STUDY ON AVIAN FRUGIVORY AND SEED DISPERSAL IN THE SHOLA FORESTS OF NILGIRI HILLS, WESTERN GHATS, INDIA

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in

BOTANY

by

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June 2013

CERTIFICATE

This is to certify that the thesis, entitled " Study on avian frugivory and seed dispersal in the Shola forests of Nilgiri Hills, Western Ghats, India" submitted to the Bharathiar University, in partial fulfillment of the requirements for the award of the Degree of Doctor of Philosophy in Botany, is a record of original research work done by Mr. C. Anbarasu during the period January 2009 to July 2011 of his research in the Department of Landscape Ecology at Salim Ali centre for Ornithology and Natural History, Coimbatore, under my supervision and guidance and the thesis has not formed the basis for the award of any Degree/Diploma/ Associateship/Fellowship/ or other similar title of any candidate of any University.

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DECLARATION

I, C. Anbarasu hereby declare that the thesis, entitled "Study on avian frugivory and seed dispersal in the Shola forests of Nilgiri Hills, Western Ghats, India" submitted to the Bharathiar University, in partial fulfillment of the requirements for the award of the Degree of Doctor of Philosophy in Botany, is a record of original and independent research work done by me during January 2009 to July 2011 under the supervision and guidance of Dr. P. Balasubramanian, Division of Landscape Ecology, Salim Ali Centre for Ornithology and Natural History, Coimbatore, and it has not formed the basis for the award of any Degree/Diploma/Associateship/Fellowship/ or other similar title of any candidate of any University.

Signature of the Candidate

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SYNOPSIS

Introduction

Most woody species in tropical forests produce fleshy fruits that attract vertebrate frugivores. Frugivorous birds and bats are the most important seed dispersal agents of tropical forest trees. The pulp of fleshy fruits, with the soft, edible, nutritive tissues surrounding the seeds, is a primary food resource for many frugivorous animals. The fruit eating animals regurgitate, defecate, spit out or otherwise drop undamaged seeds away from the parent plant; they are the seed dispersers that establish a dynamic link between the fruiting plant and the seed-seedling bank in natural communities. Therefore, frugivory is a central process in plant populations where natural regeneration is strongly dependent upon seed dissemination by animals. Due to the fact that forest birds are generally more abundant than mammals, birds are expected to move large quantities of seeds from the parent plants. However, it is not a highly specific type of plant-animal interaction. For example, a single species of frugivorous bird may disperse seeds of several species of plants, or a few species of birds may disperse seeds of one plant species. These information are not available for all the forest types in India. Hence, it was felt essential to understand fruit-frugivore interactions in the "shola" forests (tropical montane evergreen forest) which is an unique ecosystem occurring in the Western Ghats of India. The objectives of the present study were, i). study avian frugivory and find out major frugivores in the shola forests ii). assess the fruiting phenology of fleshy-fruited tree species and find out the seasonality, iii). establish the role of avian frugivores in seed dispersal and forest regeneration.

The study was carried out in two shola forests namely, Longwood and Eppanadu in the Nilgiri Hills, Western Ghats, India from January 2009 to July 2011. Longwood shola is situated between 11°43.494′ N and 076° 87.463′ E) and Eppanadu shola between 11°29.151′ N and 076° 47.223′ E. While the Longwood shola is located at an altitude of 1905 m above m.s.l., the Eppanadu shola is 2090 m.

Methodology

Vegetation sampling was done in both the shola forest sites by using quadrat method. Ten qudrats of 50x20 m size were laid in each of the shola forest. In each plot (50x20m), number of individuals of trees and GBH (>20cm) of each woody individual was noted. All the shrubs and saplings occurring with in the quadrat were recorded. Five (1x1m) plots were laid within the 50 x 20 m quadrat for recording seedlings. Fruiting periodicity was determined by monitoring tagged trees. Ten individuals per species were selected for phenology study. Fruit availability was assessed once in a fortnight by noting the presence of ripe fruits in the canopy of the tagged individuals for 24 months. Extended bird foraging observations (3 hrs continuous watch) were carried out on fruit bearing plants. The fruit bearing plants with good visibility for the observer was selected for extended observations. The observations were carried out mostly in the morning from 6 am to 9 am and in the evening between 3 pm to 6 pm, which is the active time for foraging frugivores. Data on frequency of bird visits and fruit handling behaviour were gathered during the extended observations. The distance traveled by each avian frugivore to the first perching site after leaving a fruiting tree was noted following Green (1993). Number of fruits consumed per visit was recorded for various bird species. The values of distances traveled after fruit consumption and mean number of fruits consumed per visit by each bird species would be useful in assessing the relative role of each bird species in seed dispersal. The observations were carried out using a pair of 7 x 50 binoculars. Colours of ripe fruits were assigned to one of eight broad colour categories used by Wheelwright and Janson (1985). Diameters of the fruits were measured using Vernier caliper. Twenty fruits per species were measured and mean diameter of each fruit species calculated. Seed germination experiments were conducted to compare the germination efficiency of bird defecated seeds with that of control seeds. Three types of seeds were used for germination experiments. i. bird dispersed seeds collected from the nest middens, ii. pulp removed seeds (manual removal) and iii. seeds with intact pulp. Seeds were sown in polythene bags filled with soil and sand mixture and were placed in a nursery, which had an enclosure. The poly-bags were watered regularly and the number

of seedlings emerged, heights of the seedlings were recorded every week for four months since the date of sowing.

Results

Longwood shola forest

In total, 874 individuals of 45 tree species belonging to 30 families were recorded in the Longwood shola. Highest number of individuals recorded include *Euonymus crenulatus* (n=93) followed by *Elaeocarpus oblongus* (n=89) and *Celtis tetrandra* (n=78). Highest Importance Value Index was recorded for *Euonymous dichotomous* (IVI-48.42) followed by *Euodia lunu-ankenda* (IVI-41.85) and *Elaeocarpus oblongus* (IVI-24.69). Of the 30 families recorded, Lauraceae (11.94%), Ulmaceae (9.50%), and Elaeocarpaceae (7.21%) were represented by maximum number of individuals. Highest number of species was observed for Lauraceae (n=7 species).

Fruiting seasonality of trees was noticed. A major fruiting peak was observed in June and a dip in October for both the years.

In total, 26 plant species were studied for avian frugivore visitation. 1248 hrs of observations were made. Totally 27 avian frugivore species belonging to 10 families were recorded. Maximum number of avian frugivore species belonged to Muscicapidae (8 species) followed by Pycnonotidae (5 species) and Corvidae, Columbidae (3 species each). Maximum number of foraging visits were made by Nilgiri Laughingthrush (n=1233) followed by Red-whiskered Bulbul (n=886) and Blackbird (n=557). Laughing thrushes and bulbuls formed the major frugivores in the shola forest. Pearson's Chi-square (17139, $P < 0.0001$, $df = 550$) analysis clearly indicates that bird species and the fruit tree species are NOT independent. That means the visitation rates of birds are strongly associated with composition of fruit-trees in Longwood shola.

A total of 26 fleshy-fruited species belonging to 23 genera of 20 families were found to be dispersed by birds. Lauraceae (4 species) was found to be the predominant family in the Longwood shola forest. Large proportion of avian frugivore visits was made on

Lauraceae (n=11.01%) followed by Oleaceae (n=10.63%) and Sapotaceae (9.15%). Ivlev's Preference Index (PI) values showed *Viburnum punctatum* (PI=0.89) as the most preferred fruit species by avian frugivores followed by *Ternstroemia japonica, Litsea wightiana* (PI=0.86) and *Olea paniculata* (PI=0.84).

Eppanadu shola forest

A total of 1013 individuals belonging to 46 tree species of 30 families were recorded in the 1 ha sampling area. Maximum number of individuals was represented by *Symplocos cochinchinensis* (n=176) followed by *Celtis tetrandra* (n=132) and *Actinodaphne bourneae* (n=60). Highest Importance Value Index values was recorded for *Celtis tetrandra* (IVI-42.51) followed by *Symplocos cochinchinensis* (IVI-75.77) and *Actinodaphne bourneae* (IVI-10.92). Of the 30 families recorded, Symplocaceae (20.24%), Lauraceae (16.9%), Ulmaceae (13.92%), and Myrtaceae (9.28%) had comparatively higher number of individuals. Highest number of species was represented in Lauraceae (n=6) followed by Myrtaceae (n=4).

Pronounced fruiting seasonality of trees was noticed in the Eppanadu shola. A fruiting peak was observed in June and dip during October.

A total of 28 tree species were studied for avian frugivore visitation. 1316 hrs of observations were made. In total, 29 avian frugivore species belonging to 11 families were recorded in the Eppanadu shola. Maximum number of avian frugivore species belonged to Muscicapidae (7 species) followed by Pycnonotidae (5 species) and Corvidae, Columbidae (3 species each). Totally, 5034 individuals belonging to 29 species of avian frugivores were recorded. Maximum number of foraging visits were made by Red-whiskered Bulbul (n=1068) followed by Nilgiri Laughingthrush (n=682) and Nilgiri Wood-pigeon (n=527). Highest proportion of fruit foraging visits were made by Pycnonotidae (35%) followed by Muscicapidae (31%) and Columbidae (16%). Pearson's Chi-square value (17439, $P < 0.0001$, $df = 700$) clearly indicates that bird species and fruit species are NOT independent. The visitation rates of birds are strongly associated with composition of fruit-trees in the Eppanadu shola forest.

In total 28 species of fleshy fruits belonging to 24 genera of 21 families were consumed by birds. Lauraceae (4 species) was found to be the predominant bird-dispersed family in the Eppanadu shola. Largest proportion of avian visits was recorded on Lauraceae (13.04%) followed by Ulmaceae (10.38%) and Myrtaceae (7.11%). Highest number of the frugivore species were attracted by *Ilex wightiana* (n=11) followed by *Daphniphyllum neilgherrense* (n=9). Ivlev's Preference Index (PI) showed *Viburnum punctatu*m (PI=0.89) was the most preferred fruit species by avian frugivores followed by *Ternstroemia japonica, Litsea wightiana* (PI=0.86) and *Olea paniculata* (PI=0.84).

Fruit characteristics of bird-dispersed species, frugivory, seed dispersal and germination

Eight types of fruit colours were recognized in the shola forests. Black (61%) followed by Red (23%) were found to the predominant fruit colours in the study area. Among the 47 fleshy fruited plant species, 18 produced fruits measuring <10mm, 28 had 10-20 mm size and the remaining one species (*Elaeocarpus oblongus*) had >20 mm fruit diameter. In total, four fruit types were utilized by birds in the shola forests. Berry (46.81%) formed the most used fruit type followed by drupe (42.55%) and others.

The number of fruits consumed per visit by different bird species gives an idea of relative role each species in fruit consumption and likely removal from the parent plant. Highest number of fruits/visit was consumed by Nilgiri Laughingthrush (3.12 ± 1.33) followed by Red-whiskered Bulbul (2.93± 1.09) which could be considered as highly efficient seed dispersers in the shola forest.

The distance a bird traveled after leaving a fruiting tree was recorded as the distance to the first perching site. Among the 28 avian frugivores Laughingthrushes, bulbuls, Fairy Blue-bird and mynas dispersed seeds to a distance of >50 m. Other bird species traveled lesser than 50m distances.

Fruits of five tree species consumed by the Nilgiri Laughingthrush during the breeding season were used for germination experiment. These included *Syzygium densiflorum*,

Symplocos cochinchinensis, Ligustrum perrottetii, Eurya nitida, and *Neolitsea scrobiculata*. Bird-defecated seeds and pulp removed seeds were experimented. In the case of bird defected seeds, early emergence (1st week) of seedling was noticed for *Syzygium densiflorum*. For the remaining species, seedling emergence was noticed during the 2^{nd} and 3^{rd} week only. In all the five species, bird defecated seeds showed enhanced germination. According to One-Way Anova ($P=<0.05$), significant difference was observed between the germination percentage of bird defecated and control seeds experimented.

Discussion

In the present study, Columbidae, Pycnonotidae, and Muscicapidae were found to be the major avian frugivore families in the shola forests of Western Ghats, India. Laughingthrushes, bulbuls, pigeons formed the predominant avian frugivores in the shola forests. Similarly pigeons and bulbuls were found to be the predominant avian frugivores in the wet evergreen forest of Kakachi, southern Western Ghats, India (Ganesh and Davidar, 2001).

The present study showed that Sapotaceae, Lauraceace and Myrtaceae fruits formed important food for fruit eating birds in the shola forests of Nilgiri hills. In the shola forest of Kodai hills, Western Ghats, (Somasundaram, 2006) reported that fruits of Lauraceae are favored by Nilgiri Wood-pigeon (*Columba elphinstonii*), an endemic frugivore.

The study showed that Nilgiri Laughingthrush, an endemic and threatened species playing a major role in seed dispersal. The seed germination experiments indicated that bird dispersal enhances seed germination efficiency of seeds.

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CHAPTER I

Introduction

Plants have evolved several different mechanisms of seed dispersal to achieve dispersal from the mother plant including anemochory (wind-dispersed), hydrochory (water-dispersed) barochory (gravity—dispersed), autochory (self-dispersal by explosion), and zoochory (animal-dispersed). Zoochory may be further divided into exozoochory and endozoochory. In endozoochory, the fruits are swallowed by the fruit eating animals and ultimately dispersed by means of defecation (Stoner and Henry 2007). Griz and Machado (2001) reported that among the four dispersal syndromes considered, zoochory was the most common dispersal mode represented by 36% followed by anemochory (33%), ballistic dispersal (19%) and barochory (12%). Endozoochory is commonly viewed as a mutualistic interaction whereby animals carry away seeds and are rewarded by energy in the form of edible fleshy fruits offered by plants (Herrera 1985). A true mutualistic interaction only exists between a particular seed species and its disperser when both receive a benefit from the interaction.

1.1 Fruit frugivore interaction

Fruit-frugivore interactions play a pivotal role in maintaining the structural and functional integrity of natural ecosystems. Basic knowledge about fruit-frugivore interactions and especially the seed dispersal in forest ecosystems is essential for the conservation of endangered animals and the forest itself (Corlett 1998a; Da Sivaj and Tabarelli 2000). Interactions among fleshy fruits and frugivore assemblages are important to evaluate the relative contribution of different frugivores to the seed dispersal of plant species. Fruit-frugivore interactions at the community level have been studied in several parts of southeast Asia: Yakushima Island in Japan (Noma and Yumoto 1997), Hong Kong (Corlett 1998b), Tamil Nadu state in India (Balasubramanian and Bole 1993a; Balasubramanian 1996; Balasubramanian and Maheswaran. 2003a), North Negros Island in the Philippines (Hamann and Curio 1999; Heindl and Curio 1999), and Kutai National Park in Indonesia (Leighton and Leighton 1983). Vertebrate-fruit mutualisms can result

in the benefits to the plant, not only from the movement of seeds away from the parent (Schupp 1993; Willson and Traveset 2000), but also from changes to germination caused by the passage of a seed through digestive tract of a vertebrate (Ketring 1973; Van der Pijl 1982).

In tropical forests, 50-70 % of trees possess fleshy fruits adapted for animal consumption (Howe 1984). Fleshy fruited plants may not only serve as seed sources but also in the reestablishment of other species by attracting seed-dispersing birds to the vicinity (MacDonnel and Stiles 1983). Birds by virtue of their greater mobility can be more effective seed disseminators than other fruit-eating animals. Birds play an important role in seed dispersal because of their fruit-eating habits and the long distances they travel (Ridely 1930). They carry seeds both externally and internally to far away places. Dispersal by internal carriage is generally associated with edible, small fruits. The seeds as well as the digestive system of birds have remarkable adaptations to facilitate a safe transport through the alimentary canal of birds. Seeds which are swallowed by birds are either regurgitated after digesting off the pulp or pass them rapidly through the alimentary canal. However, the real significance of internal carriage is that the seeds which pass through the alimentary canal germinate quickly (Ridely 1930).

Role of birds in the restoration of tropical forests has been dealt by Green (1993) and Whittaker and Jones (1994). Planting fleshy-fruited trees and shrubs of any king will often attract frugivores. However, knowledge of local frugivores and their role in seed dispersal could be very useful for planning an effective and efficient regeneration scheme. Key-stone plant species are said to play a vital role in the ecosystem by sustaining the vertebrate frugivores during the lean period. Information on which species of frugivore eats on a particular fruit species is very useful for forest managers to attract a variety of frugivores to regeneration sites and also to attract particular frugivore to rare plant species.

Seed dispersal has long been a topic of interest to naturalists, but it has not been until the last three decades that the ecology of dispersal has received much and rigorous scientific attention. Many theoretical and empirical advances have recently been made, although

important lacunae in our understanding still need to be filled before dispersal ecology becomes a coherent body of knowledge (Willson and Travest 2000). Seed dispersal refers the removal and deposition of seeds away from parent plant, by which a plant scatter its offspring away from the parent plant to reduce competition. Seed dispersal and its establishment are the crucial moments in the life cycle of plants which determine the success of plant populations. Seed dispersal is a key factor for understanding the mechanisms that limit or facilitate the natural regeneration of plants under different scenarios of land cover (Moore 2001).

A major proportion of the trees occurring in the tropical forests produce fruits that are consumed by numerous frugivorous birds and mammals. Seed dispersal is one of the key processes determining the spatial structure of the plant population. Seed dispersal helps in the transfer of the community from one place to the other. The advantages of seed dispersal may be, in escape from density or distance-dependent seed and seedling mortality, by colonization of suitable sites unpredictable in space and time, and by directed dispersal to particular sites with a relatively high probability of survival (Wenny 1998).

Most fruit-eating birds feed on only a portion of the fleshy fruited species produced in any habitat (Snow 1970; 1981). Fruit selection presumably depends on the behavior, morphology, and nutritional requirements of birds, the abundance of alternative food resources, and fruit characteristics such as temporal availability, habitat, taste, color, abundance, and placement on a plant (Thompson and Willson 1979; Denslow and Moermond 1982; Howe and Smallwood 1982; Morden-Moore and Willson 1982; Sorensen 1983; Wheelwright and Janson 1985a). Fruit characteristics such as pulp-to-seed ratio and nutrient composition also partly determine the net value of a fruit (Howe and Vande Kerckhove 1980). Fruit size may be critical to selection, but it has been given surprisingly little consideration, despite the demonstration in many foraging studies that the sizes of predators and prey are often positively correlated (Hespenheide 1973; Wilson 1975). Small-fruited plant species have been hypothesized to attract more species of birds than large-fruited ones (Terborgh and Diamond 1970), although Kantak (1979) found that intermediate-sized fruits drew the largest number of bird species among the five plant

species she studied in Mexico. Bill size in Panamanian flycatchers and tanagers appeared to be correlated with the size of preferred fruits (Leck 1971). Diamond (1973) reported that New Guinea fruit pigeons ignored fruits that were small relative to their own size; big birds ate big fruits, medium birds ate medium fruits and so on. Snow (1971) noted the correspondence between bellbird (*Procnias* spp.) gape widths and the sizes of their fruits.

Whatever hypothesis might be applied, in general, the seed shadow or the spatial distribution of seeds around the parent plant shows a peak under and close to the parent tree and a steady decline away (Willson 1992). Fruit-eating animals might alter the shape of the seed shadow and consequently exert varying influence on plants depending on their behavior: animals may drop seeds under the parent plant during fruit handling, destroy them or disperse them from the vicinity of the parent plant. Only in the latter case do they benefit the plant as various studies have shown that survival of seeds and seedlings is higher further away from the parent plant (Janzen 1970; Connell 1971; Augspurger 1983 & 1984a; Howe *et al.* 1985).

Consequently, seed dispersal is thought to affect seedling establishment and the spatial pattern of seedlings and saplings (Fleming and Heithaus 1981; Howe 1986). Differential seedling distribution might be a critical determinant of offspring survival and influence density, spatial patterning and composition of plant communities in general (Fleming and Heithaus 1981; Coates-Estrada and Estrada 1986; Howe 1986). Fruit-eating animals therefore might have a significant influence on the population dynamics of tropical forest communities; however, studies linking animal-mediated seed dispersal and seedling distribution with the spatial pattern and dynamics of plant populations are rare (Fleming and Heithaus 1981).

The field of seed dispersal is wrestling with a major contradiction: although ecological evidence demonstrates that frugivores are important for the reproduction of fruiting plants, any evolutionary role of seed dispersers in shaping fruit characteristics is difficult to detect. Those who believe in the evolutionary importance of seed dispersers in shaping fruit evolution point to the existence of apparently non-random combinations of fruit traits that

match the sensory abilities of the frugivores that feed on them (Janson 1983; Kalko *et al.* 1996; Korine *et al.* 2000; Lord *et al.* 2002). These studies argue that frugivores must have selected for the sesuites of traits, which are referred to as dispersal syndromes. On the opposite side of the issue are those who argue that other factors, such as phylogeny or physiological constrains, play a more prevalent role than seed dispersers in shaping fruit traits (Fischer and Chapman 1993; Herrera 1992). They explain the match between fruit traits and frugivores' sensory abilities as preexisting preferences of frugivores for certain types of fruits: the frugivores will feed on the fruits that are most easy to find and accessible to them. This process is called "ecological fitting" (Janzen 1980).

Increasing fragmentation and destruction of tropical ecosystems is known to not only affect biodiversity but also processes crucial for the maintenance of these ecosystems such as pollination and seed dispersal. Fragmentation, for example, may alter the composition of bird assemblages and the relative contribution of some species as seed dispersers (Pizo 1997; Santos and Telleria 1997). Loss of dispersal agents might lead to a break-down in seed dispersal (Howe 1984; Pizo 1997) and reduce seedling establishment and recruitment of fruiting trees. Consequently, disrupted seed dispersal has consequences for the regenerative potential of ecosystems and probably leads to changes in the abundance and spatial distribution of trees (Hubbell 1979), perhaps even to higher extinction probabilities of focal trees (Bond 1995; Tilman *et al.* 1997). In the long term, a break-down of seed dispersal processes might be a serious threat to tropical plant diversity (Bond 1995).

1.2 Uniqueness of Shola forest

Shola is a type of high-altitude stunted evergreen forest found in southern India. Patches of shola forest are usually separated from one another by undulating grassland. Together the shola and grassland form the shola-grassland complex or shola-grassland mosaic (Premalatha *et al.* 2009). Shola forests are found mostly in the southern portion of the Western Ghats mountains of Karnataka, Kerala and Tamil Nadu states, in the Southern Western Ghats montane rain forests ecoregion. The word 'shola' probably derived from

the Tamil word *solai*, meaning 'thicket'. The shola forest vegetation is classified as Southern Montane Wet Temperate Forest type (Champion and Seth 1968).

Shola forest is different from that of other forest types of the Western Ghats, and is characterized by high humidity because of low evaporation rate. The moisture content of the soil is also high. Soil and air temperature inside the "Shola" is more or equal to that of outside. Plant species distribution in Shola is regular and dense in the edges than the interior portion.

Several reservoirs were commissioned during mid 1950 in the Upper Nilgiris for generating electricity and for this purpose, several hundred hectares of Shola and grasslands were destroyed. According to an estimate, nearly 80% of the shola and grasslands have been lost sine 1850.

Due to its altitude and evergreen character, it is home to some of the most threatened and endemic species (Shibujose *et al.* 1994). Some of the species found here have close relatives only in the distant evergreen forests of northeast India or those in Southeast Asia. Some others are found nowhereelse in the world. Although generally said to occur above 2000 m mean sea level, shola forests can be found at 1600 m elevation in some hill ranges eg. Biligiriranga Hills.

Shola forests have an upper storey of small trees, generally *Pygeum gardneri*, *Schefflera racemosa*, *Linociera ramiflora*, *Syzygium spp.*, *Rhododendron nilgiricum*, *Mahonia nepalensis*, *Elaeocarpus recurvatus*, *Ilex denticulata*, *Michelia nilagirica*, *Actinodaphne bourdillonii* and *Litsea wightiana*. Below the upper story is a low understory and a dense shrub layer. These shola forests are interspersed with montane grasslands, characterized by frost and fire-resistant grass species such as *Chrysopogon zeylanicus*, *Cymbopogon flexuosus*, *Arundinella ciliata*, *Arundinella mesophylla*, *Arundinella tuberculata*, *Themeda tremula*, and *Sehima nervosum*.

Periodic brush wildfires are a key part of the shola ecosystem, helping to maintain the patchwork of grassland and forest that characterizes the sholas, and preventing the buildup of large amounts of flammable debris. However, some shola areas have suffered

from excessive amounts of burning, leading to the shrinkage of forest patches and the growth of invasive species (Thomas *et al.* 2007). Conservation of this vegetation is of utmost importance not only to save the flora, but to save the endemic fauna and micro-flora. The shola biome is lodging water and exists as the precious source of the water for the high altitude organisms and acts as a source of rivers (Rawat *et al.* 2003).

1.3 Seed dispersal

Seed dispersal has a major influence on plant fitness because it determines the locations in which seeds, and subsequently seedlings, can live or die. Theoretically, plants could increase fitness if a higher proportion of seeds were dispersed to sites where offspring have a predictably high probability of survival relative to random sites, a process known as directed dispersal (Wenny and Levey 1998). To do so, a plant must have a predictable dispersal vector, either biotic or abiotic that takes seeds to suitable sites. Such a pattern of dispersal will probably be retained in the distribution of adult plants (Schupp 1993), in which case a particular dispersal agent has a disproportionate effect on plant recruitment.

Seed dispersal by vertebrates is a key process in the dynamics of natural vegetation and in vegetation recovery after human impacts (Corlett 1996). Seed dispersal by birds has many potential benefits, it can help seeds escape from predation (Janzen 1972; Wenny, 2000) and take up a new habitat. Seed dispersal is the process of seed transportation from the mother plant to another place, and thus plays a key role in the subsequent recruitment of new plants (Herrera 2002). When considering dispersal by frugivores, the process of seed dispersal and the seed fall pattern can affect seed viability, seed survival, germination, emergence, survival and growth of new plants (Balasubramanian 1998).

Seed dispersal research that considers different aspects of avian activity (e.g. fruit removal, seed ingestion and post-feeding microhabitat use), together with seed deposition and germination, from the perspective of the disperser effectiveness is a powerful tool for understanding the ecological consequences of bird-plant interactions for the regeneration patterns of plant species (Jordano and Schupp 2000). The effectiveness of frugivores as seed dispersers is the contribution a frugivore makes to plant fitness, defined as the

proportion of seedlings in a population that result from the activity of the dispersal agent (Schupp 1993). Fruit is a primary resource for many birds and provides a key ecological function, seed dispersal, for much of the world's flora (Sekercioglu *et al.* 2004)

Seed dispersal processes are essential for the persistence of plant populations, and are fundamental mechanisms for the organization and maintenance of species richness in plant communities (Bascompte and Jordano 2007). Despite the importance of frugivores as agents of seed dispersal, the general mechanisms by which animals potentially shape plant populations and influence community organization are still absent from the theoretical core of community ecology (Carlo *et al.* 2007).

1.4 Literature review

Fruiting phenology

In areas where strong seasonal fluctuations of bird abundance occur, it is expected that, in general, bird dispersed plants should tend to produce fruits at times of the year when fniit-eating birds are most abundant (Snow 1971; Thompson and Willson 1979; Stiles 1980). The tropical forests have a distinctive array of species different from temperate and rain forests. It supports different varieties of over storey and under-storey plant species, which are major food resources for a variety of biota (Bhat and Murali 2001). In the Indian subcontinent many of the studies on phenology have come from dry tropical forests (Murali 1992; Prasad and Hegde 1986; Singh and Singh 1992).

Information on reproductive phenology and seed production is necessary for understanding vegetative functioning and dynamics, since the reproductive potential of vegetation is fundamental in landscape (Kurt and Morag 2005). Plant phenologies are a result of interactions of biotic and climatic factors that, through natural selection, determine the most efficient timing for growth and reproduction (Van Schaik *et al.* 1993).

Studies of tropical rain forests suggest that phenological patterns of trees are driven by a variety of factors including: abiotic characters such as rainfall and temperature (Ashton *et*

al. 1988; Newbery *et al.* 1998; Opler *et al.* 1976; van Schaik 1986; van Schaik *et al.* 1993; Sun *et al.* 1996; Tutin and Fernandez 1993); mode of seed dispersal (Charles-Dominique *et al.* 1981; Smythe 1970; Snow 1965; Wheelwright 1985b); activity of pollinators or seed dispersers (Frankie *et al.* 1974; Rathke and Lacey 1985; Snow 1965); variation in germination conditions (Frankie *et al.* 1974; Janzen 1967); canopy position (Newstrom *et al.* 1994); and relative abundance of the trees themselves (van Schaik *et al.* 1993). For example, it is thought that fruit ripening may occur at a time when conditions for dispersal are optimal. Some evidence suggests that wind-dispersed seeds may ripen during the dry season when trade winds are stronger and leaves are often absent, allowing for greater wind dispersal (e.g., Newstrom *et al.* 1994). In contrast, some animal-dispersed fleshy-fruited species have their peak fruiting period during the rainy season, perhaps due to increased moisture levels necessary for fruit production (Lieberman 1982; Rathke and Lacey 1985). Phenological studies of temperate forests and tropical dry forests often detect clearly defined seasonal patterns associated with marked changes in rainfall and temperature (Hilty 1980; Lieberman 1982). However, some studies have suggested that phenological patterns of tropical lowland rain forests are not as well defined (Putz 1979). The more continuous high temperatures and moisture that typify lowland rain forests foster growth all year long (Richards 1996). The phenological patterns that results are diverse and the environmental cues influencing the patterns remain generally obscure (van Schaik 1986).

