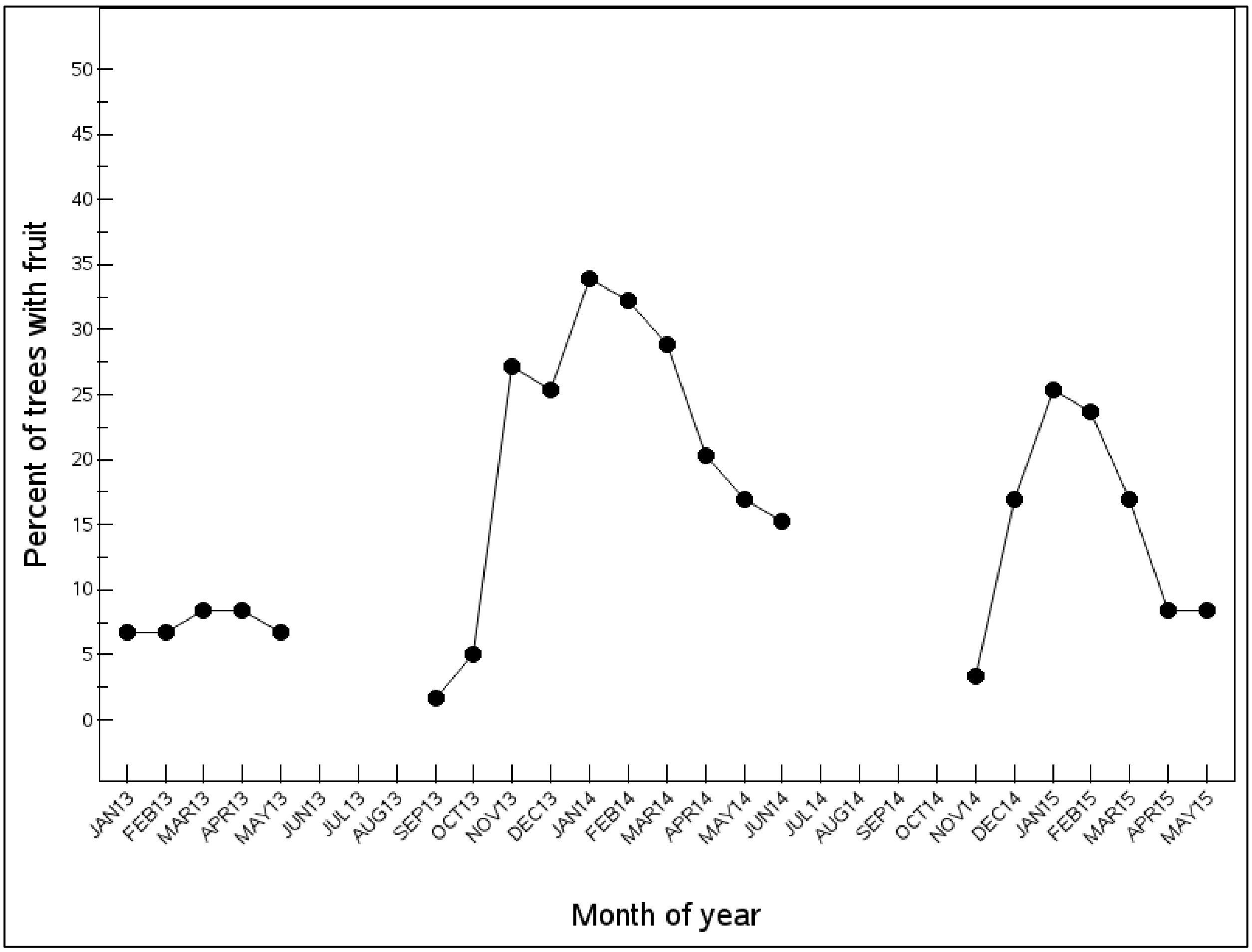

Figure 15. Fruiting phenology of all six large-seeded tree species at Site ‘C1’ in the Vazhachal Reserve Forest from January 2013 to May 2015. (Gaps indicates no fruiting during a particular month)

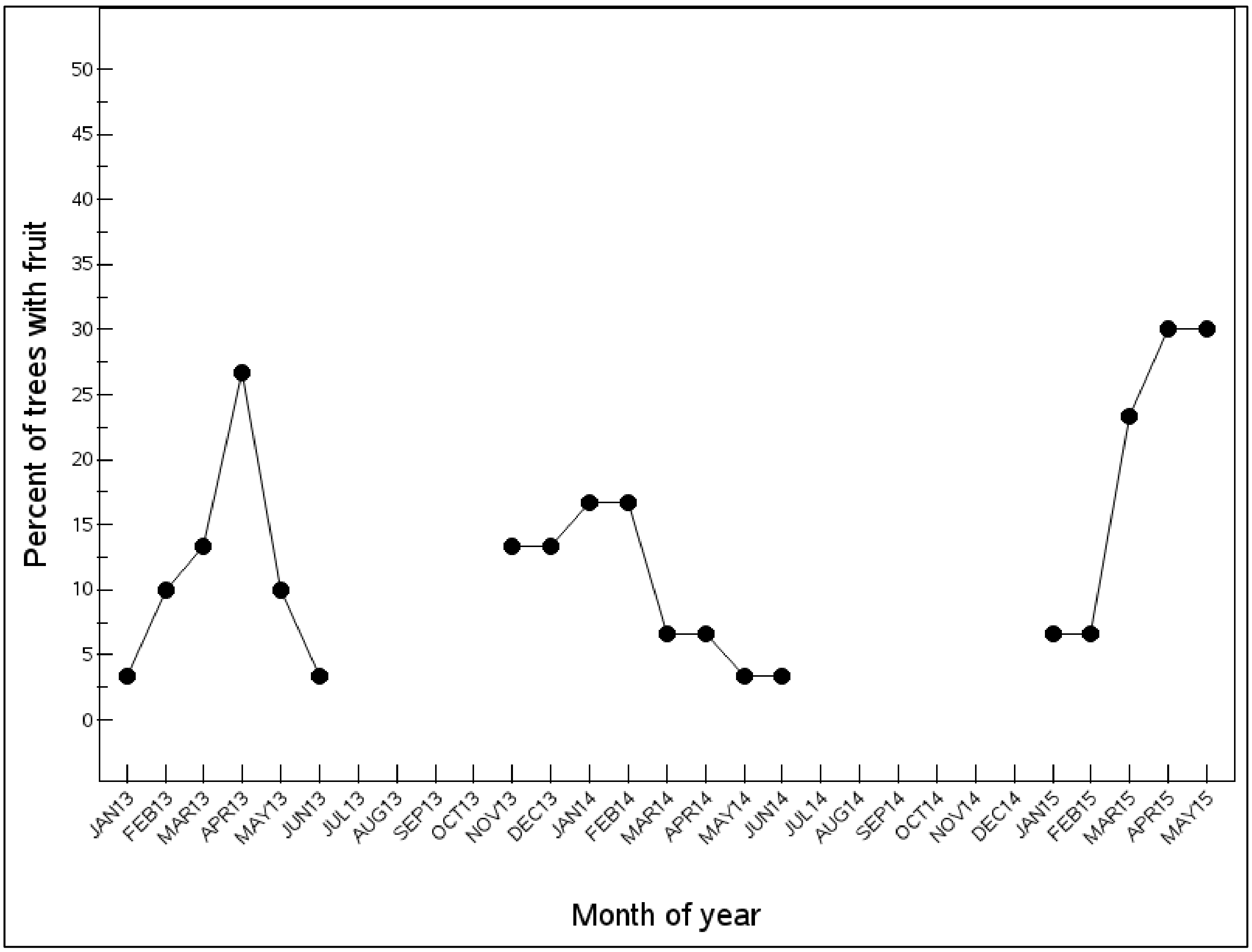

Figure 16. Fruiting phenology of all six large-seeded tree species at Site 'C2' in the Vazhachal Reserve Forest from January 2013 to May 2015. (Gaps indicates no fruiting during a particular month)

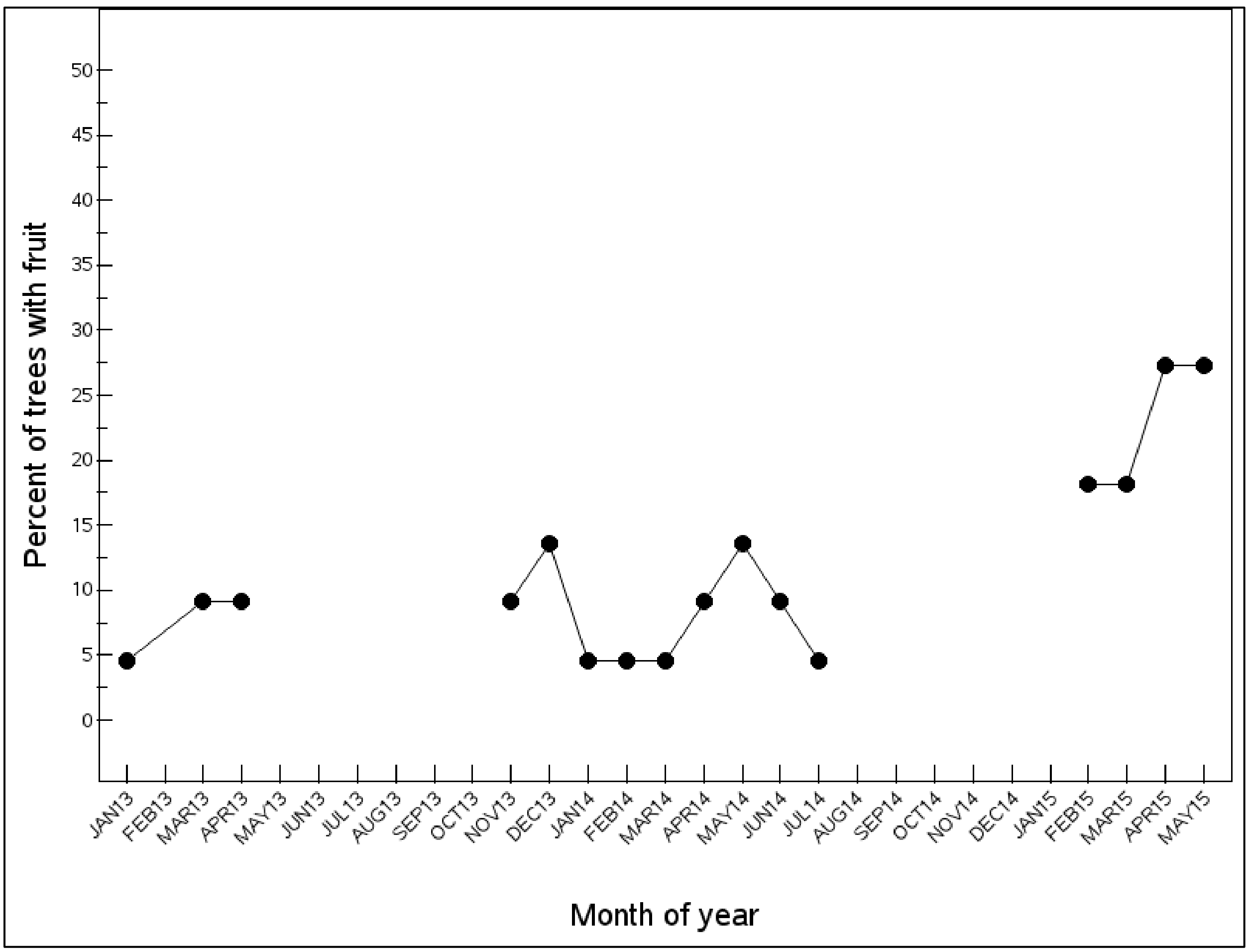

Figure 17. Fruiting phenology of all six large-seeded tree species at Site 'C3' in the Vazhachal Reserve Forest from January 2013 to May 2015. (Gaps indicates no fruiting during a particular month)

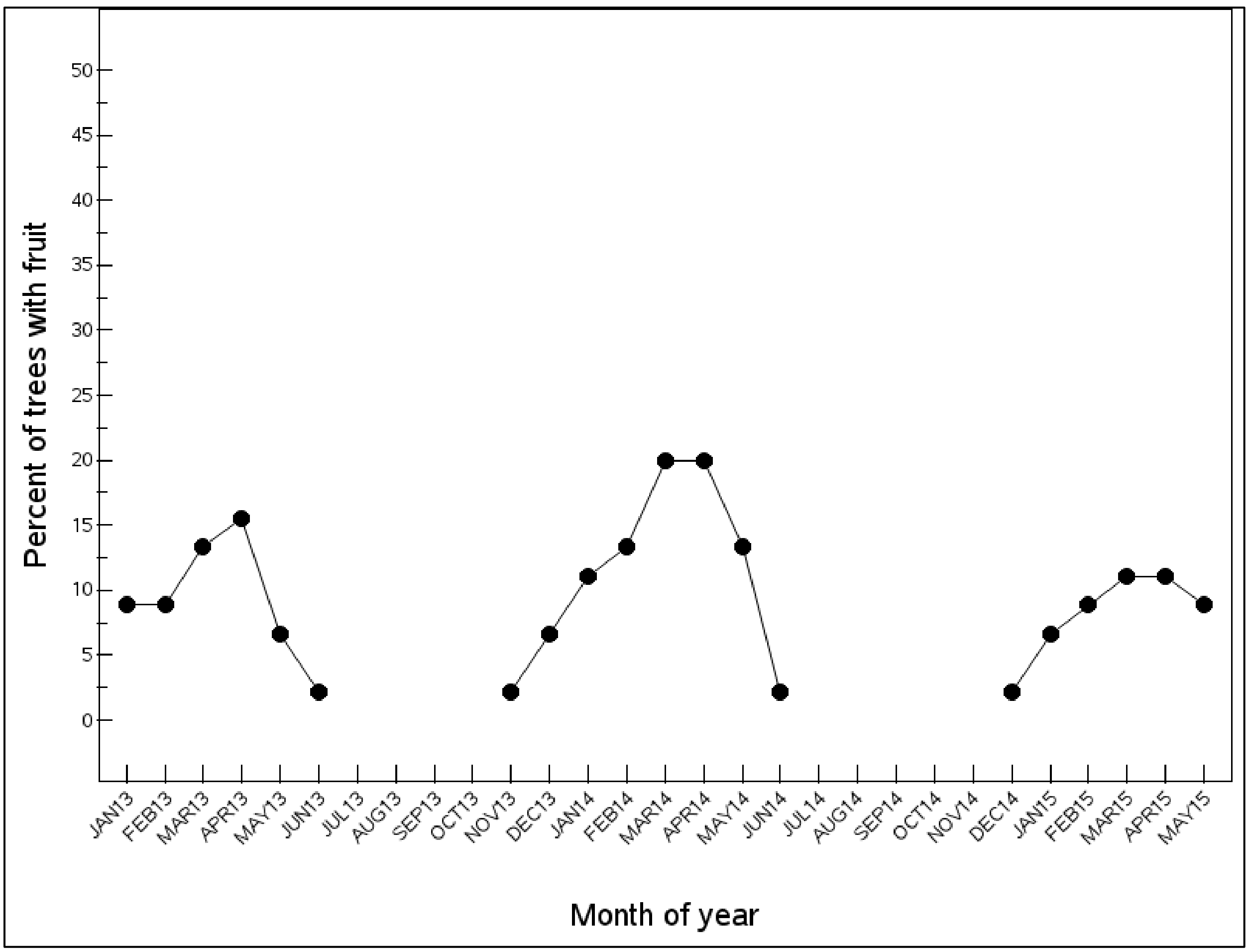

Figure 18. Fruiting phenology of all six large-seeded tree species at Site "C4" in the Vazhachal Reserve Forest from January 2013 to May 2015. (Gaps indicates no fruiting during a particular month)

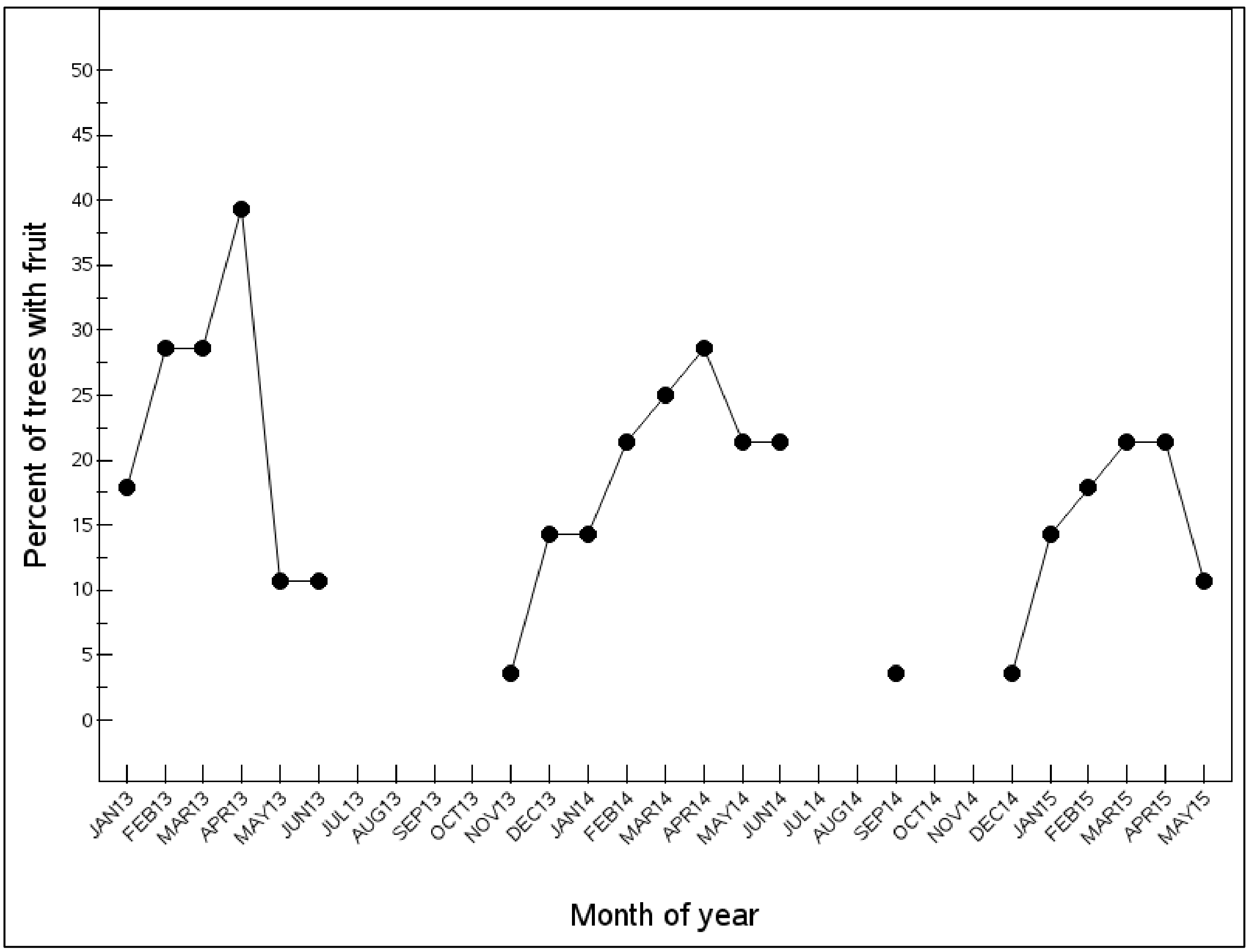

Figure 19. Fruiting phenology of all six large-seeded tree species at Site 'F1' in the Vazhachal Reserve Forest, from January 2013 to May 2015. (Gaps indicates no fruiting during a particular month)

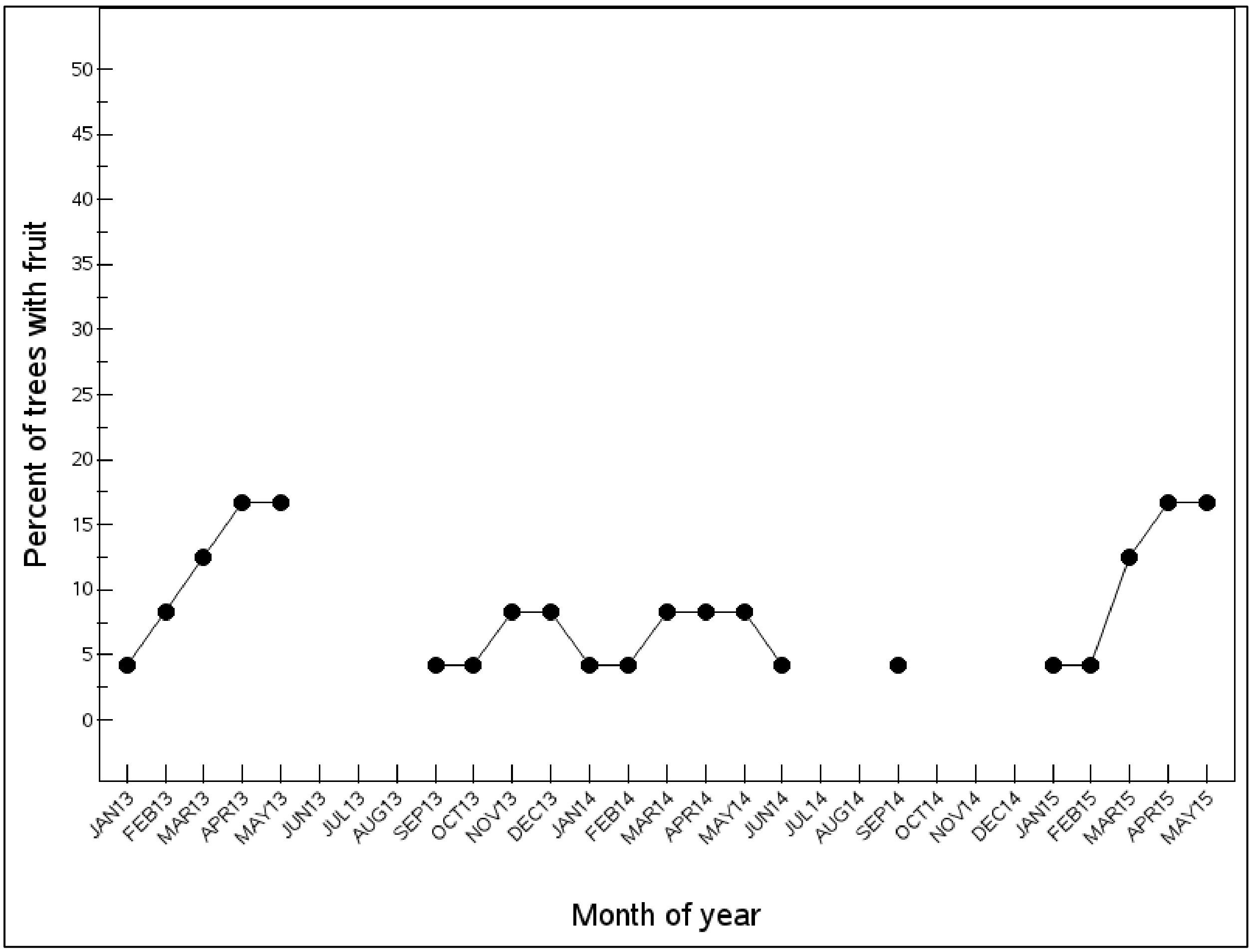

Figure 20. Fruiting phenology of all six large-seeded tree species at Site "F2" in Vazhachal Reserve Forest, from January 2013 to May 2015. (Gaps indicates no fruiting during a particular month)