An understanding of the phenological patterns in different geographical regions and of factors underlying these patterns is important for a number of reasons. First, frugivores are the dominant group of vertebrates in most tropical forests (Emmons *et al.* 1983; Fleming *et al.* 1987; Gautier-Hion *et al.* 1985; Terborgh 1986), and regional differences in their abundance may be caused by differences in food availability (Terborgh and van Schaik 1987). Second, an understanding of phenological patterns and factors underlying these patterns will assist conservation scientists in predicting consequences of perturbations such as atypical climatic events (Foster 1982) or global warming (Tutin and Fernandez 1993). Third, phenological patterns are linked to many processes governing forest function and structure including: population biology of pollinators, dispersers, seed

predators, and herbivores, interspecific competition among trees, and processes of primary production (Newstrom et *al.* 1994; Smythe 1970; van Schaik *et al.* 1993). Thus, an understanding of what governs phenological process is valuable in understanding forest function and structure and in providing the basis for developing management options. For example, during timber harvesting, maintenance of trees producing fruit in periods of habitat-wide fruit scarcity could increase the carrying capacity of the post-harvest area for frugivores (White 1994) or logging could be initiated after the period of peak seed set to facilitate regeneration.

The phenological traits of fruits can be one of the keys to identifying loosely defined guild structures and their relationship between animal-dispersed plants and frugivorous animals in a temperate climate (Thompson and Willson 1978; Skate 1987). Seed-dispersers, which are usually long-lived mammals and birds, change their diet periodically. Fruiting phenology determines the availability of their food and will therefore be correlated with diet composition (Hoppes 1987). Periodic behaviour of plants in tropical environments has received much attention in recent years. The knowledge of phenology of plants has helped to understand the influence of phenological events on feeding, movement patterns, and sociality of insects, birds and mammals (Appanah 1985; Coates-Estrada and Estrada 1986).

Avian frugivory and Seed dispersal

Seed dispersal is usually a crucial stage in the life cycle of a plant as it allows offspring to colonize sites, near or far from the parent plant, at the same time that it increases the chance that those seeds will survive and become established adults. In the case of fleshy fruited plants, animals play an important role in determining the success of this critical stage (Levey *et al.* 2002 and references therein). Most such studies, however, consider only the 'seed-movement' effect, examining the seed shadows produced by frugivores and evaluating the probability of seed (and sometimes also seedling) survival in different microhabitats where those seeds are deposited (Houle 1998; Herrera *et al.* 1994; Jordano 1995; Schupp 1995; Rey and Alcántara 2000; Holl 2002; Traveset *et al.* 2003). In the case of endozoochory, which is especially frequent in plants bearing fleshy fruits, the

other quality component (besides seed-deposition patterns) of seed dispersal effectiveness (Schupp 1993) is that of seed treatment in the dispersers's digestive tract the capacity of seeds to germinate after ingestion by frugivores.

This component has generally received less attention, although an increasing number of studies are devoted to this subject (see reviews by Traveset 1998; Traveset and Verdú 2002), which is important for the population dynamics of many plant species and significant for the evolution of plant–frugivore interactions. For a given plant species, the outcome of seed passage through a digestive tract may depend on the animal species that consumes it. Both morphological traits (e.g. length of digestive tract, presence of a gizzard) and physiological traits (e.g. digestive fluids in the guts) of frugivores affect seed treatment. As the digestive systems of frugivores such as reptiles, birds and mammals differ greatly in both types of trait (Stevens 1988; Robbins 1993; King 1996), we may expect differences in this quality component of seed dispersal, which may counteract other components such as the quality of seed.

Interactions between fleshy-fruited plant species and the community of vertebrate frugivores have been studied in the tropics (e.g., Leighton 1982; Gautier-Hion *et al.* 1985; Dowsett-Lemaire 1988), where zoochorous plant species make up the majority of the flora (Howe and Smallwood 1982). The fleshy pulp of endozoochorous fruits attracts its consumers with a wide array of morphological traits and offers a nutritional reward for potential seed dispersers.

Large frugivores are considered to be important seed dispersers for many tropical plant species (Kitamura *et al.* 2001). In the tropical forests, up to 90% of tree species rely on frugivorous animals for the dispersal of their seeds (Howe and Smallwood 1982). Fruit consumption by birds is an important species interaction that contributes to seed dispersal in forests. Majority of the woody plants in tropical forests rely on vertebrates, especially birds for seed dispersal (Van der Pijl 1957; Snow 1971; Morton 1973; Howe and Smallwood 1982; Stutchbury and Morton 2001).

Bird visitation to fruiting trees and movement of seeds in fragmented habitats can influence the longevity and genetic diversity of plant species in disturbed areas (Nason and Hamrick1997). At the same time, the presence of fruiting trees in fragmented habitats influences the maintenance of frugivorous bird communities (Whitney and Smith 1998). The relationship between fruiting plants and their seed dispersers may affect both plant and bird species composition in fragmented areas (Howe 1984; Willson 1992).

Dispersal of seeds away from parent plants is the underlying selective force in the evolution of fleshy fruits attractive to vertebrates. Presumably, selection and digestive processing of fruits by frugivorous animals have influenced the evolution of fruit and seed traits to enhance seed dispersal to appropriate habitats and maximize seed germination and seedling survival. Frugivorous birds may either regurgitate or defecate seeds, and this difference in seed processing mode has been thought to have influenced the evolutionary interactions between fruiting plants and avian seed-dispersers. Snow (1971) and McKey (1975) proposed that regurgitation of seeds is one component of high quality seed dispersal, and that large seeded, lipid-rich fruits are produced by plants to attract dependable, specialized frugivores that regurgitate seeds.

Frugivory and Seed dispersal studies in India

Frugivores help seeds escape from the deleterious effect of seed and seedling predators under the parent plant. The fruit frugivore interaction have been studied in the Tropical dry evergreen forest of Point Calimere India (Balasubramanian 1996), mixed dry deciduous forest, Anaikatty hills, Western Ghats (Aruna *et al.* 2011). Fruit preferences of hornbills in southern India was studied by Balasubramanian and Maheswaran (2002); Balasubramanian *et al.* (2003b); Balasubramanian and Santhoshkumar (2009). Fruit frugivore interactions in Sriharikota Island was studied by David *et al.* (2011). Avian frugivory and seed dispersal of *Santalum album* in Tamil Nadu was highlighted by Balasubramanian *et al.* (2011).

Bird dispersed fruits were usually small and fleshy with colour ranging from purple to orange, while mammal fruits were large, fleshy and mostly green to brown in colour at

the mid-elevation evergreen forest of Kalakad-Mundanthuari Tiger reserve, Western Ghats (Ganesh and Davidar 2001). Frugivory and seed dispersal has brought into focus the importance of fruit characters such as size, colour and nutritional value in fruit selection by hornbills in the riverine forest of Western Ghats (Balasubramanian and Maheswaran 2004). In fleshy fruited plants, fruit size helps and constrains seed dispersal by animals. In tropical communities, small fruits attract a wider array of dispersal agents than larger ones. Plant species with small fruits are often visited by more species of dispersal agents (Balasubramanian *et al.* 2009). In the shola forests of Kodai hills. (Somasundaram and Vijayan 2010a) reported that fruits of several members of Lauraceae were consumed by the Nilgiri Wood-pigeon.

Role of birds in enhancing seed germination

Frugivores affect the germination success of seeds which they either defecate or regurgitate, as the gastrointestinal enzymes and acids within the gut of the birds soften the hard seed coat, thus breaking dormancy in seeds (Fleming and Heithaus 1981). The effect of ingestion of fruits by vertebrate frugivores on seed germination has received considerable attention (Traveset and Verdu 2002). Many studies show that germination is more successful after seeds pass through the digestive tract of frugivores. The advantages of dispersal are not mutually exclusive; they can be assessed only if deposition sites and post-dispersal fates are known. Another possible benefit for vertebrate-dispersed seeds is enhanced germination after gut passage. The evidence for enhanced germination is mixed and depends on the plant and animal species involved (Janzen 1983; Chapman 1995).

Frugivores play a crucial role in areas where endozoochory contributes toward regeneration of altered areas or maintenance of forests (Graziele *et al.* 2010). Frugivorous vertebrates frequently play an important role in plant recruitment in native and invaded areas by dispersing seeds away from parent plants and by the effects of seed passage through their guts, thereby altering germination patterns (Samuels and Levey 2005). Seed passage through the gut of frugivores can be, by varied ways, alter seed viability (i.e., cause mortality of the embryo = seed predation) and affect the germinability (the percentage of seeds that germinate) and the germination rate (or germination speed).

Mechanical and chemical actions in the gut are common effects of frugivores on seeds, while release of germination inhibitors and high osmotic pressure in exocarp are less frequently mentioned effect (Traveset 1998; Samuels and Levey 2005).

Effects of avian gut passage on seed germination is an essential component of the research protocol for analysing the effectiveness of frugivores as seed dispersers in any landscape context, this assessment is often omitted. A review of post-dispersal seed germination assays shows that frugivores can significantly enhance seed germination, but only for about half of the species that have been tested (Traveset 2001a). Enhanced seed germination can occur either through enhanced seed germinability (the percentage of germinated seeds at the end of the growing season) or the rate of seed germination (Schupp 1993; Traveset 2001b; Traveset and Verdu 2002; Traveset *et al.* 2007).

Frugivorous birds also remove fruit skin and pulp from seeds, regardless of whether seeds are defecated or regurgitated. Pulp and cutinous skin can inhibit germination by virtue of their imperviousness to water or high osmotic pressure from dissolved sugars, factors known to influence water uptake and hence germination of seeds (Mayer and Poljakoff-Mayber 1989). Fruit pulp can also contain germination inhibitors (Evenari 1949; Mayer and Poljakoff- Mayber 1989). In addition, uncleaned seeds may suffer from microbial or fungal attack (Ng, 1983; Jackson *et al.* 1988). Thus, seeds in unconsumed fruits may suffer not only from lack of dispersal, but also from effects of the attendant fruit pulp.

Frugivores can enhance seed germination by three mechanisms: (1) through mechanical or chemical scarification (degradation) of the impermeable seed coat or endocarp (scarification effect; Barnea *et al.* 1990; Traveset 1998); (2) through the removal of the pulp that contains chemicals that can block germination pathways (deinhibition effect; Cipollini and Levey 1997; Samuels and Levey 2005); and (3) through the effect of the faecal material surrounding the seed (fertilization effect; Traveset and Verdu 2002). However, few studies have tested the occurrence of scarification, deinhibition and fertilization mechanisms in field or laboratory assays (Kelly *et al.* 2004; Samuels and Levey 2005; Linnebjerg *et al.* 2009).

Once ingested, seeds may undergo both chemical and mechanical treatment in the digestive tract, influencing their germination success (McKey 1975; Barnea *et al.* 1991). Seed coat abrasion (Barnea *et al.* 1990) and pulp removal (Evenari 1949; Barnea *et al.* 1991) are the predominant ways in which germination rates may be affected by frugivores. Benefits following pulp removal may include evading seed predators dependent on olfactory or visual cues (Nystrand and Granstrom 1997; Moles and Drake 1999), as well as reduced bacterial and fungal attack (Witmer and Cheke 1991; Moore 2001). In addition to processing behaviour and digestive physiology of different frugivorous species (Jordano 2000), seed retention time may influence the degree of seed coat abrasion (Sorensen 1984; Murray *et al.* 1994) and potential dispersal distance (Ridley 1930).

In the above background, it was felt that a study on avian frugivory and seed dispersal in the shola forest would be highly useful for the scientific management of the precious ecosystem. Hence, the present study was envisaged with the following objectives.

- Study avian frugivory and find out major frugivores in the shola forests
- Assess the fruiting phenology of fleshy-fruited tree species and find out the fruiting seasonality
- Establish the role of avian frugivores in seed dispersal and forest regeneration.

CHAPTER II

STUDY AREA

2.1 WESTERN GHATS

The Western Ghats also known as the " Sahyadri Mountains " is a mountain range along the western side of India. It runs north to south along the western edge of the Deccan Plateau, and separates the plateau from a narrow coastal plain along the Arabian Sea. The range starts near the border of Gujarat and Maharashtra, south of the River Tapti, and runs approximately 1600 km through the states of Maharashtra, Goa, Karnataka, Tamil Nadu and Kerala ending at Kanyakumari, at the southern tip of India (Rodgers *et al.* 2000).

These hills cover 1,60,000 km² and form the catchment area for a complex of river systems that drain almost 40% of India. The average elevation is around 1,200 m. It is one of the world's ten "Hottest biodiversity hotspots" and has over 5000 species of flowering plants, 139 mammals, 508 birds and 179 amphibians. At least 325 globally threatened species occur in the Western Ghats (Daniels 1997; Stattersfield 1998).

2.1.1 Hill stations in Western Ghats

The Western Ghats extend from the Satpura Range in the north, go south past Goa, through Karnataka and into Kerala and Tamil Nadu. The major hill range starting from the north is the *Sahyadhri* (*the benevolent mountains*) range. This range is home to many hill stations like Matheran, Lonavala-Khandala, Mahabaleshwar, Panchgani, Amboli Ghat, Kudremukh and Kodagu. The range is called *Sahyadri* in northern Maharashtra and *Sahya Parvatam* in Kerala. In the south, the range is known as the *Nilagiri malai* in Tamil Nadu state. The Biligiri-rangana Betta southeast of Mysore in Karnataka meet the Shevaroys (Servarayan range) and Tirumala range farther east, linking the Western Ghats to the Eastern Ghats.

Smaller ranges including the Cardamom Hills and the Nilgiri Hills are in northwestern Tamil Nadu. The Nilgiri Hills are home to the hill station Ootacamund. In the southern part of the range is the Anamalai Hills in western Tamil Nadu. Anamudi 2,695 m in Kerala is the highest peak in the Western Ghats. Chembra Peak 2,100 m, Banasura Peak 2,073 m, Vellarimala 2,200 m and Agasthya malai 1,868 m are also found in Kerala. Doddabetta in Tamil Nadu is 2,637 m. Mullayanagiri (1,950 m) is the highest peak in Karnataka. The major gaps in the range are the Goa gap between the Maharashtra and Karnataka sections, and the Palghat Gap on the Tamil Nadu/Kerala border between the Nilgiri Hills and the Anamalai Hills.

2.1.2 Fauna of Western Ghats

The Western Ghats are home to thousands of animal species including 325 globally threatened species. Many are endemic species, especially in the amphibian and reptilian classes (Stattersfield 1998). A review of the literature on the fauna of the Western Ghats has reported 5626 species/subspecies, out of which 439 are endemic. Information on the invertebrates of the Western Ghats is confined mainly to insects with about 4056 species. Kumar *et al.* (1999) reported 330 species of butterflies, including 37 endemics. Among the 209 species of freshwater fishes and the 133 species of amphibians known from the Western Ghats, 120 species of the former and 106 species of the latter are endemic (Lakshminarayana *et al.* 2002).

The reptile fauna of the Western Ghats consists of 163 species, of which 89 are endemic to the area. Snakes constitute more than 50% of them and endemics is especially high in the family Uropeltidae with 33 species.

The Western Ghats has around 508 species of birds out of which 144 are aquatic including those which are found in the coastal habitats (Daniels 1997). Eighteen species of endemic birds are recorded in the Western Ghats. It included the endangered Rufous-breasted Laughingthrush (*Garrulax cachinnans*), the vulnerable Nilgiri Wood Pigeon (*Columba elphinstonii*), White-bellied Shortwing (*Brachypteryx major*) and Broad-tailed Grassbird *(Schoenicola platyurus)*, the near-threatened, Grey-breasted

Laughingthrush *(Garrulax jerdoni)*, Black-and-rufous Flycatcher (*Ficedula nigrorufa*), Nilgiri Flycatcher *(Eumyias albicaudatus)*, and Nilgiri Pipit *(Anthus nilghiriensis)* and Malabar Parakeet *(Psittacula columboides)*, Malabar Grey Hornbill (*Ocyceros griseus)*, White-bellied Treepie (*Dendrocitta leucogastra*), Grey-headed Bulbul *(Pycnonotus priocephalus)*, Rufous Babbler, (*Turdoides subrufa)*, Wynaad Laughingthrush *(Garrulax delesserti*), White-bellied Blue-flycatcher (*Cyornis pallipes*) and the Crimson-backed Sunbird (*Leptocoma minima*).

Mammals in the Western Ghats are represented by 125 species including 41 bats and 27 rodents (Kumar *et al.* 1999). Fourteen species are endemic to the Western Ghats. A critically endangered mammal of the Western Ghats is the nocturnal Malabar Large-spotted Civet (*Viverra civettina)*. The arboreal Lion-tailed Macaque (*Macaca silenus*) is endangered. The largest population of India's Tiger (*Panthera tigiris*) outside the Sundarbans is found in the forests bordering Karnataka. The largest numbers and herds of vulnerable Gaur are found in the Bandipur National Park and Nagarhole together holding over 5000 Gaur. To the west the forests of Kodagu hold sizeable populations of the endangered Nilgiri Langur (*Trachypithecus johnii*). Bhadra Wildlife Sanctuary and Project Tiger Reserve in Chikmagalur have large populations of Indian Muntjac (*Muntiacus muntjak*).

2.1.3 Flora of Western Ghats

According to Hajra *et al.* (1997), the following forest types occur in Western Ghats. Evergreen or Tropical rain forests, Moist deciduous forest, Dry deciduous forest, Scrub or Thron forests, Shola or Montane wet temperate forest and Montane grasslands. Plantations of various types are also found. Approximately 4000 plant species occur in the Western Ghats of which about 1400 (35%) are endemic. There are also 58 endemic plant genera, 42 of which are monotypic (Nair 1986).

Evergreen forests of Western Ghats are mostly restricted in pockets, high plateau, steeper slopes and deep valleys along the mountains range in the Silent Valley (Kerala), Anmod (Goa), Kodachandra and Anshi National Park in Karnataka (Pascal 1988). Moist

deciduous forest occurring in the flatter areas and over gentle slopes of hills and hillocks are perhaps the most extensive type of vegetation on either side of the Western Ghats. Mudumalai, Bandipur and Dandeli Wildlife Sanctuaries sustain luxuriant moist deciduous forests.

Dry deciduous forests spread over to areas receiving low rain fall occur in the lower elevations between 300 m to 900 m. Scrub forests, mainly dry deciduous scrub occur in the semi-arid zone in the foot hills along the eastern slopes of the Western Ghats at 200 m to 500 m alitudes. The Savannas are supposed to be a mixture of luxurious grassland and arboreal vegetation. Trees are a few, many of which are deciduous while scattered fire hardy shrubs and tall coarse grasses are common. The characteristic species of this vegetation type are *phoenix humilis*, *Adina cordifolia* and *Lagestroemia parvifolia* (Sanjappa 1991). The montane forests and grasslands are restricted to higher hills particularly in the Anamalais, Pulney and Nilgiri hills between 1000 m and 1600 m.

Plantations of various types such as the Eucalyptus, Acacia, Wattle, Pine, Teak, Rubber etc are also common in various parts of Western Ghats. Tea (*Thea sinensis*) and Coffee (*Coffea arabica*) plantations occur over extensive areas of Nilgiris, Pulney and other hills of southern Western Ghats.

2.1.4 Climate

The Nilgiri hills is situated at 11° north of Equator. The mountain block of Nilgiris and its ecosphere is distinguished by four identifiable seasons. The Winter season can be said to extend almost for four months from November to the following February, with an average temperature of 12-17 degrees centigrade almost throughout the uplands. The northeast monsoon emerging around October generally overlaps this season. This season is also characterized by hoar-frost on ground for nearly two months in almost all localities situated above 1400 mm. The night time minimum falling to freezing point and below is not infrequent during December to January. The summer is called simply, "The Season". It is the time of the year bejeweled for almost couple of months April and May by a very aggreable climate. While in the surrounding plains-country, the day time

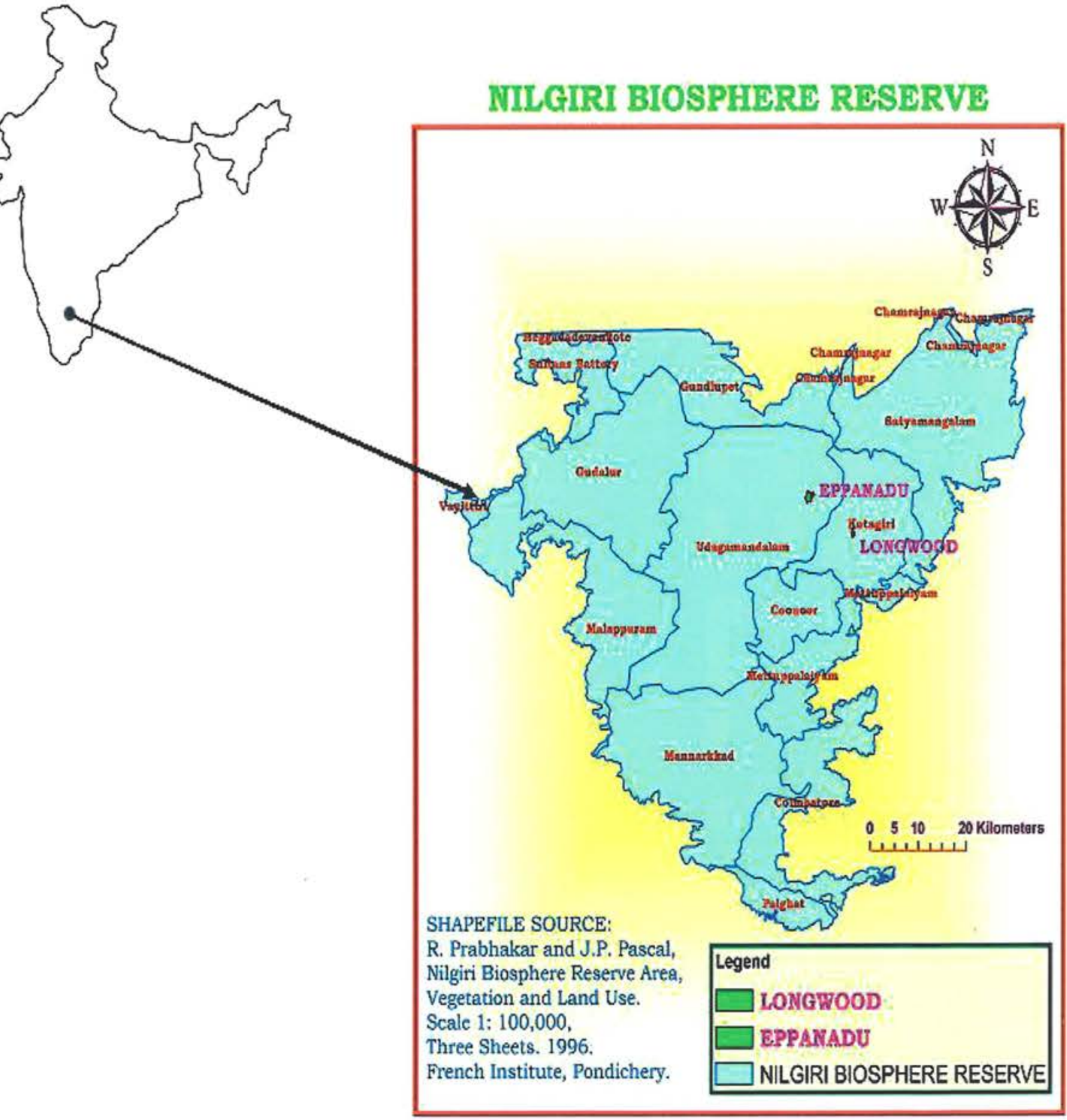
temperatures rise to 30-35 degree centigrade and above, in the hills it is seldom above 25 °C during day and the nocturnal cooling seldom touches below 10 degree centigrade and consequently most pleasant. The southwest monsoon season is prevalent for four months between June and September. It is characterized by overcast, windy and extremely wet conditions especially in all portions of the highlands. Copious rainfall easily exceeding 2000 mm is a common occurrence. Sunshine drops to as low as 2.8 hours per day even though maximum and minimum temperatures are not radically different from those of the summer months (roughly 12-11 degree centigrade as compared to 21-11 degree centigrade). The inter-monsoon season occurs from October to November. This transitional period is cool and humid. During this period, on an average 15-20 days of rainfall (250-300 mm) are registered over most of the Nilgiris.

2.1.5 Nilgiri Hills

The study was carried out in the Nilgiri hills of Western Ghats. The Nilgiri hills is located between 10° 45'- 2° 5'N and 76° 10'-77° 10' E in the peninsular region of India. The variety of altitudinal climate conditions is responsible for different types of vegetation. The people inhabiting the Nilgiris from the earliest discernible times consist of the Todas, the Badagas, the Kotas and the Kurumbas in the upper region and the Irulas in the lower region. The Nilgiris or literally the BLUE MOUNTAIN is situated at the trijunction of the three states of Tamil Nadu, Karnataka, Kerala in Southern India. Presently, a revenue district of Tamil Nadu state, the administrative unit covers an area of 2478.63 km^2. Wide range of climate and peculiar topographic features of the Nilgiri hills provide opportunity for a diversity of its vegetation communities. Vegetation of the Nilgiri plateau is one of the interesting subjects with respect to Phyto-geography. Natural vegetation of the plateau consists of vast stretches of grasslands interspread with numerous isolated, compact, sharply defined and usually small woodlands, which are known as Shola forest that fall under a category of tropical rain forest occurring under extreme and limiting conditions of the montane locations. Floristics of shola includes tropical as well as temperate elements. The shola forest occupies the depressions and valleys and is classified as Southern Montane Wet Temperate Forest (Champion and Seth 1968).

PLATE-1

Nilgiri Biosphere Reserve



Various researchers have documented the flora of Nilgiris. Sharma *et al.* (1983) reviewed the flora of this region and reported 2760 species of vascular plants including 2611 angiosperms belonging to 942 genera and 163 families. Remaining species belong to gymnosperms and ferns or fern allies. Blasco (1970) observed 82 species of endemic to the higher altitude of the Nilgiris. The Sispara slope leading to the Silen Valley National Park was considered as an area of high biological diversity (Sharma 1977). 160 species of fern and fern allies, countless types of flowerless plants, mosses, fungi, algae, land lichens are found in the sholas of the Nilgiris. No other hill station has so many exotic species. Apart from several reserve forests, important Sanctuaries and National Parks such as Silent Valley, Mukurthi National Park and Wynaad, Mudumalai, Bandipur and Nagarhole Wildlife Sanctuaries are found in Nilgiri hills.

Mudumalai Wildlife Sanctuary: The Mudumalai National Park and Wildlife Sanctuary (now also declared a Tiger Reserve, lies on the northwestern side of the Nilgiri Hills, in Nilgiri District, about 150 km (93 m) north-west of Coimbatore city in the westernmost part of Tamil Nadu, on the interstate boundaries with Karnataka and Kerala states in South India. Mudumalai, which means 'first hills', is one of the first wildlife sanctuaries established in India.

The elevation of the sanctuary varies from a minimum of 960 meters to a maximum of 1,266 meters. The Mudumalai Sanctuary is as an important wildlife habitat due to its strategic position as a Wildlife corridor between several other protected areas that are a part of the Nilgiri Biosphere Reserve.

Mukurthi National Park: Mukurthi National Park has an elongated crescent shape facing to the west between 11°10' to 11°22' N and 76°26' to 76°34' E. The peak of Mukurthi is 2556 m. The park was created to protect its Keystone species, the Nilgiri Tahr. The park is characterized by Montane grasslands and shrublands interspersed with sholas in a high altitude area of high rainfall, near-freezing temperatures and high winds. It is home to an array of endangered wildlife, including Royal Bengal Tiger and Asian Elephant, but its main mammal attraction is the Nilgiri Tahr. The park was previously known as Nilgiri Tahr National Park.

Peak in Nilgiri hills

Doddabetta Peak located 4 km east southeast from Udhagamandalam (11°24′10″N 76°44′14″E), with a height of 2,637 m is the highest point in the Nilgiris. **Kolaribetta** (height: 2,630 m), **Hecuba** (2,375), **Kattadadu** (2,418 m)) and **Kulkudi** (2,439 m) are closely linked peaks in the west of Doddabetta range and nearby Udhagamandalam.

Snowdon (height: (2,530 m) 11°26′N 76°46′E is the northern extent of the range. **Club Hill** (2,448 m) and **Elk Hill** (2,466 m) 11°23′55″N 76°42′39″E are significant elevations in this range. Snowdon, Club Hill and Elk Hill with Doddabetta, form the impressive Udhagamandalam Valley.

Devashola (height: 2,261 m), notable for its blue gum trees, is in the south of Doddabetta range.

Kulakombai (1,707 m) is east of the Devashola. The Bhavani Valley and the Lambton's peak range of Coimbatore district stretch from here.