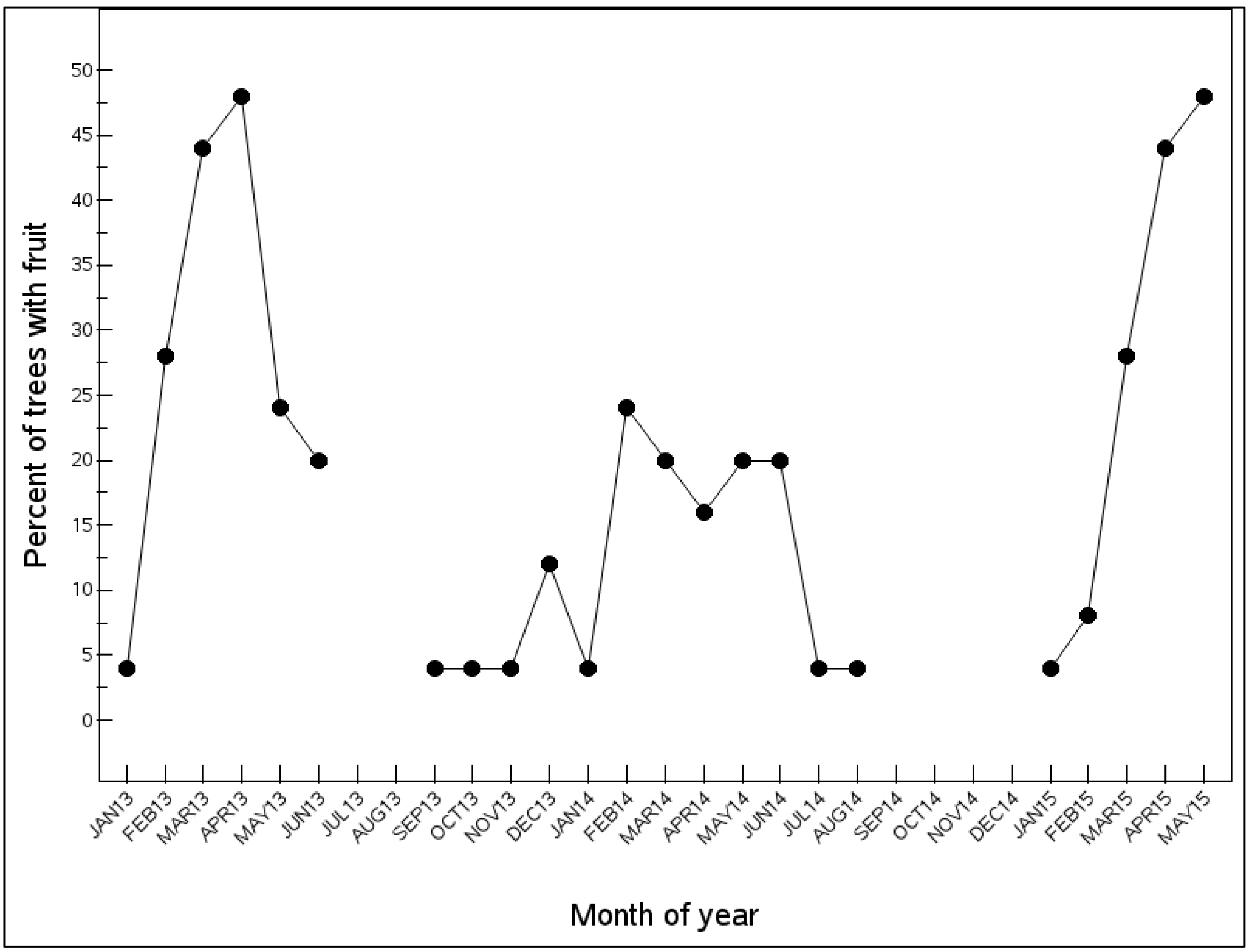

Figure 21. Fruiting phenology of all six large-seeded tree species at site 'F3' in Vazhachal Reserve Forest, from January 2013 to May 2015. (Gaps indicates no fruiting during a particular month)

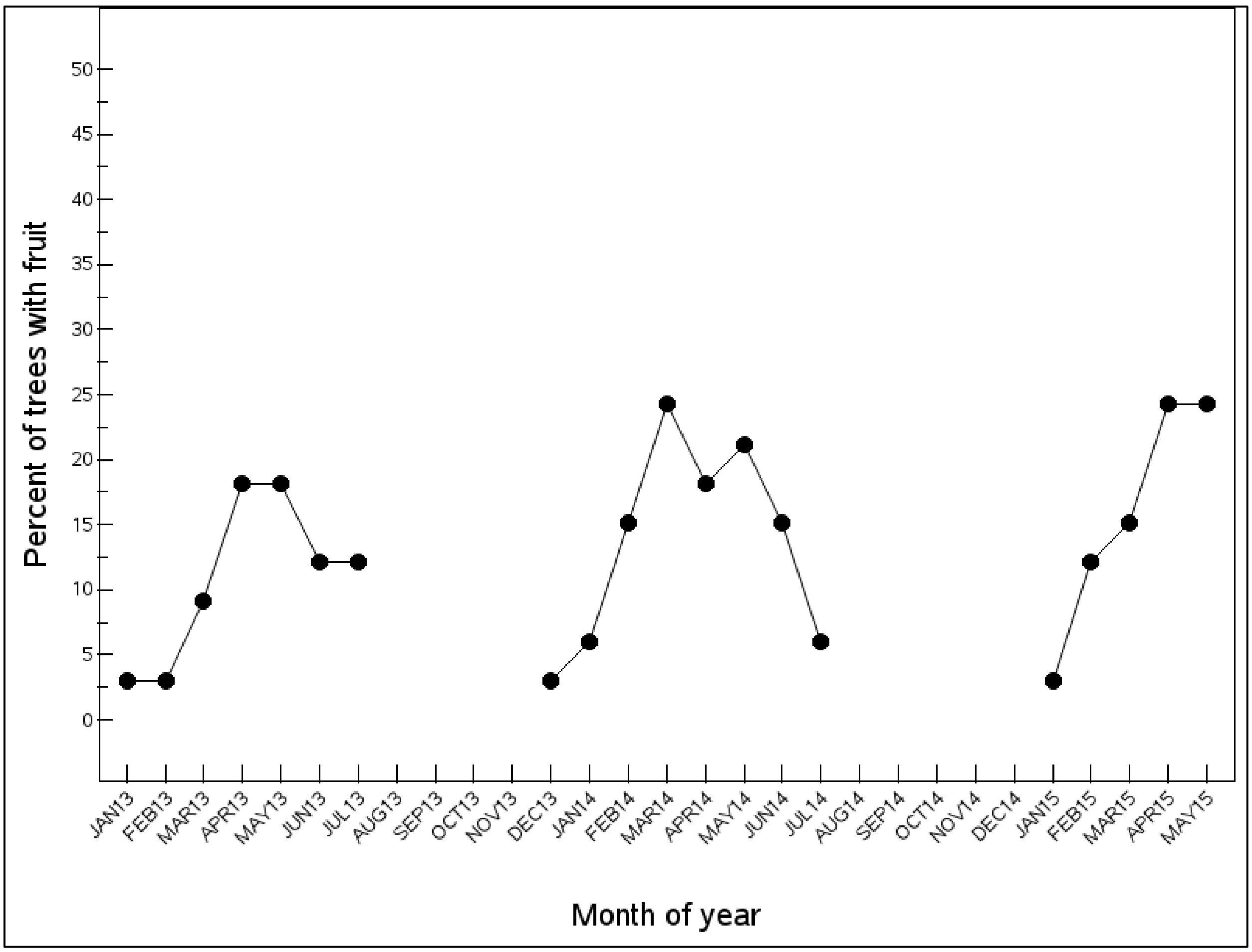

Figure 22. Fruiting phenology across six large-seeded tree species at site 'F4' in Vazhachal Reserve Forest, from January 2013 to May 2015. (Gaps indicates no fruiting during a particular month)

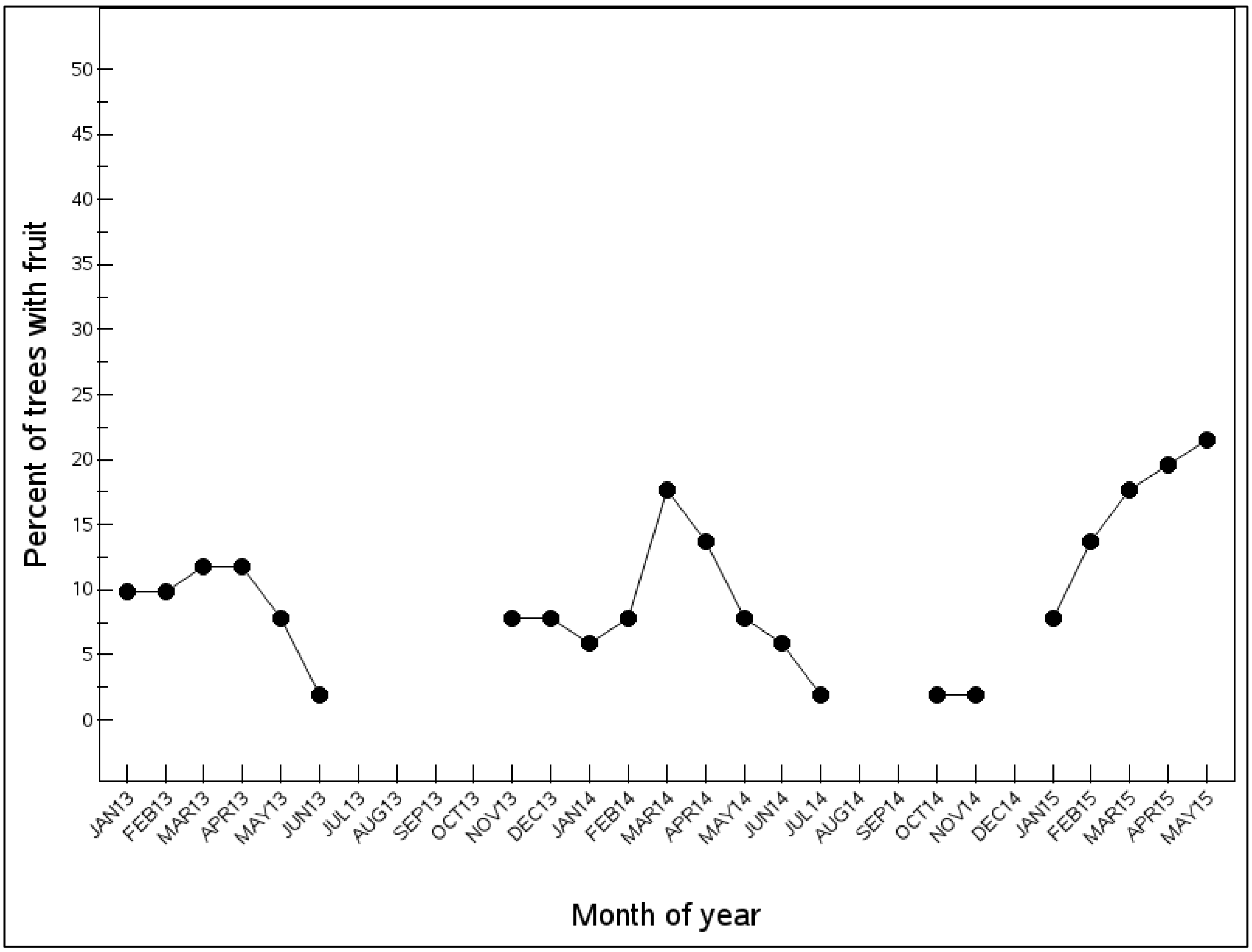

Figure 23. Fruiting phenology across six large-seeded tree species at site ‘F5’ in Vazhachal Reserve Forest, from January 2013 to May 2015. (Gaps indicates no fruiting during a particular month)

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Chapter 2.

Regeneration and survival of large-seeded tree species under Great Hornbill and Malabar Grey Hornbill nests in Vazhachal Reserve Forest, Western Ghats, India.

Abstract

The Great Hornbill (*Buceros bicornis*) and Malabar Grey Hornbill (*Ocyceros griseus*) are among the few large-bodied avian seed dispersers in the Vazhachal Reserve Forest in the Anamalai Hill Range of the Western Ghats of Kerala, India. In the present study, germination patterns and survival of seedlings and saplings of large-seeded species were documented in and around nest trees. The observed data indicates significantly higher numbers in front of the nests than at the back of the nests. These results indicate that hornbills are moving these seeds away from fruiting parent trees and transporting them to other germination sites where they can escape mortality due to host-specific pathogens, competition and other factors. At the genus level number of seedlings and saplings, and their survival over time was observed to be different for individual genus. Species of *Myristica* and *Dysoxylum* germinated in the highest numbers under the nest trees, but species of *Myristica* (93% survived) survived better than other genera, followed by species of *Dysoxylum* at 79%. This study was the first to record these patterns in forests adjacent to but outside of protected areas such as national parks and wildlife sanctuaries and can potentially act as important buffering zones in Western Ghats. Most of the large-seeded species considered in this study are also important livelihood resources for indigenous ‘Kadar’ tribal community. These findings will help enable the development of more effective conservation strategies for species of hornbill and large-seeded tree species in the Vazhachal Forest Division.

Introduction

The ecological relationships between flowering plants and fruit-eating birds and mammals date back 90 million years (Fleming and Kress 2011). Tropical forests are known to be florally very rich and diverse, which could result from a combination of ecological processes that have been proposed over the years by members of the scientific community (Janzen 1970, Hubbell 1979, Schupp 1992). A model proposed by Janzen (1970) to explain this tropical tree diversity and its distribution patterns points to the role of seed dispersers, which remove seeds from their parent trees and help them escape host-specific plant parasites under the parent trees and interspecific competition (Janzen 1970). The process of seed dispersal has been an important part of angiosperm evolution, since seeds' germination sites determine the composition, spread, and persistence of plant communities (Levin et al. 2003, Frohlich and Chase 2007). Not only are 88% of tropical tree species animal pollinated (Ollerton et al. 2011),but animals also disperse the seeds of more than 70% of tropical tree species, which in return fulfil their nutritional requirements (Howe and Smallwood 1982). In tropical forests this mutual dependency among animals and plants cannot be underestimated as the loss of one can negatively impact survival of the other. As this evidence suggests that fruit-eating animals play an essential role in the reproduction of many tropical plant species, especially fleshy fruits, which offer many animals critical source of nutrition (Fleming and Kress 2011). The evidence also points to the high diversity and abundance among animals, especially birds, that depend on such fleshy fruits and the influence of these frugivores on the distribution of these plant species. For example, Terborgh (1985) reported that 80% of the avian and mammalian fauna in Cocha Cashu, Peru was comprised of frugivores. Studies of fruit-frugivore interaction in tropical forests cannot be neglected if one seeks to understand how such biologically diverse systems are maintained over millennia (Nathan and Muller-Landau 2000, Condit et al. 2002, Naniwadekar and Datta 2013).

In the seed dispersal loop as outlined by Wang and Smith (2002) indicates that seed dispersal begins with fruit production and ends with the establishment of an adult plant, and this process includes several minor and major stages. There are practical limitations on studying the entire ‘seed dispersal loop’ because in most cases it is very difficult to follow the seed once it has been removed from the parent plant. Because of these constraints, only few examples of studies have looked at the entire seed dispersal loop (Herrera et al. 1994). The distribution of dispersed seeds, though influenced by several variables, depends most directly on the post-feeding habitat choices of the disperser. Most of the studies have focused on understanding the relative importance of a particular stage of seed dispersal on observed recruitment patterns such as documentation of seed rain in primate sleeping nests (Julliot 1997, Rogers et al. 1998, Voysey et al. 1999), mammal latrines (Dinerstein and Wemmer 1988, Dinerstein 1991, Fragoso et al. 2003), and middens or roosts of birds (Kinnaird 1998, Kitamura et al. 2004). Large-seeded species have a larger challenge since they are likely to depend on relatively small coteries of frugivores that can transport the seeds without damaging these structures (Howe and Smallwood 1982, Jordano and Schupp 2000, Tiffney 2004). The effectiveness of the disperser has both quantitative and qualitative aspects (Schupp 1993). However, studying qualitative aspect of efficient seed dispersal can pose many challenges such as long-term monitoring, and larger study sites causing it to be extremely labor intensive

Studying Asian hornbills can yield information about importance of seed dispersal in the tropical forests of Asia and in particular the Indian subcontinent. Asian hornbills are wide-gaped, large-bodied, wide-ranging avian frugivores, 70 – 100 % of whose diet is comprised of fruits (Kinnaird and O'Brien 2007). Across the old-world tropical forests of Africa and Asia, there are 14 genera comprising of total 61 species of hornbills. Asia alone, boasts spectacular degree of diversity, with 32 species of hornbills classed nine genera, all with high degrees of endemicity. Hornbills' unique breeding behavior, dietary requirement, and foraging habits distinguish them from other birds. They exhibit unusual nesting behavior, with female incarcerating themselves inside nest cavities during the breeding period. The breeding period can last for a few months depending on the species, and during this period the male is solely responsible for providing food to the female and the growing chicks. Hornbill nesting sites may therefore be important seed deposition sites as well, yet few studies have examined at hornbills' efficiency and efficacy as seed dispersers (Kinnaird 1998, Kitamura et al. 2008, Datta and Rane 2013). Kinnaird and O'Brien (2007), in their book titled 'Ecology and conservation of Asian Hornbills' called hornbills as "farmers of the forest" due to their wide-ranging foraging habits, predominantly frugivorous diet, capacity to fly over fragmented forest landscapes, and ability to handle fruits without damaging seeds granted by their wide gapes (Kinnaird and O'Brien 2007).

Asian tropical forests where hornbills occur span over 10,000 km from east to west and 4,200 km from south to north, covering a total of more than 8.3 million square km. Hornbills currently face various threats such as the hunting, especially of hornbill chicks, the direct and indirect effects of forest fragmentation, and logging and constant landscape level changes due to anthropogenic activities. The IUCN Red List shows that 34% of the 32 Asian species of hornbills as “Near Threatened”, 19% as “Vulnerable”, 9% as “Endangered”, and 6% as “Critically Endangered” (IUCN 2018). Many species including the ones occurring in India have also shown “Decreasing” trends in recent years. It is important to note that large portions of the once a contiguous forest where hornbills have roamed is now fragmented and this drastic reduction of contiguous forest poses a threat to the persistence of hornbill species since one of their nesting requirements is old growth trees (Kannan 1994).

Of the 32 species of Asian hornbills, nine occur in India, and four of these inhabit the forests in the Western Ghats: the Malabar Pied Hornbill (*Anthracoceros coronatus*) and Indian Grey Hornbill (*Ocyceros birostris*), endemic to Indian subcontinent, Malabar Grey Hornbill (*Ocyceros griseus*) endemic to Western Ghats, and the endangered Great Hornbill (*Buceros bicornis*). The present study focused on the Malabar Grey Hornbill and the Great Hornbill found within the elevational range of 200 to 1500 m above sea level in the southern Western Ghats. Past research on hornbills has had ‘focal species’ approach to understand nesting habitats, dietary requirements, breeding biology and was concentrated in areas that enjoy a high level of protection, such as national parks and wildlife sanctuaries but, few have examined the ecosystem services provided by species of hornbill (Kannan 1994, Kannan 1997, Mudappa and Kannan 1997, Kannan and James 1999, Datta 1998, Datta and Rawat 2003, Balasubramanian et al. 2004, Datta and Rawat 2004, James and Kannan 2009). More recent research on hornbills has begun to focus on forested lands that fall outside this network of protected areas, particularly forests adjoining protected areas, and community-owned and private forests, in order to understand habitat utilization by different species (Naniwadekar et al. 2015b). Most recent long-term studies of hornbills come from the northeastern India and there are very few long-term studies have been conducted in the southern Western Ghats in recent years to understand the efficiency of hornbills as seed dispersers. (Mudappa and Raman 2008, Naniwadekar et al. 2015a, Naniwadekar et al. 2015b, Viswanathan et al. 2015).

Studying the role of hornbills as seed dispersers is not only important for scientific understanding but is also a prerequisite for developing effective conservation strategies for hornbills and the plant species that depend on them for seed dispersal. The World Resource Institute reported concerns about threats to existing contiguous forested lands and forests' survival prospects across the Asian tropics (Bryant et al. 1997). Among the tropical forests of India, the Western Ghats represents an important ecoregion. with biodiverse forests and dependency of people on these forests for resources such as water, timber, non-forest products, land for agriculture. The Western Ghats is recognized as a global biodiversity hotspot, and its tropical forests harbor many endemics (Raman and Mudappa 2003). The mountain chain accommodates the highest human density (> 300 persons/ km^2) among all other global biodiversity hotspots (Mittermeier et al. 1998, Myers et al. 2000). Given its resource richness, the biogeography of the Western Ghats has also been altered over the years by commercial agro-forestry, commercial ago-forestry, hydropower projects, mining, and large-scale commercial plantations for tea, coffee, cardamom, *Acacia*, *Eucalyptus*, cashew, rubber, bananas, arecanut, and coconut (Nair 1991, William 2003, Kumar et al. 2004). Between 1920 and 2013 roughly 36% of previously forested land along the Western Ghats experienced loss of natural vegetation (Kumar et al. 2004). This has led to a four-fold increase in of forest fragmentation and an 83% reduction in existing forest patches. The Western Ghats of the

Kerala in particular, where the present study was carried out, occupies 17% of the total area covered by the Western Ghats of India, and just in this state has lost 63% percent of natural vegetation.

The Anamalai Hill Range along the Western Ghats in the state of Kerala is a stronghold for hornbill populations (Raman and Mudappa 2003, Mudappa and Raman 2008) but, only 37% of the total 1322 km^2 of remaining forests here is primary, and the rest exists in various degraded and fragmented stages scattered across protected and unprotected areas (Ramesh and Gurukkal 2007). Forty-three national parks and wildlife sanctuaries exist in the Western Ghats, but area outside these protected lands, while equally important, have received far less attention from the scientific community. Frugivores such as hornbills, which are highly nomadic species, and can fly across large distances, play an important role in dispersing seeds to fragmented and/or disturbed forest areas. The present study therefore sought to examine the role that hornbills play as seed disperser. The purpose was to understand the distribution of seedlings and saplings of large-seeded tree species as listed in next section under nest trees and their survival during 29 months of study period. It also looked at how seedling-sapling demography changed based on where these plants were established in relation to the nest trees.

Study Area

The Western Ghats is a long chain of hills spread across the west coast of India from 8^0 N near Kanyakumari in the south to 21^0 N at the river Tapti in the north (Reddy et al. 2016). The Western Ghats is narrowly distributed between 73^0 - 77^0 E and is less than 100 km wide for most of its length. It passes through Gujarat, Maharashtra, Goa, Karnataka, Kerala, Tamil Nadu and the union territory of Daman Diu. The Western Ghats enjoys a varied tropical climate. The average annual rainfall is 2,500 mm but varies with locality by an order of magnitude between 500 mm and nearly 7,500 mm. This variation can be largely attributed to varied distribution of rainfall across different seasons and elevation. The southern end of the Western Ghats has a short dry season (2 – 5 months) and is fed by both southwest (June - September) and northeast (October - January) monsoons, as opposed to the northern regions, which have a longer drier season (5–8 months) and receive rain mostly during the southwest monsoon.