Hullikal Durg: (height: 562 m), 11°19′N 76°53′E In the Kannada language, Hulikal Durg means Tiger Rock Fort. The Sanskrit name of his place is Bakasura Parvata. It is 3 km southeast of Coonoor. Tropical pine forest flourishes at the base of this hill.

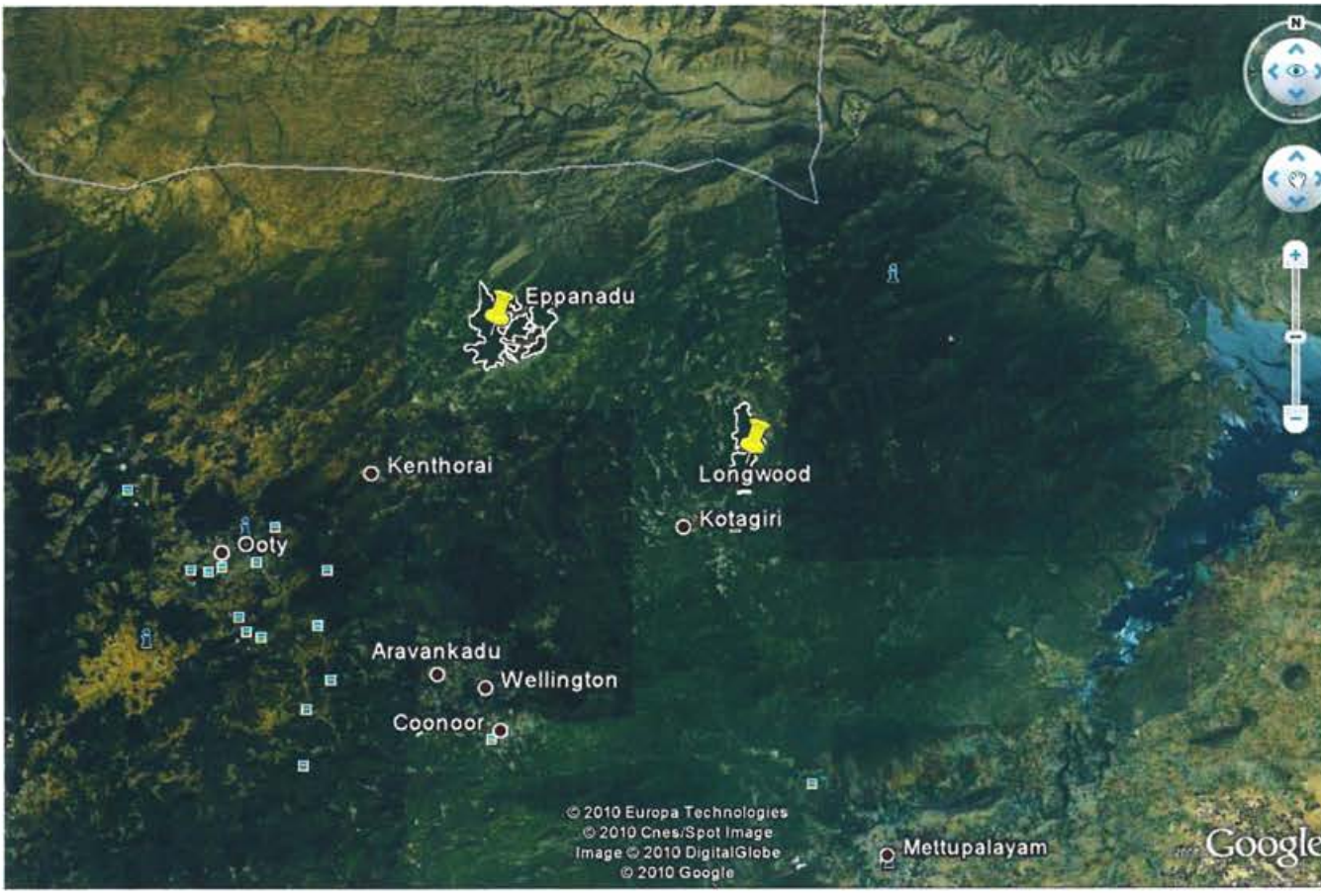
Coonoor Betta (2,101 m) is also called Teneriffe. It is on the northern side of the gorge, accommodating the Nilgiri Mountain Railway to Coonoor.

Rallia Hill (height: 2,248 m) 11°25′N 76°53′E is in the midst of a reserved forest and almost equidistant from Udhagamandalam and Kotagiri.

Dimhatti Hill (height: 1,788 m) 11°26′N 76°01′E is above the Gajalahatti pass, which provided a short cut from Mysore to the Carnatic plains and was of much strategic importance in the eighteenth century. This peak, dedicated to the deity Rangaswamy, is considered holy by the people of the surrounding villages.

PLATE-2

Satellite image of showing the two study sites in Nilgiris, Western Ghats



Waterfalls

The highest waterfall, Kolakambai Fall, north of Kolakambai hill, has an unbroken fall of 120 m. Nearby is the 46 m Halashana falls Second is Catherine Falls, near Kotagiri, with a 76 m fall, named after the wife of M.D. Cockburn, believed to have introduced coffee plantations to the Nilgiri Hills. The Upper and Lower Pykara falls have falls of 55 m, and 61 m, respectively. The 52 m Kalhutti Fall is off the Segur Peak.

2.1.6 Study Sites

Two study sites namely Longwood shola and Eppnadu shola were chosen the study (Map 2). Longwood Shola Forest is located at 1905 m altitude and it is the only major pocket of natural shola left in the immediate vicinity of Kotagiri Town in the Nilgiris. This shola is an integral part of the very fragile Nilgiri ecosystem with an area of 116 hectares. It is also one of the key areas for the conservation of birds, especially Rufous-breasted or Nilgiri Laughingthrush *Garrulax cachinnnans*, White-bellied Shortwing (*Brachypteryx major*) and the Nilgiri Wood Pigeon *Columba elphinstonii*, listed as threatened by the Birdlife International (2011). Longwood shola is classified as Southern Montane Wet Temperate Forest by Champion and Seth (1968). Tall trees of up to 20 m are commonly seen in this shola. Important tree species include *Actinodaphne bourneae, Ilex denticulata, Litsea wightiana, Michelia nilagirica, Microtropis ramiflora, Pithecellobium subcoriaceum, Symplocos pendula* and *Syzygium arnottianum*. Tea plantations surround this site.

The small size of Longwood Shola and its isolation from the neighboring sholas limits the population of most of the large animals. Leopard *Panthera pardus* and Tiger *P. tigris* are rarely seen even though their prey Sambar *Cervus unicolor* and Barking Deer *Muntiacus muntjak* are relatively common. Other mammal species seen here include Gaur *Bos frontalis*, Mouse Deer *Moschiola menminna*, Wild Boar *Sus scrofa*, Porcupine *Hystrix indica*, Bonnet Macaque *Macaca radiata*, Indian Giant Squirrel *Ratufa indica* and Black-naped Hare *Lepus nigricollis*.

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PLATE-3

Study area

Eppanadu shola forest

Longwood shola forest

The Eppanadu shola is located at 2090 m above msl at the Kotagiri Forest Division in Nilgiri district and located 35 km away from Kottagiri. This shola forest extends to 120 hectares (Fig.1). The vegetation of Eppanadu has been classified as Southern Montane Wet Temperate Forest by Champion and Seth (1968). Common tree species found here include *Actinodaphne bourneae, Litsea wightiana, Michelia nilagirica, Syzygium wightianum, Syzygium montanum, Symplocos foliosa* and *Syzygium arnottianum* . Eppanadu shola is home to several important bird species such as the Nilgiri Wood Pigeon, Nilgiri Laugingthrush and the White-bellied Shortwing. The area is also rich in mammalian fauna.

Fig. 1 Map showing study locations

CHAPTER III

VEGETATION ECOLOGY OF THE STUDY SITES

Introduction

Tropical montane evergreen forest known as 'shola' forest occurs in the higher elevations of the Western Ghats and its associated hill range in southern India (Champion and Seth 1968). It is discrete and patchy, mainly confined to sheltered valleys, hollows and depressions and is surrounded by grasslands. It consists of stunted short-boled evergreen trees that are unable to regenerate in open areas due to lack of tolerance to fire and frost (Meher-Homji, 1967; 1987). These forests were found extensively in the higher elevations of the Nilgiris and Palni ranges of Western Ghats, southern India, but due to agricultural expansion, conversion to plantations, livestock grazing pressure and development, a high proportion of this forest type has been destroyed. It has been estimated that half the shola forests in the Nilgiris have been destroyed since 1849 and that the current area under sholas is about 4225 ha (Kumar, 1993). A large proportion of the loss is due to expansion of agriculture and plantations (Kumar, 1999). Blasco (1970) listed 223 plant species known only from the sholas and grasslands of the higher altitude ranges of the Western Ghats. The shola forest also harbors many endemic and threatened plant species that cannot regenerate in grasslands and exposed sites due to lack of tolerance to fire and frost (Meher-Homji, 1967). The montane forests are more vulnerable to climate change, fire and human disturbance than the lowland forests, due to their small extent and harsher environment. Monitoring population dynamics and structural characteristics of shola forests over time can provide insights into the responses of these forests to climate and environmental changes.

Methodology

Vegetation sampling was done in two Shola forests namely Longwood shola and Eppanadu shola. Quantification of flora was carried out using quadrat method. For each of the forest, 10 qudrats of 50x20 m size were laid. In total, 20 plots were laid. In each of the plot, number of individuals of trees and Girth at Breast Height (GBH >20cm) of each individual were noted. All the shrubs and saplings occurring with in the quadrat were recorded. Five 1x1m plots were laid within the 50 x 20 m quadrat for recording seedlings. The data collected was analysed to obtain quantitative ecological values such as density, abundance, frequency by following Curtis and McIntosh (1950). The relative values of density, abundance and frequency was determined as per Philips (1959). From the vegetation data, the abundance and density of fleshy fruited species were calculated. All plant species were identified to species level using the regional floras. Nomenclature was followed after Flora of Tamil Nadu and Flora of Palni hills (Henry *et al.*, 1987; Nair and Henry 1983). Identification of specimens was confirmed at the Botanical Survey of India, Coimbatore.

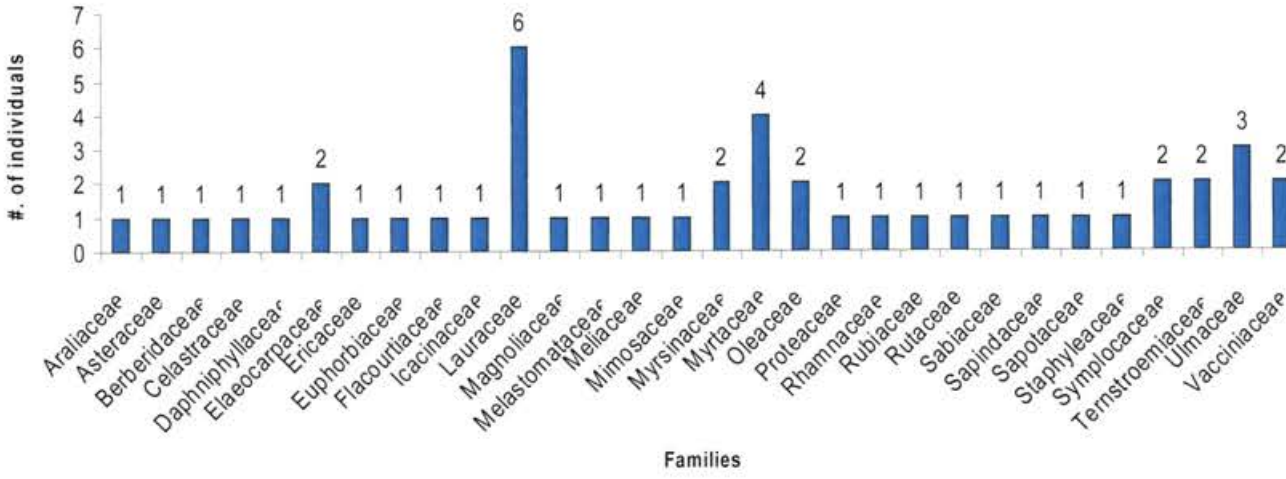
Results

Eppanadu shola

A total of 1013 individuals belonging to 46 tree species of 30 families were recorded in the 1 ha plot (Fig. 1). Maximum number of individuals was represented by *Symplocos cochinchinensis* (n=176) followed by *Celtis tetrandra* (n=132) and *Actinodaphne bourneae* (n=60). Highest relative density values were recorded for *Symplocos cochinchinensis* (17.37), *Celtis tetrandra* (13.03) and *Actinodaphne bourneae* (5.92). Most dominant tree species include *Celtis tetrandra* (IVI-42.51) followed by *Symplocos cochinchinensis* (IVI-75.77) and *Actinodaphne bourneae* (IVI-10.92). The vegetation community can be described *Actinodaphne bourneae-Celtis tetrandra-Symplocos cochinchinensis* type. The Shannon Wiener Diversity Index for the tree community in Eppanadu shola forest works out to be 3.23.

Out of the 30 families recorded, Symplocaceae (20.24%), Lauraceae (16.9%) and Ulmaceae (13.92%) had the maximum number of individuals. Highest number of species was observed in Lauraceae (n=6) followed by Myrtaceae (n=4) (Fig.2). Out of the 46 tree species recorded here, 19 (36.13%) were endemic to the Western Ghats. An endangered tree species, *Rhododendron arboreum* was also found in the plot.

Fig.2 Family wise distribution of species in the Eppanadu shola forest

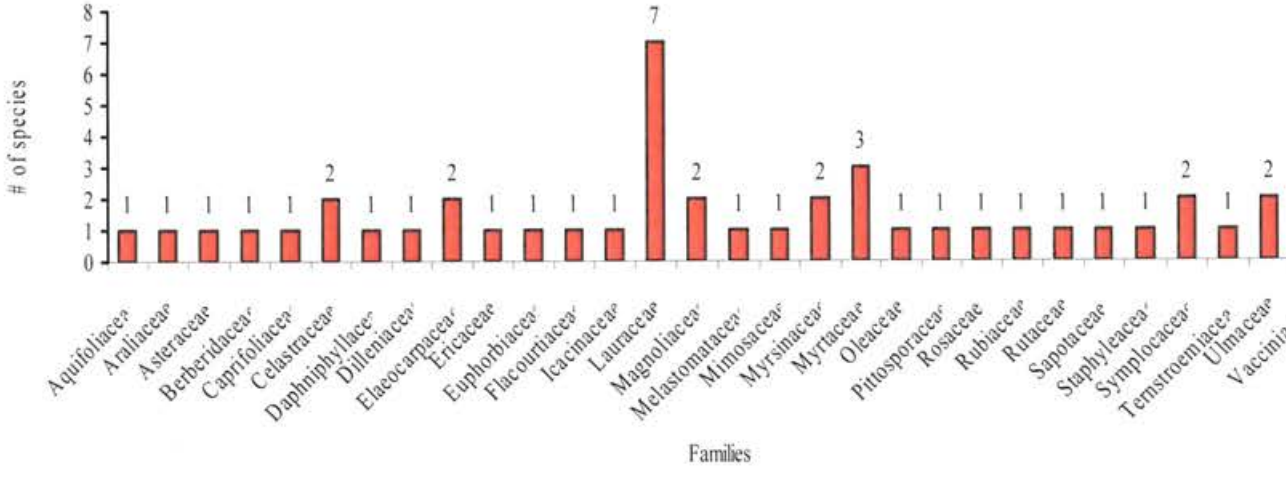


Longwood shola

In total, 874 individuals of 45 tree species belonging to 30 families were recorded in the Longwood shola (Fig. 5). Maximum number of individuals were recorded for *Euonymous dichotomouss* (n=93) followed by *Elaeocarpus oblongus* (n=89) and *Celtis tetrandra* (n=78). Highest relative density values was recorded for *Euonymous dichotomous* (10.64) followed by *Elaeocarpus oblongus* (10.18) and *Celtis tetrandra* (8.92).

Out of the 30 families recorded, Lauraceae (11.94%), Ulmaceae (9.50%), and Elaeocarpaceae (7.21%) were represented by maximum number of individuals. Highest number of species was observed for Lauraceae (n=7 species) followed by Myrtaceae (n=3) (Fig. 3). Out of 45 tree species, 20 (44.85%) were endemic to Western Ghats. One endangered species *Rhododendron arboreum* was also found in the study plot.

Fig. 3 Family-wise distribution of species in the Longwood shola forest



Most dominant tree species of this forest include *Euonymous dichotomous* (IVI-48.42) followed by *Euodia lunu-ankenda* (IVI-41.85) and *Elaeocarpus oblongus* (IVI-24.69). The vegetation community can be described *Symplocos cochinchinensis, Euodia lunu-ankenda-Euonymous dichotomous-Elaeocarpus oblongus*. The Shannon Wiener Diversity Index for Longwood shola forest workout to 3.29.

Table 1 Comparison of tree community parameters in the two shola forests of the Nilgiri hills

Parameters	Eppanadu	Longwood
# of families	30	30
# of genera	39	37
# of species	46	45
# of individuals	1013	874
Shannon's diversity index	3.23	3.29

3.2.1 Abundance of bird-dispersed plant species

A total of 47 species of avian frugivore food plants were observed in the study sites. Out of these 47 species, 40 were enumerated in the sample plots, of which 34 species were recorded in Eappanadu shola and 37 at Longwood shola (Table 2).

Table 2 Distribution of avian frugivore food plants in the two shola forests of Nilgiri hills, Western Ghats

S.No	Name of the Plant	Eppanadu			Longwood		
		# of individuals	Density	Relative density	# of individuals	Density	Relative density
1	*Actinodaphne bourneae*	60	6	5.92	25	2.5	2.86
2	*Celtis tetrandra*	132	13.2	13.03	78	7.8	8.92
3	*Celtis timorensis*	3	0.3	0.3	-	-	-
4	*Cinnamomum wightii*	21	2.1	2.07	1	0.1	0.11
5	*Cryptocarya lawsonii*	23	2.3	2.27	8	0.8	0.92
6	*Daphniphyllum neilgherrense*	36	3.6	3.55	16	1.6	1.83
7	*Elaeocarpus munronii*	15	1.5	1.48	4	0.4	0.46
8	*Elaeocarpus oblongus*	30	3	2.96	89	8.9	10.18
9	*Euonymous dichotomous*	8	0.8	0.79	93	9.3	10.64
10	*Eurya japonica*	1	0.1	0.1	18	1.8	2.06
11	*Euodia lunu-ankenda*	2	0.2	0.2	51	5.1	5.84
12	*Glochidion neilgherrense*	7	0.7	0.59	35	3.5	4
13	*Ilex wightiana*	-	-	-	10	1	1.14
14	*Isonandra perrottetiana*	12	1.2	1.18	34	3.4	3.89
15	*Ixora notoniana*	21	2.1	2.07	32	3.2	3.66
16	*Ligustrum perottetti*	12	1.2	1.18	14	1.4	1.6
17	*Litsea wightiana*	19	1.9	1.88	1	0.1	0.11
18	*Mahonia leschenaultii*	6	0.6	0.59	11	1.1	1.26
19	*Memecylon malabaricum*	5	0.5	0.49	15	1.5	1.72

20	*Michelia nilagirica*	10	1	0.99	6	0.6	0.69
21	*Michelia champaca*	-	-	-	6	0.6	0.11
22	*Microtropis densiflora*	-	-	-	7	0.7	0.8
23	*Myrsine wightiana*	8	0.8	0.79	24	2.4	2.75
24	*Neolitsea scrobiculata*	29	2.9	2.86	25	2.5	2.86
25	*Neolitsea zeylanica*	-	-	-	9	0.9	1.03
26	*Nothapodytes nimmoniana*	28	2.8	2.76	20	2	2.29
27	*Olea bournei*	5	0.5	0.49	-	-	-
28	*Phoebe lanceolata*	19	1.9	1.88	31	3.1	3.55
29	*Pittosporum neilgherrense*	-	-	-	15	1.5	1.72
30	*Schefflera racemosa*	17	1.7	1.68	5	0.5	0.57
31	*Symplocos cochinchinensis*	176	17.6	17.37	24	2.4	2.75
32	*Symplocos foliosa*	29	2.9	2.89	8	0.8	0.92
33	*Syzygium densiflorum*	56	5.6	5.53	14	1.4	1.6
34	*Syzygium cumini*	12	1.2	1.18	22	2.2	2.52
35	*Syzygium montanum*	8	0.8	0.79	16	1.6	1.83
36	*Ternstroemia japonica*	3	0.3	0.3	-	-	-
37	*Turpinia nepalensis*	12	1.2	1.18	11	1.1	1.26
38	*Vaccinium leschenaultii*	8	0.8	0.79	15	1.5	1.76
39	*Vaccinium neilgherrense*	44	4.4	4.34	9	0.9	1.03
40	*Viburnum hebanthum*	-	-	-	12	1.2	1.37

Celtis timorensis, *Ternstroemia japonica*, *Olea bournei* were not present in the Longwood shola, where as in the Eppanadu shola six species namely *Ilex wightiana*, *Michelia champaca*, *Microtropis densiflora*, *Pittosporum neilgherrense*, *Viburnum hebanthum*, *Neolitsea zeylanica* were absent (Table 2).

Comparison of vegetation features at two sites showed rich diversity of fleshy fruited plants (Table 3). Twenty one plant families, 30 genera, 37 tree species were recorded in the Longwood shola, where as in the Eppanadu shola 20 families, 29 genera and 34 tree species were found.

Table 3 Comparison of avian food plant diversity in the two shola forests in Nilgiri hills, Western Ghats

Parameters	Longwood	Eppanadu
# of families	21	20
# of genera	30	29
# of species	37	34
# of individuals	780	877
Shannon's diversity	3.18	2.88

3.2.2 Human impacts on vegetation in the bird habitat

The shola foress are subjected to various sorts of human disturbances. Agricultural practices along the forest fringes by local people, livestock grazing and Non-timber Forest Produces (NTFP) collection constituted major disturbances. As a result of these activities, food plant densities are affected.

Some plant species recorded in the vegetation assessment plots

PLATE-4

Ixora notoniana

Elaeocarpus oblongus

PLATE-5

Vernonia monosis

Viburnum hebanthum

Discussion

The present study shows that the difference in tree species richness among various shola forest sites in Western Ghats was not significant. Totally, 55 tree species were recorded in our study site. While 46 species was recorded in Eppanadu, 45 observed in Longwood shola. A total of 60 tree species was recorded in a one hectare plot of Thiashola, a large shola forest about 20 km east of our study site (Narendran *et al.*, 2001). Mohandass and Davidar (2009) recorded 57 tree species from two shola forest sites in the Nilgiri hills. In a shola forest site in Palni hills, Western Ghats, 67 tree species were recorded from a 1.08 ha area (Davidar *et al.* 2007).

Lauraceae is found to be the most species rich family in the shola forests of Nilgiri hills. In our study area, most speciose family was Lauraceae (6 species) in Eppanadu and Longwood (7 species) respectively. A study by Mohandass and Davidar (2009) in Korakundha and Upper Bhavani shola forests in Nilgiris indicates that Lauraceae (15 species) was the most speciose family. Lauraceae was found to be the most speciose family in the shola forests of Palni hills also (Davidar *et al.*, 2007). Fruits of Lauraceae form an important diet of birds in the study sites. Lauraceae, Euphorbiaceae constitute the dominant avian frugivore attracting plant families in the evergreen forest of northern Western Ghats, India (Medhavi *et al.* 2012). Lauraceae is the major avian frugivore attracting plant family in the wet evergreen forest of Kakachi, southern Western Ghats (Ganesh and Davidar 2001). The lipid rich Lauraceae and Daphniphyllaceae fruits form important food item for hornbills in the Western Ghats (Kannan and James 1999; Maheswaran 2002).

CHAPTER IV

FRUITING PHENOLOGY

Introduction

Phenology is the study of the seasonal variation of a species, including a description of variations in structure at different seasons, such as budding, flowering and fruiting (Mishra *et al.* 2006). Pattern of phenological events are variously used for characterization of vegetation type (Opler *et al.* 1980; Shim well 1972). The study of plant phenology provides knowledge about the pattern of plant growth and development as well as the effects of environment and selective pressures on flowering and fruiting behavior (Zhang *et al.* 2006). To know the flowering and fruiting season of the plants, phenological studies are very essential. There is lack of sufficient information on the relationship between fruiting phenologies with that of frugivorous bird abundance (Balasubramanian and Bole 1993a).

There are several explanations for the evolution of the timing of life cycle event in trees. Resource allocation to different physiologically active sites which are competing for resources may be optimized; thus selection may act for flowering to occur when resource availability is not a constraint. Plants also compete for resources, such as pollinators or dispersers, and hence may have evolved staggered flowering and fruiting phenologies (Waser *et al.* 1991). However, others have argued that phonologies may simply be random.

There is growing concern regarding the potential effects of climate change on phenological patterns of plants in tropical ecosystems since some studies have documented changes in ecological processes such as fruit abundance in association with weather anomalies over the past decades (Wright and Calderon 1995). Although the evidence suggests that natural ecological patterns may be severely modified by global weather changes, there are two main reasons why it is difficult to generalize and predict changes in the reproductive activity of tropical forest plants in response to climate

anomalies. Firstly, weather does not behave the same way in all tropical forests (Malhi and Wright 2004). Secondly, despite the advances in understanding gross phenological changes at the community level for many tropical ecosystems, we still have a poor knowledge on the proximate causes that trigger phenological processes for the vast majority of tropical plants (Sven Gunter *et al.* 2008). Tropical plant communities are composed of a diverse array of species, usually showing a variety of phenological strategies (Rivera *et al.* 2002; Diaz and Granadillo 2005; Singh and Kushawaha 2006), and to date, the effects of proximate factors driving phenological patterns have been assessed with strong experimental evidence for only a few species (*e.g.*, Garwood 1983; Wright and Cornejo 1990; Rivera *et al.* 2002). Furthermore, there is evidence for phenological plasticity for some wide-ranging species (Borchert *et al.* 2004). The timing and duration of flowering and fruiting for instance is crucial in understanding forest regeneration dynamics as the pronounced seasonality affects the reproductive output and performances such as seed production, germination, survival, and seedling growth (Augspurger 1981).

An understanding of the phenological patterns in different geographical regions and of factors underlying these patterns is important for a number of reasons. First, frugivores are the dominant group of vertebrates in most tropical forests (Emmons *et al.* 1983; Fleming *et al.* 1987; Gautier-Hion *et al.* 1985; Terborgh 1986), and regional differences in their abundance may be caused by differences in food availability (Terborgh and van Schaik 1987). Secondly, an understanding of phenological patterns and factors underlying these patterns will assist conservation scientists in predicting consequences of perturbations such as atypical climatic events (Foster 1982) or global warming (Tutin and Fernandez 1993). Thirdly, phenological patterns are linked to many processes governing forest function and structure including population biology of pollinators, dispersers, seed predators, and herbivores, interspecies competition among trees, and processes of primary production (Newstrom *et al.* 1994; Smythe 1970; van Schaik *et al.* 1993). Thus, an understanding of what governs phenological process is valuable in understanding forest function and structure and in providing the basis for developing management options.

Information on reproductive phenology is necessary for understanding vegetative functioning and dynamics, since the reproductive potential of vegetation is fundamental in landscape evolution (Günter *et al.* 2008). Phenological patterns can be described as the periodic variations in the flowering and fruiting patterns of a species. It could be defined as variations in a) the number of species in flower or fruit, b) the proportion of plants bearing flowers or fruits and c) the abundance of flowers or fruits over time (Blake *et al.* 1990). Plant phenological studies are fundamental to understand the forest as a resource base for dependent species, populations and communities. Tropical plant communities display conspicuous seasonal pattern in vegetative and reproductive phenophases at both community and species level (Frankie *et al.* 1974; Williams-Linera1997). Variations in flowering and fruiting can be influenced by both abiotic and biotic factors and thus the plants would choose a favorable time to reproduce. Fruit production has been shown to vary greatly over time in all major blocks of tropical forests of South-East Asia (Leighton and Leighton 1983). Information on phenological patterns of the natural forests of the Western Ghats, however, is limited (Murali and Sukumar 1994; Kannan and James 1999; Sundarapandian *et al.* 2005) and studies are scanty in the montane wet temperate forest.

Almost all tropical environments vary seasonally in rainfall, temperature, humidity, wind speed and day length (Richards 1952). These variations in abiotic factors strongly influence the pattern of flowering and fruiting. In fact, most studies of tropical fruiting phenologies report seasonalities and also reveal extreme seasonality in annual fruiting patterns among plants with fleshy-fruits in forests with distinct wet and dry season (Howe and Smallwood 1982; Engel and Martins 2005). It has been found that a majority of the fleshy-fruited species across the globe produce fruits during the peak rainy season or just before the onset of the peak rainy season (Lieberman 1982; Bhat 1992). This fruiting pattern may reduce seedling mortality by dispersing seeds when soil moisture conditions are favourable for seed germination and rapid seedling growth (van Schaik *et al.* 1993).

Methodology

Fruiting Phenology of trees

Fruiting periodicity was monitored by tagging 300 plants belonging to 30 fleshy fruited species for two years from January 2009 to December 2010. All the 300 individuals were tagged with aluminum tags and were numbered. Plant taxa were identified provisionally in the field. Plant specimens with fruits or flowers were collected and identification was confirmed with the help of flora books. Tagged plants were monitored once in a fortnight for fruit availability. Binoculars were used for observation, wherever necessary. Percentage of fruit in the canopy was visually estimated and then the estimate was divided into percentage of ripe and unripe fruit, based primarily on colour changes indicating ripeness (Anggraini *et al.* 2000; Balasubramanian *et al.* 2004).

Results

4.2.1 Fruiting phenology of trees

Site 1. Longwood shola

The phenology data indicates seasonal variations of fruiting in the bird-habitat. Fruit production occurs year round in the shola forest. Number of species and the number of individuals in fruits varied in different months. In the study area, a major fruiting peak was observed in June. During the peak fruiting period of 2009, 2010, 87 individuals belonging to 10 species and 112 individuals belonging to 14 species were recorded.

Of the 21 plant species tagged for phenological studies, Ulmaceae (*Celtis tetrandra*), Rutaceae (*Euodia lunu-ankenda*) fruited for more than five months. Highest number of fruiting species was recorded in Lauraceae (*Neolitsea scrobiculata, Nothapodytes nimmoniana, Phoebe lanceolata*). All other species showed seasonal fruiting activity (Table 4). *Nothapodytes nimmoniana* fruits were available from February to April.

Microtropis densiflora showed extended fruiting with a peak in June, July. *Daphniphyllum neilgherrense* fruits were available for seven months.

In both the years of study, highest number of tree species was in fruiting during June and the lowest in October. Number of fruiting individuals also showed similar trend, with a peak in June and trough in October in both the years (Fig 4, 5).

Fig. 4 Fruiting phenology of trees (# of species in fruiting) in the Longwood shola (n=21)

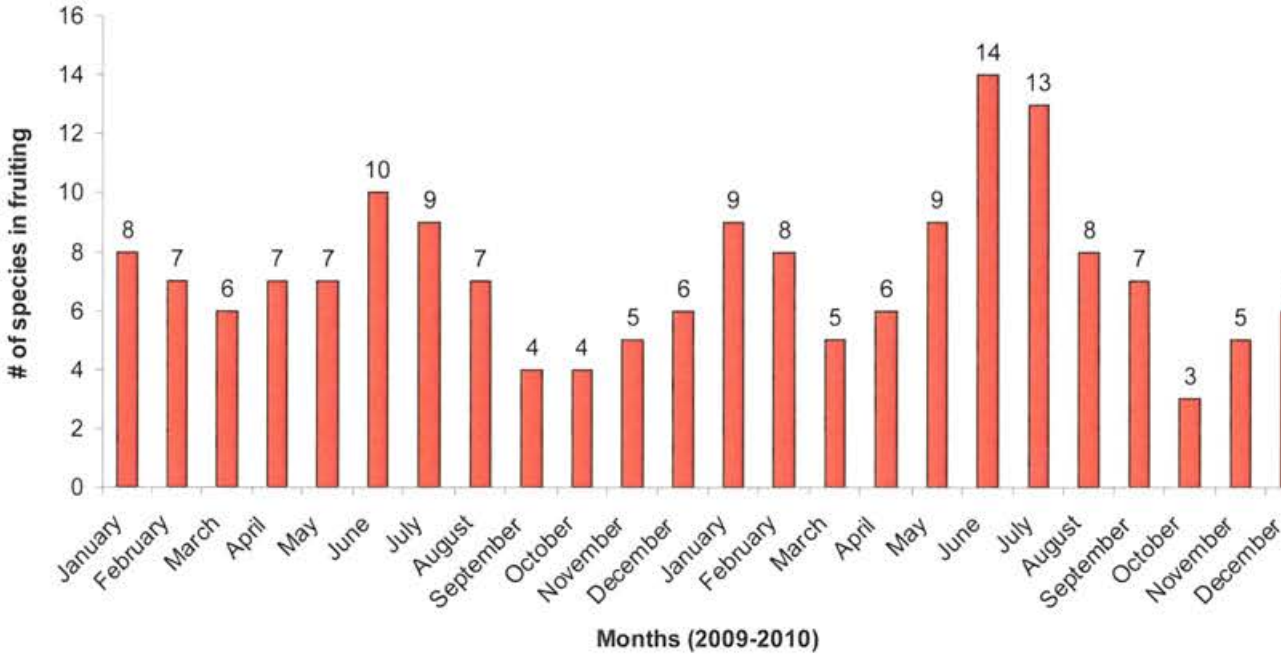
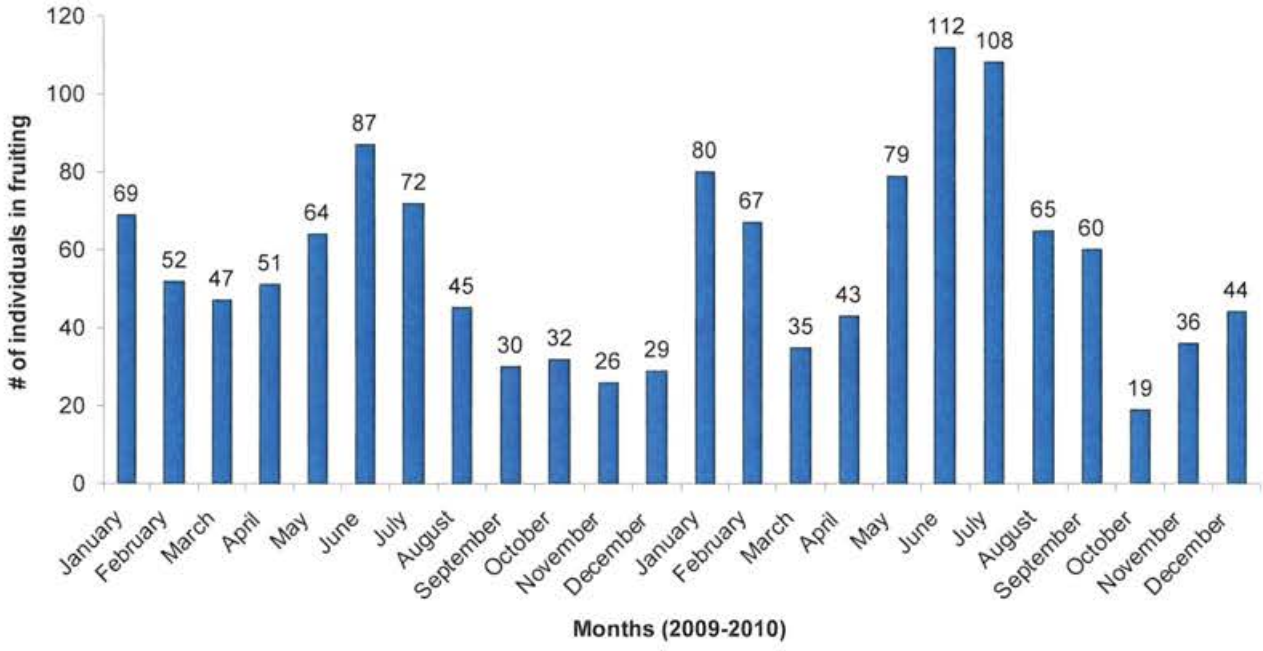


Fig. 5 Fruiting phenology of trees (# of individuals in fruiting) in the Longwood shola (n=210)



Site 2. Eppanadu Shola

A total of 65 individuals of 11 species and 114 individuals of 14 species were recorded in the year of 2009 and 2010 respectively. Fruiting peak was noticed during June and trough in October (Fig. 6 and Fig. 7).

Of the 22 plant species belonging to 16 families tagged for phenological studies, *Celtis tetrandra*, *Daphniphyllum neilgherrense*, *Euodia lunu-ankenda* had fruits for more than 5 month. Dominant fruit-yielding families include Lauraceae (*Neolitsea scrobiculata, Litsea wightiana, Cryptocarya lawsonii*), Myrtaceae (*Syzygium montanum, Syzygium densiflorum*), Ulmaceae (*Celtis tetrandra, Celtis timorensis*). All other species showed highly seasonal fruiting activity (Table 5). *Litsea wightiana* fruits were available from

July-September. *Symplocos* species had extended fruiting with a peak during April-May. *Daphniphyllum neilgherrense* fruits were available for six months.

Highest numbers of species were in fruits in June (11 in 2009 and 14 in 2010) and lowest (2) in October during both the years of study (Fig. 7).

Fig. 6. Fruiting phenology of trees (# of species in fruiting) in the Eppanadu shola (n=22)

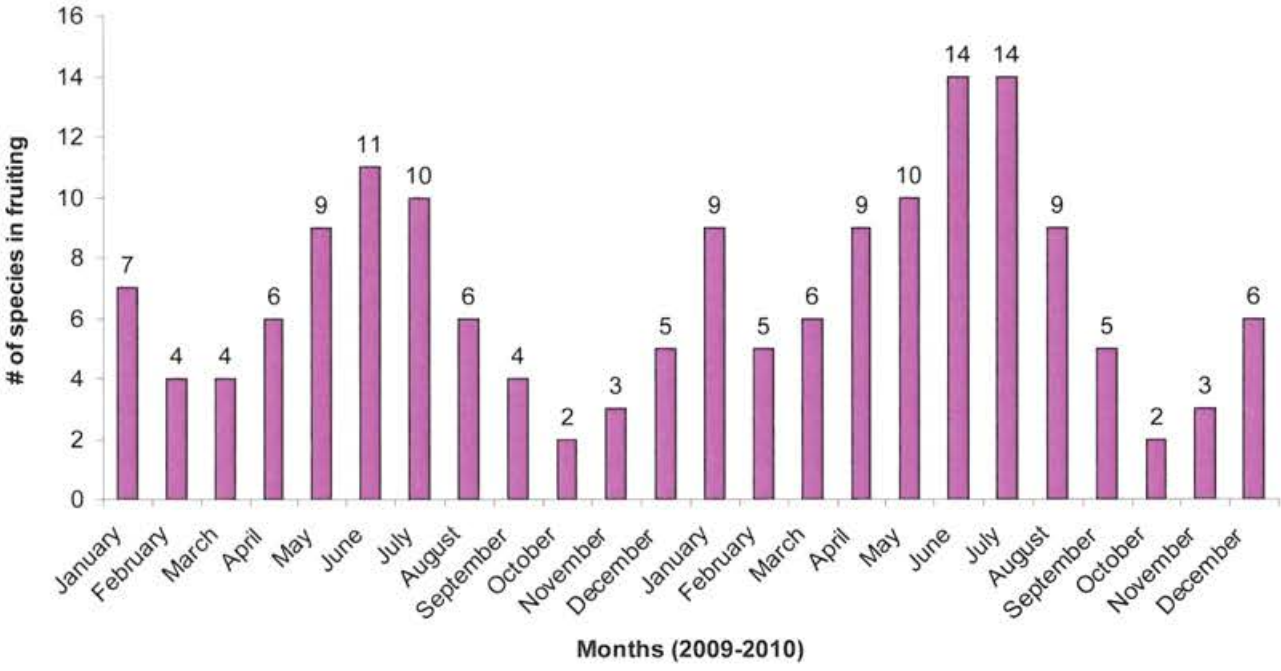


Fig. 7. Fruiting phenology of trees (# of individuals in fruiting) in the Eppanadu shola (n=220)

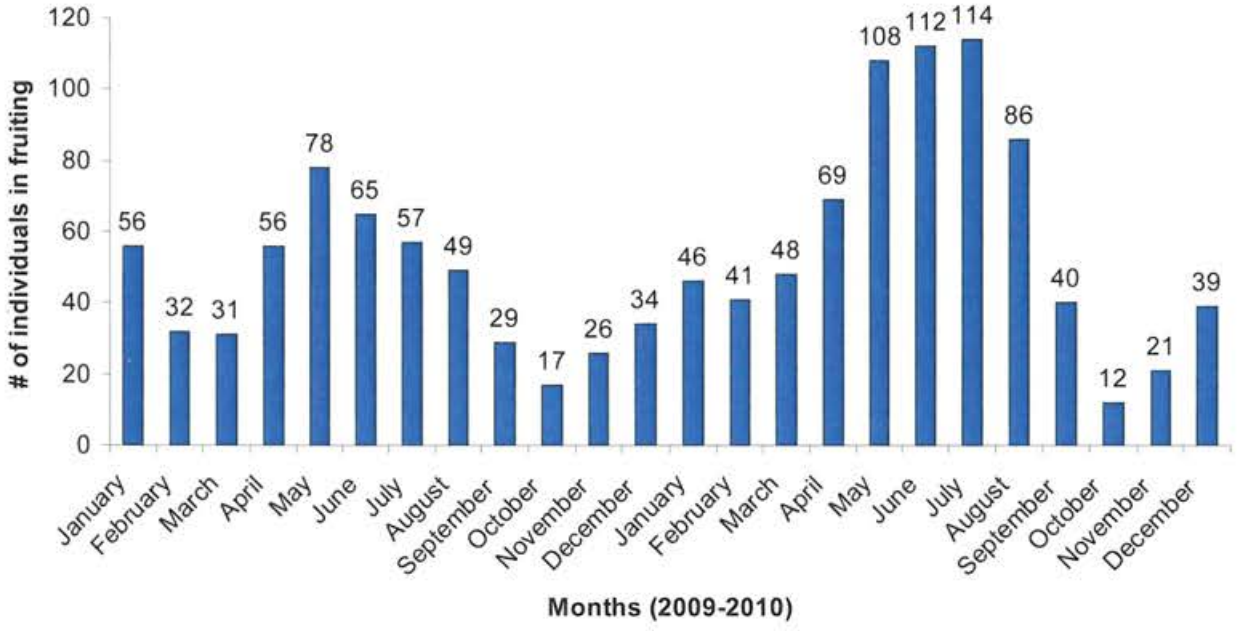


Table 4. Fruiting periods of fleshy-fruited species in the Longwood shola forest, Western Ghats

S.No	Species Name	Family	Fruiting month
1	*Celtis tetrandra*	*Ulmaceae*	3,4,5,6,7,
2	*Daphniphyllum neilgherrense*	*Daphniphyllaceae*	1,2,3,6,7,8,11
3	*Elaeocarpus oblongus*	*Elaeocarpaceae*	3,4,5,6,7
4	*Euonymous dichotomous*	*Celastraceae*	11,12,1,2
5	*Eurya nitida*	*Theaceae*	7,8,9
6	*Euodia lunu-ankenda*	*Rutaceae*	1,5,6,7,11,12
7	*Glochidion neilgherrense*	*Euphorbiaceae*	5,6,7
8	*Isonandra perrottetiana*	*Sapotaceae*	2,3,4,5
9	*Ixora notoniana*	*Rubiaceae*	5,6,7,8
10	*Ligustrum perrottetii*	*Oleaceae*	1,6,7,8,12
11	*Memecylon malabaricum*	*Melastomataceae*	1,2,3,4,
12	*Michelia champaca*	*Magnoliaceae*	5,6,7,8,9
13	*Microtropis densiflora*	*Celastraceae*	6,7,11,12
14	*Myrsine wightiana*	*Myrsinaceae*	4,5,6
15	*Neolitsea scrobiculata*	*Lauraceae*	1,2,5,6,7
16	*Nothapodytes nimmoniana*	*Icacinaceae*	2,3,4
17	*Phoebe lanceolata*	*Lauraceae*	1,2,3,9,10
18	*Symplocos cochinchinensis*	*Symplocaceae*	1,4,5,11,12
19	*Syzygium densiflorum*	*Myrtaceae*	6,7,8
20	*Syzygium montanum*	*Myrtaceae*	6,7,8
21	*Turpinia nepalensis*	*Staphyleaceae*	1,11,12

Some common plant species marked for phenology study

PLATE-6

Symplocos cochinchinensis

Neolitsea scrobiculata

Table. 5 Fruiting periods of fleshy-fruited species in the Eppanadu shola forest forest, Western Ghats

S.No	Species Name	Family	Fruiting month
1	*Celtis tetrandra*	*Ulmaceae*	4,5,6,7
2	*Celtis timorensis*	*Ulmaceae*	4,5,6,7,8
3	*Cryptocarya lawsonii*	*Lauraceae*	6,7,8
4	*Daphniphyllum neilgherrense*	*Daphniphyllaceae*	1,2,3,5,6,7
5	*Elaeocarpus oblongus*	*Elaeocarpaceae*	3,4,5,6,7
6	*Euodia lunu-ankenda*	*Rutaceae*	1,5,6,7,11,12
7	*Glochidion-neilgherrense*	*Euphorbiaceae*	5,6,7
8	*Ixora notoniana*	*Rubiaceae*	1,5,6,7,8
9	*Ligustrum perrottetii*	*Oleaceae*	1,5,6,7,8
10	*Litsea wightiana*	*Lauraceae*	7,8,9
11	*Microtropis densiflora*	*Celastraceae*	1,6,7,11,12
12	*Michelia nilagirica*	*Magnoliaceae*	1,3,7,11,12
13	*Myrsine wightiana*	*Myrsinaceae*	3,4,5
14	*Neolitsea scrobiculata*	*Lauraceae*	1,2,5,6,7
15	*Nothapodytes nimmoniana*	*Icacinaceae*	2,3,4,9,10
16	*Phoebe lanceolata*	*Lauraceae*	1,2,3,4
17	*Schefflera racemosa*	*Araliaceae*	3,4,5
18	*Symplocos cochinchinensis*	*Symplocaceae*	1,4,5,11,12
19	*Symplocos foliosa*	*Symplocaceae*	1,4,5,11,12
20	*Syzygium densiflorum*	*Myrtaceae*	6,7,8
21	*Syzygium montanum*	*Myrtaceae*	6,7,8
22	*Turpinia nepalensis*	*Staphyleaceae*	1,11,12

4.2.2 Fruiting profile of the fleshy-fruited tree species

The phenology is discussed with regard to four seasons namely, summer (March – May), South-west Monsoon (June – August), North-east Monsoon (September – November) and Post Monsoon (December – February). In the Longwood shola there was a peak in fruiting during south west monsoon (14 species). Post monsoon had 11 fruiting species, while summer showed 10 species and north-east monsoon was 11 species. Fruiting schedule of fleshy fruited plants of the study area shown in Table 6.

The Eppanadu shola also had the fruiting peak (15 species) in southwest monsoon season. Post monsoon had 11 fruiting species, while summer showed 13 species, north-east monsoon with 12 species. Fruiting schedule of fleshy fruited plants of the study area is shown in Table 7.

PLATE-7

Syzygium montanum

Vaccinium leschenaultii

Bird-dispersed plant species in the Eppanadu shola forest

PLATE-8

Gaultheria fragrantissima

Syzygium densiflorum

PLATE-9

Vaccinium neilgherrense

Litsea floribunda

PLATE-10

Berberis tinctoria

Maesa indica

PLATE-11

Euodia lunu-ankenda

Celtis tetrandra

Table. 6 Fruiting profile of fleshy-fruited tree species in the Longwood shola forest

S.No	Botanical Name	Summer	South-West Monsoon	North-East Monsoon	Post-Monsoon
1	*Celtis tetrandra*	√	√		
2	*Daphniphyllum neilgherrense*	√	√	√	√
3	*Elaeocarpus oblongus*	√	√		
4	*Euonymous dichotomous*			√	√
5	*Eurya nitida*		√	√	
6	*Euodia lunu-ankenda*	√	√		√
7	*Glochidion-neilgherrense*	√	√		
8	*Isonandra perrottetiana*	√			√
9	*Ixora notoniana*		√	√	
10	*Ligustrum perrottetii*		√	√	√
11	*Memecylon malabaricum*	√			√
12	*Michelia champaca*		√	√	
13	*Microtropics densiflora*		√		√
14	*Myrsine wightiana*	√			
15	*Neolitsea scrobiculata*	√	√	√	√
16	*Nothapodytes nimmoniana*	√			√
17	*Phoebe lanceolata*			√	√
18	*Symplocos cochinchinensis*		√	√	
19	*Syzygium densiflorum*		√	√	
20	*Syzygium montanum*		√		
21	*Turpinia nepalensis*			√	√

Table. 7 Fruiting profile of fleshy-fruited tree species in the Eppanadu shola forest

S.No	Botanical Name	Summer	South-West Monsoon	North-East Monsoon	Post-Monsoon
1	*Celtis tetrandra*	√	√		
2	*Celtis timorensis*	√	√		
3	*Cryptocarya lawsonii*		√		
4	*Daphniphyllum neilgherrense*	√	√	√	
5	*Elaeocarpus oblongus*	√	√		√
6	*Euodia lunu-ankenda*	√	√	√	√
7	*Glochidion neilgherrense*		√		√
8	*Ixora notoniana*		√	√	
9	*Ligustrum perrottetii*	√	√	√	
10	*Litsea wightiana*		√	√	
11	*Microtropis densiflora*		√	√	√
12	*Michelia champaca*	√	√	√	
13	*Myrsine wightiana*	√			
14	*Neolitsea scrobiculata*		√		√
15	*Nothapodytess nimmoniana*	√		√	√
16	*Phoebe lanceolata*	√		√	√
17	*Schefflera racemosa*	√			
18	*Symplocos cochinchinensis*	√		√	√
19	*Symplocos foliosa*	√		√	√
20	*Syzygium densiflorum*		√		
21	*Syzygium montanum*		√		√
22	*Turpinia nepalensis*			√	√

Discussion

The present study on fruiting phenology of trees in two montane forest sites of Western Ghats, India show the occurrence of definite seasonality. Fruiting reached a peak during the onset of southwest monsoon and trough in north-east monsoon. This observation corresponds with the trend reported from other tropical forests (Koptur *et al.* 1988; Sun *et al.* 1996) and in the Kukkal shola, Western Ghats in India (Somasundram and Vijayan 2010b). Similar pattern of phenology has also been reported in a Brazilian montane forest site (Funch *et al.* 2002). In the Kukkal shola of the Western Ghats, ripe fruits were available round the year with a peak in July, after the onset of south-west monsoon. Similar pattern was reported in many tropical forests (Kannan and James 1999; Griz and Machado 2001; Kitamura *et al.* 2001; Sundarapandian *et al.* 2005).

Phenology cycle of tree species in the present study shows the occurrence various guilds of fruiting species. While three species produced fruits throughout the year, 21 produced seasonally and two irregularly. A comprehensive 4-year study of the phenology of flowering and fruiting in a Philippine submontane rain forest found 34 tree species reproduced once a year, 13 reproduced continuously, 3 superannually and 7 irregularly (Hamann 2004). Fleshy-fruited species of the 'montane group' fruited all the year round without a distinct fruiting season. Such an seasonal tendency resulted from high proportions of plants bearing fruits continuously and annual/biannual fruiting species fruiting all through the year. Plant species with continuous fruiting usually bore a little fruit in every census and even plant species with annual, biannual fruiting produced less fruits when they fruited asynchronously (Kitamura *et al.* 2001). Such a low rate of fruit production through the year may be adaptive for a low density of birds and a small number of resident bird species (Poulin *et al.* 1999; Thompson and Willson 1979).

A universal tendency for tropical forests to fluctuate seasonally in fruit production with abundance peaks and periods of scarcity has been established in South-east Asia (Leighton and Leighton 1983; Kannan and James 1999; Balasubramanian 1996; Balasubramanian and Maheswaran 2002). Fruiting plants that provide a critical resource for frugivores during periods of scarcity are called keystone plant resources (Leighton

and Leighton 1983; Terborgh 1986). They are of great ecological importance, because they appear to establish the carrying capacity of the frugivores (Terborgh 1986). In many tropical forests, the Moraceae family, *Ficus* spp., act as keystone species (eg., Kannan and James 1999; Balasubramanian and Maheswaran 2002), whereas in the montane forest only a single species of *Ficus* (*Ficus drupacea*), was present and its fruiting did not coincide with the lean season. In the montane shola forest, its place is taken by *Olea paniculata* (Oleaceae) and *Trichillia connoroides* (Meliaceae).

CHAPTER V

Avian frugivory and seed dispersal in shola forests

Introduction

Fruits constitute an unusual kind of "prey" for animals. These structures are usually the units of dissemination of a plant's offspring and consequently, they benefit from being carried away from the parent by a dispersal agent (Howe and Westley 1988). A fleshy fruit can be described as a nutritious "package", containing the seeds inside and "designed" to be eaten by animals (Snow 1971). The animals may act as dispersers when they ingest the entire fruit, thus gaining a meal, and transport the seeds undamaged to a different place where germination may occur (Traveset *et al.* 2008).

Frugivores eat a lot of fruits; they are highly dependent on the abundance and nutritional composition of fruits (Augspurger and Kelly 1984b). Frugivores can either benefit fruit-producing plants by dispersing seeds. When both the fruit-producing plant and the frugivore species benefit by fruit-eating behavior, their interaction is called a mutualism (Levey *et al.* 2002). Frugivores to be good seed dispersers, they must digest fruits without consuming a high proportion of the seeds. Many seed-dispersing animals have specialized digestive systems to process fruits which leave seeds intact (Traveset *et al.* 2008). Some bird species have shorter intestines to rapidly pass seeds, while some frugivorous bat species have longer intestines. Some seed-dispersing frugivores have short gut-retention times and others can alter intestinal enzyme composition when eating different types of fruits (Gautier-Hion *et al.* 1985).

Seed dispersal by frugivores is a common phenomenon in many ecosystems. However, it is not a highly specific type of plant-animal interaction (Loiselle and Blake 2002). For example, a single species of frugivorous bird may disperse fruits from several species of plants, or a few species of birds may disperse seeds of one plant species. This lack of specialization could be because fruit availability varies by season and year, which tends to discourage frugivore animals from focusing on just one plant species. Furthermore,

different seed dispersers tend to disperse seeds to different habitats, at different abundances, and distances depending on their behavior and numbers.

Most woody species in tropical rain forests produce fleshy fruits that attract vertebrate seed dispersers (Howe and Smallwood 1982; Willson *et al.* 1989). Frugivorous birds and bats are the most important seed dispersal agents for tropical forest seeds in to grasslands and early successional vegetation because the simple structure of these habitats poses less barrier to them than it does to other frugivorous vertebrates (Barbel and Bohning-gaese 2001).

The survival of a plant species is best ensured by the dispersal of fruits and seeds to as many different and far off localities as possible (Venkateshwaralu 1982). Among the regular methods of seed dispersal, birds play a vital role, because of their fruit eating habits and the long distances they travel (Ridely 1930). It is generally regarded that seeds defecated by birds germinate much faster than the normal seeds. A variety of birds and mammals depend predominantly on fruits to fulfill their nutritional requirements (Zafer Ul-Islam *et al.* 2004). Frugivorous animals also help seeds to escape from the deleterious effects of seed and seedling predators (Janzen 1970). Due to the fact that forest birds are generally more abundant than mammals, birds are expected to move large quantities of seeds from the parent plants.

Although fruit-frugivore interactions with reference to avian frugivory have been studied in different forests of India (Balasubramanian *et al.* 1996; Ganesh and Davidar 2001; Kannan and James 1999; Balasubramanian and Maheswaran 2003a; Somasundaram and Vijayan 2010b; Balasubramanian *et al.* 2011; Aruna *et al.* 2011; David *et al.* 2011; Santhoshkumar and Balasubramanian *et al.* 2011). Information on avian frugivory of shola forests was lacking and hence, the present study investigation was made.

Methodology

Observations on frugivory and seed dispersal

Data on bird feeding was recorded by the activities of birds foraging on fruit-bearing plants. The fruit bearing plants with good visibility for the observer was selected for extended observations. Observations were carried out mostly in the morning, 6 am to 9 am and in the evening between 3 pm to 6 pm, which is the active time for foraging.

Fleshy-fruited plants were selected for the study. It includes plants with fruit types such as drupe, berry and capsule. Feeding behavior such as pecking or swallowing was noted for each bird species. The distance traveled by each avian frugivore to the first perching site after leaving a fruiting tree was noted following Green (1993). Number of fruits consumed per visit was recorded for various bird species. All the observations were carried out using a pair of 7 x 50 binoculars. As doves and parakeets digest seeds, they are considered as seed predators. All the remaining birds were considered seed dispersers.

Contingency Table or Cross-Tab Analysis was used to examine if the visitation rates of frugivorous bird species is strongly associated with the fleshy fruited tree species. We used contingency Table or Cross-Tab Analysis to examine the significant association between the visitation rates of frugivorous bird species to the fleshy fruited plant species.

Efforts were made to find out bird preferred fruit species for different bird species. Preference index (PI) was calculated by using Ivlev's Index of Selectivity (Ivlev 1961), [PI= (U-A)/ (U+A), where U denotes utilization of the species and A denotes availability of corresponding species]. Availability of the fruit tree species was enumerated from one hectare vegetation plot in the study area. Utilization of the species was driven from the number of feeding observations recorded. Values of Preference Index (PI) ranged between -1 and +1. While -1 indicates avoidance, +1 indicates highest preference.

Results

5.2.1 Frugivory and seed dispersal

Bird attracting plant families in Eppanadu shola forest

A total of 28 fleshy fruited species belonging to 24 genera and 21 families was consumed by birds. Lauraceae (4 species) was found to be predominant bird-dispersed family in the Eppanadu shola (Table 8).