The study described herein was carried out in the southern Western Ghats in the Vazhachal Reserve Forest in Anamalai Hill Range in Kerala, between 76^0 09' 06"–76^0 54'E and 10° 07' 08"-10° 23'16"N. The Vazhachal Forest Division falls in the Mukundpuram tehsil, Thrichur district (equivalent of a county) and Aluva tehsil, Ernakulam district. This forest division covers 413 sq. km in total area and encompasses five forest ranges: Athirappilly, Charpa, Vazhachal, Kollathirumedu, and Sholayar. The intense study sites were in the Sholayar Forest Range between 600 and 1100 m above sea level, encompassing approximately 30 sq. km of area. In the Anamalais, a stronghold for hornbill populations in the Western Ghats (Mudappa and Raman 2008, Bachan et al. 2011), only 37% of the 1322 km^2 of remaining forest is primary, and the rest exists in various degraded states scattered across protected and unprotected areas (Ramesh and Gurukkal 2007). According to a recent landscape study, the Anamalai corridor has been recognized as a critical link based on endemism, potential forest connectivity, ranges of landscape species, and its topography (CEPF 2007). In the state of Kerala some of these forests are connected by natural corridors, such as the riparian belt of the Chalakudy River (Kerala) that connects the Vazhachal area and the adjacent Parambikulam Wildlife Sanctuary to the reserve forests farther west. A conservation status survey carried out by Raman and Mudappa (2008) points to the importance of the Anamalai-Parambikulam-Vazhachal landscape for hornbill conservation, but also calls for more intensive studies in these sites. Many species, especially the MGH and GH, rely heavily on key forests like Vazhachal, that are joined to protected areas (Mudappa, and Raman, 2008). The 'Kadar' are a non-agricultural tribal community indigenous to the Anamalai Hill Range of Kerala state and have been displaced over the years and pushed outside national parks and reserve forest limits. They still have access to the forest and certain non-timber forest products such as honey, wild nutmeg, black and white dammar and fishing sites. Hunting of hornbill adults and chicks during their nesting season has been recorded in the study area, but since 2005 nest monitoring programs run by the Kerala Forest Department have partnered with members of the tribal community to protect existing hornbill nests. This participatory program has now become part of the Joint Forest Management. No signs of hunting were recorded during the study period.

Study Species

Asian hornbills are one of the charismatic species of these forests, and their size and unique casque makes them spectacular as well as conspicuous against the lush green backdrop of the tropical forest. The study presented herein was carried out on the western side of the southern Western Ghats and focused on two of the four species of hornbills found in Western Ghats, namely the Great Hornbill (*Buceros bicornis*) which is in the 'Near Threatened' category of IUCN Red list and the Malabar Grey Hornbill (*Ocyceros griseus*), which is endemic to Western Ghats. The Great Hornbill will be referred as GH and the Malabar Grey Hornbill as MGH from this point onwards. In Asian tropical forests hornbills are among the few large-bodied birds with high a degree of frugivory that have the ability to swallow and regurgitate large seeds unharmed and travel long distances across contiguous and fragmented landscapes. Because of these features, they may play crucial role in the dispersal of large-seeded tree species and ultimately to maintaining floral diversity.

The GH is the largest of the three species in to genus *Buceros,* weighing up to 3,400 g and with a body length of 95 - 105 cm. This species is boldly colored with black and white plumage and brightly colored eye and colorful throat regions. The casque unique to hornbills is reddish yellow in GH with large yellow bill. There are slight differences of coloration and size between males and females. The overall coloration of the female is similar to that of the male, but the orbital skin is reddish in females as opposed to bare in the male GH. The back of the casque in females has an orange-reddish patch but is black in males. GH produces a very conspicuous loud sound 'kok' that is repeated at regular intervals and can be heard from as far as 500 m in a thick evergreen tropical forest of the Western Ghats. GH in India have a disjunct distribution, occurring in north, north-east and south India. GH is territorial, and a monogamous species and the nesting period ranges between 113 and 140 days. During this period the female incarcerates herself inside the cavity and the male responsible for feeding her and the chicks. This also makes them vulnerable to hunting pressure. In addition to habitat loss this species has faced hunting pressure as hornbill meat has been used for food and as medicine by tribal communities across its range and has resulted in population declines (Kannan 1994, Datta 1998).

MGH, on the other hand, is among the smaller hornbills and belongs to the genus *Ocyceros*, which includes three species, two of which occur in India. MGH is a smaller grey hornbill with a size between 45-50 cm and weighs under 400 g. Interestingly, among the two species of *Ocyceros* MGH is endemic to tropical evergreen forests of the Western Ghats, whereas the other Indian Grey Hornbill (*Ocyceros birostris*) is the only Indian hornbill species that is not confined to forests. The MGH unlike other hornbills, lacks a conspicuous casque and instead has a low-ridge like structure. its bill is long and curved, with a yellowish orange tinge, and its head and under sides have white streaks. The female MGH is slightly smaller than the male and has a paler-colored bill with a dark brown iris, unlike the golden brown in the male. Similar to nesting behavior of GH, the MGH female also incarcerates herself inside the nest cavity and the nesting period can last on average up to 90 days in the Western Ghats. Even though this is a commonly found species in the Western Ghats, little research has been carried out its to understand its role in dispersal of large-seeded tree species (Mudappa 2000, Maheswaran and Balasubramanian 2003).

The populations of GH species have been on decline due to habitat loss, forest fragmentation and their commodification as pets, for body parts, and as a result, this species has been enlisted in Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES - Appendix 1). MGH Populations are sympatric with GH populations in southern Western Ghats. A survey carried out by Raman and Mudappa (2008) noted that MGH populations in Anamalai are more adaptable to plantations in this landscape of Anamalai and fragmentation than GH populations (Mudappa and Raman 2008). MGH is fairly common in the study area and has been categorized as “Least Concerned” on the IUCN Red list, although it is still experiencing population loss (Birdlife International 2016).

In this study, five genera of large-seeded species of trees were considered: namely *Litsea*, *Myristica*, *Knema*, *Canarium*, and *Dysoxylum*. All of these genera are known to produce large seeds (>2 cm) and produce lipid-rich fruits. Since this study involved monitoring seedlings and saplings, and species-level identification is difficulty, the analysis was done only to the genus level. The family Myristicaceae (commonly called as wild nutmegs) includes the genera *Knema* and *Myristica*, which have been studied extensively across the Asia-Pacific region, but no studies from the south Western Ghats in India have examined them in relation to the effects of seed dispersal by hornbills at their nest sites. The only studies that have looked at impacts on recruitment and establishment come from North East India (Datta and Rane 2013). Myristicaceae is a diverse family, with 500 species and 20 genera spread across the pantropical region and it is listed as one of the most important tropical tree families (Kitamura and Poonswad 2013). Members of the genus *Myristica* produce dehiscent fruits which display a bright orange-red aril when ripened, attracting large-bodied frugivores such as hornbills and certain pigeon species. *Myristica dactyloides,* commonly found in the present study area, is over-harvested for its seeds and aril, both of which are used as spices across the globe. Most harvest is unregulated and unchecked in this part of the country (Haridasan et al. 2015). Tribal community members typically harvest only arils and discard the seeds and as a result, during the study, many piles of discarded seeds were observed in the forest (pers. obs.). The genus *Knema* is also known to produce dehiscent fruits, that display bright red aril when the fruits ripen. *Knema attenuata* is the commonly found in the study area and during fruiting season, it is frequently visited by hornbills and Mountain Imperial Pigeons (pers. obs.). The fruit size is between 2 and 4 cm, which is slightly smaller than that of *Myristica dactyloides* (4 - 6 cm).

Dysoxylum belongs to the family Meliaceae and is commonly called as white cedar. Trees of species of *Dysoxylum* are large canopy trees that are endemic to the evergreen and semi-evergreen forests of the Western Ghats between 200 and 1,200 m in elevation above sea level. *Dysoxylum malabaricum* Bedd. grows to a height of 30-40 m or more. *Dysoxylum. malabaricum*, commonly known 'Vellakil', produces a capsular fruit that varies in size from 5 to 7.5 cm and, once ripe, exposes 3 - 4 seeds along its furrows (Ved et al. 2015). It is known for its sweet-scented wood, which, like its fruits, possesses medicinal properties, which in conjunction with its cultural importance, make it vulnerable to commodification. Tribal communities have long used the white cedar's wood and fruits across its distribution range, and the populations of *D. malabaricum* have declined over the years (Bodare et al. 2013). Although *D. malabaricum* has not yet been assessed by the IUCN Red List, it has already been categorized as Endangered (EN) under the Indian National Threat Assessment using the same criteria as the IUCN(Bodare et al. 2013).

Canarium strictum Roxb. belongs to the family Burseraceae and is a commercially harvested species throughout South and Southeast Asia for the hard resin that can be extracted from its bark. The tapping techniques used on *C. strictum* have been shown to negatively impact the population dynamics and community structures of the species. The indigenous tribal 'Kadar' community in the Vazhachal forest region has also been reported to collect resin, but no study has assessed the impact on *C. strictum* populations in this region. Few studies have evaluated the impact of harvest techniques on tree populations elsewhere in India, and none of them has looked at the role that hornbills play in recruiting seedlings of this species (Varghese and Ticktin 2008).

Tropical evergreen forests on Asia are known for plant diversity within family the Lauraceae, to which the genus *Litsea* belongs. *Litsea* is one of the most diverse tree genera, with fifty-two species of evergreen trees and shrubs distributed across tropical and sub-tropical Asia and North and South America. There are 44 species of the genus *Litsea* distributed across India from the north east to the peninsular India. Regarding scientific publications related to ethnobotanical studies and pharmacological research on the genus *Litsea,* India is one the leading countries worldwide. Species belonging to this genus occur commonly in forests near human settlements in the study area (pers. obs.). Although many studies have assessed medicinal properties, none have examined its seed dispersal and recruitment in tropical forests (Wang et al. 2016).

Methods

For this study three hornbill nests were selected to provide insights into their role in dispersing the seeds of large-seeded tree species. Two of the nests at sites 'D' and 'P', belonged to Great Hornbill, and the third site, 'T' belonged to Malabar Grey Hornbill. All three were located in the Sholayar Forest Range across the Sholayar water reservoir and away from tribal settlements. All three nest sites were selected being feasible to access every month for data collection and monitoring. These nest sites were known to tribal assistants who helped locate them in the begining of the study period and have been monitored in the past through the Forest Department's nest monitoring program. The Great Hornbill nest sites 'D' and 'P' were located on the trees of species *Palaquium ellipticum*, which is one of the dominant evergreen climax tree species in wet evergreen forests of Vazhachal region, and the nest at site 'T' was located on *Dysoxylum malabaricum* tree. Each nest was active or inactive at different times during the study period, which lasted from January 2013 until May 2015. The nest of Malabar Grey Hornbill at site 'T' was active only during 2013 and was not occupied during 2014 or 2015. The nest at site 'P' was not occupied by the GH pair during the 2013 or 2014, and although the pair was observed visiting and perching on the nest tree during 2015 they did not not resume the nesting. The Great Hornbill pair successfully occupied the nest at site 'D' only in 2015, the last year of the study period. At each nest site obstruction such as fallen branches, trails, or a tree growing beneath the nest entrances were recorded. No such obstruction was were observed at nest site 'T'. Nest sites 'D' and 'P' each had a tree growing in front of the nest at 5 m and 6 m, respectively, and these trees' growing crown may have deflected falling seeds that might otherwise have fallen directly in frot of the nest.

The efficiency of hornbills as seed dispersers was examined by comapring the seedling and sapling density of large seeded plant species at the front of the nest cavity (potentially areas with high seed rain), on either side of the nest cavity and behind the nest tree (where no seed rain is assumed to occur). To understand seedling and sapling demography under the nest, six quadrats, each 4 m^2, were established under each nest tree. The study design was adapted and modified from the Kitamura et al's. (2004) hornbill nest study. The direction faced by the nest entrance was identified as a crucial factor in seeds dispersed by hornbills at all nest sites. As such, quadrats were placed along four radii at 90^0 intervals around the base of the nest tree. Four quadrats, one in front of the nest (F2), one quadrat behind the nest (B), and two on each side (S1 and S2) were placed 5 meters from the nest tree. Two additional quadrats were also placed at 1 m (F1) and 9 m (F3) in front of the nest entrance to measure the effect of distance from nest tree on seedling abundance and survival. The borders of the quadrat had to be maintained and monitored periodically in case of uprooting by wild animals, wind, or rain.

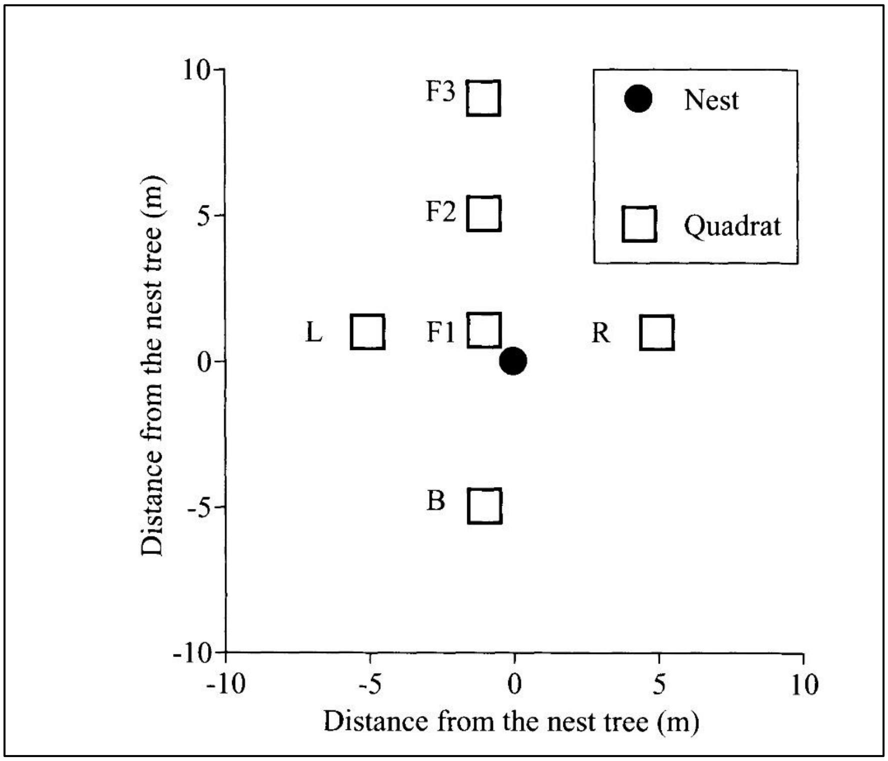

Figure 1. Layout design of quadrat locations (4m^2, open squares) used for studying seedling and sapling density at nest adapted from Kitamura et al 2004.

Seedlings and saplings in all six quadrats under each nest tree were tagged, identified to the genus level and categorized by height. The seedlings and saplings were tagged irrespective of whether the hornbill nest was active or inactive for the period of the study. Four height classes were assigned, <30 cm (seedlings), 30 - 50 cm (large seedlings), 50 - 100 cm (saplings), and 100 - 150 cm (large saplings) (Naniwadekar et al. 2015c). This study represents an effort to provide a snapshot of seedling and sapling demography at a particular moment in time. A total of 72 seedlings and saplings were assigned tags with temporary identification codes, and their heights were recorded. Of the 72 individually tagged plants, three were eliminated as identification to genus level could not be confirmed. Each quadrat at all nest sites was monitored every month, and survival rates among the tagged individuals were recorded. Seedlings that could be identified were not considered for the analysis in this study. It should be noted that all the seedlings and saplings of targeted genera were tagged irrespective of the year that they germinated as long as they were in the seedling or sapling height classes at the time of the study.

Analysis was carried out in R (version 3.4.3 (2017-11-30)). Packages 'ggplot2' (Wickham 2009), 'dplyr' (Wickham et al. 2017), 'tidyrr' (Wickham and Henry 2018) and SAS 13. 1 (SAS Institute Inc. 2013). To analyze the differences in abundance of seedlings in six quadrats in four directions, the generalized linear model was applied using the "GLIMMIX" program in SAS.

Results

There were on average 23 seedlings and/or saplings tagged per nest in the study area. The front quadrat had an average of seven seedlings-saplings across the three nest sites, higher than any other quadrat location. Figure 1 shows the distribution of seedlings-saplings at each quadrat location across the three nest sites. As the distance from the base of the tree increased, the number of seedling or saplings decreased drastically. Nearly 18 times as many seedlings / seedlings were recorded in front of the nest (quadrat F1- location) than behind the nest (quadrat B location). Two and four times more seedlings and/or saplings were recorded in front of the nest entrance than the beside the nest (quadrat S1 and S2- locations, respectively) and at quadrats F2 and F3, seven and 35 times lower than at F1 quadrat (Figure 2).

Statistical analysis using the generalized linear model revealed significant differences between the number of seedlings-saplings recorded in various quadrat locations, the quadrat F1 had significantly higher number of seedlings-saplings compared to quadrat B (f= 6.85, df= 5, p= 0.0182). As predicted, seed germination in front of the nest cavity where high seed rain occurs, was significantly higher than behind the nest (where no seed rain occurs) (mean= 11.08, t-value= 13.86, df= 5, p= 0.0001). As described in the section above, seeds may potentially get deflected due to the crown of the tree growing underneath the nest cavity and the results reveal seedling-sapling abundance was significantly higher in quadrat S1 compared to B quadrat (mean= 5.15, t-value= 6.59, df= 5, p= 0.0006). This also suggest that the numbers of germinated seeds were not just recorded in F1 location (closest to nest) but were also on the side of the nest, but no significant difference was observed between F1 and S1 seedling-sapling abundance. The nest sites were significantly different from each other, but caution should be taken interpreting this data since only three nest sites were examined in the study (f-value= 5.53, df= 2, p= 0.0434). Each nest site displayed a different pattern of seedlings-saplings abundances and their distribution across quadrat locations. At nest D, the quadrat S1 had highest number of seedlings-saplings compared to any other quadrat locations (Figure 3). Nest site P had very different seedling-sapling abundance with an almost equal number of tagged plants in both quadrat F1 and S1 locations (Figure 4). Nest site T, as predicted had the highest number of seedlings-saplings in quadrat F1 location and the number decreased as the distance from the nest increased. No seedlings-saplings were recorded in quadrat B at nest site T (Figure 4).

The number of tagged seedlings/ saplings of different genera changed depending on the nest site and quadrat location. As seen in Table 1, which combines seedling/ sapling data from all nest sites, f1 quadrat was dominated by seedlings/saplings of the genus, *Myristica*, whereas the S1 quadrat was dominated by the genus *Dysoxylum*. Almost 76% of the tagged seedlings /

saplings were in these two quadrat locations. Species of *Myristica* and *Dysoxylum* each represented almost 41% of all tagged individual plants. Species of *Canarium*, one of the endangered taxa were recorded only in the S2 quadrat at nest site D, known to be old HB nesting site (Amitha Bachan, pers comm). Of all the seedlings-saplings, only 14% belonged to the genus *Litsea* and only three percent of seedlings were of species of *Knema*. The relevance of the composition of the seedlings-saplings and their height classes will be considered in next section.

Across the three nest sites 74% of the plants tagged were at the seedling stage (Figure 5) and rest only 26% were at sapling stage, but different patterns are seen at the genus level and across quadrat locations. Species of *Myristica* displayed a gradual decrease in the number in each height class, with highest numbers of plants at the seedling stage and the lowest number in the large-sapling stage (Figure 6). Of the total seedlings - saplings, 68% belonged to *Myristica*. On the other hand, the species of *Dysoxylum* showed the highest abundance in the large-seedling category, with lowest in the seedling class (Figure 7). Both species of *Myritica* and species of *Dysoxylum* dominate at both seedling and sapling stages compared to other genera. In the case of species of *Litsea,* there were no tagged plants at the sapling or large-sapling stage; all plants of this genus were very young and at the seedling stage (Figure 8).

It should be noted that when comparing height classes in the different quadrat location, the genera were combined, and all tagged individuals were considered. Height of the tagged plants across all genera in the F1, S1, and S2 quadrats was different as seen in figure 9, 10 and 11. The F1 quadrat, closest to the nest showed the highest number of individuals at the seedling stage. In the S1 quadrat almost 50% were at the seedling stage and the rest are at the sapling stage. On the other side, in quadrat S2, more than 80% were at the seedling stage Different nest sites also display differences in seedlings-saplings abundances at the genus level. The Great Hornbill nest sites (D and P) were dominated by the genus *Dysoxylum*, 81% and 66%, respectively, and at the Malabar Grey Hornbill nest Site (T) had 58% of tagged individuals belonged to the genus *Myristica*.

Monitoring tagged seedlings and saplings yielded different patterns depending on quadrat location and nest sites. 84 % of seedlings across all tree genera at all quadrat locations and nest sites survived through the study period of 29 – months study period. About three percent of the seedlings-saplings died in first year, 10% in the second year and about 3% in the last 5 months of the study. The one sapling at quadrat F3 (farthest from nest) did not survive through the study period. At quadrat B, only two living seedlings were at the end of the study. Other quadrat locations recorded the mortality rates: highest with 22 % in S2 (side location), 20% in F2 (5 m away from nest tree), 18 % in S1 (side location) and least of all with the 11 % in F1 (closest to the nest tree) location. Survival rates also varied among the nest sites, with the highest rate of survival, 94 % at the nest site D (GH nest), followed by 84 % at nest site T (MGH nest) and the lowest 71 % at nest site P (GH nest).

Discussion

Hornbills, with their large bill and wide-gape, can transport seeds to their roosting and nesting sites without damaging them. Both Great Hornbills and Malabar Grey are secondary cavity nesters, i.e. both females and chicks are confined to the nest cavity during the nesting period (Kemp 1995). The few studies documenting seed rain and seedling establishment in protected areas have shown significantly higher numbers of seedlings of hornbill diet species in front of their nests than behind the nest (Datta 1998, Kinnaird 1998, Kitamura et al. 2004). The results of the present study support these findings with respect to abundance and germination of large-seeded hornbill diet tree species under hornbill nests and more importantly, for the nests that are located outside the protected areas network, with fewer restrictions on the harvesting of forest products apply. This finding has particular relevance to large-seeded tree species that are likely to rely on small coteries of dependable seed dispersers. (Howe and Smallwood 1982, Kannan 1994). In Vazhachal Reserve Forest, the species of *Myristica* and *Canarium,* are harvested for their fruits and resin, respectively, and documenting their germination and survival is critical for local conservation planning. Very few studies focusing on the role of hornbills as disperser have been conducted in India and fewer in the Western Ghats (Sethi and Howe 2009). The study reported herein was the first attempt to look at germination and distribution patterns of seedlings-saplings at hornbill nests in a reserve forest in the southern Western Ghats. Documentation of the phenological patterns of large-seeded tree species in tropical forests shows that the four genera examined in this study display aseasonal patterns of fruiting and hence their seeds cannot be dispersed throughout the year (Kannan 1994, Datta 1998, Kinnaird and O'Brien 2007, Naniwadekar and Datta 2013, Naniwadekar et al. 2015a, Pawar 2016). Fig fruits are a major part of the hornbill diet, but during the breeding and nesting seasons the demand for high energy food items increases and lipid-rich fruits play important role in fulfilling this dietary need and nourishing hornbill female and chicks (Kannan and James 2007, Kitamura 2011).

From the plant's perspective, hornbills remove seeds from density-dependent mortality under parent trees, and the findings of this study indicate that hornbill nests may be important sites for germination of large-seeded tree species. Significantly higher number of germinated seeds in front of the nest is the first evidence in the 'seed dispersal loop' pointing that hornbills dispersing these large-seeded species and the evidence for the same is gathered from this study (Wang and Smith 2002). Of the total seedlings-saplings tagged in the study, almost one third were recorded beside the nest. Even such minor change in location can have significant impacts on plant's survival rates since herbivory, light conditions and resource competition are often more intensive in front of the nest, due to the heavy seed rain (Datta 1998, Kinnaird 1998, Kitamura et al. 2004). Identifying these germination patterns in the present study could be result of obstructions such as trees growing beneath the nests and deflect falling seeds. However, given the time constraints on the present study, it cannot be established whether the mortality pattern of seedlings-saplings growing in front of the nest differ from those of seedlings-saplings growing beside hornbill nests.

In ascertaining the efficiency of hornbills as seed dispersers it is important to look at of germination and survival patterns at the genus level. These patterns can dictate the community structure of these forests in long-term plant community succession. During the 29 months monitoring period, 83% survival of all tagged seedlings-saplings survived but this pattern differs from genus to genus. Seedlings-saplings of species of *Myristica* and *Dysoxylum* were recorded in the highest numbers under the nest trees, but at the end of the study, 93% of plants of species of *Myristica* survived, compared to 79% of species of *Dysoxylum*. Kitamura et al. (2004) reported that among hornbill diet species, *Cinnamomum subavenium* Miq. established most successfully (Kitamura et al. 2004), Similarly, in the case of the Sulawesi Red-Knobbed hornbill (*Aceros cassidix*) nests in the Indonesian tropical forests, only three of its diet species dominated the germinated seedlings stage(Kitamura et al. 2004). This can have implications for future floral community structures and needs to be investigated longer, especially as forest loss is a concern in tropical forests.