Table 8 Avian frugivore attracting plant families in Eppanadu shola

S.No	Plant family	Genera	Species
1	Lauraceae	4	4
2	Ulmaceae	1	2
3	Myrtaceae	1	2
4	Elaeocarpaceae	1	2
5	Vacciniaceae	1	2
6	Rosaceae	1	1
7	Melastomataceae	1	1
8	Flacourtiaceae	1	1
9	Rubiaceae	1	1
10	Oleaceae	1	1
11	Pittosporaceae	1	1
12	Araliaceae	1	1
13	Aquifoliaceae	1	1
14	Caprifoliaceae	1	1
15	Theaceae	1	1
16	Ericaceae	1	1
17	Myrsinaceae	1	1
18	Rutaceae	1	1
19	Berberidaceae	1	1
20	Daphniphyllaceae	1	1
21	Symplocaceae	1	1

Table 9 Percentage proportion of avian visits to different plant families in Eppanadu shola forest

S.No	Plant family	Bird visits	
		#	%
1	Lauraceae	657	13.04
2	Ulmaceae	523	10.38
3	Myrtaceae	358	7.11
4	Elaeocarpaceae	348	6.91
5	Vacciniaceae	319	6.33
6	Rosaceae	269	5.34
7	Melastomataceae	237	4.71
8	Flacourtiaceae	228	4.53
9	Rubiaceae	210	4.17
10	Oleaceae	208	4.13
11	Pittosporaceae	203	4.03
12	Araliaceae	189	3.75
13	Aquifoliaceae	187	3.71
14	Caprifoliaceae	186	3.69
15	Theaceae	169	3.36
16	Ericaceae	162	3.22
17	Myrsinaceae	152	3.02
18	Rutaceae	127	2.52
19	Berberidaceae	124	2.46
20	Daphniphyllaceae	122	2.42
21	Symplocaceae	59	1.17

Among the 21 plant families, large proportion of avian visits was recorded on Lauraceae (13.04% followed by Ulmaceae (10.38%) and Myrtaceae (7.11%) (Table 9), which are found to be the predominant food plant families for avian frugivores in the Eppanadu shola forest.

Bird-dispersed plant species in the Eppanadu shola forest

A total of 28 plant species were consumed by 29 avian frugivores in the Eppanadu shola. Majority of the avian foraging visits was noticed on *Celtis tetrandra* (n=350) followed by

Photinia integrifolia (n=269) and *Actinodaphne bourneae* (n=241), they constituted the major food plants of avian frugivores in the Eppanadu shola (Table 10).

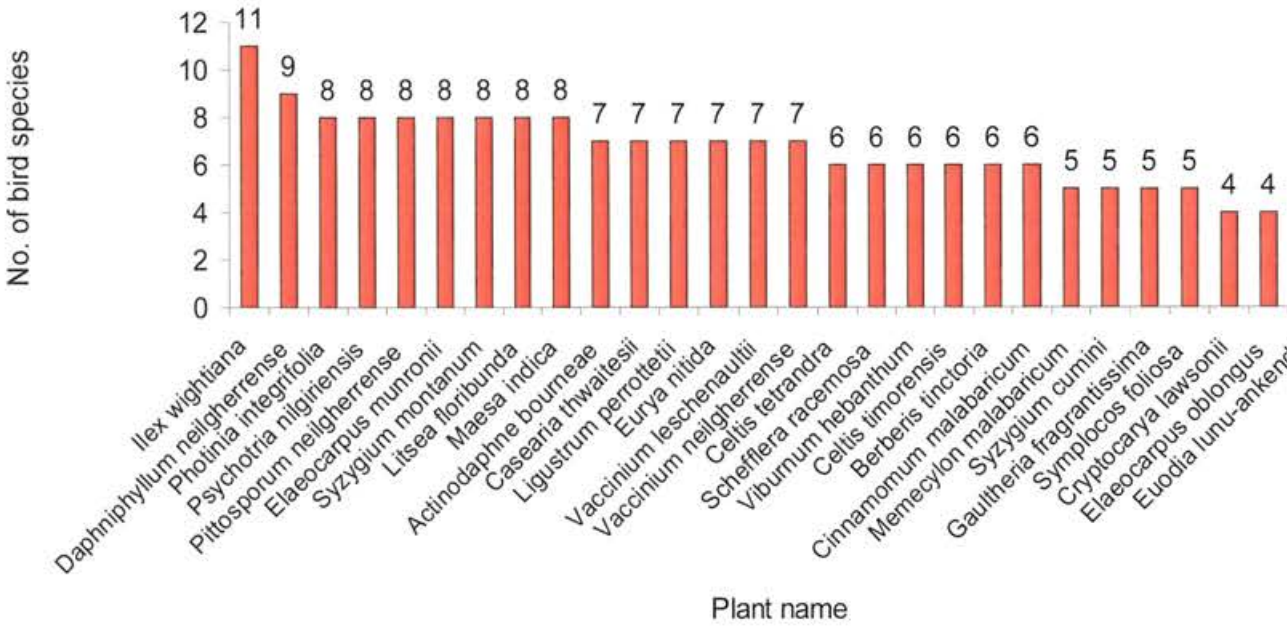
Table 10 Bird-dispersed plant species in the Eppanadu shola forest

S.No	Plant species	# of bird species	Fruit foraging visits	
			#	%
1	*Celtis tetrandra*	6	350	6.95
2	*Photinia integrifolia*	8	269	5.34
3	*Actinodaphne bourneae*	7	241	4.78
4	*Memecylon malabaricum*	5	237	4.71
5	*Casearia thwaitesii*	7	228	4.53
6	*Psychotria nilgiriensis*	8	210	4.17
7	*Ligustrum perrottetii*	7	208	4.13
8	*Pittosporum neilgherrense*	8	203	4.03
9	*Syzygium cumini*	5	200	3.97
10	*Elaeocarpus munronii*	8	192	3.81
11	*Schefflera racemosa*	6	189	3.75
12	*Ilex wightiana*	11	187	3.71
13	*Viburnum hebanthum*	6	186	3.69
14	*Celtis timorensis*	6	173	3.43
15	*Eurya nitida*	7	169	3.36
16	*Vaccinium leschenaultii*	7	164	3.26
17	*Gaultheria fragrantissima*	5	162	3.22
18	*Cryptocarya lawsonii*	4	159	3.16
19	*Syzygium montanum*	8	158	3.14
20	*Elaeocarpus oblongus*	4	156	3.10
21	*Litsea floribunda*	8	156	3.10
22	*Vaccinium neilgherrense*	7	155	3.08
23	*Maesa indica*	8	152	3.02
24	*Euodia lunu-ankenda*	4	127	2.52
25	*Berberis tinctoria*	6	124	2.46
26	*Daphniphyllum neilgherrense*	9	122	2.42
27	*Cinnamomum malabaricum*	6	101	2.01
28	*Symplocos foliosa*	5	59	1.17

Highest number of the frugivore species was attracted by *Ilex wightiana* (n=11) followed by *Daphniphyllum neilgherrense* (n=9) and *Photinia integrifolia, Psychotria nilgiriensis,*

Litsea floribunda, Pittosporum neilgherrense, Elaeocarpus munronii, Maesa indica, Syzygium montanum (n=8 each) (Fig. 8).

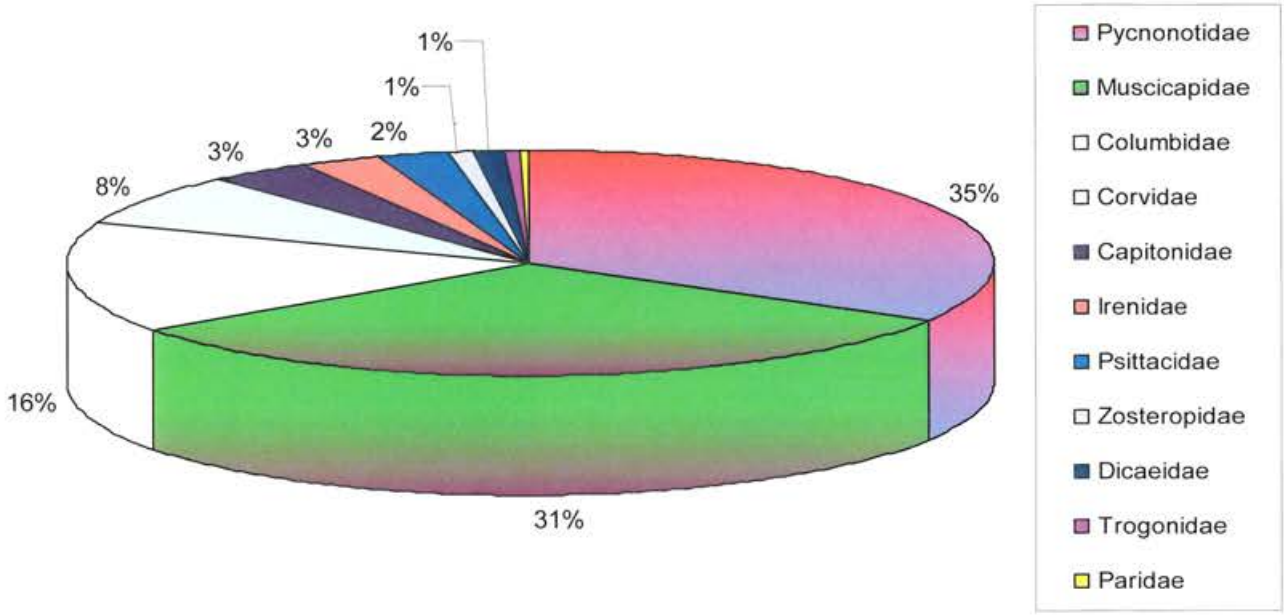
Fig. 8 Number of avian frugivore species recorded on various tree species in Eppanadu shola forest



Avian families in the Eppanadu shola forest

Totally 29 avian frugivore species belonging to 11 families were recorded. Maximum number of avian frugivore species belonged to Muscicapidae (7 species) followed by Pycnonotidae (5 species) and Corvidae, Columbidae (3 species each).

Fig. 9 % proportion of visits by various avian families in the Eppanadu shola forest



Highest proportion of fruit foraging visits was made by Pycnonotidae (35%) followed by Muscicapidae (31%) and Columbidae (16%) (Fig. 9).

Percentage proportion of foraging visits by different bird species in the Eppanadu shola

A total of 28 tree species were studied for avian frugivore visitation. Totally, 5034 individuals belonging to 29 species of avian frugivores were recorded. Maximum number of visits were made by Red-whiskered Bulbul (n=1068) followed by Nilgiri Laughingthrush (n=682) and Nilgiri Wood-pigeon (n=527) (Table 11). Red-whiskered Bulbul visited the highest number of species (26) followed by Nilgiri Wood-pigeon (18) and Nilgiri Laughingthrush (16). Bulbuls, thrushes, pigeons formed the major avian frugivores in the Eppanadu shola forest.

Table 11. Percentage proportion of foraging visits by different bird species

(Data based on 1344 hrs of observation on 28 plant species)

S.No	Common Name of the bird	# of plant species visited	Fruit foraging visits	
			#	%
1	Red-whiskered Bulbul	26	1068	21.20
2	Nilgiri Laughingthrush	16	682	13.54
3	Nilgiri Wood-pigeon	18	527	10.46
4	Blackbird	15	505	10.03
5	Jungle Myna	8	273	5.42
6	Jungle Crow	4	179	3.55
7	Wynaad Laughingthrush	4	179	3.55
8	White-cheeked Barbet	8	173	3.43
9	Black Bulbul	11	166	3.30
10	House Crow	4	150	2.98
11	Spotted Dove	9	149	2.96
12	Asian Fairy-bluebird	7	146	2.90
13	Malabar Whistling-thrush	8	133	2.64
14	Mountain Imperial-pigeon	9	117	2.32
15	Red-vented Bulbul	3	101	2.01
16	Blue-winged Parakeet	4	86	1.71
17	Yellow-browed Bulbul	5	76	1.51
18	Indian Scimitar-babbler	6	57	1.13
19	White-bellied Treepie	2	55	1.09
20	Oriental White-eye	3	52	1.03
21	Indian Hanging-parrot	3	36	0.71
22	Thick-billed Flowerpecker	3	32	0.64
23	Malabar Trogon	1	22	0.44
24	Tickell's Flowerpecker	1	19	0.38
25	Verditer Flycatcher	3	14	0.28
26	Grey-headed Bulbul	2	12	0.24
27	Great Tit	2	10	0.20
28	Quaker Tit-babbler	1	10	0.20
29	Yellow-cheeked Tit	1	8	0.16

Pigeons, bulbuls, thrushes are found to be the major avian frugivores in the shola forest.

Some common avian frugivores in the Eppanadu shola

PLATE -12

Red-whiskered Bulbul

Oriental White-eye

PLATE-13

Jungle Crow

Verditer Flycatcher

Avian frugivore preferred fruit species in Eppanadu shola forest

The results of Ivlev's Preference Index (PI) showed that *Photinia integrifolia* (PI=0.92) was the most preferred fruit species for the avian frugivores. This was followed by *Casearia thwaitesii* (PI=0.91) and *Pittosporum neilgherrense* and *Psychotria nilgiriensis* (PI=0.90) (Table 12).

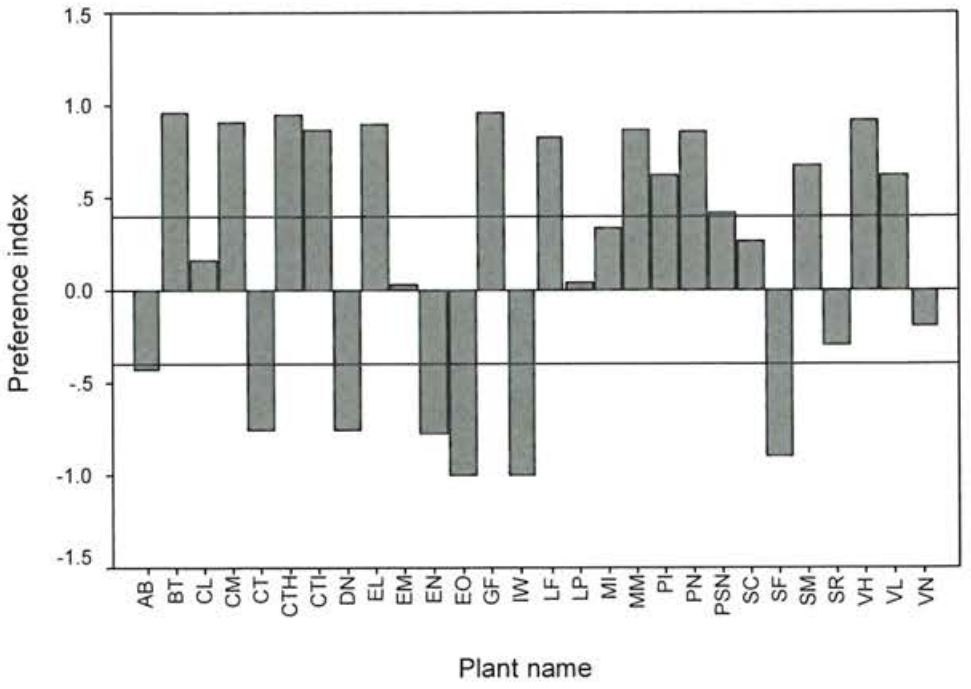
Table 12 Preference index (PI) of different fruit species consumed by birds in Eppanadu shola

S.No	Name of the food plant species	PI = U-A/U+A
1	*Actinodaphne bourneae*	-0.46
2	*Berberis tinctoria*	0.84
3	*Casearia thwaitesii*	0.91
4	*Celtis tetrandra*	-0.61
5	*Celtis timorensis*	0.68
6	*Cinnamomum malabaricum*	0.80
7	*Cryptocarya lawsonii*	-0.23
8	*Daphniphyllum neilgherrense*	-0.53
9	*Elaeocarpus munronii*	0.08
10	*Elaeocarpus oblongus*	-0.36
11	*Euodia-lunuankenda*	0.70
12	*Eurya nitida*	0.88
13	*Gaultheria fragrantissima*	0.87
14	*Ilex wightiana*	0.89
15	*Ligustrum perrottetii*	0.22
16	*Litsea floribunda*	0.87
17	*Maesa indica*	0.11
18	*Memecylon malabaricum*	0.62
19	*Photinia integrifolia*	0.92
20	*Pittosporum neilgherrense*	0.90
21	*Psychotria nilgiriensis*	0.90
22	*Schefflera racemosa*	0.01
23	*Symplocos foliosa*	-0.69
24	*Syzygium cumini*	0.20
25	*Syzygium montanum*	0.28
26	*Vaccinium neilgherrense*	-0.49
27	*Vaccinium leschenaultii*	0.28
28	*Viburnum hebanthum*	0.89

Red-whiskered Bulbul

Red-whiskered Bulbul consumed 26 fruit species in the Eppanadu shola. Four species namely, *Berberis tinctoria, Gaultheria fragrantissima* (PI=0.96), followed by *Casearia thwaitesii* (PI=0.95) and *Viburnum hebanthum* (PI=0.92) were highly preferred by Red-whiskered Bulbul (Fig. 10).

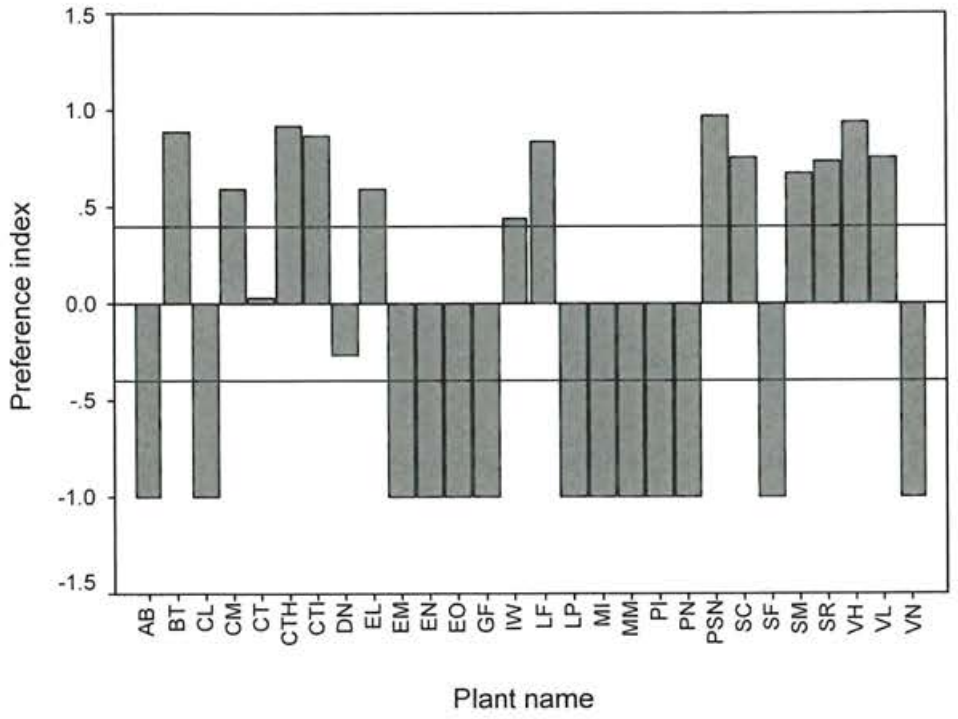
Fig. 10 Fruit species preference by Red-whiskered Bulbul



Blackbird

Blackbird consumed 14 fruit species in the Eppanadu shola. *Psychotria neilgherrense* (PI=0.97) followed by *Viburnum hebanthum* (PI=0.94) and *Casearia thwaitesii* (PI=0.92) were highly preferred by Blackbird (Fig.11).

Fig. 11 Fruit species preference by Blackbird



Nilgiri Laughingthrush

Nilgiri Laughingthrush consumed 16 fruit species in the Eppanadu shola. Its highly preferred fruits were *Litsea floribunda* (PI=0.97) followed by *Pittosporum neilgherrense* (PI=0.96) and *Psychotria nilgiriensis* (PI=0.94) (Fig. 12).

Fig. 12 Fruit species preference by Nilgiri Laughingthrush

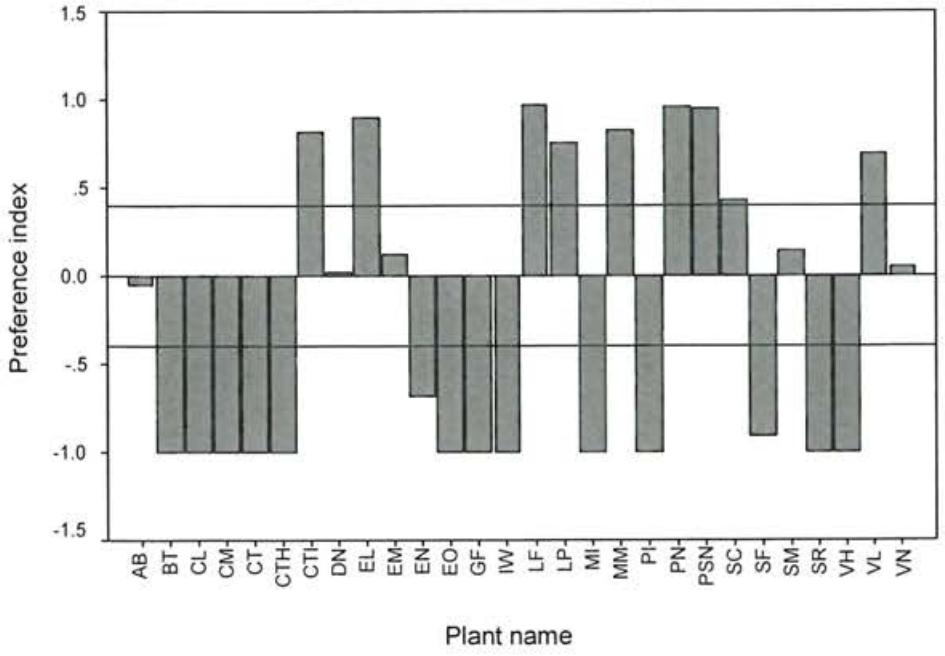


PLATE-14

House Crow

Spotted Dove

PLATE- 15

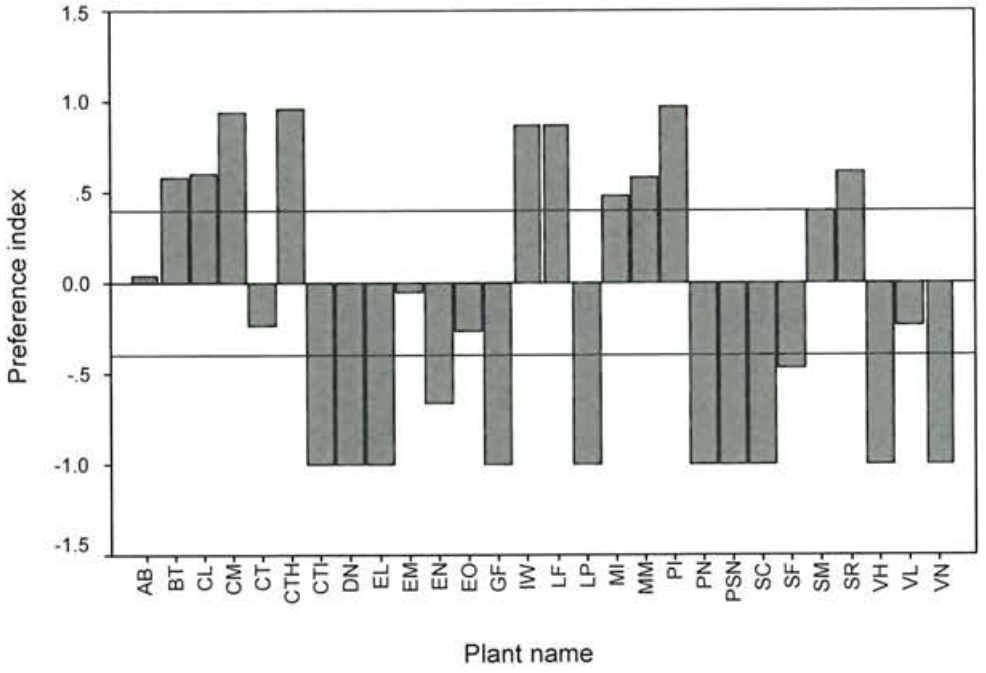
Nilgiri Wood-pigeon

Jungle Myna

Nilgiri Wood-pigeon

NIlgiri Wood-pigeon consumed 18 fruit species in the Eppanadu shola. It's highly preferred fruit species were *Photinia integrifolia* (PI=0.97) followed by *Casearia thwaitesii* (PI=0.96) and *Cinnamomum malabaricum* (PI=0.94) (Fig. 13).

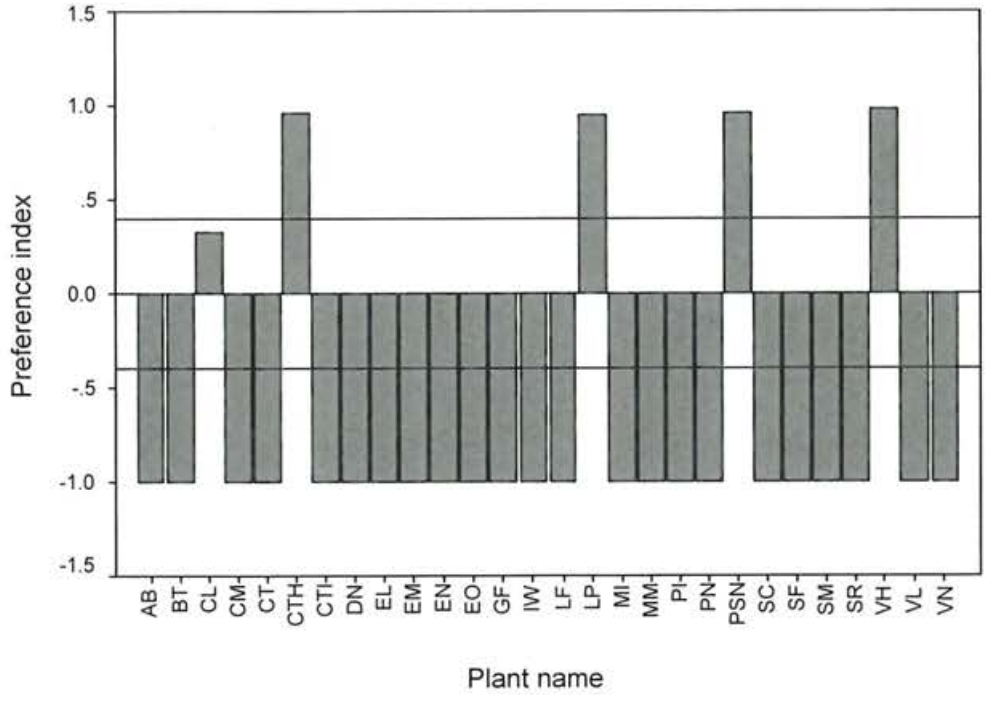
Fig. 13 Fruit species preference by Nilgiri Wood-pigeon



Yellow-browed Bulbul

Yellow-browed Bulbul consumed four fruit species in the Eppanadu shola. *Viburnum hebanthum* (PI=0.98) followed by *Casearia thwaitesii, Psychotria nilgiriensis* (PI=0.96) and *Ligustrum perrottetii* (PI=0.95) formed the highly preferred fruit species of Yellow-browed Bulbul (Fig. 14).

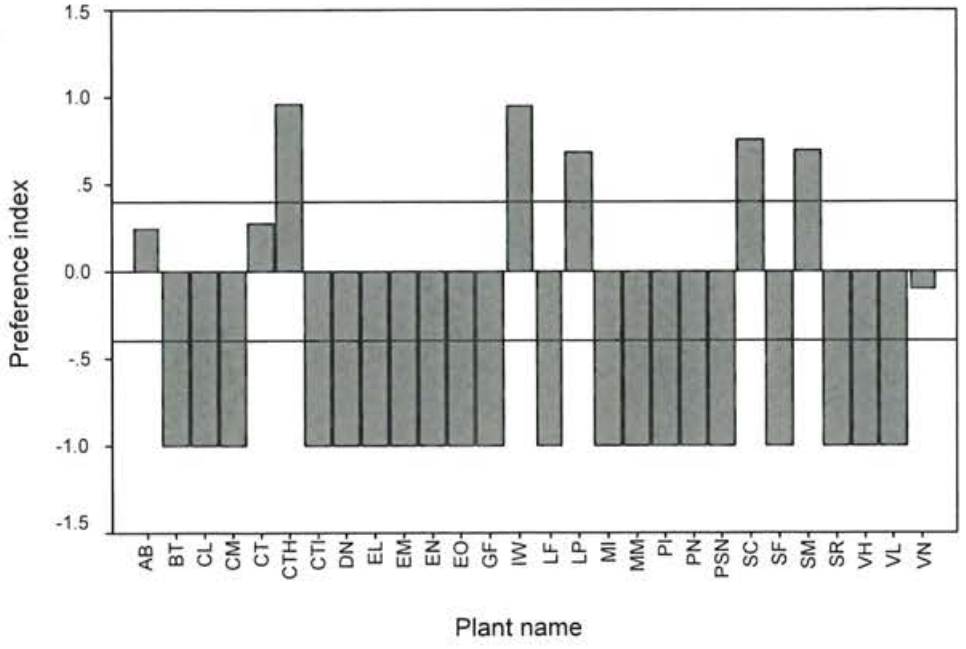
Fig. 14 Fruit species preference by Yellow-browed Bulbul



Jungle Myna

Jungle Myna consumed eight fruit species in the Eppanadu shola. *Casearia thwaitesii* (PI=0.96) followed by *Ilex wightiana* (PI=0.95) and *Syzygium cumini* (PI=0.76) were preferred by Jungle Myna (Fig. 15).