Asian hornbill as a disperser, nest sites are one of the locations of seed deposition, but during non-breeding periods the hornbill foraging ranges are different and seed deposition sites are different from nest sites, which may lead to a very different pattern of seed dispersal than one seen at nest site. Vazhachal Forest Division has a hornbill nest monitoring program established by the Kerala Forest Department in partnership with members of the local tribal community in order to monitor and protect hornbill nests across the whole forest division. The findings of this study can be incorporated into documentation of seed rain under nest tree while monitoring the nests over time. Monitoring the status of hornbill nests is important, but understanding what fruits are utilized during the breeding season can be critical too especially when developing strategies for plant conservation.

Animal-plant interactions are pivotal in shaping and maintaining forest ecosystems. This study is of particular importance since it was conducted in less protected forests, and land outside national parks and wildlife sanctuaries. Outside protected areas, land is always under threat of conversion for plantations, hydroelectric projects that can submerge vast areas of landscape in this part of the Western Ghats. Indigenous ‘Kadar’ tribal community of Vazhachal have been in forefront opposing the proposed hydroelectric project of Athirapilly in the Vazhachal Forest Division. The proposed project threatens to submerge vast forested areas, including an important elephant migratory corridor, and to displace tribal communities and destroy much of the region’s endemic biodiversity. This forest is an important habitat for species of hornbills but the large-seeded tree species alike. The Vazhachal Forest Division in particular is as an important habitat link between lower and higher elevations in the Western Ghats of Kerala, is one the few locations where all four species of hornbills (Great Hornbill, Malabar Grey Hornbill, Malabar Pied Hornbill, and Indian Grey Hornbill) found in the Western Ghats occur. This forest division is home to 12 of the 16 endemic bird species and has been identified as a globally important bird area.

Though hornbill surveys, nest monitoring program, and other initiatives have produced valuable data, this is one of the few long -term studies that evaluates data collected consecutively over two years. This study seeks to lay groundwork for future long-term projects to continue documenting germination patterns and seedlings-sapling distribution and survival. It is extremely important to reemphasize that tree species that hornbills help disperse are also important for the livelihood of the “Kadars” community. The ecosystem service provided by hornbills provide by dispersing these seeds also has helped communities and future conservation projects of hornbills and plant species must take this into account and use holistic approach towards protection of these forests.

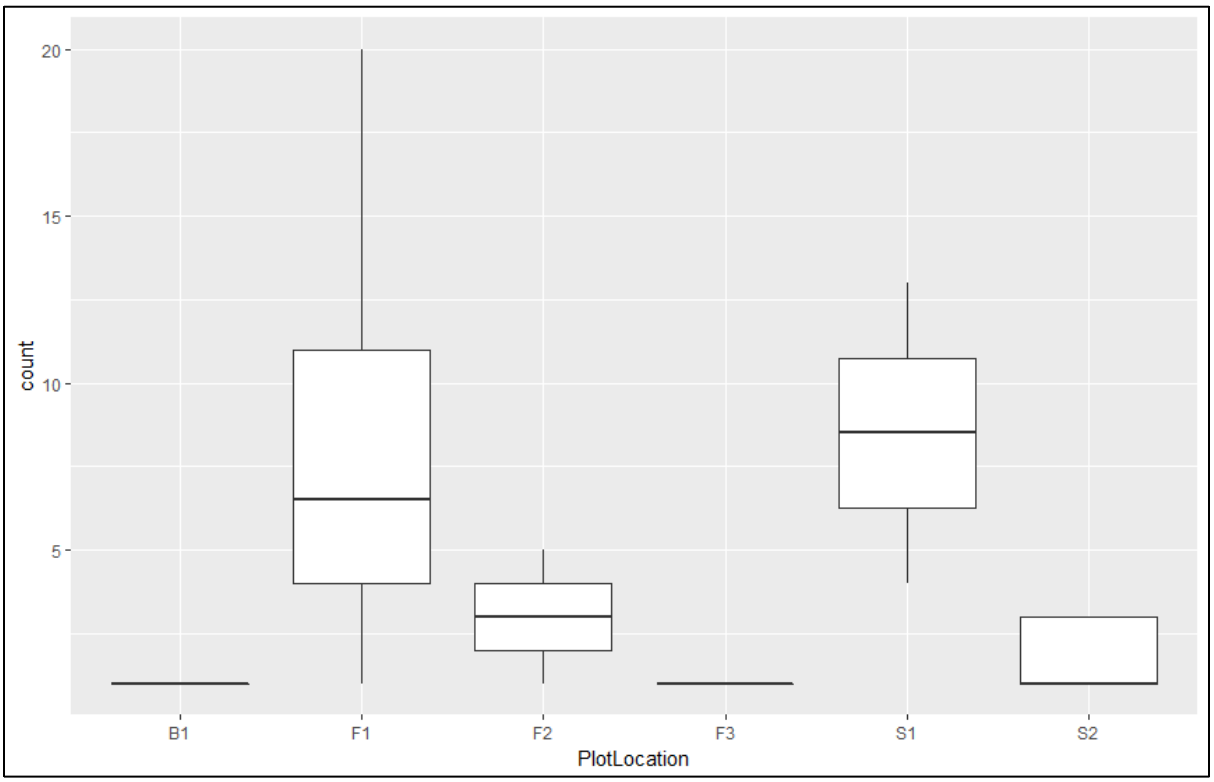

Figure 2. Seedling-sapling abundance at each quadrat location (B, F1, F2, F3, S1, S2) across all 3 hornbill nest sites (D, P, and T).in Vazhachal Reserve Forest, Kerala, India.

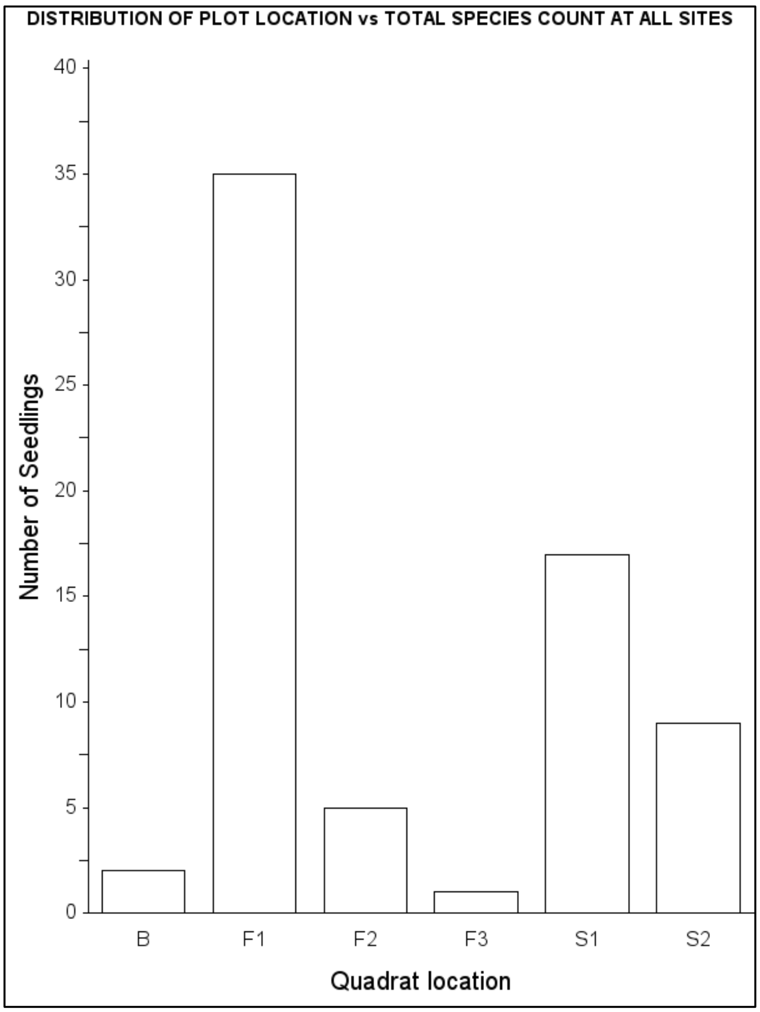

Figure 3. Seedling-sapling counts at each quadrat location across all 3 nest sites (D, P, and T) in Vazhachal Reserve Forest, Kerala, India.

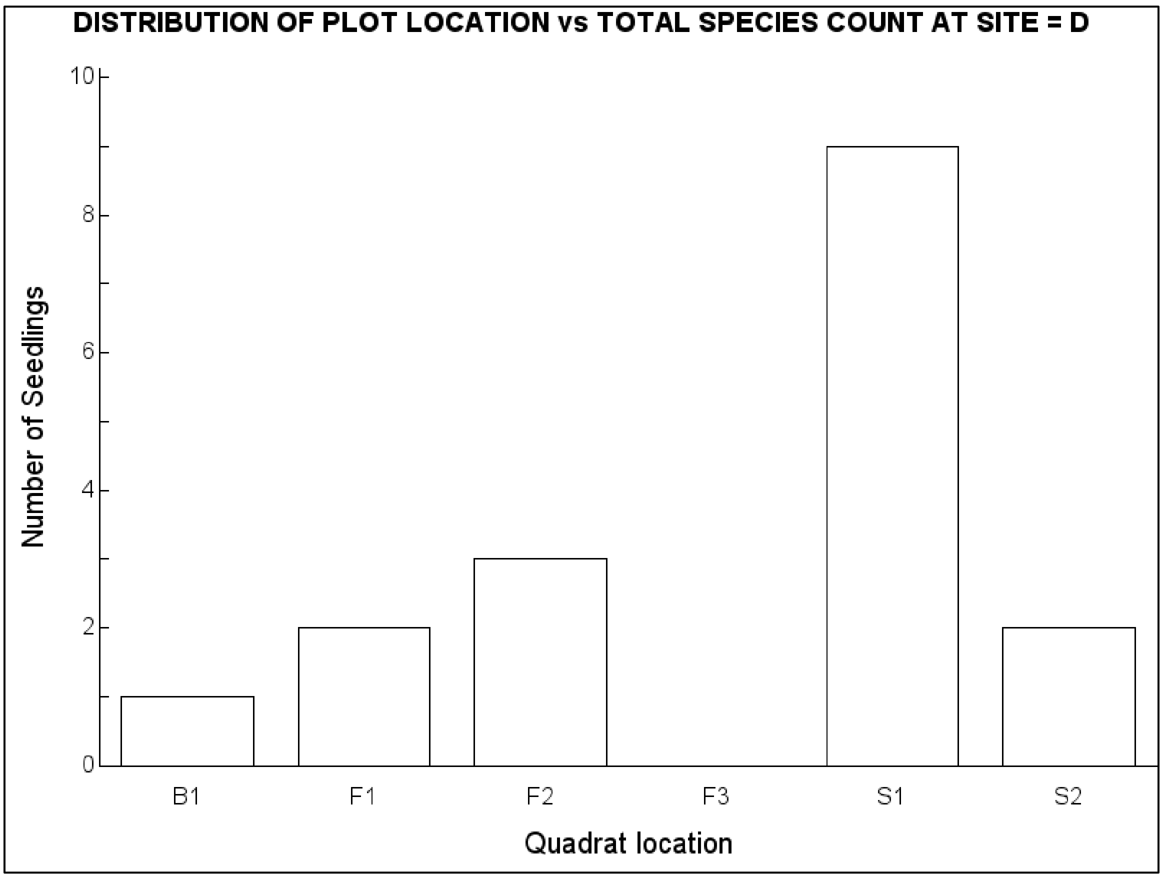

Figure 4. Seedling-sapling distribution at nest site D at different quadrat location (at F3 no seedlings-saplings were found) in Vazhachal Reserve Forest, Kerala, India.

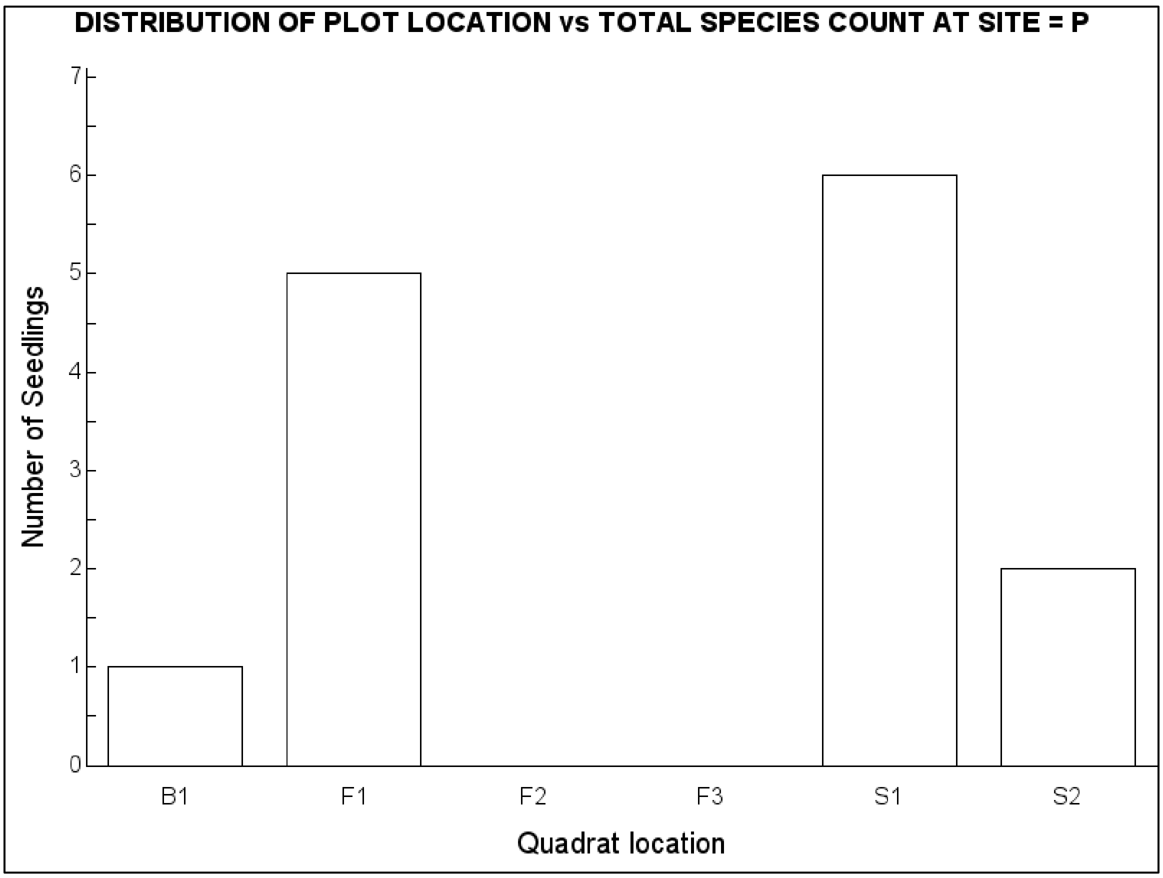

Figure 5. Seedling-sapling distribution at nest site P at different quadrat location (at F2 and F3 no seedlings-saplings were found) in Vazhachal Reserve Forest, Kerala, India.

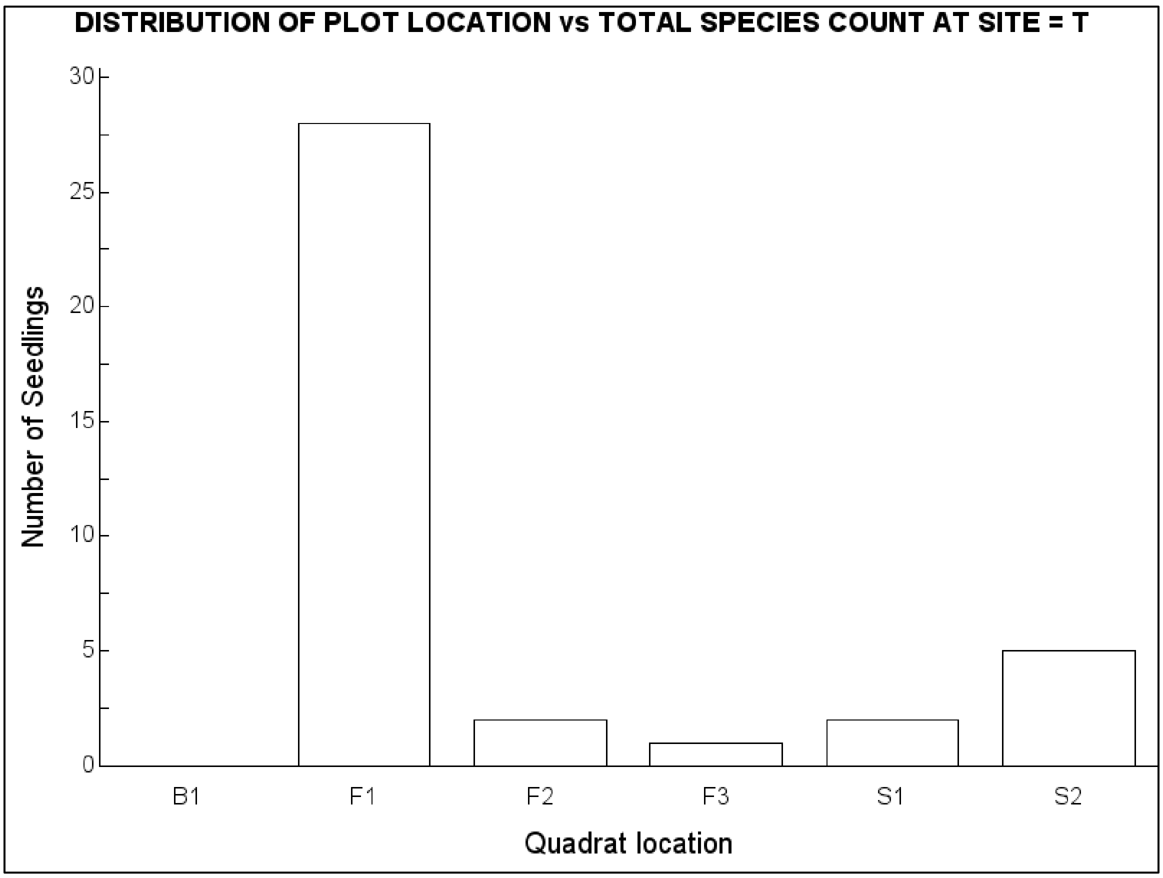

Figure 6. Seedling-sapling distribution at nest T at different quadrat location (at quadrat B no seedlings-saplings were found) in Vazhachal Reserve Forest, Kerala, India.

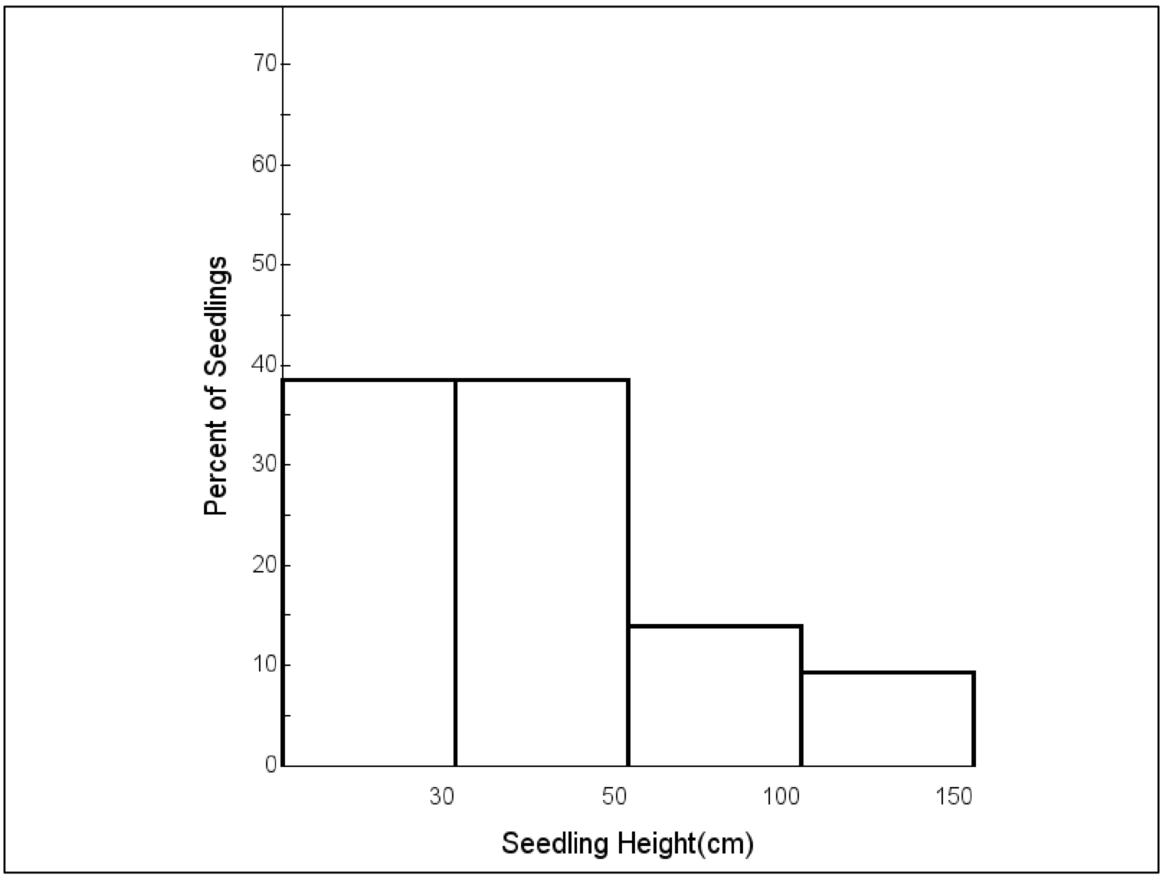

Figure 7. Overall percent of tagged plants in each height class across all three nest sites(up to 30 cm = seedlings, 30 -50 cm= large-seedlings, 50 -100 cm = saplings, and 100 -150 cm = large saplings) in Vazhachal Reserve Forest, Kerala, India.