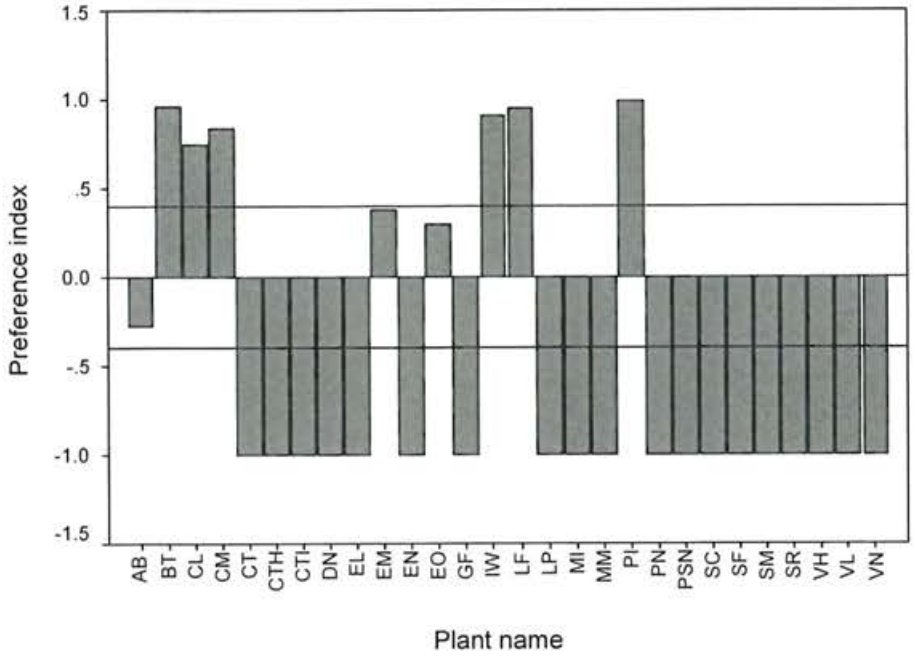
Fig. 15 Fruit species preference by of Jungle Myna



Mountain Imperial-pigeon

Mountain Imperial-pigeon consumed nine fruit species in the Eppanadu shola. *Photinia integrifolia* (PI=0.99) followed by *Berberis tinctoria* (PI=0.96) and *Litsea floribunda* (PI=0.95) were highly preferred by Mountain Imperial-pigeon (Fig.16).

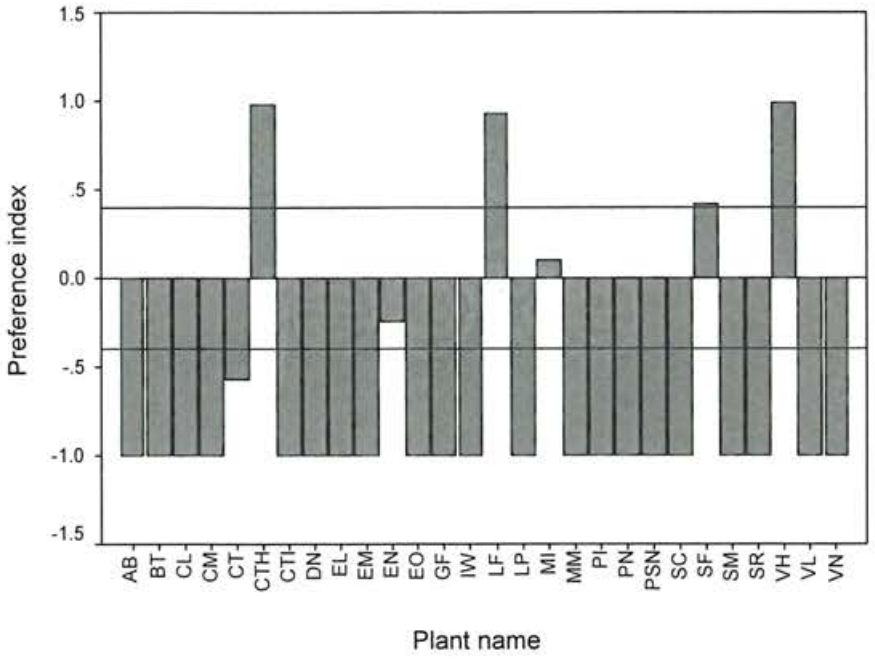
Fig. 16 Fruit species preference by Mountain Imperial-pigeon



Asian Fairy-bluebird

Asian Fairy-bluebird consumed seven fruit species in the Eppanadu shola. Its highly preferred fruit species were *Viburnum hebanthum* (PI=0.99), *Casearia thwaitesii* (PI=0.98) and *Litsea floribunda* (PI=0.93) (Fig. 17).

Fig. 17 Fruit species preference by Asian Fairy-bluebird



LONGWOOD SHOLA

Bird attracting plant families in the Longwood shola

A total of 26 fleshy fruited species belonging to 23 genera and 20 families were found to be bird-dispersed. Lauraceae (4 species) was found to be the predominant family (Table 13).

Table 13 Avian frugivore attracting plant families in the Longwood shola forest

S.No	Plant family	Genera	Species
1	Oleaceae	2	2
2	Sapotaceae	1	1
3	Lauraceae	3	4
4	Daphniphyllaceae	1	1
5	Aquifoliaceae	1	1
6	Symplocaceae	1	1
7	Magnoliaceae	1	2
8	Myrtaceae	1	2
9	Myrsinaceae	1	1
10	Caprifoliaceae	1	1
11	Euphorbiaceae	1	1
12	Theaceae	1	1
13	Icacinaceae	1	1
14	Vacciniaceae	1	1
15	Ternstroemiaceae	1	1
16	Elaeocarpaceae	1	1
17	Staphyleaceae	1	1
18	Berberidaceae	1	1
19	Rubiaceae	1	1
20	Celastraceae	1	1

The favored plant families for the avian frugivores were observed. Majority (31%) of the fruit foraging visits was made on Oleaceae (*Ligustrum perrottetii, Olea paniculata*) followed by Sapotaceae (*Isonandra perrottetiana*) and Lauraceae (*Cinnamomum wightii, Litsea wightiana, Neolitsea scrobiculata, Neolitsea zeylanica*).

Table 14 Percentage proportion of avian visits to different plant families in the Longwood shola forest

S.No	Plant family	Fruit foraging visits	
		#	%
1	Lauraceae	628	11.01
2	Oleaceae	606	10.63
3	Sapotaceae	522	9.15
4	Daphniphyllaceae	490	8.59
5	Aquifoliaceae	416	7.30
6	Symplocaceae	310	5.44
7	Magnoliaceae	278	4.88
8	Myrtaceae	264	4.63
9	Myrsinaceae	248	4.35
10	Caprifoliaceae	221	3.88
11	Euphorbiaceae	214	3.75
12	Theaceae	200	3.51
13	Icacinaceae	184	3.23
14	Vacciniaceae	183	3.21
15	Ternstroemiaceae	178	3.12
16	Elaeocarpaceae	177	3.10
17	Staphyleaceae	174	3.05
18	Berberidaceae	144	2.53
19	Rubiaceae	140	2.46
20	Celastraceae	125	2.19

Large proportion of avian frugivore visits was recorded on Lauraceae (n=11.01 %) followed by Oleaceae (n=10.63%) and Sapotaceae (9.15%) (Table 14).

Bird attracting plants in the Longwood shola

Highest number of avian frugivore visits were recorded on *Isonandra perrottetiana* (n=522) followed by *Daphniphyllum neilgherrense* (n=490) and *Ligstrum perrottetii* (n=454) (Table 15).

Table 15 Bird-dispersed plant species in the Longwood shola forest

S.No	Plant species	# of bird species	Fruit foraging visits	
			#	%
1	*Isonandra perrottetiana*	17	522	9.15
2	*Daphniphyllum neilgherrense*	9	490	8.59
3	*Ligustrum perrottetii*	7	454	7.96
4	*Ilex wightiana*	10	416	7.30
5	*Symplocos cochinchinensis*	5	310	5.44
6	*Myrsine wightiana*	11	248	4.35
7	*Viburnum punctatum*	6	221	3.88
8	*Glochidion neilgherrense*	6	214	3.75
9	*Neolitsea zeylanica*	5	208	3.65
10	*Michelia nilagirica*	8	207	3.63
11	*Eurya nitida*	6	200	3.51
12	*Nothapodytes nimmoniana*	6	184	3.23
13	*Vaccinium neilgherrense*	4	183	3.21
14	*Litsea wightiana*	7	181	3.17
15	*Ternstroemia japonica*	5	178	3.12
16	*Elaeocarpus oblongus*	4	177	3.10
17	*Turpinia nepalensis*	5	174	3.05
18	*Olea paniculata*	9	152	2.67
19	*Syzygium arnottianum*	7	147	2.58
20	*Mahonia leschenaultii*	6	144	2.53
21	*Ixora notoniana*	8	140	2.46
22	*Neolitsea scrobiculata*	4	131	2.30
23	*Microtropis densiflora*	6	125	2.19
24	*Syzygium montanum*	9	117	2.05
25	*Cinnamomum wightii*	5	108	1.89
26	*Michelia champaca*	5	71	1.25

Huge number of avian species were attracted by *Isonandra perrottetiana* (n=17) followed by *Myrsine wightiana* (n=11) and *Ilex wightiana* (n=10) (Fig. 18).

Bird-dispersed Plant species in the Longwood shola forest

PLATE- 16

Litsea wightiana

Ilex wightiana

PLATE-17

Michelia champaca

Daphniphyllum neilgherrense

PLATE-18

Michelia nilagirica

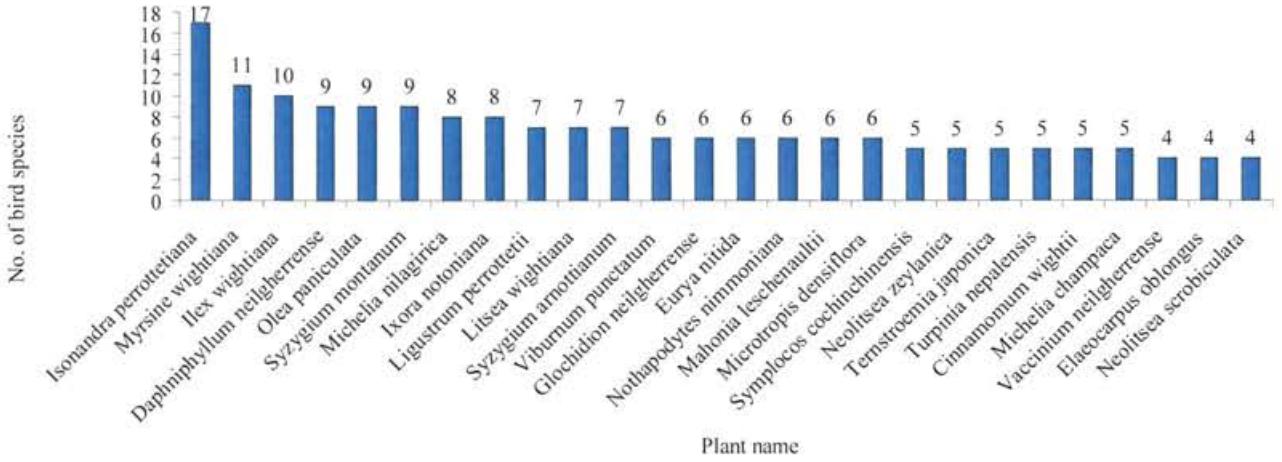
Microtropis densiflora

PLATE-19

Ligustrum perrottetii

Nothapodytes nimmoniana

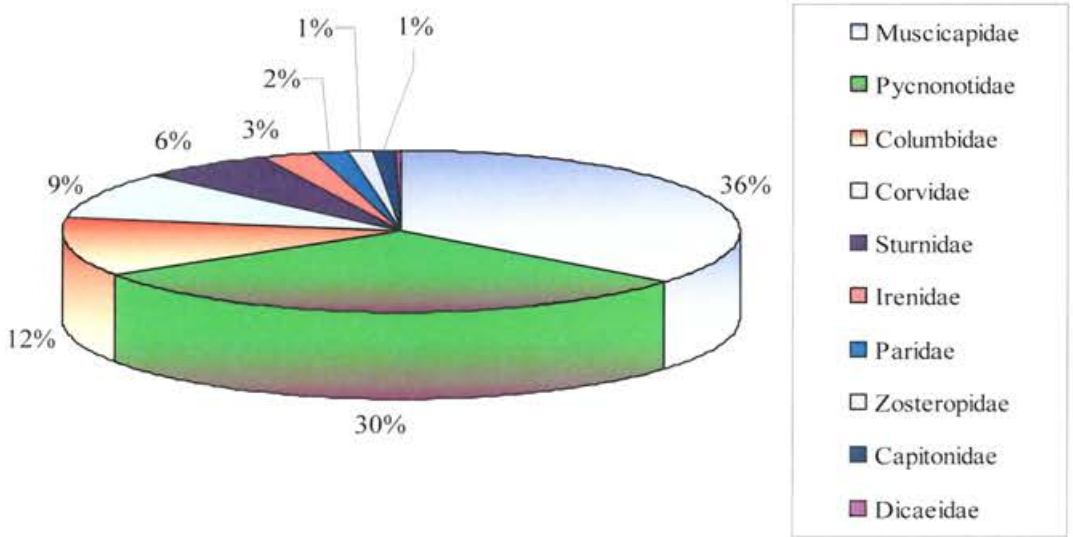
Fig. 18 Number of avian frugivore species recorded on various tree species in the Longwood shola



Avian frugivore families in the Longwood shola forest

Totally 27 avian frugivore species belonging to 10 families were recorded. Maximum number of avian frugivore species belonged to Muscicapidae (8 species) followed by Pycnonotidae (5 species) and Corvidae, Columbidae (3 species each).

Fig. 19 % proportion of visits by various avian families in the Longwood shola



Large proportion of fruit foraging visits were made by Muscicapidae (36%) followed by Pycnonotidae (30%) and Columbidae (12%) (Fig. 19).

FRUGIVORY AND SEED DISPERSAL

In total, 26 tree species were observed for avian frugivore visitation. A total of 27 species of birds consumed fruits. Maximum number of fruit feeding visits were observed for Nilgiri Laughingthrush (n=1233) followed by Red-whiskered Bulbul (n=886) and Blackbird (n=557). Bulbuls and thrushes are found to be the major frugivores in the shola forest (Table 16).

Table 16. Percentage proportion of foraging visits by different bird species

(Data based on 1248 hrs of extended feeding watches on 26 plant species)

S.No	Bird species	# of tree species visited	Fruit foraging visits	
			#	%
1	Nilgiri Laughingthrush	22	1233	21.62
2	Red-whiskered Bulbul	23	886	15.54
3	Blackbird	17	557	9.77
4	Spotted Dove	12	364	6.38
5	Jungle Myna	8	360	6.31
6	Jungle Crow	3	356	6.24
7	Black Bulbul	13	350	6.14
8	Yellow-browed Bulbul	12	269	4.72
9	Nilgiri Wood-pigeon	9	229	4.02
10	House Crow	2	161	2.82
11	Asian Fairy-bluebird	9	132	2.31
12	Red-vented Bulbul	2	116	2.03
13	Jungle Babbler	3	101	1.77
14	Grey-headed Bulbul	7	93	1.63
15	Great Tit	4	88	1.54
16	Mountain Imperial-pigeon	6	82	1.44
17	Oriental White-eye	1	71	1.25
18	Indian Scimitar-babbler	4	69	1.21
19	White-cheeked Barbet	5	66	1.16

20	Malabar Whistling-thrush	5	27	0.47
21	Verditer Flycatcher	3	24	0.42
22	Quaker Tit-babbler	3	19	0.33
23	White-bellied Treepie	3	18	0.32
24	Common Iora	2	13	0.23
25	Thick-billed Flowerpecker	1	8	0.14
26	Wynaad Laughingthrush	1	8	0.14
27	Nilgiri Flowerpecker	2	2	0.04

Nilgiri Laughingthrush (22 species) and Red-whiskered Bulbul (23 species) visited large number of plant species in the shola forest.

Ivlev's Preference index of dominant bird species in the Longwood shola

Ivlev's preference index (PI) values indicate that *Viburnum punctatu*m (PI=0.89) was the most preferred fruit species for avian frugivores followed by *Ternstroemia japonica, Litsea wightiana* (PI=0.86) and *Olea paniculata* (PI=0.84) (Table 17).

Some common avian frugivores in the Longwood shola

PLATE – 20

Nilgiri Laughingthrush

Red-whiskered Bulbul

PLATE-21

Oriental White-eye

Great Tit

Table 17 Preference Index (PI) of different fruit species consumed by birds in the Longwood shola forest

S.No	Name of the plant	PI
1	*Cinnamomum wightii*	0.24
2	*Daphniphyllum neilgherrense*	0.40
3	*Elaeocarpus oblongus*	-0.74
4	*Eurya nitida*	-0.08
5	*Glochidion neilgherrense*	-0.36
6	*Ilex wightiana*	0.52
7	*Isonandra perrottetiana*	0.08
8	*Ixora notoniana*	-0.50
9	*Ligustrum perrottetii*	0.42
10	*Litsea wightiana*	0.86
11	*Mahonia leschenaultii*	0.00
12	*Michelia champaca*	0.69
13	*Michelia nilagirica*	0.45
14	*Microtropis densiflora*	0.15
15	*Myrsine wightiana*	-0.12
16	*Neolitsea scrobiculata*	-0.43
17	*Neolitsea zeylanica*	0.28
18	*Nothapodytes nimmoniana*	-0.18
19	*Olea paniculata*	0.84
20	*Symplocos cochinchinensis*	-0.01
21	*Syzygium densiflorum*	-0.11
22	*Syzygium montanum*	-0.28
23	*Ternstroemia japonica*	0.86
24	*Turpinia nepalensis*	0.09
25	*Vaccinium neilgherrense*	0.21
26	*Viburnum punctatum*	0.89

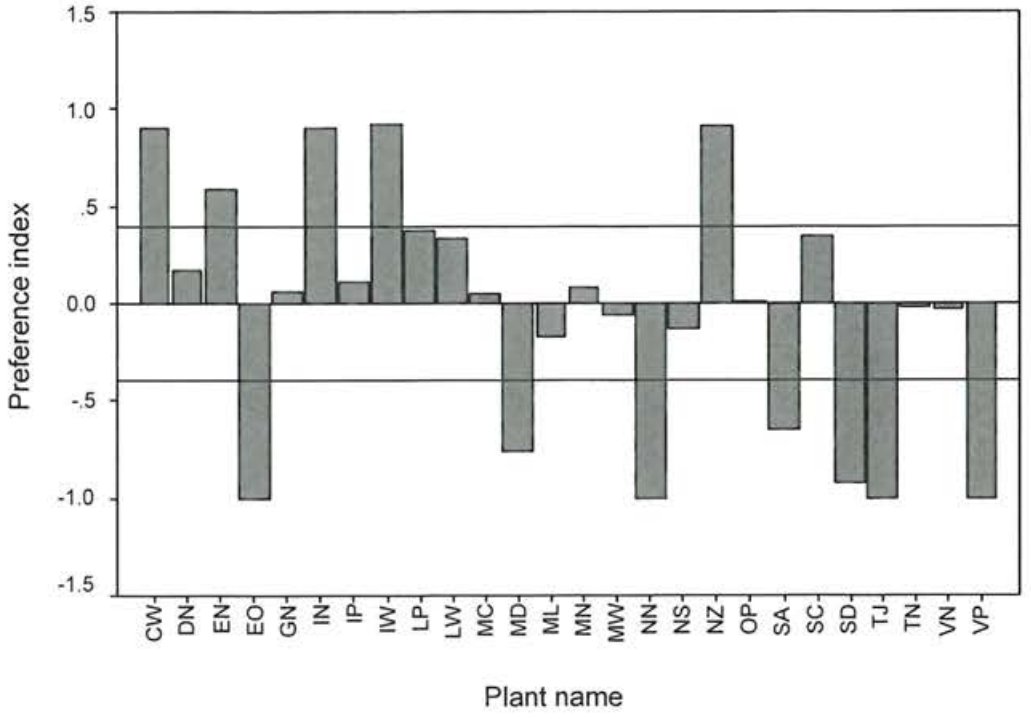
Bird-wise preference index of food plants in the Longwood shola

A total of eight bird species were examined for evaluating their food preferences in the Longwood shola forest.

Nilgiri Laughingthrush

Nilgiri Laughingthrush consumed 22 fruit species in the Longwood shola. Four species namely, *Ilex wightiana* (PI=0.92) followed by *Neolitsea zeylanica* (PI=0.91) and *Celtis wightii* (PI=0.90), *Ixora notoniana* (PI=0.90) were highly preferred by the Nilgiri Laughingthrush (Fig. 20).

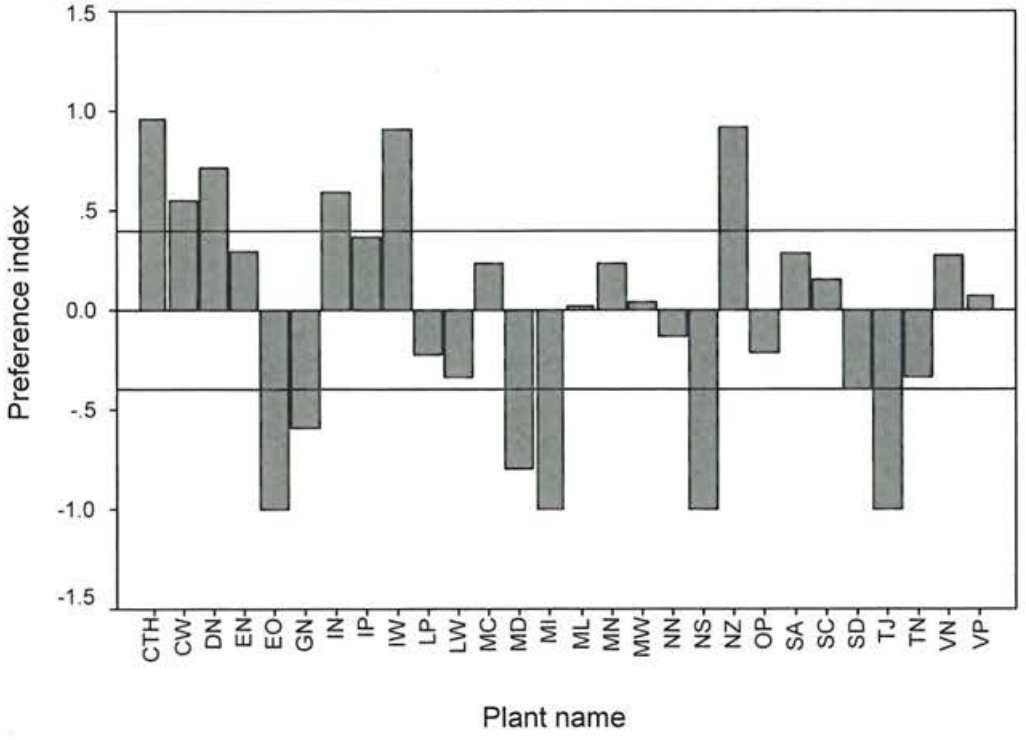
Fig. 20 Fruit species preference by Nilgiri Laughingthrush



Red-whiskered Bulbul

Red-whiskered Bulbul consumed 24 fruit species. Three species namely, *Neolitsea zeylanica* (PI=0.92) followed by *Ilex wightiana* (PI=0.91) and *Daphniphyllum neilgherrense* (n= 0.71) were highly preferred by the Red-whiskered Bulbul (Fig. 21).

Fig. 21 Fruit species preference by Red-whiskered Bulbul



Blackbird

Seventeen tree species were consumed by Blackbird. *Ternstroemia japonica* (PI= 0.96) followed by *Ligustrum perrottetii* (PI=0.77) and *Viburnum punctatum* (PI=0.59) were the highly preferred fruit species (Fig. 22).

Fig. 22 Fruit species preference by Blackbird

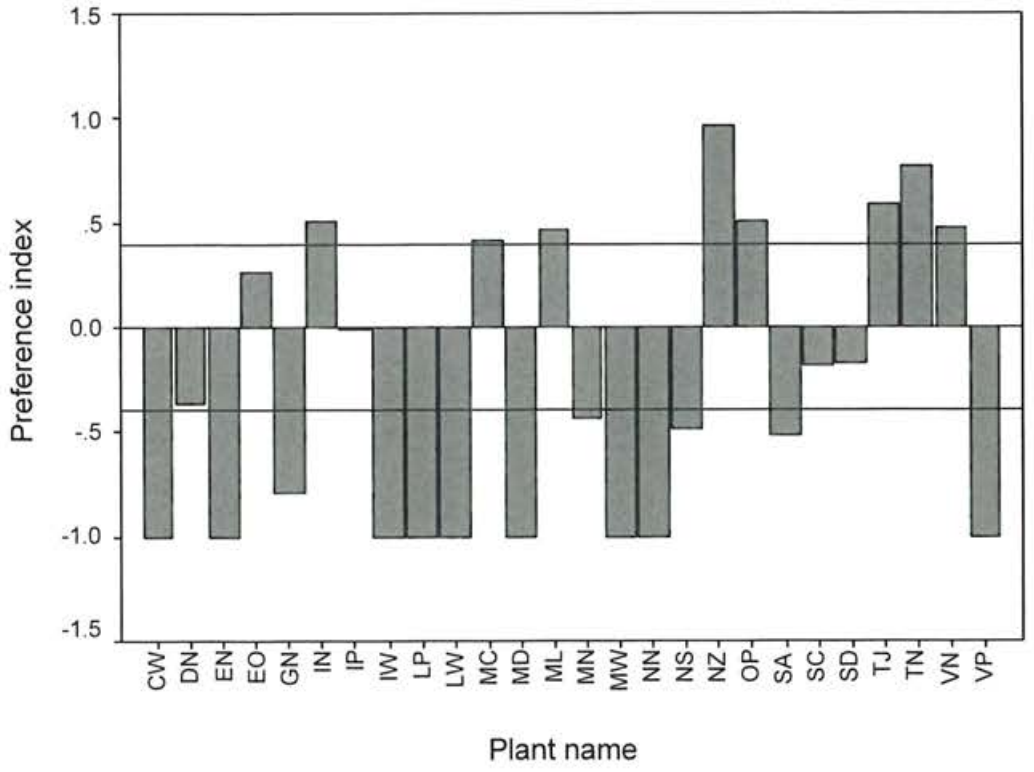


PLATE-22

Nilgiri Wood-pigeon

Quaker Tit-babbler

PLATE-23

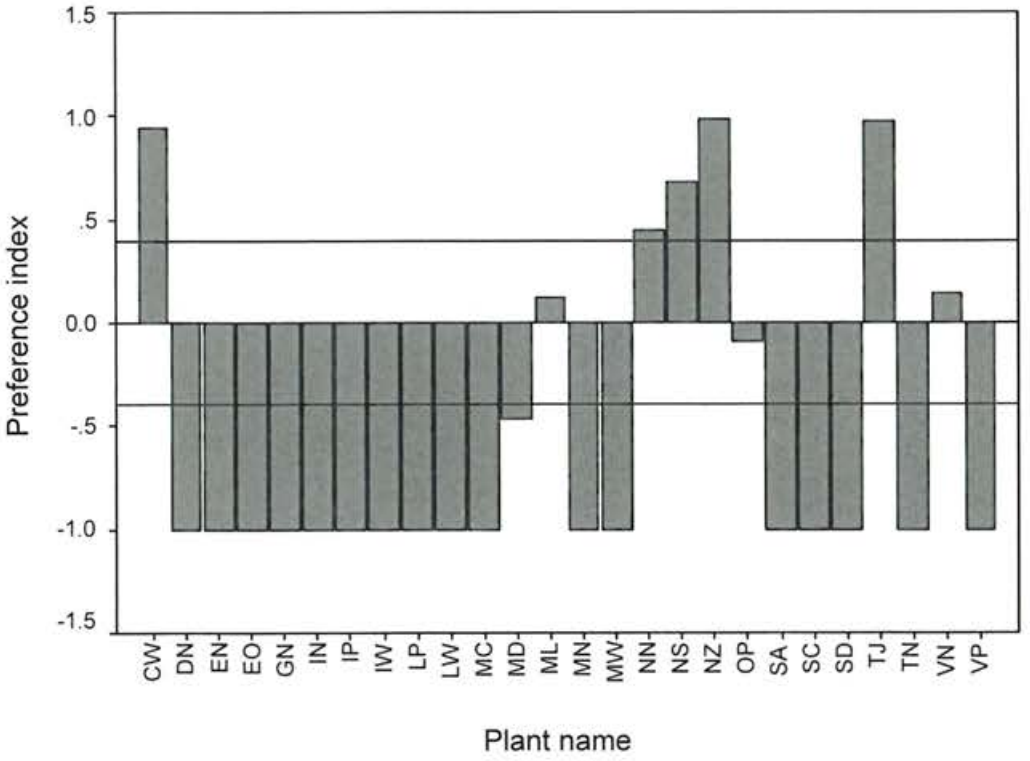
Black Bulbul

Asian Fairy-bluebird

Nilgiri Wood-pigeon

Nilgiri Wood-pigeon foraging on nine fruit species. *Ternstroemia japonica* (PI=0.98) followed by *Viburnum punctatum* (PI=0.97) and *Olea paniculata* (PI=0.94) constituted the highly preferred fruit species (Fig. 23).