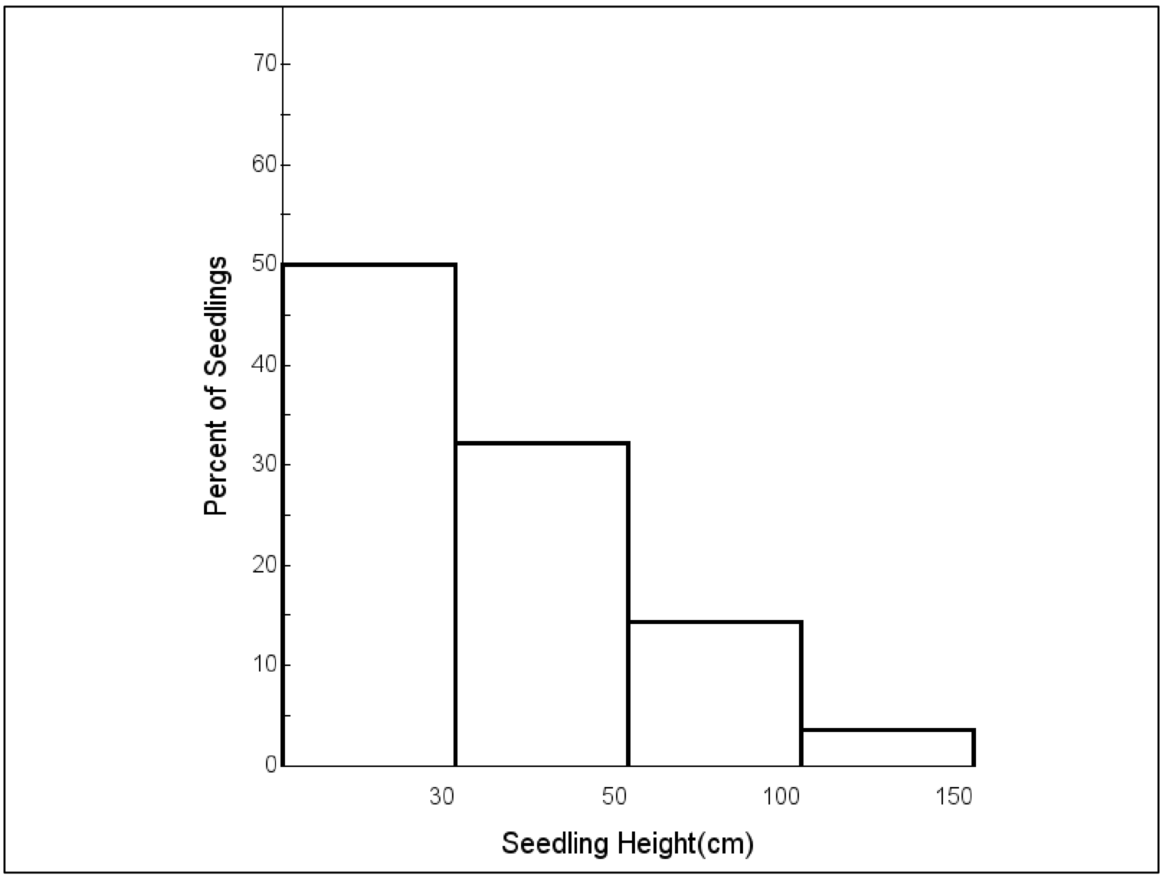

Figure 8. Percent of tagged plants of the genus *Myristica* in each height class across all three nest sites(up to 30 cm = seedlings, 30 -50 cm = large-seedlings, 50 -100 cm = saplings, and 100 -150 cm = large saplings) in Vazhachal Reserve Forest, Kerala, India.

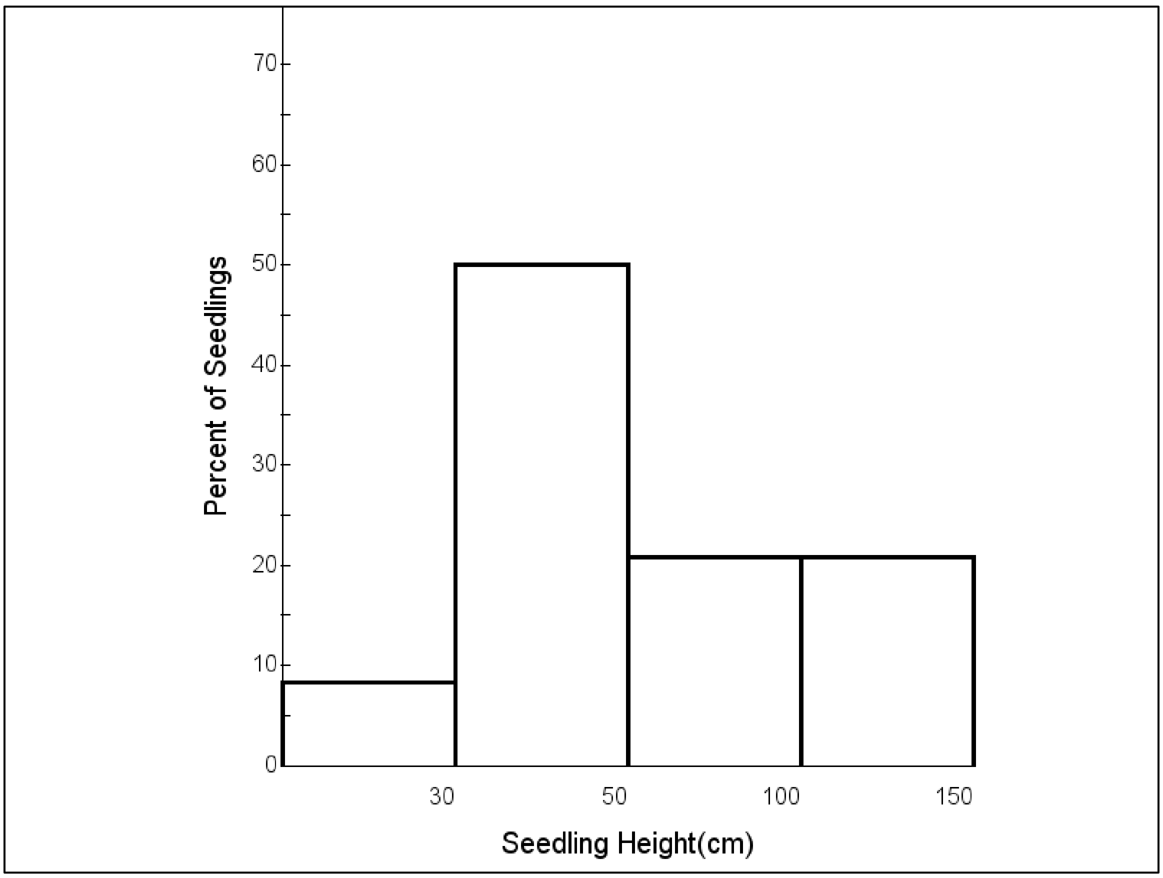

Figure 9. Percent of tagged plants of the genus *Dysoxylum* in each height class across all three nest sites(up to 30 cm = seedlings, 30 -50 cm = large-seedlings, 50 -100 cm = saplings, and 100 -150 cm = large sapling) in Vazhachal Reserve Forest, Kerala, India

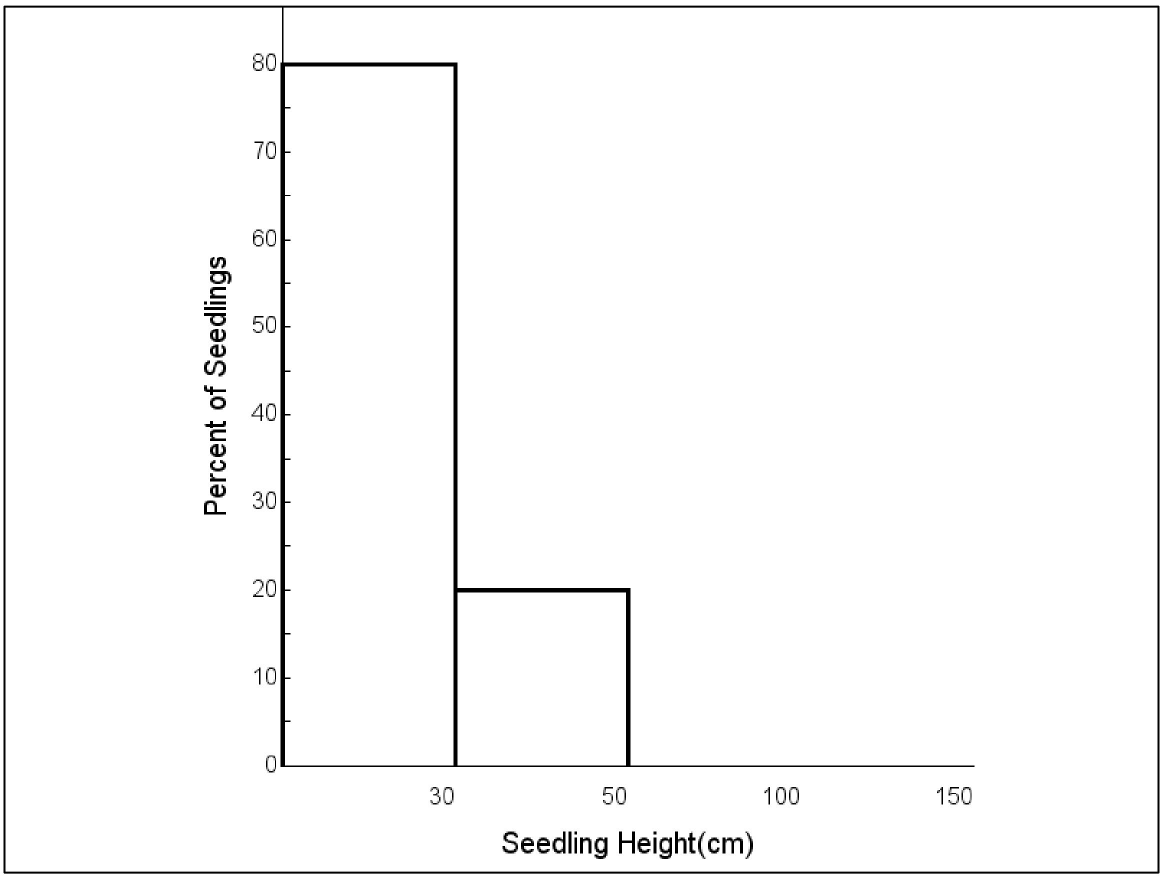

Figure 10. Percent of tagged plants of the genus *Litsea* in each height class across all three nest sites(up to 30 cm = seedlings, 30 -50 cm = large-seedlings, 50 -100 cm = saplings, and 100 -150 cm = large saplings) in Vazhachal Reserve Forest, Kerala, India

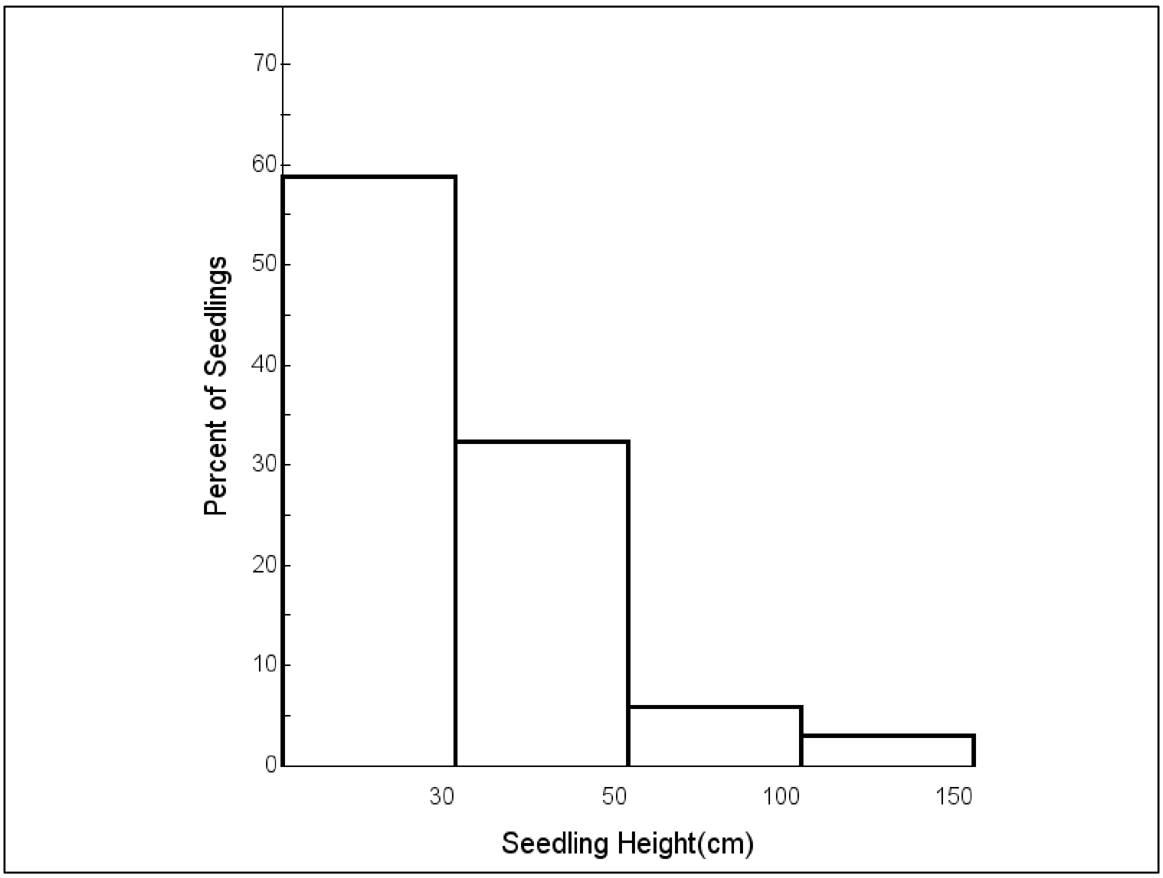

Figure 11. Percent of indivisual plants in each height class at F1 quadrat location across all three nest. (up to 30 cm = seedlings, 30 -50 cm = large-seedlings, 50 -100 cm = saplings, and 100 -150 cm = large saplings) in Vazhachal Reserve Forest, Kerala, India

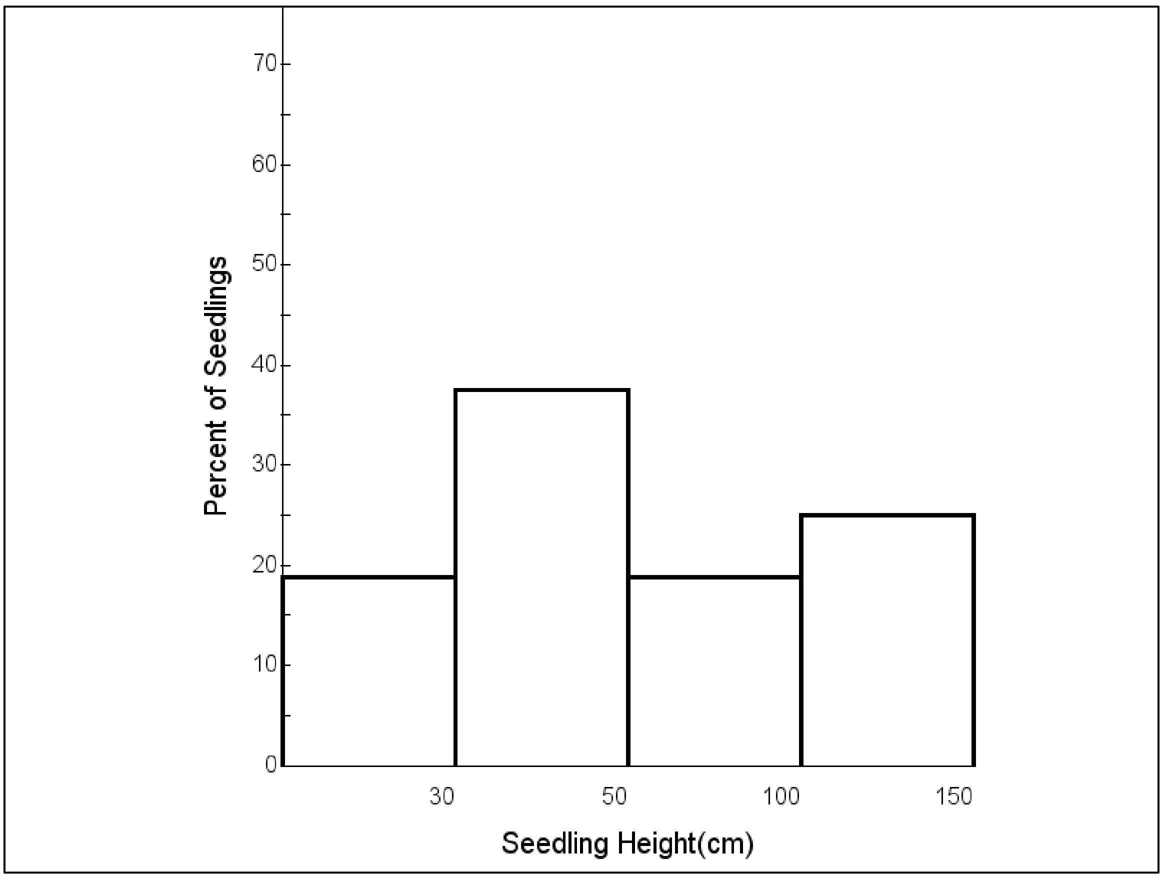

Figure 12. Percent of indivisual plants in each height class at S1 quadrat location across all three nest. (up to 30 cm = seedlings, 30 -50 cm = large-seedlings, 50 -100 cm = saplings, and 100 -150 cm = large saplings) in Vazhachal Reserve Forest, Kerala, India.

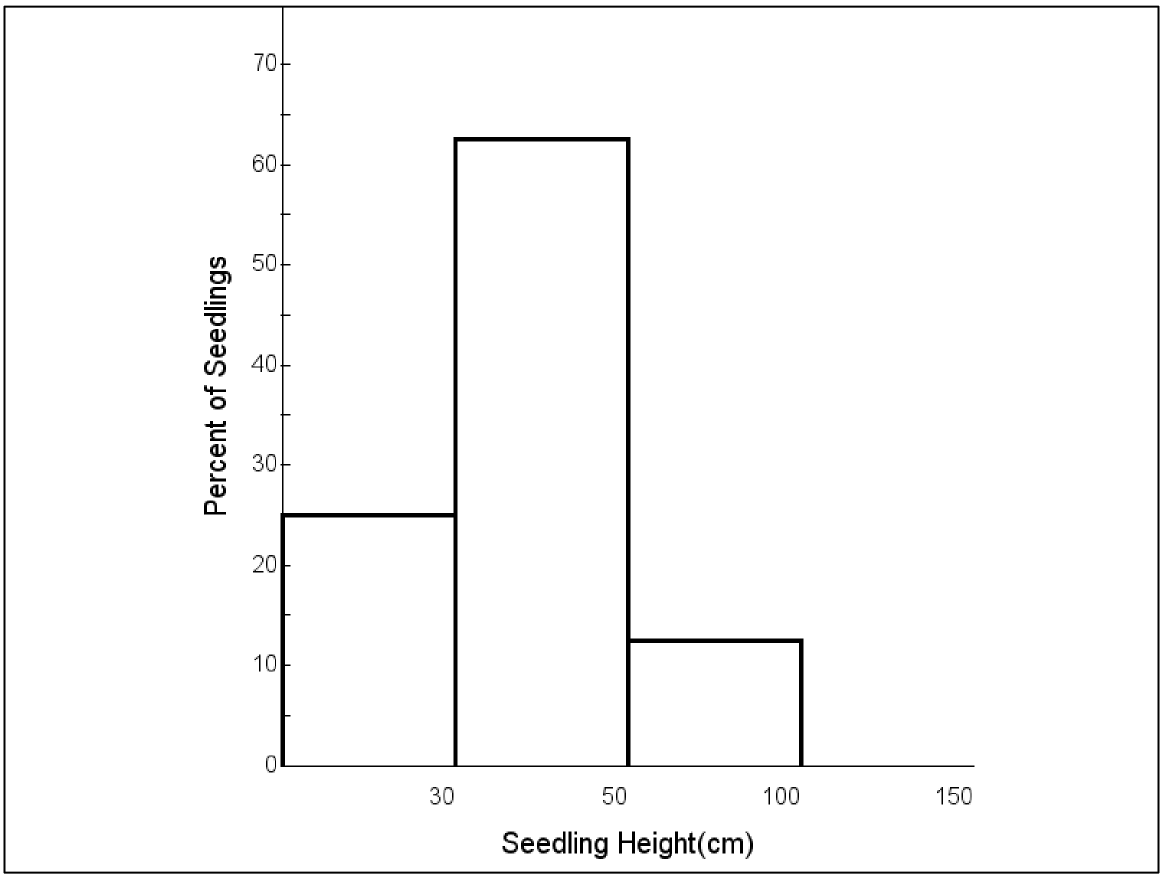

Figure 13. Percent of indivisual plants in each height class at S2 quadrat location across all three nest(up to 30 cm = seedlings, 30 -50 cm = large-seedlings, 50 -100 cm = saplings, and 100 -150 cm = large saplings) in Vazhachal Reserve Forest, Kerala, India.

Table 1. Composition of targeted genera and abundance of seedlings-saplings at three hornbill nest sites in Vazhachal Reserve Forest, Kerala, India

Seedling and sapling genus	F1	F2	F3	S1	S2	B	Total seedlings and saplings per species
Myristica species	20	0	0	4	3	1	28
Knema species	2	0	0	0	0	0	2
Dysoxylum species	5	5	1	13	3	1	28
Litsea species	8	0	0	0	2	0	10
Canarium species	0	0	0	0	1	0	1
Total number of seedlings	35	5	1	17	9	2	69

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Chapter 3.

Encounter rates of Great Hornbill (*Buceros bicronis*), Malabar Grey Hornbill (*Ocyceros griseus*), and Mountain Imperial Pigeon (*Ducula badia*) in Vazhachal Reserve Forest, Western Ghats, India

Abstract

The present study attempted to record the encounter rates of three species of large-bodied frugivores in Vazhachal Reserve Forest during 27-month period of from 2013 to 2015. The encounter rates of Great Hornbill and Malabar Grey Hornbill were found to be 1 detection/km and 5.7 detections/km and were higher than recorded in previous surveys carried out in the region. The study also recorded the encounter rates for Mountain Imperial Pigeon with 5.5 detections/km. The three locations where transect data was collected were also displayed significant differences in encounter rates across all species. With lowest encounter of 2.4. detections/km on a transect located near human habitation. The encounter rates for all three species showed gradual increase during the month of March-April when large-seeded tree species fruit and the post-hatching period for the hornbill species begins. The findings indicate that there is a need for collection of more information to estimate the densities for each species of frugivore. Future studies need to include more inaccessible area that was not possible due to logistic challenges.

Introduction

Asian tropical forest ecosystems are powerhouse of global biodiversity, and their endemic flora and fauna have long drawn the attention of the scientific community. Global biodiversity hotspots, which occupy only 2.3 % of the earth's surface, harbor more than 50 % of known endemic plant species and 42 % of known vertebrate species (Newmark 1996) These forests also provide numerous important resources and have attracted developers, loggers, settlers, and farmers whose presence have substantially altered these landscapes. In the scientific community, it is widely acknowledged that tropical forests are disappearing at an alarming rate. At a global scale, deforestation is occurring in the tropics faster than in most regions, and activities such as mining, construction of hydropower dams, and unchecked harvesting of forest products are only a few of the factors threatening the biodiversity and persistence of these forests (Hughes 2017). Today, the biggest challenge for policy makers, conservationists, and the scientific community is not just to mitigate the impact such as of forest loss, but also to understand the complex network of factors contributing to deforestation and design policies to both preserve the endangered ecosystems and sustain the continuously increasing human population (Wright 2005). Once contiguous tropical forests throughout South and South East (SE) Asia now face continual degradation, fragmentation, conversion, and deforestation leading to declining biodiversity and deterioration of ecosystems. Protected areas may provide some protection for the remaining tropical forest ecosystems, but studies have indicated that the current network of protected areas will not be sufficient to safeguard their biodiversity. The scientific community, economists, and policy makers are now emphasizing the need to look beyond the protected area network in order to preserve these ecosystems and the to ensure the continued availability of the vital natural resources they provide.

Western Ghats, a mountain chain running parallel to the west coast of India, is recognized as the hottest of hotspots, home to many endemic bird species and one of the world’s most ecologically important regions (Mittermeier et al. 1998, Olson and Dinerstein

1998, Myers et al. 2000) Western Ghats is a mosaic of at least six kinds of forests types with vegetations differentiated by north – south variations in moisture levels and altitudinal gradients. Animal diversity is equally impressive, about 10 % of fishes found in India are from Western Ghats, and of those, 42% are endemic to Western Ghats (Kumar et al. 2004). Amphibians, mammals, and reptiles show similar patterns of diversity and high degrees of endemism to Western Ghats. Western Ghats is home to a spectacular 507 species of birds, with the highest number of endemic and range-restricted bird species inhabiting the tropical evergreen forest (Daniels 1997). Western Ghats is also known for its high human population density, made possible by an abundance of natural resources such as water, medicinal plants, and enumerable forest products (Cincotta et al. 2000). This also means that the landscape of Western Ghats has been heavily altered over the years to make way for hydropower projects, road construction, agricultural expansion, monoculture plantations, mining, and urbanization. Needless to say, these projects have resulted in forest loss and fragmentation impacting wildlife and their ecosystems (Nair 1991, William 2003, Kumar et al. 2004).