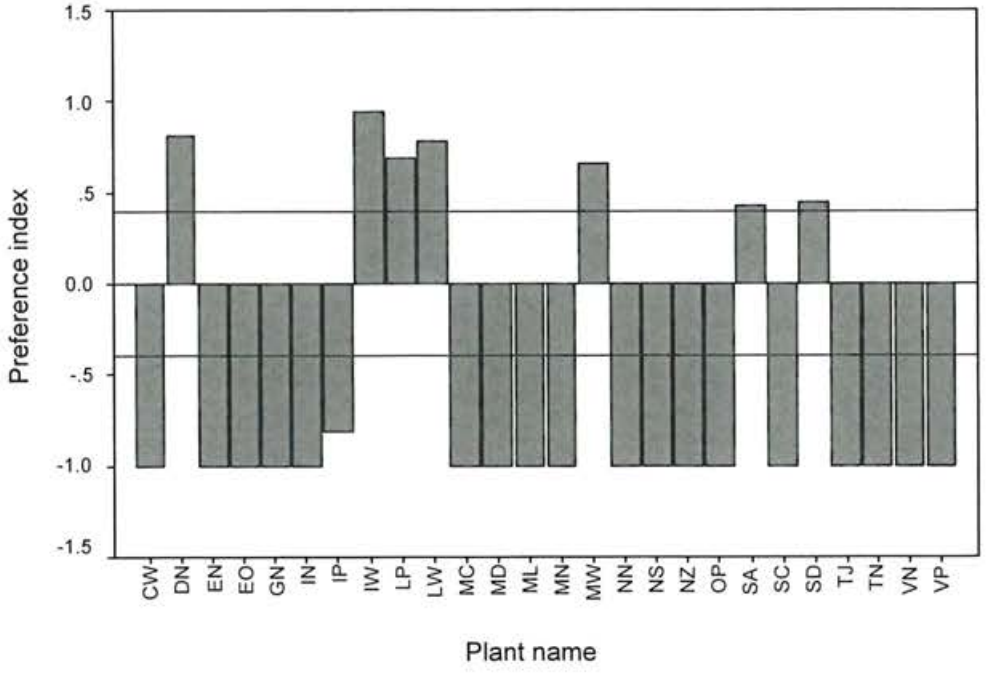
Fig. 23 Fruit species preference by Nilgiri Wood-pigeon



Jungle Myna

Jungle Myna visited eight fruit species. *Michelia champaca* (PI=0.94) followed by *Mahonica leschenaultii* (PI=0.78) and *Cinnamomum wightii* (PI=0.81) formed the highly preferred fruit species (Fig. 24).

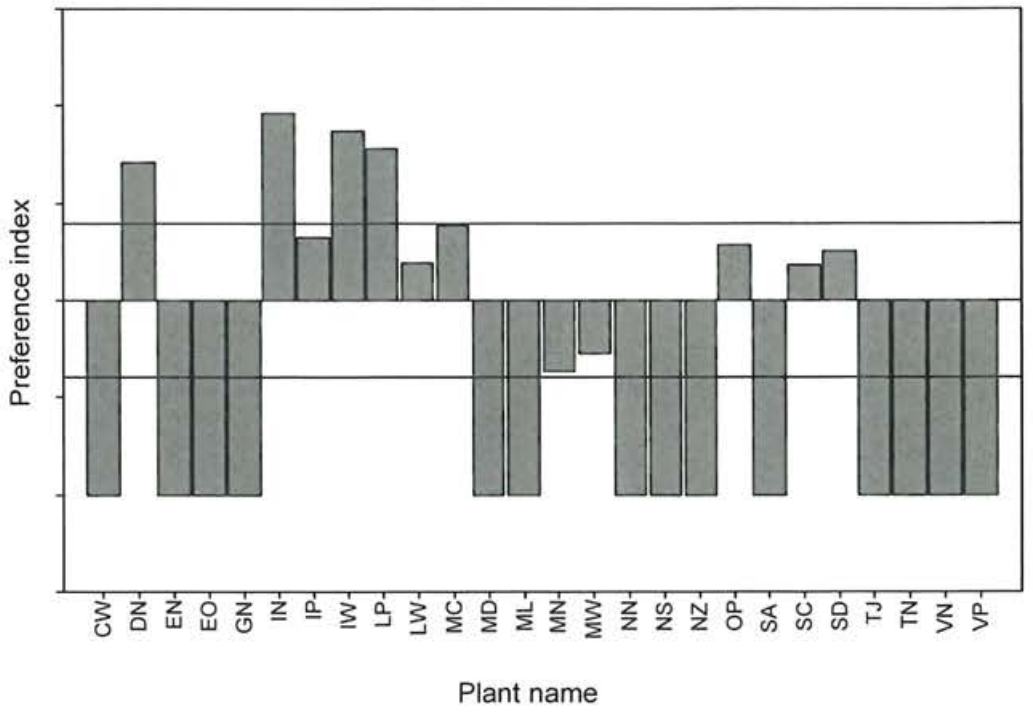
Fig. 24 Fruit species preference by Jungle Myna



Yellow-browed Bulbul

Yellow-browed Bulbul consumed 12 fruit species. *Litsea wightiana* (PI=0.96) followed by *Michelia champaca* (PI=0.87) and *Daphniphyllum neilgherrense* (PI=0.78) formed the highly preferred fruit species (Fig. 25).

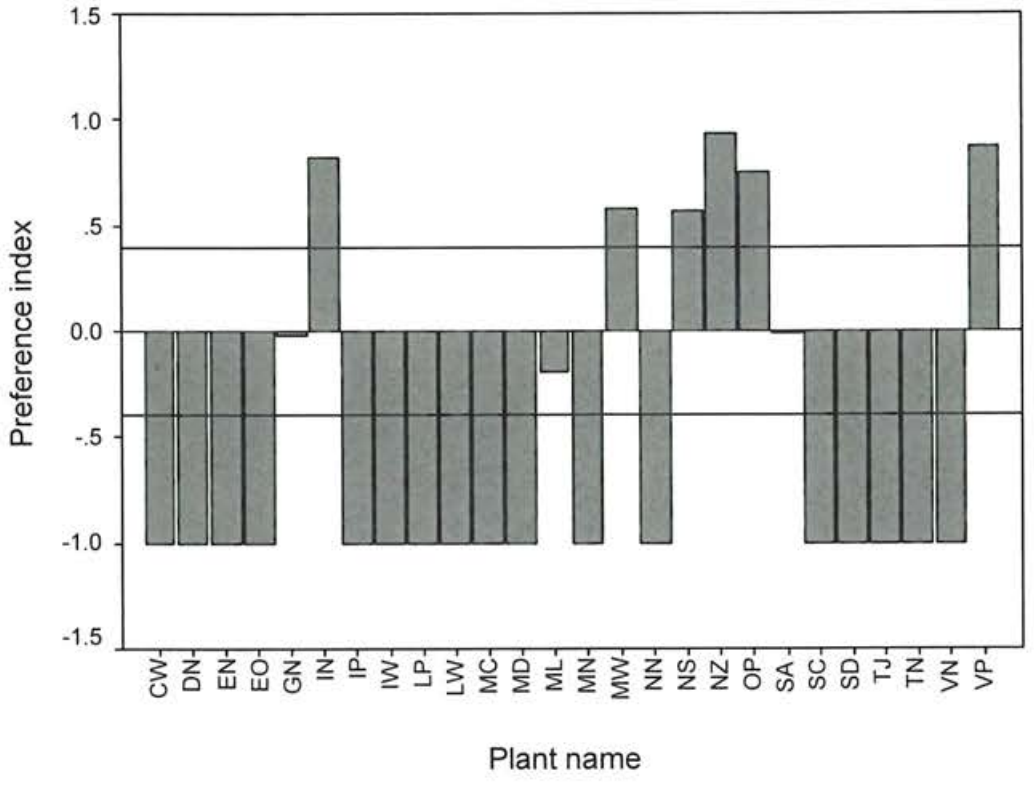
Fig. 25 Fruit species preference by Yellow-browed Bulbul



Asian Fairy-bluebird

Asian Fairy-bluebird consumed nine fruit species. *Ternstroemia japonica* (PI=0.93) followed by *Turpinia nepalensis* (PI=0.87) and *Litsea wightiana* (PI=0.82) were highly preferred by the Asian Fairy-bluebird (Fig. 26)

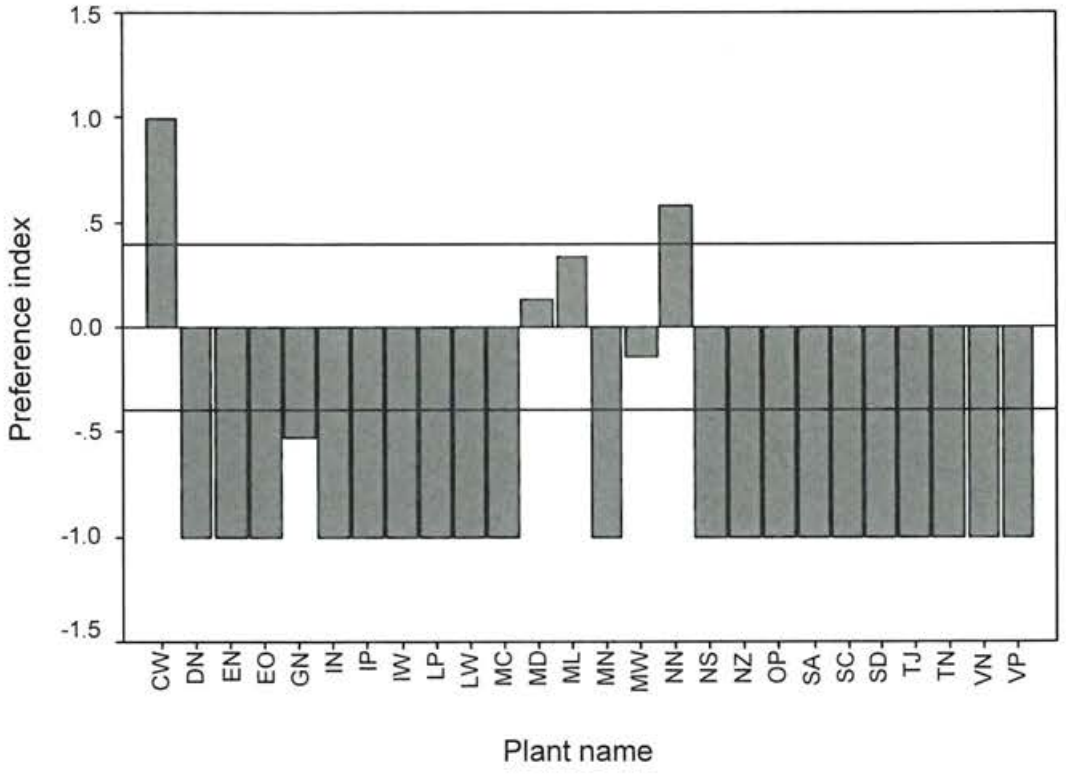
Fig. 26 Fruit species preference by Asian Fairy-bluebird



Mountain Imperial-pigeon

Mountain Imperial-pigeon consumed nine fruit species. *Olea paniculata* (PI=0.99) followed by *Neolitsea scrobiculata* (PI=0.58) and *Symplocos cochinchinensis* (PI=0.33) were highly preferred by Mountain Imperial-pigeon (Fig. 27)

Fig. 27 Fruit species preference by Mountain Imperial-pigeon



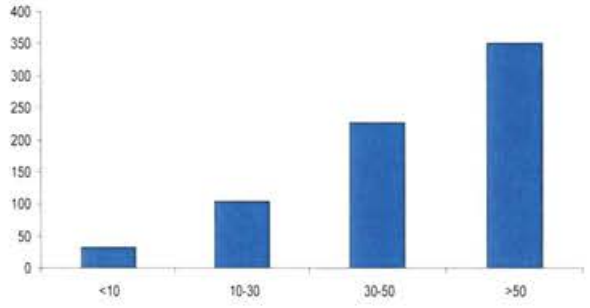
5.2.2 Distance traveled by avian frugivores after fruit consumption

Distance traveled by some major avian frugivores in the shola forests

The distance a bird traveled after leaving a fruiting tree was recorded as the distance to the first perching site. Hence, the distances shown in figure 6 serve as indicators of relative distances traveled by each species rather than actual distances of seed dispersal. This helps us to know which bird species to a plant species has moved the seeds farthest from the parent plant. Twenty eight avian frugivore species were recorded from 15 plant species in the shola forests. Among them thrushes, bulbuls, blue-bird, mynas dispersed seeds to longer distances (>50 m) (Fig. 28).

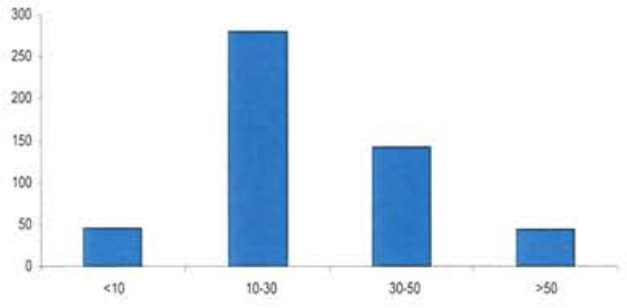
Fig. 28 Distance traveled by some avian frugivores after consuming fruits at the food tree (in metres)

Nilgiri Laughingthrush (n=711)



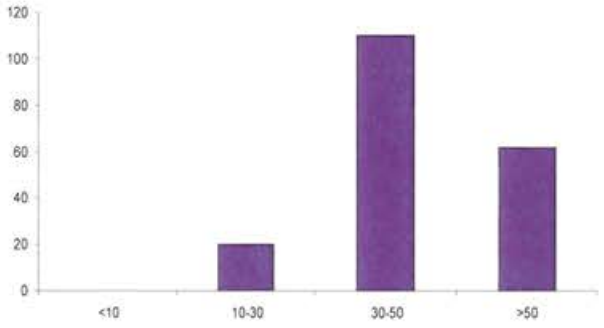
(in metres)

Red-whiskered Bulbul (n=506)



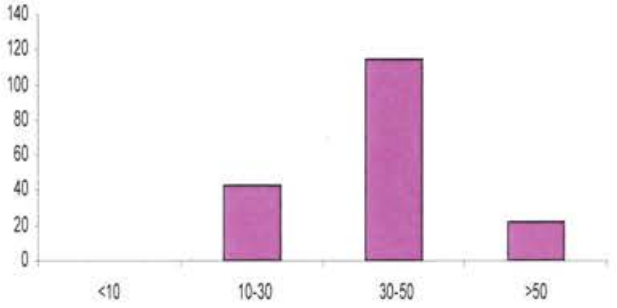
(in metres)

Jungle Myna (n=192)



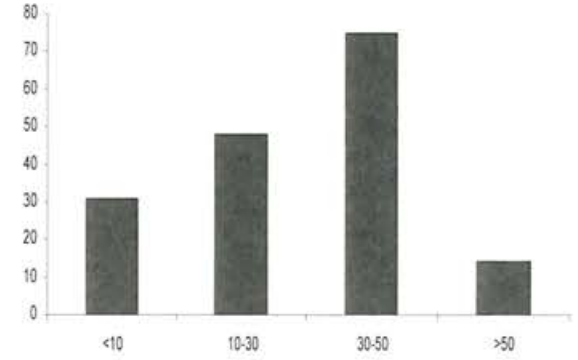
(in metres)

Yellow-browed Bulbul (n=180)



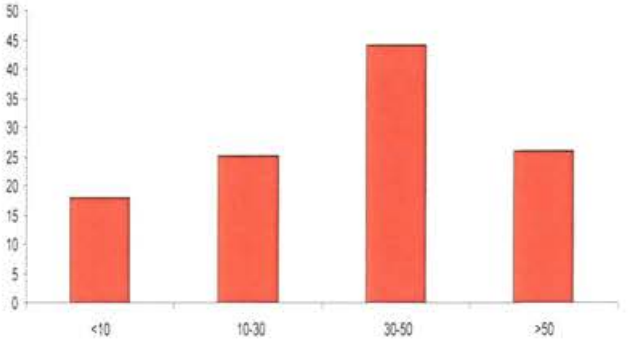
(in metres)

Blackbird (n=168)



(in metres)

Asian Fairy-bluebird (n=102)



(in metres)

From the graphs, it is known that Nilgiri Laughingthrush moved the seeds to longer distances than other bird species in the study area. Seed dispersal distances of major avian frugivorous species showed that they play an important role in plant survival. Thrushes, bulbuls, Fairy blue-bird and mynas are found to be effective seed dispersers in the shola forest.

5.2.3 Fruit consumption rate by various avian frugivores

Table 18 Fruit consumption by avian frugivores in the shola forests

S.No	Bird species	# of visits	Total number of fruits consumed	Mean number of fruits consumed
1	Nilgiri Laughinghthrush	711	2221	3.12 ± 1.33
2	Red-whiskered Bulbul	506	1482	2.93 ± 1.09
3	Common Iora	4	11	2.75 ± 0.95
4	Malabar Whistling-thrush	19	51	2.68 ± 1.16
5	Grey-headed Bulbul	16	42	2.63 ± 1.2
6	Spotted dove	89	232	2.61 ± 1.03
7	Nilgiri Flowerpecker	2	5	2.50 ± 0.70
8	Nilgiri Wood-pigeon	99	246	2.48 ± 1.35
9	Jungle Myna	192	464	2.42 ± 0.96
10	Quaker Tit-babbler	11	26	2.36 ± 0.92
11	Yellow-browed Bulbul	180	422	2.34 ± 0.80
12	White-bellied Treepie	9	21	2.33 ± 0.87
13	Jungle Crow	87	192	2.21 ± 0.76
14	Oriental White-eye	71	156	2.20 ± 0.79
15	Jungle Babbler	52	114	2.19 ± 0.98
16	Wynaad Laughingthrush	11	24	2.18 ± 0.75
17	Asian Fairy-bluebird	102	221	2.17 ± 0.89
18	House Crow	35	76	2.17 ± 0.89
19	Malabar Trogon	22	46	2.09 ± 0.81
20	Great Tit	33	69	2.09 ± 0.58
21	White-cheeked Barbet	37	75	2.03 ± 0.60
22	Mountain Imperial-pigoen	68	137	2.01 ± 0.86
23	Verditer Flycatcher	20	39	1.95 ± 0.69
24	Red-vented Bulbul	15	29	1.93 ± 0.80
25	Black Bulbul	86	165	1.90 ± 0.71
26	Indian Scimitar Babbler	10	18	1.80 ± 0.63
27	Thick-billed Flowerpecker	8	14	1.75 ± 0.46
28	Blackbird	168	289	1.72 ± 0.71

From Table 18 it is known that the Nilgiri Laughingthrush consumed highest number of fruits per visit (3.12 ± 1.33) and constituted the most effective seed disperser. In addition bulbuls, pigeons and mynas also formed important seed dispersers.

Association between frugivorous bird species and fleshy-fruited plants in terms of visitation rates:

Contingency Table or Cross-Tab Analysis was done to examine if the visitation rates of frugivorous bird species is strongly associated with the fleshy-fruited species. **Pearson's Chi-square test** was done to test the association, with 9999 Monte Carlo simulations to compute the statistical significance of the effect size. The influences are given below.

Eppanadu shola forest

Pearson's Chi-square value = 17439, $P < 0.0001$, df = 700

It is clear that bird species and fruit species are NOT independent, which means the visitation rates of birds are strongly associated with composition of fruit-trees in the Eppanadu shola forest.

Longwood shola forest

Pearson's Chi-square = 17139, $P < 0.0001$, df = 550

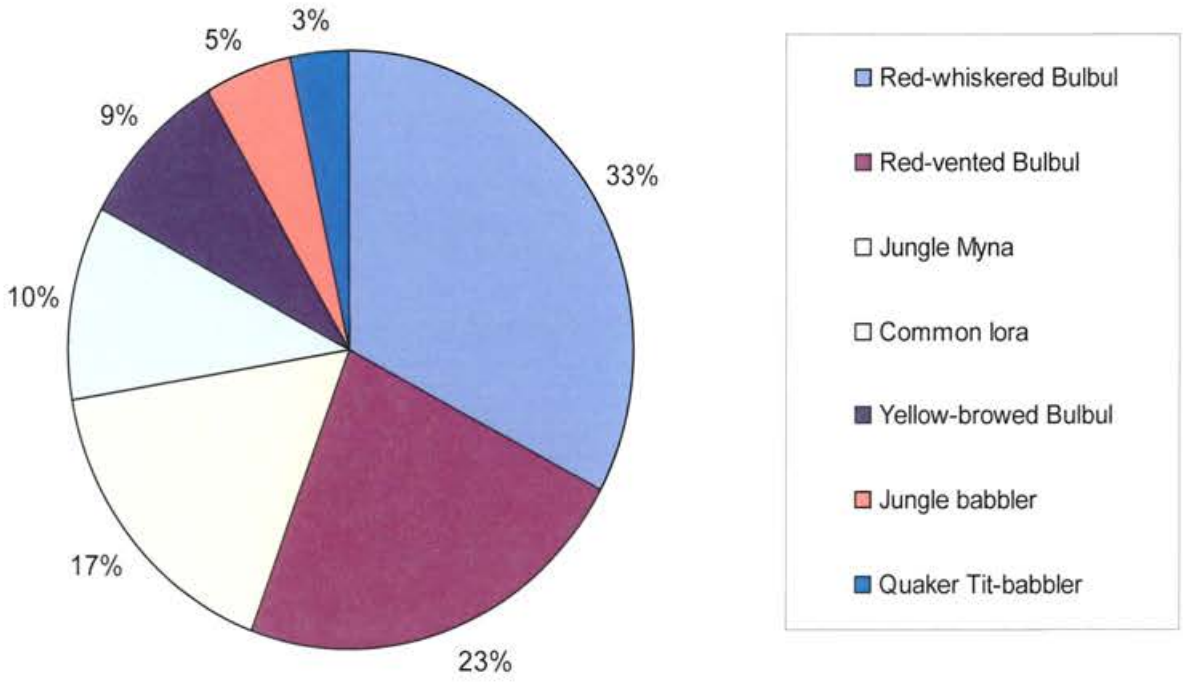
It is clear that bird species and the fruit tree species are NOT independent, which means the visitation rates of birds are strongly associated with composition of fruit-trees in the Longwood shola.

5.2.4 Dispersal of exotic weeds by birds

Two exotic plant species namely *Lantana camara* and *Solanum erianthum* were observed for assessing the role of birds in frugivory and seed dispersal. Totally nine bird species belonging to six families were found foraging on exotic species. Among the nine bird species, the Red-whiskered Bulbul contributed majority of the visits (32.72%).

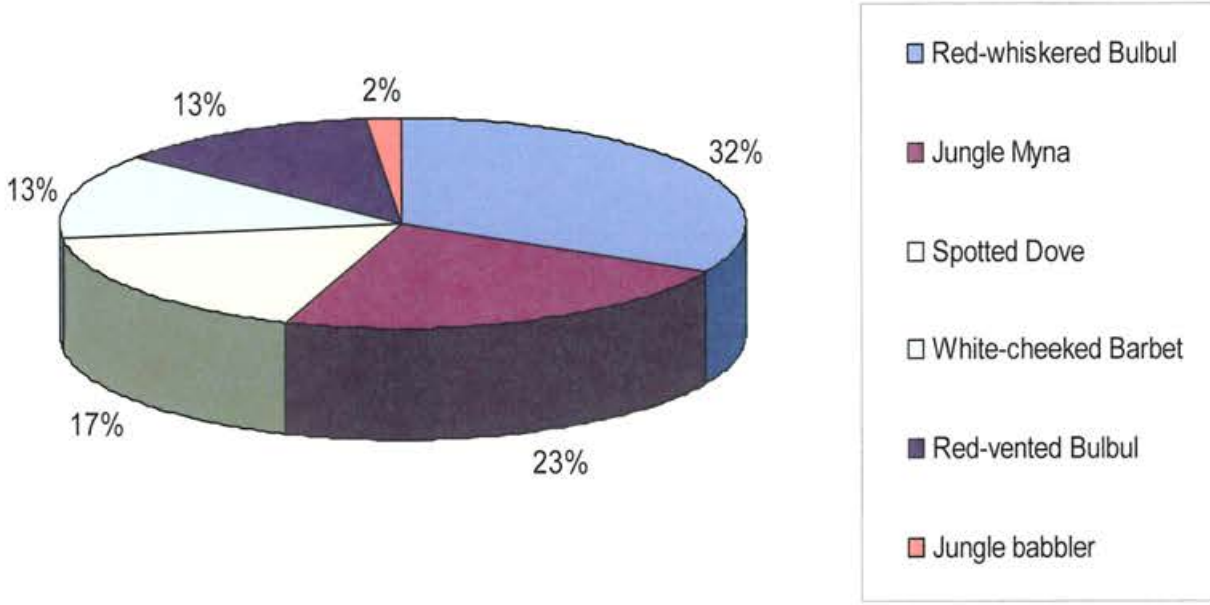
A total of 144 individuals belonging to seven species of avian frugivores were recorded on *Lantana camara*. Maximum number of visits were made by Red-whiskered Bulbul (32.64%) followed by Red-vented Bulbul (22.92%) and Jungle Myna (16.67%) (Fig. 29).

Fig. 29 Proportion of foraging visits by avian frugivores *to Lantana camara*



A total of 126 visits were made by six species of avian frugivores on *Solanum erianthum*. Maximum number of visits was made by Red-whiskered Bulbul (29.17%) followed by Jungle Myna (20.14%) and Spotted Dove (15.28%) (Fig. 30).

Fig. 30 Proportion of foraging visits by avian frugivores to *Solanum erianthum*



Both *Solanum erianthum* and *Lantana camara* were in fruits throughout the year and supported the frugivorous birds.

Seed dispersers of the exotic weeds

PLATE-24

Red-whiskered Bulbul

Red-vented Bulbul

Discussion

The present study indicates that Sapotaceae, Lauraceace and Myrtaceae fruits form important food for the fruit eating birds in the shola forests. In the shola forest of Kodai hills, Western Ghats Somasundram (2006) reported that fruits of Lauraceae are favored by the endemic frugivore, the Nilgiri Wood-pigeon. Lauraceae, Euphorbiaceae were found to be the dominant avian frugivore attracting plant families in the evergreen forest of northern Western Ghats (Medhavi *et al.* 2012). Lauraceae is the major avian frugivore attracting plant family in the wet evergreen forest of Kakachi, southern Western Ghats (Ganesh and Davidar 2001). The lipid rich Lauraceae and Daphniphyllaceae fruits form important food item for the hornbills in Western Ghats, India (Kannan and James 1999; Maheswaran 2002).

Laughingthrushes, bulbuls and pigeons constituted the predominant avian frugivores in our study area. Similarly, pigeons, bulbuls were the predominant avian frugivores in the wet evergreen forest of Kakachi, southern Western Ghats (Ganesh and Daviadar 2001). Thrushes, mynas, bulbuls, and white-eyes were frequently observed feeding on fruits in the Philippine montane rainforest (Nina and Ingle 2003).

In the sholas of Nilgiris, Laughingthrushes were found to disperse the seeds to more than 50 m. Likewise *Sylvia melanocephala, Sylvia undata* dispersed the seeds to >50m in the shrublands and woodlands of the Mediterranean region (Josep *et* a*l.* 2005). Neotropical frugivorous birds dispersed the seeds to longer distances (>50m) (Jordan Karubian *et al.* 2012). Grackles, bulbuls dispersed the seeds to more than 50m in Israel (Orr Spiegel and Ran Nathan 2007). A study by Balasubramanian *et al.* (1998) in the Western Ghats showed three species of bulbuls, (*Pycnonotus cafer, P. luteolus, P. jocosus*) dispersed the seeds to a shorter distance only (<20m).

In our study site in Nilgiris Columbidae, Pycnonotidae and Muscicapidae were found to be the predominant avian frugivore families. Turdidae and Corvidae members constituted the predominant frugivore families in the montane forest of Borneo (Kitamura *et al.*

2001). Pycnonotidae and Columbidae formed dominant avian frugivore families in the montane rain forest of Philippines (Nina and Ingle 2003).