Currently, a network of 13 National Parks and 43 Wildlife Sanctuaries in the Western Ghats affords some measure of protection, but this only covers 10 % of the land area in Western Ghats (Kumar et al. 2004). The protected areas are designated with two critical goals: one to serve as the repository of diversity and safeguard basic ecological services provided through biological and non-biological components of these ecosystems. Given that land is a scarce resource in India, protected areas across the country are considered well represented, but many are too small to sustain their ecological value and maintain their biological diversity (Rawat 2005). Assessment of protected areas in India reveals that the health of ecosystems within protected areas depends heavily on the health of the ecosystems in forests outside of the protected areas. Only one fourth of the tropical evergreen forests in Western Ghats remains relatively un-fragmented, and of this land, almost 74 % is located outside the protected area network on reserve forests, community forests, and private forests according CEPF's assessment of ecosystems in southern India (CEPF 2007).The sites where the present study was conducted falls out in a belt of wet evergreen forests that are classified as semi-protected. Economic pressure to convert forested lands to commercial plantations for tea, coffee and other commodities, increasing tourist traffic, and the unchecked harvesting of medicinal plants and other forest products all threaten the wet, tropical evergreen forests of southern Western Ghats (Rawat 2005).

Most of conservation efforts in India that use the focal species approach have been focused on state-administered protected areas despite the fact that vast forested lands exist outside these areas (Naniwadekar et al. 2015b). Camera trap studies in recent years have shown that big prey populations are declining even in some of the protected areas that once supported healthy wildlife populations (Datta et al. 2008). Areas surrounding national parks and sanctuaries play many roles, acting as buffer zones and migration routes for various species. Studies have shown some bird species using forest fragments to varying degrees (Raman 2007). As wildlife loss and deforestation continues the importance of understanding the landscapes surrounding protected forests and the wildlife they harbor becomes increasingly evident. The species that are most susceptible to forest fragmentation and are those that require large home ranges, special breeding habitats, and / or special dietary needs. In southern India, and throughout Western Ghats, large-bodied frugivores such as hornbills and some mountain pigeon species play important roles in these ecosystems. Hornbills in particular, known for their unique nesting behavior and dependence on a plethora of fruit species, potentially providing the service of dispersing seeds of important and rare tree species and thus helping to maintain the forest ecosystem (Cordeiro and Howe 2001). Loss of such large-bodied avian frugivores could negatively impact the ecosystem as a whole as they are the largest avian frugivores in these forest ecosystems. It is therefore necessary to determine whether these species are utilizing habitats that are outside of protected areas.

Hornbill species and Mountain Imperial Pigeon are the only large-bodied avian frugivores that are predominantly found in southern Western Ghats. Their unique anatomy of wide gape allows them to feed on plethora of small to large-seeded fruit species, especially rare rain forest species, without damaging the seeds, which they may subsequently transport to various germination sites. Hornbills with their large bodies, bold coloration, and loud calls, have long attracted the attention of the scientific community. In southern India, especially in Western Ghats, researchers have thoroughly documented hornbill breeding and nesting patterns, dietary needs, and their abundance in some areas (Kannan 1994, Mudappa and Kannan 1997, Raman and Mudappa 2003, James and Kannan 2009). Few studies from India that researched the role of hornbill species in providing ecosystem services, mainly seed dispersal came from the evergreen forests of the northeast India (Datta 1998, Datta and Rawat 2004). In case of the Mountain Imperial Pigeon, there are only references pointing to their ability to feed on large-seeded fruit species due to a wide gape but apart from few records of sighting there is no thorough study done to document their abundances in different forests in the Western Ghats (Kannan 1994, Raman 2007). Some evidence does suggest that the Mountain Imperial

Pigeon may be helping to disperse seeds even in disturbed forested habitats where hunting has reduced hornbill population (Sethi and Howe 2009). The present study aimed to record abundances of Great Hornbill, Malabar Grey Hornbill and the Mountain Imperial Pigeon in a wet evergreen forest habitat in Western Ghats. The present study was carried out in Vazhachal Reserve Forest, which falls outside of the protected area network where no previous study of the aforementioned avian species' has been conducted.

Hornbills belong to the order Becerotiformes, a species rich group distributed across sub-Saharan Africa, India, southern Asia and the Sunda shelf islands of Indonesia (Kinnaird and O'Brien 2007). The order is comprised of 14 genera and 61 species of hornbills across its entire range. Asia alone, hosts 32 of these species classed into nine genera, all with high degrees of endemicity. Asian hornbills are known for their frugivorous nature unlike the African hornbill species that feed mainly on animal matter. India in specific is home to nine species of hornbills with two endemics both of which namely Malabar Grey Hornbill (*Ocyceros griseus*) and Narcondam Hornbill (*Rhyticeros narcondami*) occur in Western Ghats. Hornbills are among the most important frugivores in the wet evergreen forests that cover the western slopes of the Western Ghats. Hornbills have wide - ranging habits, and require old growth trees for nesting, and are known to depend on patchily distributed fruit resources, which they have been shown to track at various spatial scales (Naniwadekar and Datta 2013). Forest loss has the potential to adversely affect the animal-plant interactions and forest dynamics that sustain the region's biodiversity. Large-bodied frugivores such as hornbills play integral role in tree recruitment by helping to remove seeds from zones of high density and distance-dependent mortality and transporting them to new macro and micro environments, thereby offering these plants critical survival benefits (Chapman and Chapman 1995, Wenny and Levey 1998, Wenny 2001). This animal-plant interaction becomes even more critical for large-seeded evergreen tree species that depend on small coteries of seed dispersers (Kitamura 2011) Research on hornbills shows that their population metrics serves as good indicators of the state of the forest as a whole because they need large trees to nest in and lipid-rich fruits to feed on especially during nesting period when metabolic energy demand is high (Kannan 1994, Mudappa and Kannan 1997).

In Vazhachal Reserve Forest, where the present study was conducted, local tribal communities are allowed harvest forest products, but commercial activities are not permitted (Rawat 2005). The perianal tributaries of river Chalakudy River have been dammed to generate electricity, and this project has gradually displaced “Kadar”, an indigenous tribal community, who are primarily hunter-gatherers. This tribal community depends on Vazhachal region for non-timber forest products such as honey, black dammar (used in incense), wild nutmeg, and most importantly, fresh-water fish (Bachan et al. 2011). A 2008 revealed that for hornbills,, Vazhachal Reserve Forest represents one of the important conservation sites outside the protected areas (Mudappa and Raman 2008). Between year 2004 and 2005, fifty-seven Great Hornbill and Malabar Pied Hornbill nests were recorded in the wet evergreen forest of Vazhachal by way of a pioneering program conducted by the Kerala Forest Department in collaboration with members of the local tribe. Even though this has been an encouraging initiative, it has not yielded much information on the abundance of large-bodied frugivores, availability of diet fruiting species, or the long-term importance of Vazhachal Reserve Forest for these large-bodied frugivore species.

The findings presented here are part of a study designed to document the abundances of three species of large-bodied frugivores over 27 months at three different locations within Vazhachal Reserve Forest. The study focused on only the three species of large-bodied frugivores most commonly seen in the Sholayar range of Vazhachal Reserve Forest, where the study was carried out. The main goals of this study were to establish baseline data on encounter rates for these three large-bodied frugivorous avian species to study differences in encounter rates among locations and species, and to study variations in encounter rates from year to year. The encounter rate was defined as the number of individuals of a given species detected per unit area in a given time period. In addition to these specific goals, this study also seeks to initiate a shift away from reliance on brief survey towards long-term data collection.

Study Area

Western Ghats is a long chain of hills spread from 8^0 N near Kanyakumari in the south to 21^0 N at the river Tapti in the north along the west coast of India (Reddy et al. 2016). Western Ghats is narrowly distributed between 73^0 and 77^0 E and is less than 100 km wide over most of its length. It passes through Gujarat, Maharashtra, Goa, Karnataka, Kerala, Tamil Nadu, and the union territory of Daman Diu, wherein different hill ranges link up to form Western Ghats in its entirety. With its north-south, east-west, and altitudinal spreads, Western Ghats enjoys varied tropical climate. Average annual rainfall is of 2,500 mm but varies with locality by an order of magnitude from 500 mm to nearly 7,500 mm. This variation can be explained by varied distribution of rainfall across the year and differs depending on latitude. The southern end has a short dry season (2–5 months) and is fed by both the southwest (June-September) and the northeast (October-January) monsoons, as opposed to the northern regions, which have a longer drier season (5–8 months) and, receive rain mostly during the southwest monsoon.

The following study was conducted in southern Western Ghats in Vazhachal Reserve Forest, which falls in the Anamalai hill range in the state of Kerala, between 76^0 09' 06" – 76^0 54'E and 10° 07' 08" – 10° 23'16"N. Vazhachal Forest Division falls in Mukundpuram tehsil of Thrichur county and Aluva tehsil of Ernakulam county, covers 413 sq. km of area, and consists of five forest ranges: Athirappalli, Charpa, Vazhachal, Kollathirumedu and Sholayar. The natural vegetation of the area is classified as mid-elevation (600–1100 m) tropical wet evergreen forest of the *Cullenia exarillata – Mesua ferrea – Palaquium ellipticum* type (J.P 1988). The eastern boundary of the Sholayar range consists of a mosaic of wet evergreen forests interspersed with plantations for tea (*Camellia sinensis*), coffee (*Coffea arabica* and *Coffea canephora*), cardamom (*Elettaria cardamomum*), and Eucalyptus spp. As well as human settlements including housing for tribal members and plantation worker (Pawar 2016). Transects of varying lengths were located in the Sholayar forest range between 600 and 1,100 m above sea level. One of the transects ran along a riparian habitat close to a tribal colony and a coffee plantation, and other two transects were located in forested areas away from human settlements

Most of the forests in the Anamalai hill range, a stronghold for hornbill populations in Western Ghats , exists in various stages of degradation and fragmentation across a mosaic of protected and unprotected areas (Ramesh and Gurukkal 2007, Mudappa and Raman 2008). In the state of Kerala, some of these forests are connected by natural corridors, such as the riparian belt of the Chalakudy River that connects the Vazhachal area and the adjacent Parambikulam Wildlife Sanctuary to the reserve forests farther west. According to recent ecosystem level assessment study, Anamalai corridor has been recognized as critical link based on endemism, potential forest connectivity, ranges of landscape species and topography (CEPF 2007). A conservation status survey carried out by T. R. S. Raman and Divya Mudappa (2008) indicates the importance of Anamalai-Parambikulam-Vazhachal landscape for conservation of hornbills and mentions lack dearth of studies from the Vazhachal Forest Division.

Though displaced over the years by hydropower projects, delineation of national parks and wildlife sanctuaries the indigenous Kadar community retains access to the forest in Vazhachal Reserve Forest and continue to harvest non-timber forest products such as honey, wild nutmeg, black and white dammar and fishing. In the past, hunting of hornbill adults and chicks was commonly reported in the Vazhachal region, but concerted efforts by the Kerala Forest Department have made it possible to successfully run nest monitoring program that involves the tribal community members and generate revenue for them (Bachan et al. 2011). This participatory program has become part of the Joint Forest Management, and perhaps thanks to this initiative, no signs of hunting were recorded during the study period (pers. obs.).

Study Species

Asian hornbills are one of the most charismatic species in these forests, and their conspicuous size and unique casque makes them stand out against the lush green backdrop of the tropical wet evergreen forest. In Asian tropical forests, hornbills are among the very few large-bodied birds with high a degree of frugivory that have the ability to swallow and regurgitate large seeds unharmed and travel long distances across contiguous and fragmented landscapes. Nine species of the 32 Asian hornbill species occur in India, and four occur in Western Ghats: The Great Hornbill (GH) (*Buceros bicornis*) Linnaeus (1758), the Malabar Pied

Hornbill (*Anthracoceros coronatus*) Boddaert (1783), the Indian Grey hornbill (*Ocyceros birostris*) Scopoli (1786) and the Malabar Grey Hornbill (MGH) (*Ocyceros griseus*) Latham (1790). The present study focused on the Great Hornbill and the Malabar Grey Hornbill, distributed along the altitudinal range of 600–1,100 m where the present study was carried out in southern Western Ghats.

For over two decades, the GH has been one of the most well studied species in India (Kannan 1994, Datta 1998, Raman and Mudappa 2003, Balasubramanian et al. 2007). Weighing up to 3,400 g and with a body length of 95 - 105 cm, the GH is the largest is the largest of the three species in the genus *Buceros* as well as the largest avian frugivore in India. It is also the only species of hornbill that has disjunct distribution in India, with populations in northeast and Western Ghats represents the western most limit of its distribution (Kinnaird and O'Brien 2007). This species is boldly colored, with black and white plumage and brightly colored eye and colorful throat regions. The casque, unique to hornbills is yellow in Great Hornbill matching with large yellow bill. Males and females display slight differences in size and coloration. The casque in females is predominantly yellow with reddish tinge and in males it displays black coloration at the base of yellow casque. The orbital skin is reddish in females as opposed to darker in the male. Great Hornbill. is a monogamous and highly territorial species, and its disjunct populations nest at slightly different times (Kannan 1994, Datta 1998). Its nesting period ranges between 113 and 140 days, during which the female incarcerates herself inside the cavity and the male remains responsible for feeding her and the chicks. In India, Great Hornbill is protected under Schedule-I of the Wildlife Protection Act, 1972 because their numbers are declining due to hunting pressure and habitat loss and it is listed in ‘Near

Threatened’ category by the IUCN Red list (Birdlife International 2018). The Great Hornbill also faces commodification as pets and for its body parts, especially its casque and feathers, and as a result has been listed under CITES-Appendix 1.

The Malabar Grey Hornbill is the smallest of the nine species found in India and is endemic to Western Ghats. Populations of MGH are distributed from northern Western Ghats in the state of Maharashtra , all the way to the southern-most part of the Ghats, and from the foothill up to 1,500 m altitude above sea level (Ali and Ripley 1987, Mudappa and Raman 2008). This species is observed in moist deciduous, riverine, semi-evergreen and evergreen habitats in the Western Ghats. Malabar Grey hornbill is a smaller grey hornbill with a size between 45 and 50 cm and weighing less than 400 g (Kinnaird and O'Brien 2007). The Malabar Grey Hornbill, unlike other hornbills, lacks a conspicuous casque and instead has a low, ridge-like structure. Its bill is long and curved, with a yellowish-orange tinge, and white streaks adorn its head and its underside. The female Malabar Grey Hornbill is slightly smaller than the male and has a paler bill and a dark brown iris, unlike the golden brown of the male (Kemp 1995). During the nesting period like in the Great Hornbill, the female incarcerates herself inside the nest cavity. In the Western Ghats, nesting takes place from December to May in the Western Ghats (Mudappa 2000). Even though this is a commonly found species in the Western Ghats, little research has been carried out to quantify its populations (Mudappa 2000, Maheswaran and Balasubramanian 2003). A survey carried out by Raman and Mudappa (2008) noted that MGH populations in Anamalai are more adaptable to plantations and fragmentation than GH populations. MGH is fairly common in the present study area and has been categorized as

“Least Concerned” on the IUCN Red list, although it is still experiencing population decline (Birdlife International 2016).

The Mountain Imperial Pigeon (*Ducula badia*) is a wide-ranging species distributed across the following Asian countries: Bhutan, Brunei Darussalam, Cambodia, China, India, Indonesia, Lao People's Democratic Republic, Malaysia, Myanmar, Nepal, Thailand and Viet Nam. Mountain Imperial-pigeon is one of the largest and a most common pigeons found in the tropical and subtropical lowland forests. Though classified as “Least Concerned” the Mountain Imperial Pigeon has recently started showing population decline as a result of accelerated habitat destruction and conversion (Birdlife International 2016). Apart from few sporadic references in the literature to the Mountain Imperial Pigeon as one of the larger frugivorous species in the region and to the wide gape that allows it to consume large-seeded fruit species, little research has addressed its role in the ecosystem.

Methods

Transects of varying lengths were used to document encounter rates with three species of large-bodied frugivores. The first transect (Transect ‘M’) was located near a tribal settlement, and the other two (Transects ‘OP’ and ‘TOT’) were established along existing trails in the forest, totaling to 4.6 km. Transect ‘M’ passed through a tribal settlement and coffee plantation on one side and along the riparian forest on the other. Visibility was far better within the tribal settlement and the coffee plantation. The other two transects passed through forest trails, where visibility is much lower due to dense foliage. Transect ‘M’ was 2.1 km in length, Transect ‘OP’ was 1 km and Transect ‘TOT’ was 1.5 km. Each transect was walked in the morning between 7:00 and 9:30 am depending on the transect length. In a preliminary study, the hornbills were seen to be most active during these morning hours and hence were more likely to be counted during these times. Each transect was walked once every month from January 2013 until May 2015 except for the month of July, when heavy monsoon rains substantially reduce visibility. The transects were walked at a slow, uniform pace of approximately 1 km/ hour with carefully scanning the canopy for presence of individual bird species. Individuals of three bird species heard or seen immediately ahead on the transect or on either side of the transect were counted and recorded. Once the bird was seen or heard, its distance from the transect line was calculated using a Bushnell Laser Range Finder. The following parameters were recorded: the number of individuals of each species, whether they were seen or heard, and their distance from transect. The perpendicular distance intervals (meters) used were 0-10, 10-20, 20-30, 30-40, 40-50, beyond which visibility decreased sharply making further detections unlikely. The mean encounter rate was calculated for each species over the entire study period as were the mean monthly encounter rates across all transect locations. Analysis was carried out in R (version 3.4.3 (2017-11-30)). Packages ‘ggplot2’ (Wickham 2009), ‘dplyr’ (Wickham et al. 2017), ‘tidyrr’ (Wickham and Henry 2018) and SAS 13. 1 (SAS Institute Inc. 2013).

Results

During the 27 months of the study period 1,306 encounters were detected, 53 detections of Great Hornbill, 653 of Malabar Grey Hornbill, and 600 of Mountain Imperial Pigeon (Table 1). The analysis of variance showed that the encounter rates differed significantly depending on the species across all transects (f-value= 88.05, df= 2, p-value= < 0.0001), with Great Hornbill occurring at a significantly lower rates than encounters with Malabar Grey Hornbill and Mountain Imperial Pigeon. (t-value = 0.01, mean± SE = 1± 0.11, p-value = <

0.0001). The mean encounter rate for the Great Hornbill was recorded as 1 bird/km, as compared to 5.7 birds/km for Malabar Grey Hornbill and 5.5 birds / km for the Mountain Imperial Pigeon (Fig 1). There were no significant differences in encounter rate between Malabar Grey Hornbills and Mountain Imperial Pigeons. Analysis of the data after separating detections into two categories based on 'Seen' or 'Heard' showed that encounter rates of three species of birds were significantly different in 'Seen' category. Great Hornbill encounters classified as "Seen" category occurred at a mean rate of 1 bird/km, Malabar Grey Hornbill in "Seen" category occurred at mean rate of 5 birds/km and the Mountain Imperial Pigeon encounters in the "Seen" category occurred at a mean rate of 3.4 birds/km (Fig 2). The Great hornbill encounters in the "Heard" category occurred at a mean rate of 0.8 birds/km, compared to 1.6 birds/km for the Malabar Grey Hornbill and almost 3 birds/km of Mountain Imperial Pigeon (Fig 3). 89% of all encounters with Malabar Grey Hornbills and 81% of all encounters with Great Hornbills were classified as "Seen" whereas only 57% of Mountain Imperial Pigeons were detected as "Seen". Mountain Imperial Pigeons are smallest among the three species, and their camouflage is well adapted to their wet evergreen forest habitat. Though active and vocal, they were often difficult to see.

Analysis also revealed that the encounter rates combining all three species differed significantly depending on the location of the transect (f-value = 9.19, df = 2, p-value = 0.0002). Transect OP showed the highest mean encounter rate, with 4.3 observations/km, compared to 2.4 observations/km at M and almost 3 observations/km at TOT (Fig 4). Encounters in the "Seen" category occurred at a significantly higher rate on Transect OP than Transect M or TOT (t-value = 9.75, mean± SE = 3.71± 0.5, p-value = < 0.0001). But differences in encounter rates in the “Heard” category between the three transect locations were only marginally significant (f-value = 3, df = 32, p-value = 0.055). Encounters in “Seen” category represented 40% of the total sightings at Transect M and 33% at Transect OP and 27% at Transect TOT. Transect M was the only one that passed through coffee plantations and, tribal settlement, and along the riparian habitat, and it therefore had more visibility due to sparse tree coverage compared to the thick foliage of the wet evergreen forest. Encounter rates considering both location and species showed a loose pattern, the Great Hornbill seemed to prefer forested habitat and the Malabar Grey Hornbills were common in transect location closer to human habitation and with such preference was noticed with the Mountain Imperial Pigeon. Among all three transects, highest detection (45%) of the Great Hornbill were on Transect TOT but same transect recorded 26% of Malabar Grey Hornbill and 31% of Mountain Imperial Pigeon. This transect was located in a contiguous forest and surrounding region also had continuous forested habitat with old growth trees. The Malabar Grey Hornbill seemed to prefer the Transect ‘M’ closer to plantations and among human settlements. Mountain Imperial pigeon didn’t show any specific preference to transect location. They were as common around houses as in contiguous forest.

Sightings across all species increased significantly every year during the dry and hot season, around March-April, when large-seeded, lipid-rich fruits become available in the forest. Mountain Imperial Pigeon sightings steadily declined over the study period (Fig 7) and did not show a consistent pattern of increase even when large-seeded trees in the area were fruiting. On the other hand, the Malabar Grey Hornbill did not show a consistent pattern of increase or decrease from year to year but did show a general increase in abundance when large-seeded trees were fruiting between April and September, for two consecutive years (2013 and 2014).

Great Hornbills were the least abundant, and encounters spiked during the hottest time of the year, between January and May, coinciding with the fruiting of large-seeded species.

The pattern of encounters with birds along each transects during each month of the study period can be seen in Figure 8. At each transect, mean encounter rates gradually increase during the hot and dry season when large-seeded trees are fruiting in the region. The encounters did not show any pattern of consistent increase or decrease from year to year of except during the last five months of 2015, when encounter rates at each transect was comparatively lower.

Discussion

This was the first study to document abundance and encounter rates with large-bodied frugivore species of Great Hornbill, Malabar Grey Hornbill, and Mountain Imperial Pigeon in the reserve forest in southern Western Ghats outside of protected area network for more than two consecutive years. Vazhachal Reserve Forest is located adjacent to Parambikulam Tiger Reserve and has been identified as an important region for conservation of hornbill species (Mudappa and Raman 2008). In southern Western Ghats, especially in the Anamalai Hills, hornbill natural history has been studied in detail, but lacks information from Vazhachal Reserve Forest, whose contiguous evergreen forest makes it an important habitat for hornbills. The present study attempts to fill this knowledge gap by providing evidence that these large-bodied frugivore utilizing areas outside of the national parks and wildlife sanctuaries. It is not only an important region not only for Hornbills, but also for many deep forest, large-seeded tree species that fulfil the dietary needs of the large-bodied frugivores considered in this study. The encounter rates of two species of hornbill recorded during this study were higher than those recorded in a survey done a decade ago that studied the presence of hornbills in different habitats across Western Ghats (Mudappa and Raman 2008). The Great Hornbill encounter rate in the present study was 1 detection/km compared to 0.18 detections/km as recorded in 2008 survey. Similarly, for the Malabar Grey Hornbill, the present study recorded an encounter rate of 5.7 detections/km compared to 3.13 detections/km in the survey.

The present findings come after a decade of previous study and followed up with hornbill abundances and envisions future studies to include larger area of Vazhachal Reserve Forest to provide further comprehensive data on abundances. Due to sample size limitations, it was not possible to estimate the density of each of the species, but future studies can incorporate the findings of the present study. The present study also documented encounter rates with Mountain Imperial Pigeons, which many publications have suggested are as important to the local ecosystems as hornbills, despite the dearth of quantitative information on its abundance (Kannan 1994, Datta 1998, Sethi and Howe 2009). Similar encounter rates with Mountain Imperial Pigeon were recorded along all three transects, suggesting their ability to adapt to human modified regions. In northeastern India, study has found that in logged and disturbed forests where hornbill species are found less abundant, *Dysoxylum binectariferum* and *Polyalthia simiarum*, important evergreen tree species, are dispersed by Mountain Imperial Pigeon and a similar study to understand their role needs in Vazhachal region can be helpful. The present study also found that Malabar Grey Hornbill occurred more commonly near human habitation and human-modified landscapes of coffee plantations than in contiguous forests in the study area, bolstering findings by other studies that Malabar Grey Hornbills are accustomed to human-modified landscapes, and may even have traverse both contiguous and fragmented forest patches (Raman and Mudappa 2003). This species has also commonly seen perching on shade trees growing in coffee plantations, suggesting that it may play a significant role in seed dispersal in plantations and forest fragments (pers. obs.).

The findings of this study can provide critical baseline data against which future studies may measure the effects of anthropological activities on hornbill populations. Despite having only one road, Vazhachal Reserve Forest, with its famous Athirappilly Waterfalls, is rapidly becoming a popular and affordable touristic destination. As the condition of the road has improved over the last few years, it has attracted more vehicular traffic. Because Vazhachal Reserve Forest falls the outside protected area network, this tourist traffic is less regulated, and the forest staff is not as well equipped as staff in national parks and wildlife sanctuaries. Without baseline studies such as this one, understanding the effects of anthropogenic activities on the important species and ecosystems in the region will not possible.

Vazhachal Reserve Forest is peculiar in that it acts as a link connecting Anamalai Tiger Reserve in the east and Parambikulam Tiger Reserve in the north. A recent study conducted in fragmented forests and commercial plantations, near the present study area revealed that Great Hornbills and Malabar Grey Hornbills are using human modified landscapes as breeding grounds but probably depend on nearby contiguous and fragmented forest patches for food resources (Pawar 2016). The same study also pointed out the importance of Vazhachal Reserve Forest, which provides a contiguous forest habitat and fruit resources that hornbills can access even if they are breeding in modified landscape. The present study used the summary statistic approach, and despite sample size limitations, the following observations can be made: 1) encounter rates of large-bodied frugivores in the study area are higher than those previously recorded in the same study area; 2) this is the first study to record encounters of Mountain Imperial Pigeons, one of the only large-bodied frugivore common in this region; 3) both Malabar Grey Hornbills and Mountain Imperial Pigeons are detected in large numbers in locations close to human habitation and commercial coffee plantations, indicating their utilization of human-modified landscapes; 4) these findings will provide baseline information for future comparisons; and 5) the presence of all three species of frugivores underscores the importance of Vazhachal Reserve Forest and the pressing need for efforts to protect and conserve the tropical evergreen forests in southern Western Ghats.

Large-bodied frugivores provide critical ecosystem services and help to disperse the seeds of many tree species, especially rare tree species that have few dependable dispersers. Losing these frugivore species could have substantial negative impact not just at the species level, but at an ecosystem level as well. Massive habitat loss and hunting pressure generated by the pet trade threaten many large avian frugivores, in South and Southeast Asia and hornbills are no exception (Española et al. 2012). One of the crucial findings of the (Mudappa and Raman 2008) survey of hornbills throughout the Western Ghats that have exerted sustained pressure on hornbills. It is therefore essential to continue to collect information on their abundance and distribution in order to develop effective management and conservation strategies.

In India and particularly in Western Ghats, hornbill's natural history has been studied in detail, but these studies have focused exclusively on habitats that are protected. Vast stretches of forest exist outside of these protected areas, and the importance of further research these unprotected area cannot be overstated (Balasubramanian et al. 2007, Kannan and James 2007, Raman 2007, James and Kannan 2009, Mudappa and Raman 2009, Bachan et al. 2011, Naniwadekar and Datta 2013, Pawar 2016). In the case of evergreen forests in Western Ghats, 74% of the forested area, including Vazhachal lies outside the protected area network. Abundance and distribution studies of hornbills in northeast India has revealed their complete disappearance from certain protected areas, though they continue to thrive in less protected areas such as reserve forests and community forests (Naniwadekar et al. 2015b). The present study, in conjunction with a small number of previous studies, may serve as a foundation for research focusing on reserve forests in the state of Kerala, which could help strengthen local conservation management strategies. The current hornbill nest-monitoring program run by the Kerala Forest Department will benefit from the information gathered during this study, which it may utilize in designing and planning conservation policies for Vazhachal Reserve Forest, particularly in response to the proposed Athirappilly hydropower plant. This project threatens the ecosystem of the region in the near future. With such land-modification projects looming on the horizon, it is more important than ever to gather reliable data that can provide insights into the potential impacts of landscape level changes on the species and ecosystem in the region.

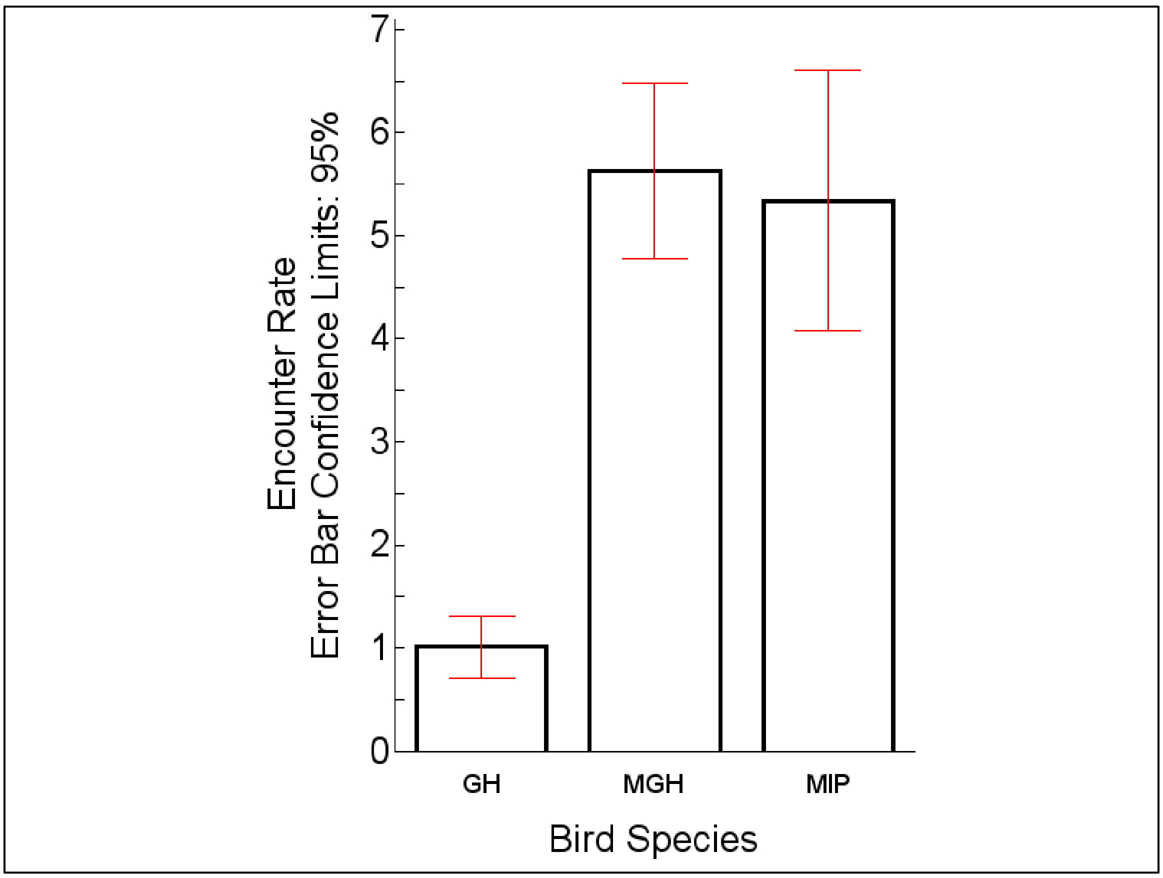

Figure 1. Mean encounter rates (detections of birds/km) with 95% CI of Great Hornbill, Malabar Grey Hornbill and Mountain Imperial Pigeon across all transects ('M', 'OP', and 'TOT') in Vazhachal Reserve Forest, Western Ghats, India during January 2013 through May 2015.

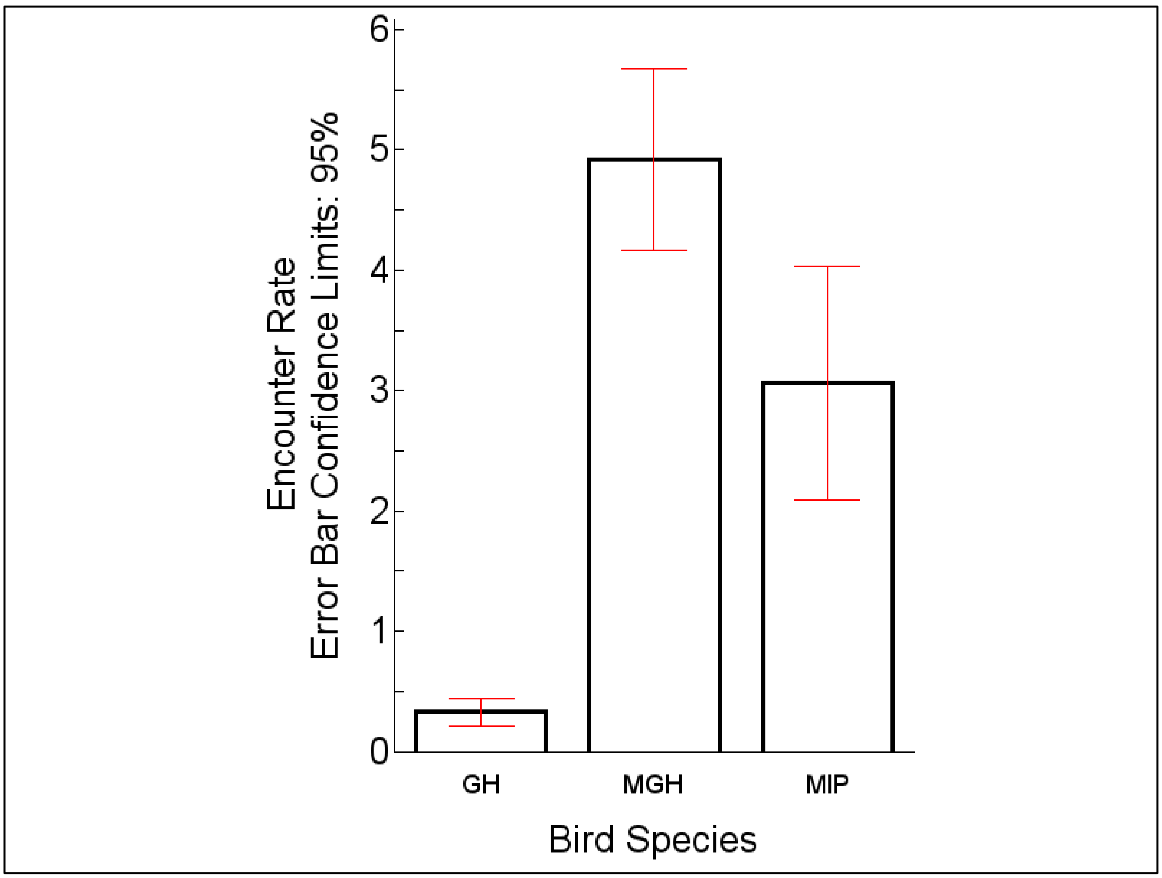

Figure 2. Mean encounter rates (detections of birds/km) with 95% CI with Great Hornbills, Malabar Grey Hornbills and Mountain Imperial Pigeons in the “Seen” category across all transects (‘M’, ‘OP’, and ‘TOT’) in Vazhachal Reserve Forest, Western Ghats, India between January 2013 and May 2015.

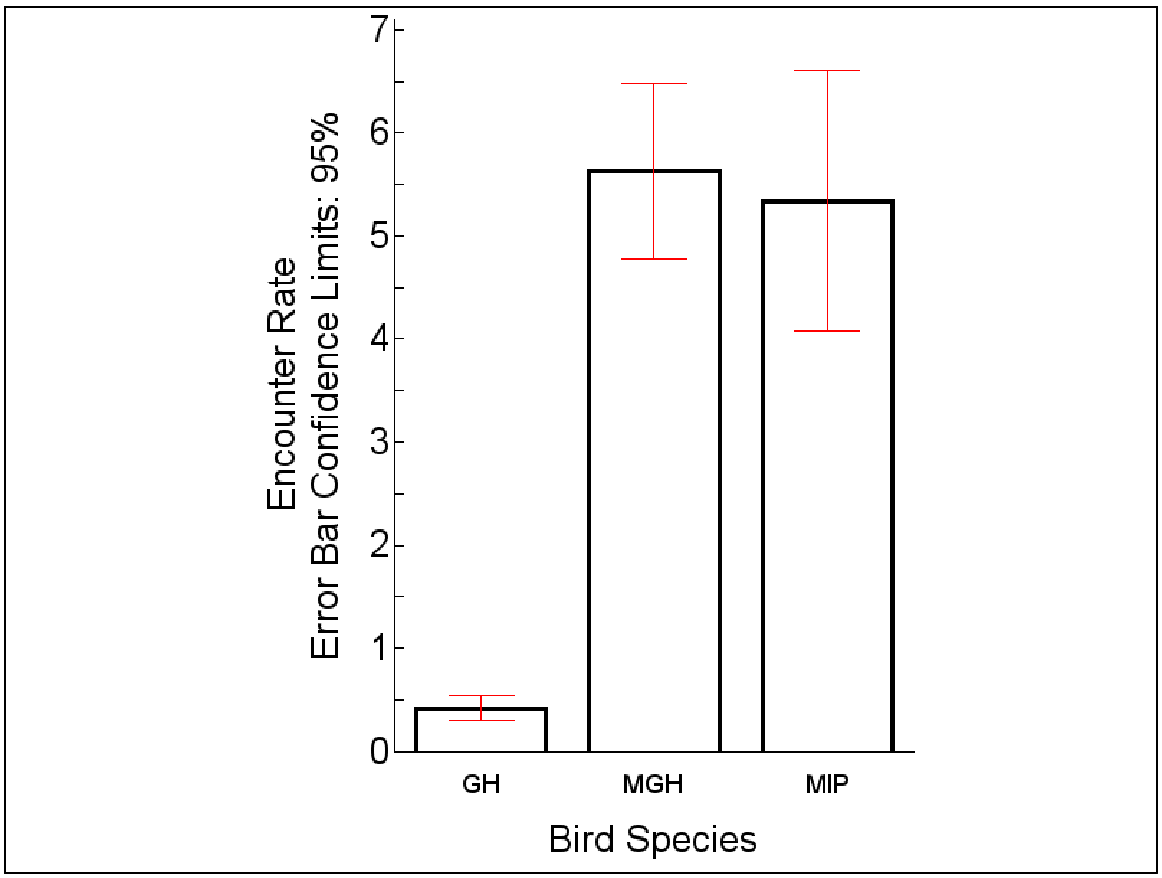

Figure 3. Mean encounter rates (detections of birds/km) with 95% CI of Great Hornbills, Malabar Grey Hornbills and Mountain Imperial Pigeons in the "Heard" category across all transects ('M', 'OP', and 'TOT') in Vazhachal Reserve Forest, Western Ghats, India between January 2013 and May 2015.

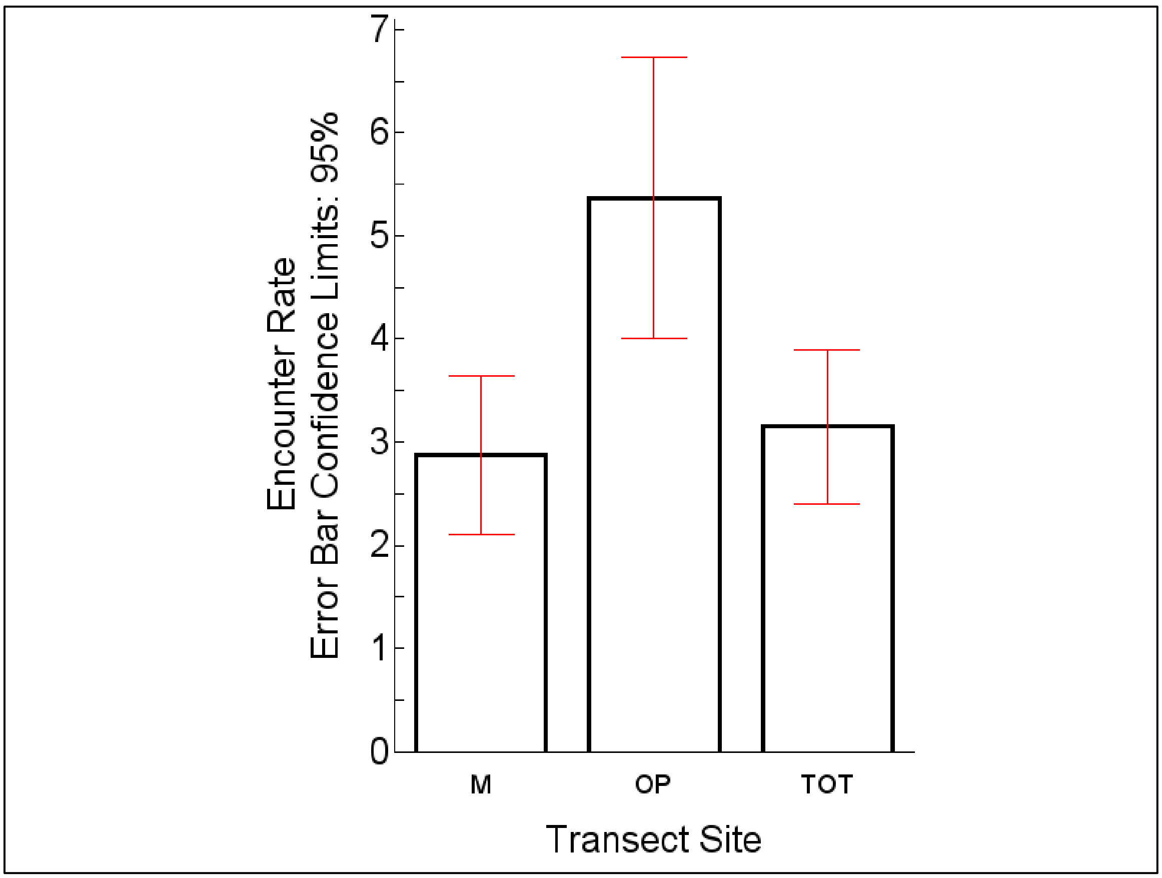

Figure 4. Mean encounter rates (detections of birds/km) with 95% CI across all species along Transects ‘M’, ‘OP’, and ‘TOT’ in Vazhachal Reserve Forest Western Ghats, India, between January 2013 and May 2015.

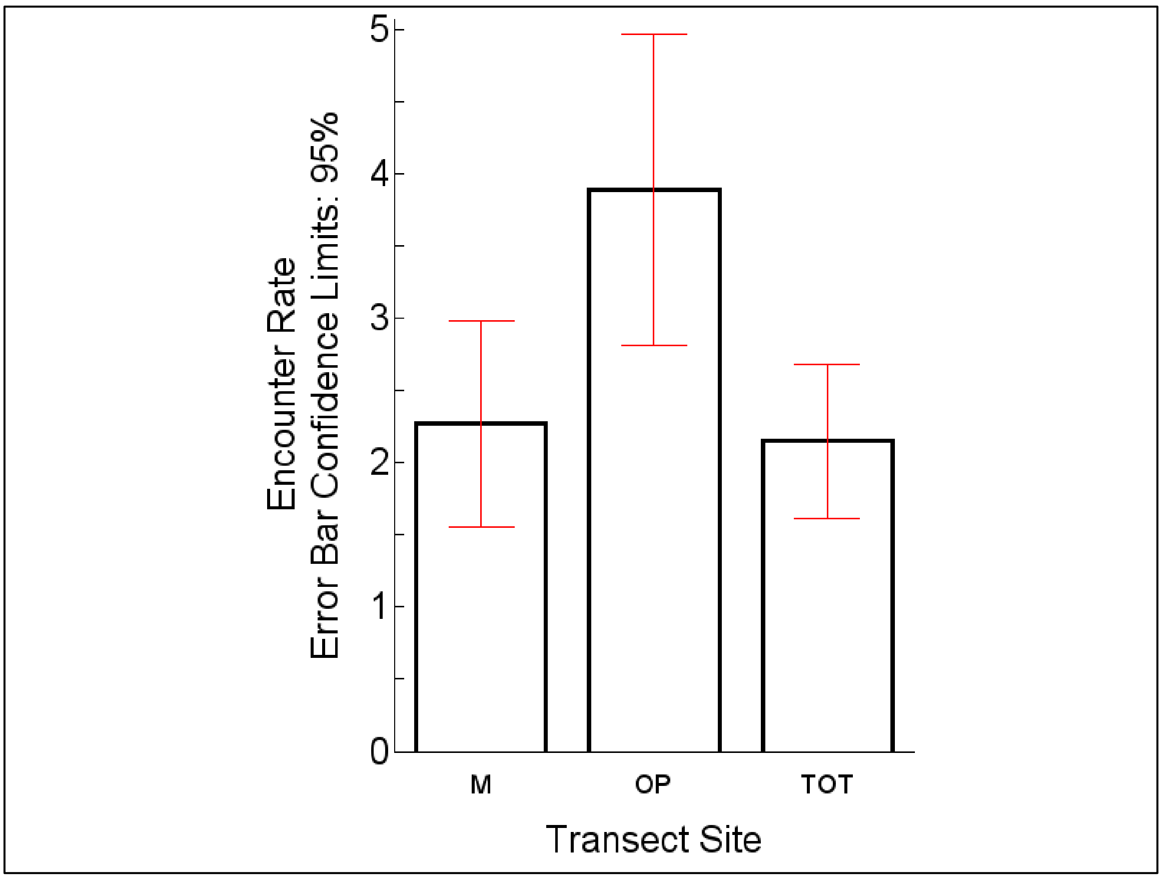

Figure 5. Mean encounter rates (detections of birds/km) with 95% CI across all species in the “Seen” category along Transects ‘M’, ‘OP’, and ‘TOT’ in Vazhachal Reserve Forest Western Ghats, India between January 2013 and May 2015.

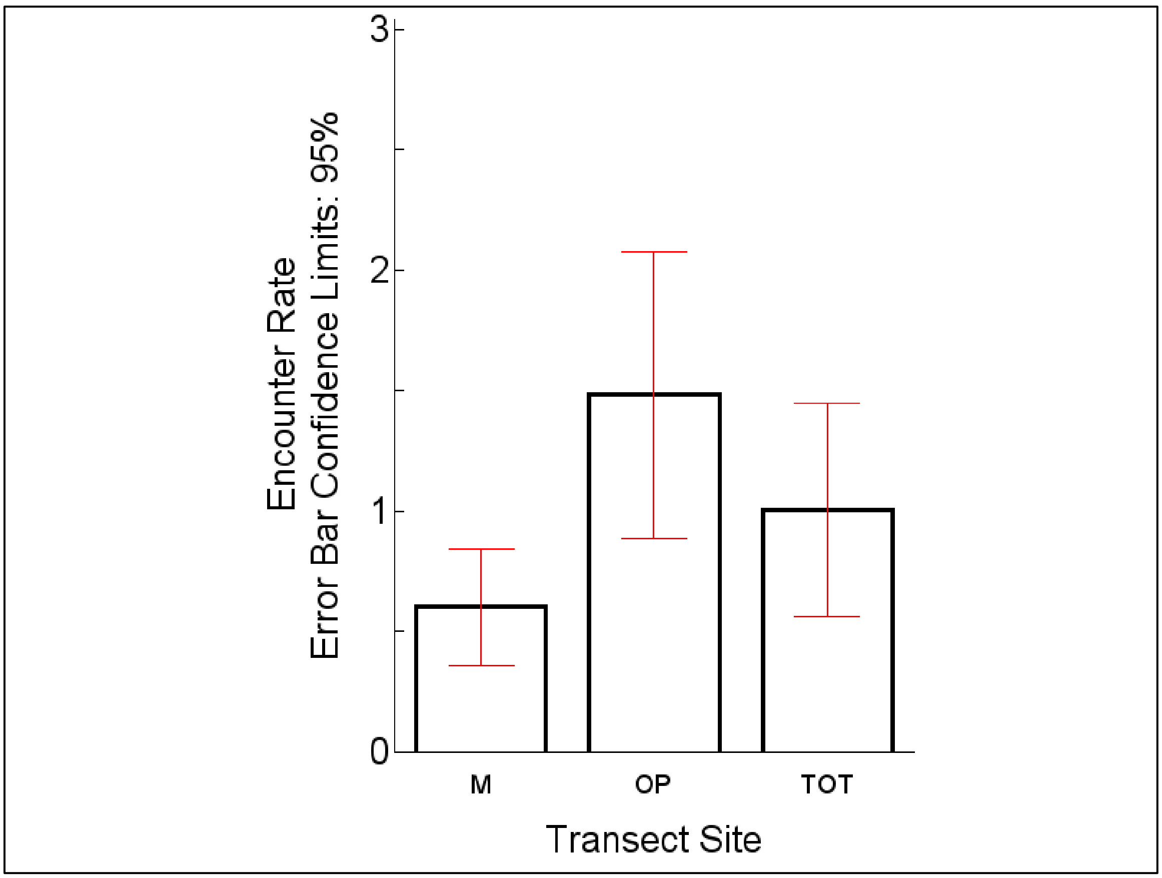

Figure 6. Mean encounter rates (detections of birds/km) with 95% CI across all species in the "Heard" category along Transects 'M', 'OP', and 'TOT' in Vazhachal Reserve Forest Western Ghats, India between January 2013 and May 2015.

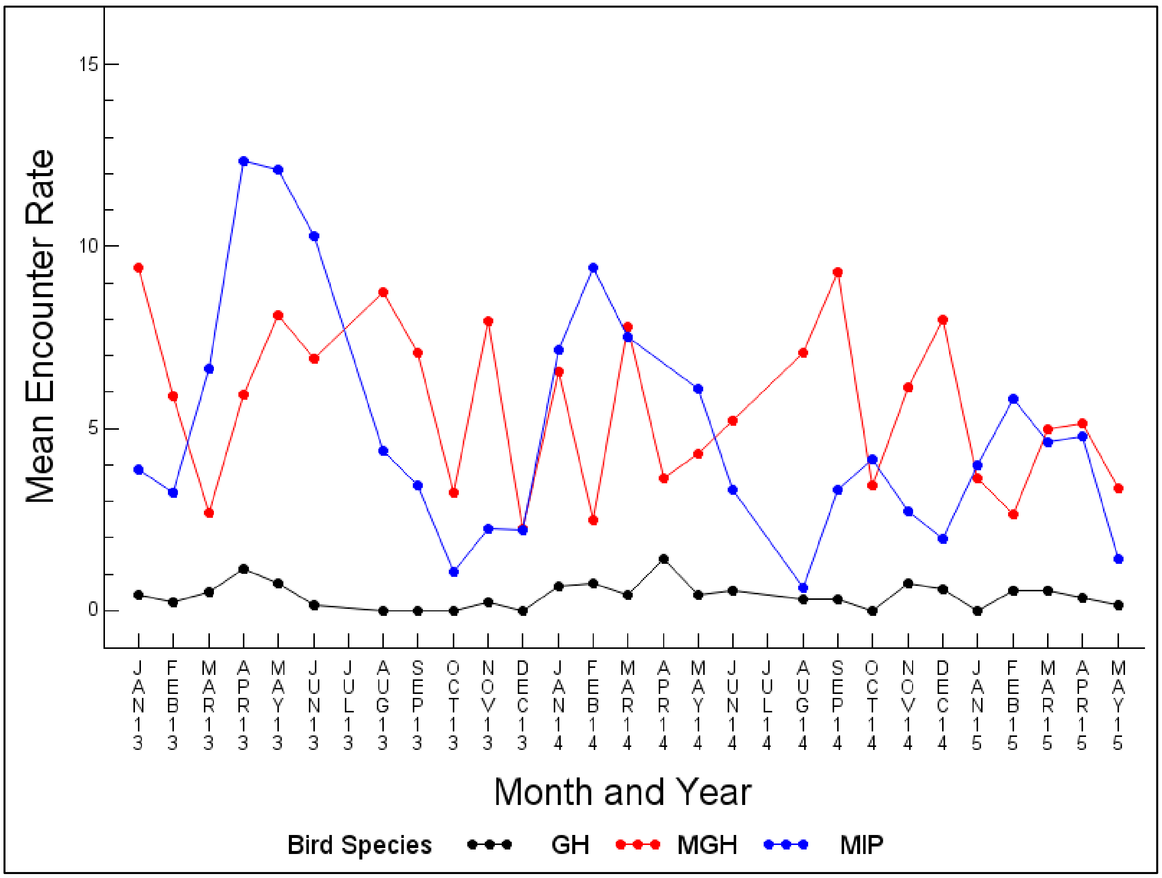

Figure 7. Mean encounter rates with Great Hornbills, Malabar Grey Hornbills, and Mountain Imperial Pigeons during each month from January 2013 and May 2015 in Vazhachal Reserve Forest, Western Ghats, India.

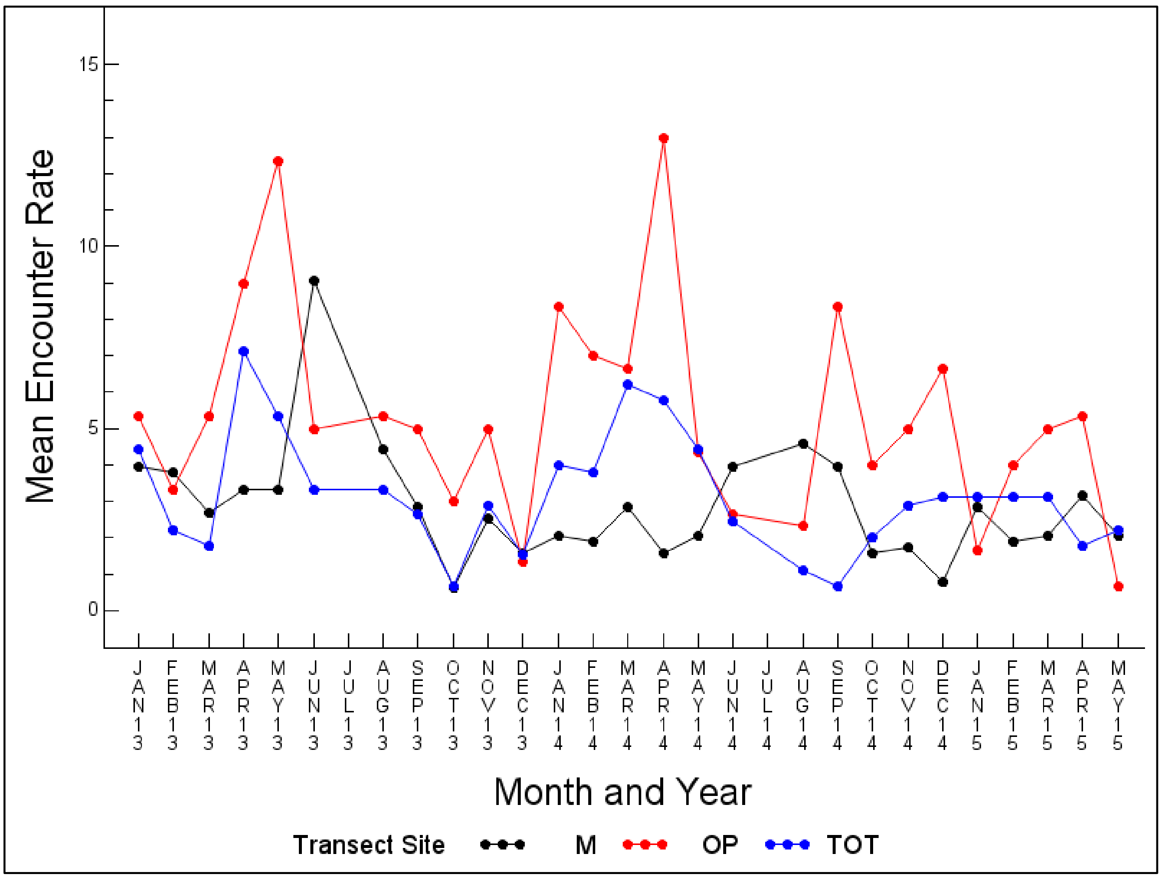

Figure 8. Mean encounter rates (detections of birds/km) along Transects 'M', 'OP', and 'TOT' during each month starting between January 2013 and May 2015 in Vazhachal Reserve Forest, Western Ghats, India.

Table 1. Total number of encounters with Great Hornbills, Malabar Grey Hornbills and Mountain Imperial Pigeons on transect M, OP, and TOT in Vazhachal Reserve Forest, Western Ghats from January 2013 to May 2015.

Bird Species	M	OP	TOT	TOTAL
Great Hornbill	21	8	24	53
Malabar Grey Hornbill	266	215	172	653
Mountain Imperial Pigeon	201	212	187	600

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Conclusions and Synthesis

Hornbills are majestic denizens of the evergreen tropical forests. Their charismatic appearance, unique nesting behavior, dependence on lofty trees in which they nest have attracted attention of the scientific community and prompted investigation of this species and its role in the ecosystem. Hornbills are known to consume a plethora of fruits, including rare, large-seeded tree species that depend on only small coterie of seed dispersers. The first long-term study of Great Hornbill breeding biology and foraging ecology in India was carried out in the hills of southern Western Ghats and paved way for follow up studies in different parts of India. Vazhachal Reserve Forest was one of the regions mentioned in that study as a potentially important habitat for Great Hornbills. Vazhachal Reserve Forest was chosen as the site for the present study because, despite the references to the importance of this region in the extant literature, no data from this region existed to inform hornbill conservation efforts.

The Anamalai Hills in the Vazhachal region are home to an indigenous tribe called the "Kadar", a primitive, seasonally nomadic, forest dwelling community. They are non-agrarian and depend on non-timber forest products to sustain their lifestyle. The "Kadar" are very closely linked to the Vazhachal region, but have been displaced repeatedly over the last century and now exist in fragmented colonies around the region. The majority of their current population, which numbers just less than 2000, is spread across the central and northern stretches of the Anamalai Hills in the state of Kerala where the current study was carried out. They mainly depend on these forests for fish, honey, wild nutmeg *(Myristica species*), black damar (*Canarium strictum*), and white damar (*Vateria indica*).

Vazhachal Reserve Forest falls outside of the protected area network in Western Ghats and has received less attention from the scientific community until recently. The present study was an attempt to understand one of the important plant-animal interactions in Vazhachal. The study focused on six genera of large-seeded tree species whose fruits arepreferred by three species of large-bodied avian frugivores namely: Great Hornbills (*Buceros bicornis*), Malabar Grey Hornbills (*Ocyceros griseus*) and Mountain Imperial Pigeons (*Ducula badia*) This study represents the first attempt to document the phenological patterns of large-seeded tree species, seedling-sapling demography under hornbill nest as indirect evidence that the seeds were being dispersed by hornbills and the abundances of hornbill species in Vazhachal Reserve Forest. Studies that have looked at hornbill foraging patterns have documented the Mountain Imperial Pigeon as another important species that has a wide gape and can consume the fruits of large-seeded species without damaging the seeds but there are no studies looking at Mountain Imperial Pigeon's role in the ecosystem from the perspective of any large-seeded tree species. Although Mountain Imperial Pigeon are commonly seen in this region no population density estimates have been published. This study was also the first attempt to record the quantitative abundances and encounter rates of Mountain Imperial Pigeon in Vazhachal region.

The present study revealed that the lipid-rich fruits of six genera of large-seeded tree species in are available to frugivores in Vazhachal Reserve Forest. These fruiting patterns were monitored over two years and was corelated positively with peaks in the encounter rates of Great Hornbills, Malabar Grey Hornbills and Mountain Imperial Pigeons during the study period. These fruits represent an important component of hornbill's diets, largely because of their nutritional quality and availability during hornbill's critical nesting period.

The findings of this study indicated that among the six monitored genera *Myristica dactyloides* and species of *Litsea* contributed highly to the fruiting and are potentially an important source of nutrition for the frugivores considered. Hornbills consume fruits of large-seeded species leaving seeds unharmed and deposit these seeds at germinating sites far from their parent trees – i.e. hornbill roosting and nesting sites-where they will not be threatened by interspecific competition between conspecifics and mortality due to host-specific pathogens. The seedling-saplings of the species of *Myristica* were found to be most abundant under the nest trees and majority (93%) survived during the study period. This is evidence that *Myristica* fruits are a critical resource for hornbill species in the Vazhachal region, and that hornbills are helping disperse their seeds to nest sites. *Myristica* species, also known as wild nutmeg is an important non-timber product harvested by the tribal community in Vazhachal for its aril. which is globally used as a spice. Aril harvesting is not regulated or monitored and over harvesting can negatively impact both frugivores and tribal community in the region. Tribal members often discard the seeds in bulk after removing the aril and seeds were frequently observed rotting on the forest floor on many occasions during the period of the study.

In another case, *Canarium*. *strictum*, an important hornbill diet species commonly known as black dammar, was found to be quite scarce in the region. None of the *C. strictum* trees that were monitored fruited at any time during the study. This species' aromatic resin is harvested by cutting or burning the area of the bark, which can lead to the death of the tree or negatively affect its fruiting and flowering capabilities. A number of burned *C*. *strictum* trees were found during the study period, and majority of old growth trees of this species displayed either burn or machete marks. The findings of this study highlighted the need for further in-depth studies of *C. strictum* populations in the Vazhachal region and suggest that resin harvesting needs to be quantified and monitored to ensure survival of this species.

Finally, the abundance study yielded slightly higher Great Hornbill and Malabar Grey Hornbill encounter rates than a survey conducted in Vazhachal Reserve Forest in 2008, underscoring that Vazhachal continues to function as a suitable habitat for these avian frugivores. Due to sample size limitations, only encounter rates were calculated, but the study area can be expanded to record the densities of the large-bodied frugivores considered in the present study.

In the past, most of the hornbill research conducted on hornbills in India has been restricted to protected areas. There has not been single long-term hornbill study carried out in Vazhachal Reserve Forest, which is not part of the protected area network, despite of its recognition as an important region for hornbills, though there have been very few hornbill conservation projects implemented in Vazhachal Reserve Forest by the Kerala Forest Department. One such project, is a Great Hornbill nest monitoring program initiated in 2005, which employs members of the “Kadar” community to curb hornbill poaching and generate sustainable employment for the tribe. No signs of poaching were recorded during the period of the study, indicating the success of this project. Yet such long-term monitoring programs none the less come with their own challenges, such as maintaining steady flow of funds and, securing commitment from the tribal community for extended periods of time. Discussions with tribal members during the period of the present study revealed declining enthusiasm for the monitoring program due to the bureaucratic complexities of the system. Informants indicated that only a few tribal members have consistently been monitoring the nests, and that there are not enough reliable individuals to thoroughly monitor the entire reserve forest.

In another initiative, the forest department at Vazhachal collaborated with Western Ghats Hornbill Foundation, a local NGO to install artificial nest cavities for Great Hornbills in six locations across the Vazhachal region in 2007 (Vazhachal Working Plan 2012). Of these six artificial nests, three were regularly observed during the present study and were never found occupied by the Great Hornbill, although one such nest box was occupied by a Malabar Giant Squirrel. Both of these projects need reevaluation and a thorough, ongoing discussion of the challenges involving both the forest department and the tribal community seems warranted.

Over the last two decades, the biggest threat looming over the region of Vazhachal is the proposed hydropower plant at Athirappilly in Vazhachal Reserve Forest. The Kerala State Electricity Board has proposed a hydropower plant that threatens to submerge 138 hectares of forest in Vazhachal region. Vazhachal region in particular exhibits high endemism of various taxa including fishes and riparian plant species. Vazhachal region not only exhibit endemic taxa but also very unique habitats such as *Myristica* swamps at as low as 200 m altitude and very high endemicity of fishes (WGEEP) (Western Ghats Ecology Expert Panel 2011). All four species of hornbills that occur in southern Western Ghats occur in the Vazhachal region including the locally endangered Malabar Pied Hornbill (*Anthracoceros coronatus*) which is found in the area that would be affected by the proposed project. The project also threatens to destroy the migration routes traditionally used by elephant populations across this region and potentially lead to human-animal conflict in the area.

Moreover, the project could threaten the life style, socio-economic structure and cause cultural damage to the indigenous tribal community. Western Ghats Hornbill Foundation have been actively involved with the “Kadar” tribal community, organizing meetings and awareness campaigns to equip the community with knowledge of their forest rights. However, literacy rates among the “Kadar” remain low, putting them at a disadvantage in legal battles against the hydropower project. The findings of this study will may bolster the legal case against the proposed project by expanding the list of taxa that can be shown to depend on this habitat and further illustrating the negative impacts that such disruptive project would have on the ecosystem of the region.

The Vazhachal region is surrounded by commercial plantation areas and fragments of rainforest that do either have very low-density trees required by hornbills or are absent. Vazhachal acts as an important tract of contiguous forested land linking surrounding protected areas in midst of the commercial plantations landscape. A recently published study on habitat utilization by Great Hornbills and Malabar Grey Hornbills in human-modified landscapes in area adjoining Vazhachal Reserve Forest, particularly Sholayar Forest Range revealed that these hornbills may be using contiguous forest in Vazhachal region to obtain nutrition from fruiting tree species native to this region, especially large-seeded species that produce highly nutritious lipid-rich fruits. The present study reveals that in Vazhachal Reserve Forest, large-seeded fruits remain available to large-bodied avian frugivores during hornbill nesting season. These findings will be made available to the Kerala Forest Department and Western Ghats Hornbill Foundation to inform future conservation efforts in the region.

Finally, I must add that a more research-conducive environment is badly needed in the Vazhachal region. Throughout India, the discouraging attitude of management officials and toward applied sciences represent a major challenge to researchers. Although official wildlife management has nominally prioritized wildlife research, Indian governmental bodies routinely deny permits to researchers, and no redressal system exists to respond to this and other obstacles. The Vazhachal region remains highly inaccessible, and researchers depend on regular hand on support from the local forest department. If the Kerala Forest Department took a more active role in inviting and supporting students to conduct research in the region, their own conservation efforts would surely benefit from the data and that these student's projects would yield. Yet instead, it is becoming increasingly challenging for student researchers, and especially single women to conduct studies in inaccessible areas such as Vazhachal region.

Unless Indian bureaucrats make a concerted effort to welcome, encourage, and facilitate research and data collection, young researchers like myself will continue to experience severe and inhibitory difficulties and will struggle to make robust and meaningful contributions to the field. This will impact not just aspiring scientists' professional careers, but also the overall quality and availability of data, which in turn will severely constrain conservation efforts. At a time when climate change, forest fragmentation, and human modification of landscapes represent ever growing threats to unprotected forests, including diverse region as Vazhachal, conservationists cannot afford to overlook the role that cultural and bureaucratic systems play in de-incentivizing data collection and impoverishing the literature available to the scientific community.

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Plate 1: Great Hornbill (*Buceros bicornis*) perched on a tree, Valparai, Tamil Nadu, India

Plate 2: Malabar Grey Hornbill (*Ocyceros griseus*) perched on Erythrina species, Malakkapara, Kerala, India.

Plate 3: Mountain Imperial Pigeon (*Ducula badia*) perched on Canarium strictum, Malakkapara, Kerala, India.

Plate 4: Forest stratification in Vazhachal Reserve Forests, Kerala, India

Plate 5: Typical fruit phenology study plot in Vazhachal Reserve Forest, Kerala, India.

Plate 6: Discarded capsules and seeds of *Myristica species* in Vazhachal Reserve Forest, Kerala, India.

Plate 7: Fruits of *Canarium strictum* in Vazhachal Reserve Forest, Kerala, India

Plate 8: Fruits of *Persea macrantha* in Vazhachal Reserve Forest, Kerala, India

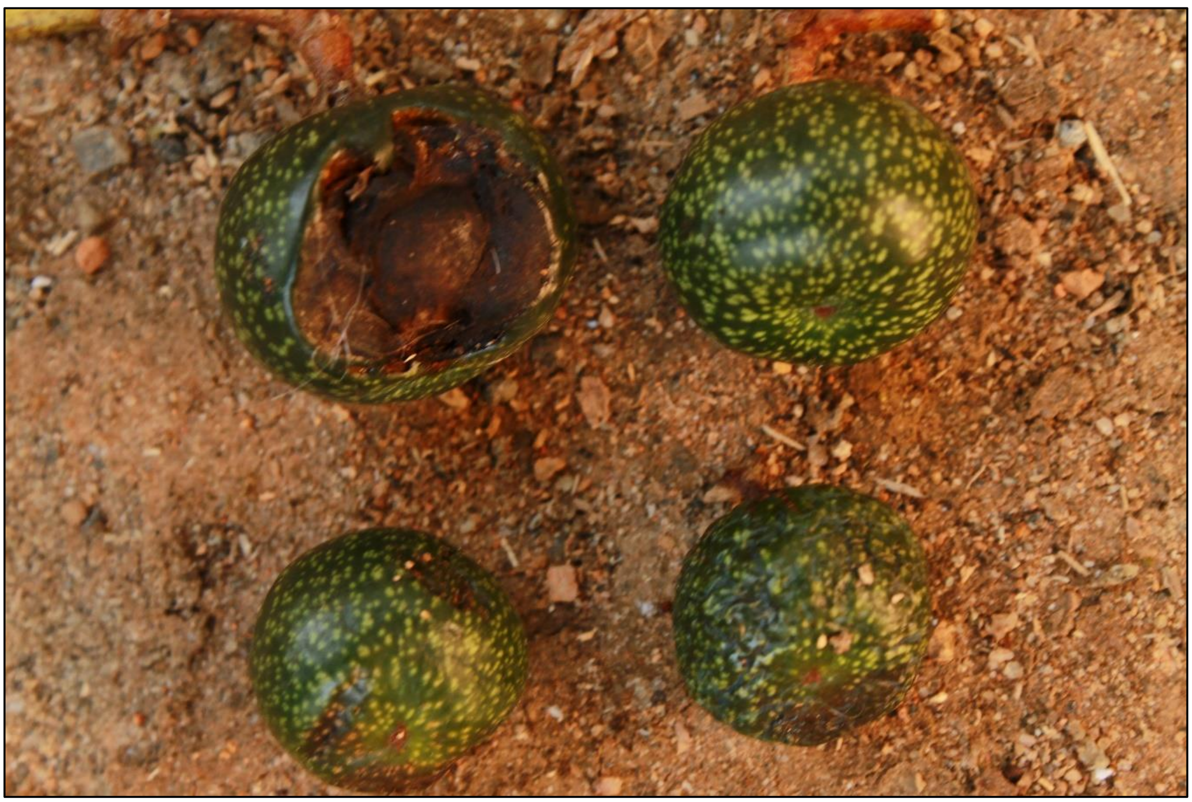

Plate 9: Seed covered with aril of *Myristica species* in Vazhachal Reserve Forest, Kerala, India

Plate 10: Wide buttressed tree of *Myristica species* in Vazhachal Reserve Forest, Kerala, India

Plate 11: Metal tags on *Myristica species* in phenology study plots in Vazhachal Reserve Forest, Kerala, India.

Plate 12: Wide buttressed tree of *Dysoxylum species* in Vazhachal Reserve Forest, Kerala, India.