In the Nilgiris, nine species of avian frugivores fed on *Lantana camara* fruits. Lantana fruits appear to be a favoured food of birds in various habitats. Thirteen species of avian frugivores fed on *Lantana camara* in Hong Kong shrubland (Corlett 1998a), while five species were reported to feed on *Lantana camara* in urban Hong Kong (Corlett 2005). A study made in the Society Archipelago (French Polynesia) shows that bulbuls, silver eye and fruit doves are the major consumers of *Lantana camara* fruits. Birds are the main dispersers of *Lantana camara* (Vivian-Smith et al. 2006), facilitating long-distance dispersal and the invasion of new areas (Cronk and Fuller 1995). According to Aravind *et al.* (2010) *Lantana's* fruits are fleshy and available year-round, making them an ideal food source for frugivores such as bulbuls, who are one of the main dispersers of *Lantana* seeds.

CHAPTER- VI

INTER-RELATIONSHIP BETWEEN FRUIT FEATURES AND FRUIT PREFERENCES BY AVIAN FRUGIVORES

Introduction

Early theories on the coevolution of fruit-eating birds and fleshy-fruited plants postulated tight, species-specific mutualisms (Mckey 1975). Now, because of a wealth of new empirical studies and the recognition of important evolutionary constraints, the consensus is that tight mutualisms between plants and frugivorous birds are rare (Wheelwright and Orians 1982; Moermond and Denslow 1983; Herrera 1986). Howe and Estabrook (1977) opined that frugivory is an example of "diffuse evolution", in which evolutionary changes in the traits result from interactions between groups of species rather than between individuals.

Fruit-eating birds are the primary seed dispersers for many plant species in various habitats (Ridley 1930; Van der Piji 1969). As seed dispersal is important for plants, the criteria that birds use in choosing fruits should directly affect the reproductive success of plants that depend on avian seed dispersal. Any fruit trait that enhances the likelihood that an appropriate seed disperser will consume the fruit should be favored (Jenkins 1969; Snow 1971). Traits such as nutritional value (Stiles 1982), seed-to-fruit ratios (Howe and Vande Kerckhove 1980), taste (Sorensen 1983), time of ripening (Wheelwright 1983) and spatial display (Denslow and Moermond 1982) have been demonstrated to influence birds' selection of fruits (Willson and Thompson 1982).

With their excellent visual perception and well-developed color vision (Jacobs 1981), birds probably use color to find and recognize fruits. If birds do notice and choose among fruits on the basis of color, existing differences in fruit colors between plant species may be the evolutionary result of differential selection by birds for increased fruit conspicuousness or attractiveness. The conspicuousness of a plant's fruit display is likely

to be a compromise between conflicting selection pressures. If plants benefit from the rapid removal of the greatest number of their fruits by appropriate seed dispersers (McKey 1975), natural selection should favor prominent fruit displays. Such displays may have associated costs, however (Snow 1971).

In bird-dispersed plants, fruit colour is one of the many factors determining fruit choice by birds in the wild (Wheelwright and Janson 1985a). Ridley (1930) noted that fruit colours are a form of long distance advertisement to fruit foragers. He observed that red and\or black are the most common colours of bird-dispersed fruits. Red and black colour fruits are mostly favored by avian frugivores (Balasubramanian *et al.* 1996). Subsequent surveys by various authors have supported his generalization for particular floras. Fruits are small, red to black in color, and lack pulp protection (e.g., Gautier-Hion *et al.* 1985; Wheelwright and Janson 1985a). The conservative nature of these characteristics may promote the formation of new plant disperser relationships when fleshy-fruited plants or frugivorous birds spread to new ranges. Red is one of the most common colours of bird dispersed fruits (Ridley 1930). Surveys of regional floras, despite their taxonomic differences, support this generalization (Gautier-Hion *et al.* 1985; Willson *et al.* 1989). Darwin (1859) noted that fruits eaten by birds tend to be brightly colored, at least to human perception. Like Darwin, Ridley (1930) interpreted bright colors as serving three functions: to draw the attention of potential seed dispersers to a fruiting plant, to reveal the location of individual fruits, and to signal ripeness.

Fruit size is a prime candidate for coevolution between plants and their dispersers, as it is correlated with disperser type (Jordano 1995). Fruit or seed size can differ, among plants within a population and among fruits within an individual plant (Parciak 2002). Although this variation in fruit size may shape the interaction between frugivores and their food plants, selection forces may be acting in opposing directions (David *et al.* 2011).

Fruit size is also one of the most important factors determining fruit choice (McConkey and Drake 2002). Positive relationships between fruit size and the average size of fruit consumers have been previously documented in other geographic locales (Rey *et al.*

1997). Small fruit and large fruit with small seeds are generally consumed and dispersed by a greater number of frugivores than large fruit with large seeds (Jordano 2000).

Fruit size may be critical to selection, but it has been given surprisingly given little consideration, despite the demonstration in many foraging studies that the sizes of predators and prey are often positively correlated (Wilson 1975). In general, both fruit and seed sizes of Angiosperms are correlated with the size of the frugivores that consume the fruits (Jordano 1995).

In tropical communities, it has been observed that small fruits attract a wider array of dispersal agents than larger ones. Plant species with small fruits are often visited by more species of dispersal agents (Snow 1971; Martin 1985; Howe and Westley 1988 and Dowsett-Lemaire 1988).

Plants bearing soft, fleshy fruits like berries, drupes or functionally analogous structures represent the most widespread and diverse vertebrate-plant dispersal system (Herrera 2002). Other fruit types can set string constraints to fruit and seed handling, e.g. when pulp and seeds are protected in hard, indehiscent capsules or pods that can only be opened with strong teeth, bills, fingers, or elaborated fruit handling techniques (Stiles 2000).

Methodology

Fruit bearing plants with good visibility for the observer were selected for making extended observations on avian frugivory. Observations were carried out mostly in the morning from 6 am to 9 am, when the bird feeding activities were higher, using a pair of 7 x 50 binoculars. Totally 2256 hours were spent for recording avian frugivory on 47 tree species.

Colours of ripe fruits for plant species were assigned to one of eight broad colour categories as used by Wheelright and Janson (1985a). Diameters of the fruits were measured using vernier caliper. Twenty fruits per species were measured and mean diameter of each species calculated (Table 19).

Results

6.2.1 Avian frugivores

During the extended bird feeding watches on 47 fleshy-fruited plant species, 31 fruit-eating birds were recorded. Among the 31 fruit-eating species, *P. columboides* is considered as seed predator as it mainly consume the seeds. Remaining species of birds ate the fruits whole or partly, and regurgitated/defecated the seeds intact and hence, considered as seed dispersers.

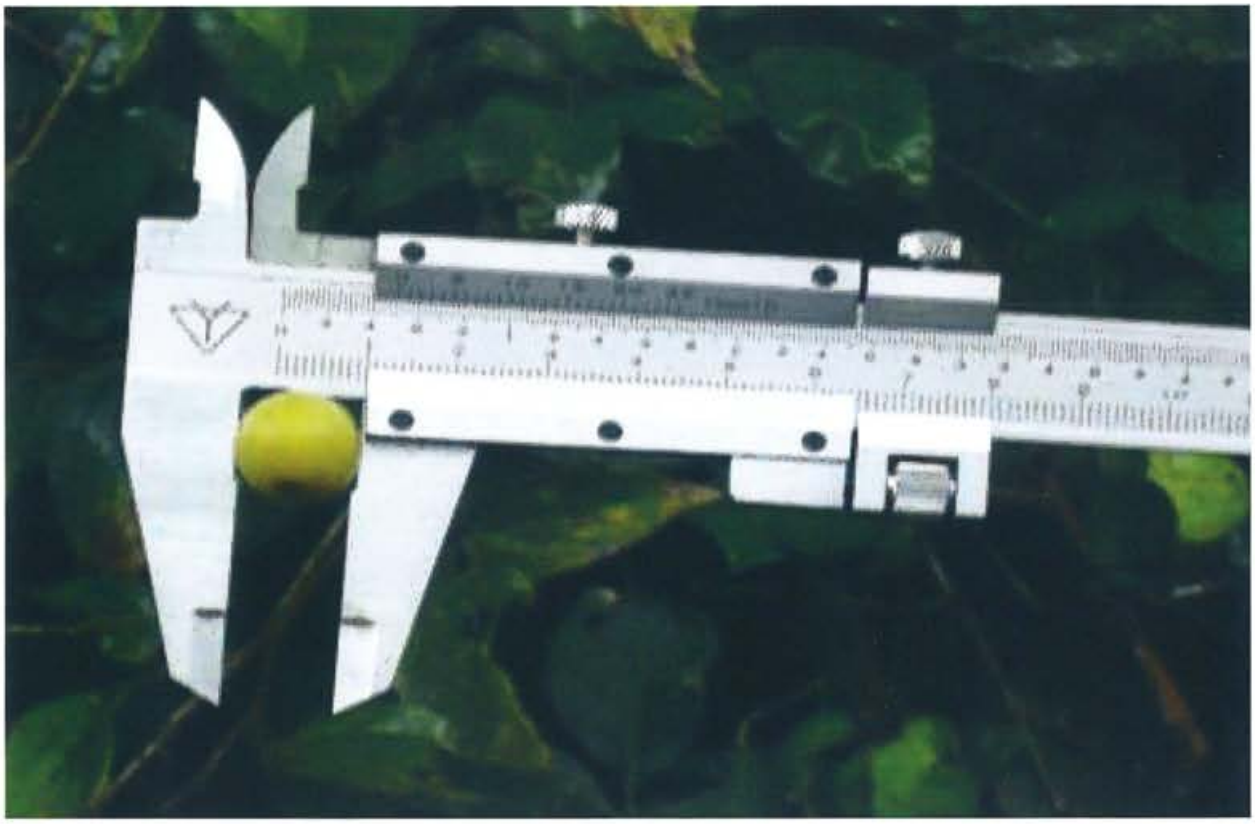
Table 19 Fruit features of bird-dispersed species in the shola forests of Western Ghats

S.No	Species Name	Family	Longwood	Eppanadu	Habit	Fruit type	Fruit colour	Size (in cm)
1	*Actinodaphne bourneae*	*Lauraceae*	-	+	Tree	Berry	Black	1.48
2	*Berberis tinctoria*	*Berberidaceae*	-	+	Tree	Berry	Blue	0.3
3	*Casearia thwaitesii*	*Flacourtiaceae*	-	+	Tree	Capsule	Yellow	1.32
4	*Celtis tetrandra*	*Ulmaceae*	-	+	Tree	Drupe	Black	0.5
5	*Celtis timorensis*	*Ulmaceae*	-	+	Tree	Drupe	Black	0.67
6	*Cinnamomum malabaricum*	*Lauraceae*	-	+	Tree	Berry	Black	1.23
7	*Cinnamomum wightii*	*Lauraceae*	+	-	Tree	Berry	Black	1.32
8	*Cryptocarya lawsonii*	*Lauraceae*	-	+	Tree	Berry	Black	1.19
9	*Daphniphyllum neilgherrense*	*Daphniphyllaceae*	+	+	Tree	Drupe	Red	1.16
10	*Elaeocarpus munronii*	*Elaeocarpaceae*	-	+	Tree	Drupe	Red	1.3
11	*Elaeocarpus oblongus*	*Elaeocarpaceae*	+	+	Tree	Drupe	Red	2.2
12	*Euodia lunu-ankenda*	*Rutaceae*	-	+	Tree	Drupe	Black	1.23
13	*Eurya nitida*	*Ternstroemiaceae*	+	+	Tree	Drupe	Black	0.48
14	*Gaultheria fragrantissima*	*Ericaceae*	-	+	Tree	Capsule	Black	1.18
15	*Glochidion neilgherrense*	*Euphorbiaceae*	+	-	Tree	Drupe	Red	1.22
16	*Ilex wightiana*	*Aquifoliaceae*	+	+	Tree	Berry	Red	0.58
17	*Isonandra perrottetiana*	*Sapotacae*	+	-	Tree	Berry	Pink	0.52
18	*Ixora notoniana*	*Rubiaceae*	+	-	Tree	Drupe	Black	1.28
19	*Ligustrum perrottetii*	*Oleaceae*	+	+	Tree	Drupe	Black	1.12
20	*Litsea wightiana*	*Lauraceae*	+	-	Tree	Berry	Black	1.21
21	*Litsea floribunda*	*Lauraceae*	-	+	Tree	Berry	Black	1.25
22	*Maesa indica*	*Myrsinaceae*	-	+	Tree	Berry	White	0.96

23	*Mahonia leschenaultii*	*Berberidaceae*	+	-	Tree	Berry	Purple	1.3
24	*Memecylon malabaricum*	*Melastomataceae*	-	+	Tree	Berry	Blue	1.45
25	*Michelia champaca*	*Magnoliaceae*	+	-	Tree	Carpel	Brown	1.5
26	*Michelia nilagirica*	*Magnoliaceae*	+	-	Tree	Carpel	Brown	1.2
27	*Microtropis densiflora*	*Celastraceae*	+	-	Tree	Capsule	Black	1.09
28	*Myrsine wightiana*	*Myrsinaceae*	+	-	Tree	Berry	Red	1.12
29	*Neolitsea scrobiculata*	*Lauraceae*	+	-	Tree	Berry	Black	1.3
30	*Neolitsea zeylanica*	*Lauraceae*	+	-	Tree	Berry	Black	1.18
31	*Nothapodytes nimmoniana*	*Icacinaceae*	+	-	Tree	Drupe	Black	1.11
32	*Olea paniculata*	*Oleaceae*	+	-	Tree	Drupe	Black	0.74
33	*Photinia integrifolia*	*Rosaceae*	-	+	Tree	Drupe	Red	0.86
34	*Pittosporum neilgherrense*	*Pittosporaceae*	-	+	Tree	Drupe	Black	0.56
35	*Psychotria nilgiriensis*	*Rubiaceae*	-	+	Tree	Berry	Black	1.02
36	*Schefflera racemosa*	*Araliaceae*	-	+	Tree	Drupe	Black	0.9
37	*Symplocos cochinchinensis*	*Symplocaceae*	+	-	Tree	Drupe	Black	1.18
38	*Symplocos foliosa*	*Symplocaceae*	-	+	Tree	Drupe	Black	1.24
39	*Syzygium cumini*	*Myrtaceae*	-	+	Tree	Berry	Black	1.2
40	*Syzygium montanum*	*Myrtaceae*	+	+	Tree	Berry	Black	0.8
41	*Syzygium densiflorum*	*Myrtaceae*	+	-	Tree	Berry	Black	0.98
42	*Ternstroemia japonica*	*Ternstroemiaceae*	+	-	Tree	Drupe	Black	0.59
43	*Turpinia nepalensis*	*Staphyleaceae*	+	-	Tree	Berry	Red	0.4
44	*Vaccinium leschenaultii*	*Vacciniaceae*	-	+	Tree	Berry	Red	0.99
45	*Vaccinium neilgherresne*	*Vacciniaceae*	+	+	Tree	Berry	Black	1.1
46	*Viburnum hebantham*	*Caprifoliaceae*	-	+	Tree	Drupe	Red	0.68
47	*Viburnum punctatum*	*Caprifoliaceae*	+	-	Tree	Drupe	Red	0.5

Fruit size measured by Vernier Caliper

PLATE- 25



6.2.2 Fruit size

Among the 47 fleshy fruited plant species, 18 produced fruits measuring < 10mm, 28 had 10-20 mm size (Table 20). While one species (*Elaeocarpus oblongus*) had >20 mm fruit diameter.

Table 20 Fruit sizes of bird-dispersed species in the shola forests

S.No	Size category	# of plant species	%
1	<10mm	17	36.17
2	10 - 20 mm	29	61.70
3	>20mm	1	2.13

Maximum number of fruit species consumed by bulbuls belonged to <10 mm (40%) size category followed by 10-20 mm (60%), where as in thrushes <10 mm (41.94%) followed by 10-20 mm (54.84%) and > 20 mm (3.23%). Fruits favored by crows belonged to < 10 mm (20%) followed by 10-20 mm (60%) and >20 mm (20%). Fruits consumed by pigeons belonged to <10 mm (42.31%) followed by 10-20 mm (55.85%) and > 20 mm (3.85%). Fruits consumed by babblers belonged to <10 mm (46.15%) followed by 10-20 mm (53.85).

6.2.3 Fruit colour

Eight types of fruit colours were observed to be consumed by avian frugivores in the shola forests. Black (61%) followed by red (23%) were found to the the major fruit colours consumed by birds (Table 21).

Table 21 Colours of bird-dispersed plants in the shola forests

S.No	Fruit colour category	Fruit species	
		#	%
1	Black	28	59.57
2	Red	11	23.40
3	Brown	2	4.26
4	Blue	2	4.26
5	Yellow	1	2.13
6	Purple	1	2.13
7	White	1	2.13
8	Pink	1	2.13

Bulbuls consumed 62% of black coloured fruits followed by red (24%). Mynas favoured black colour (64%), followed by red (21%). Crows favored red (80%) followed by black colour (20%). Pigeons favoured black colour (55%) followed by red (29%). Thrushes mostly consumed black colour (66%) fruits followed by red (21%). Babblers favoured black colour (38%) followed by red colour (30%).

Black and red are the dominant fruit colours utilized by avian frugivores in the shola forests of Nilgiris. These two colours constituted the majority (82.97%) of food plant species of avian frugivores in the shola forest.

6.2.4 Fruit type

In total, four fruit types were utilized by birds in the shola forests. Berry (46.81%) formed most utilized fruit type followed by drupe (42.55%) and others (Table 22).

Table 22 Fruit types utilized by avian frugivores in the shola forests

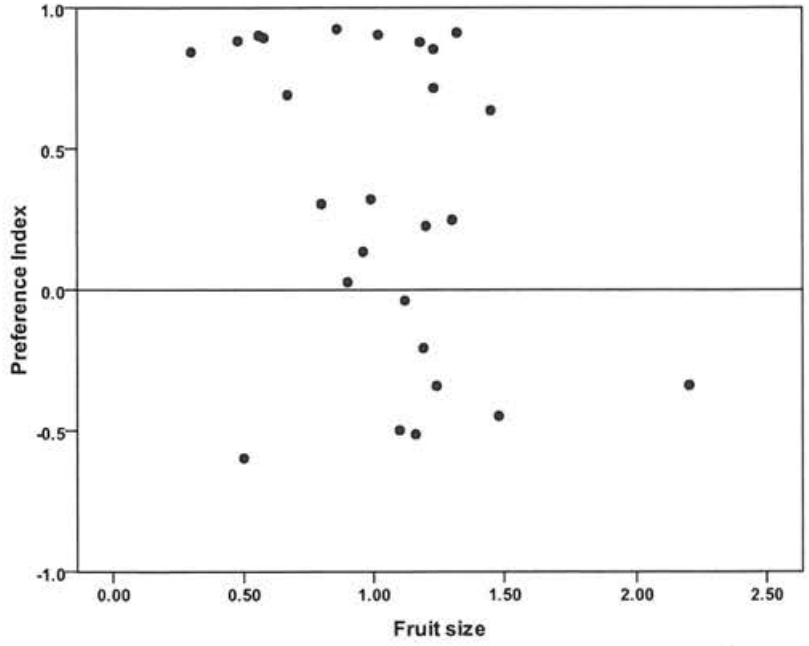
S.No	Fruit type	Fruit species consumed	
		#	%
1	Berry	22	46.81
2	Drupe	20	42.55
3	Capsule	3	6.38
4	Carpel	2	4.26

Relationship between fruit characteristics and fruit preference by birds

I. EPPANADU

The relationship between preference index and fruit size was examined by scatter plot (Fig. 31).

Fig. 31 Relationship between fruit characteristics and fruit preference by birds in Eppanadu shola forest



It is seen from the graph that there is no significant relationship between fruit size and preference index of various bird species, when we club all species together. Spearman rank correlation test also yielded insignificant results (Spearman's rho = -0.257, P = 0.205, n = 26). However, this would change if we analyse the preferences taxa-wise.

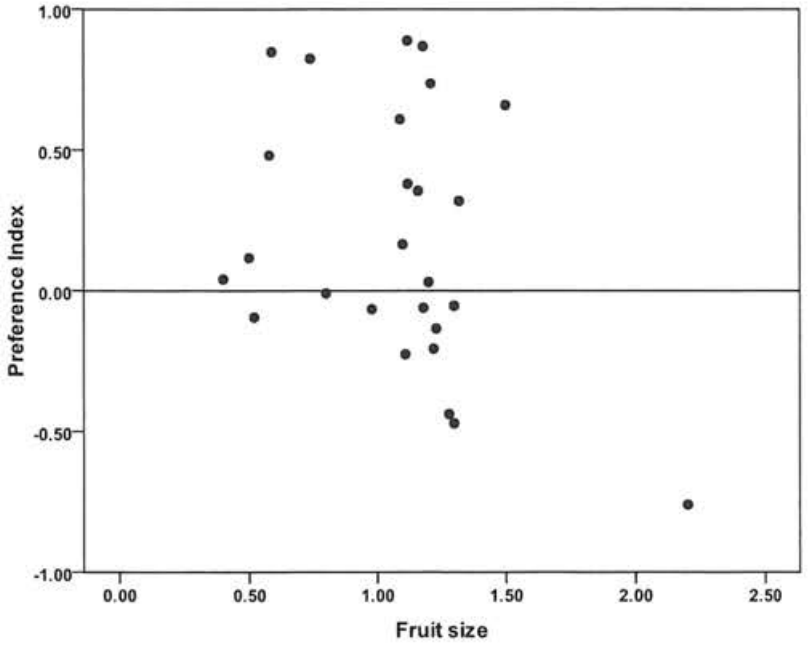
Similarly, the relationship between preference index and fruit color was found to be weak (Eta = 0.326, P > 0.05).

The relationship between preference index and fruit type was also insignificant (Eta = 0.328, P > 0.05). Again, these patterns are obtained when we club all the species together. The relationship may show a different pattern when we analyze species wise data.

II. LONGWOOD SHOLA

The relationship between preference index and the fruit size was examined by scatter plot (Fig. 32).

Fig. 32 Relationship between fruit characteristics and fruit preference by birds in Longwood shola forest



It is seen from the graph that there is no significant relationship between fruit size and preference index of birds. Spearman rank correlation test also yielded insignificant results (Spearman's rho = -0.294, P = 0.145, n = 26). However, this would change if we analyse the preferences taxawise.

Similarly, the relationship between preference index and fruit color was found to be weak (Eta = 0.210, P > 0.05).

The relationship between preference index and fruit type was also insignificant (Eta = 0.286, P > 0.05). Again, these patterns are obtained when we club all the species together. The relationship may show different pattern when we analyze species wise data.

Discussion

The present study shows that < 10m fruit size was mainly consumed by avian frugivores in the shola forests of Western Ghats. Bulbuls, barbets, blackbird and babblers mostly consumed fruits <10mm in size. Thrushes, pigeons and crows consumed large sized fruits, while mynas consumed small size fruits. Ganesh and Davidar (2001) observed that 1-2cm fruit size was favoured by birds in the wet evergreen forests in Western Ghats. Size also influenced fruit delivery at nests as 58% of fruits delivered were < 10mm in length while 32 % were in the range of 10-20 mm and only 2.5 % were > 20 mm for Malabar Grey Hornbill in the Western Ghats. (Maheswaran 2002). The high percentage of bird species favored medium-size fruits (10-20 mm), in Carrasco, Spain (Tabarelli *et al.* 2003).

According to Green (1993) large fruited, large seeded species attracted far fewer bird species than small fruits. Balasubramanian *et al.* (1998) mentioned that the fruits of *Strychnos potatorum*, slightly larger than 20mm diameter were visited by fewer species only. They further stated that *Alphonsea sclerocarpa* whose fruits are much larger >40mm, attracted only the Large Green Barbet. The major reason attributed for the infrequent visitation of birds to large fruited, large seeded plants is the gape width limitation of fruit-eating birds (Wheelwright 1985b; Green 1993). It was observed that fruits with one or a few larger seeds whose diameter measures more than the gape size of the avian consumer are adapted for dispersal by mammals (Balasubramanian and Bole 1993b).

According to Terborgh and Diamond (1970), small fruited plant species attract more species of birds than large-fruited ones. Willson *et al.* (1989) considered fruits of less than 20mm diameter to be primarily adapted for seed dispersal by Volant birds. Corlett (1996) observed that most of the bird-dispersed seeds in Hong Kong had a mean diameter of <13 mm. Highest diversity of frugivores observed at small fruited species (<15 mm) during the present study show that bird dispersed fruits tend to be small, which is in correspondence with the findings of other studies.

In the present study berries and drupes were found to be highly used by birds in the shola forests. Berry and drupes formed major bird fruits in the tropical dry evergreen forest of Point Calimere, India (Balasubramanian 1996). Most of the birds were attracted by berries, drupes in the lower monante rain forest in Costa Rica (Wheelwright and Janson 1985a). Berry and drupe formed the predominant fruit type for the avian frugivores in Mudumalai Wildlife Sanctuary in Western Ghats, India (Maheswaran 2002). Berry and drupe formed the important bird fruits in the tropical deciduous shrub land in Brazilian semiarid forests (Sandra Freitas de Vascocelos 2010). Studies in Australia (Green 1993) and Malasi (Dowsett-Lemaire 1988) have also brought out similar results.

The present study showed that majority of the bird-dispersed fruits in the shola forests include black and red. Wheelwright and Janson (1985a) mentioned that black and red are major bird fruit colours in the lower montane rain forest of Costa Rica. Red and black are important fruit colours in the lowland evergreen rain forest of Gabon (Gautier-Hion *et al.* 1985). Red, yellow and black colour fruits were mostly consumed by avian frugivores in Sriharikota Island, Southern India (David *et al.* 2011). Nilgiri Wood-pigeon predominantly used black and red fruits in the montane wet temperate forest in southern Western Ghats (Somasundaram 2006). Ganesh and Davidar (2001) recorded red and black colour fruits are predominant food for birds in the wet evergreen forests in the Western Ghats. In a tropical moist forest in Peru, "bird fruits" are mainly red, black, white, blue, and purple (Janson 1983) and in South Africa, birds prefer black, followed by orange and red (Knight and Siegfried 1983).

CHAPTER VII

Effect of avian frugivory on seed germination

Introduction

Assessing the effects of avian gut-passage on seed germination is an essential component of the research protocol for analyzing the effectiveness of frugivores as seed dispersers in any landscape context and this assessment is often omitted. A review of post-dispersal seed germination assays shows that frugivores can significantly enhance seed germination, but only for about half of the species that have been tested (Traveset 1998). Enhanced seed germination can occur either through enhanced seed germinability (the percentage of germinated seeds at the end of the growing season) or the rate of seed germination (Schupp 1993; Traveset 1998; Traveset *et al.* 2007).

Frugivores can enhance seed germination by three mechanisms, i) through mechanical or chemical scarification (degradation) of the impermeable seed coat or endocarp (scarification effect; Barnea *et al.* 1990; Traveset 2008), ii) through the removal of the pulp that contains chemicals that can block germination pathways (deinhibition effect; Cipollini and Levey 1997; Samuels and Levey 2005) and iii) through the effect of the faecal material surrounding the seed (fertilization effect; Traveset and Verdu 2002).

It is generally regarded that bird-dispersed seeds germinate much faster than the normal seeds. A variety of birds and mammals depend predominantly on fruits to fulfill their nutritional requirements. Frugivorous animals also help seeds to escape from the deleterious effects of seed and seedling predators (Janzen 1970). Due to the fact that birds are generally more abundant than mammals, birds tend to remove large quantities of seeds, favouring specialization of dispersal syndromes towards their group.

The effect that the ingestion of fruits by vertebrate frugivores on seed germination has received considerable attention (reviewed in Traveset 1998; Traveset and Verdú 2001a).

Many studies show that germination is more successful after seeds pass through the digestive tract of frugivores. However, such enhancement is not universal, and several (usually uncontrolled) factors (e.g. retention time in guts, seed size, seed age, seed source) cause the great variation found in germination response. The conditions under which germination tests are performed also influence germination success, and contrasting results are often found when comparing treated and control (uningested) seeds of the same species under different conditions (Bustamante *et al.* 1993; Figueiredo *et al.* 1995; Yagihashi, *et al.* 1998; Traveset and Verdu 2001b). Most studies are performed in the lab, testing germination in petridishes usually in growth chambers, yet these favourable conditions may sometimes obscure significant differences between treatments (Traveset *et al.* 2001b).

Frugivorous birds also remove fruit skin and pulp from seeds, regardless of whether seeds are defecated or regurgitated. Pulp and cutinous skin can inhibit germination by virtue of their imperviousness to water or high osmotic pressure from dissolved sugars, factors known to influence water uptake and hence germination of seeds (Mayer and Poljakoff-Mayber 1989). Fruit pulp can also contain germination inhibitors (Evenari 1949; Mayer and Poljakoff- Mayber 1989). In addition, uncleaned seeds may suffer from microbial or fungal attack (Ng 1983; Jackson *et al.* 1988).

Endozoochorus seeds of animal-dispersed plants have complex germination mechanisms, which are considered to include inhibitors of germination (Mayer and Poljakoff-Mayber 1989) and inducers of dormancy (Bradbeer 1988). The effect of bird digestion on endozoochorous seeds vary among plant species (Lieberman and Lieberman 1986; Traveset and Willson 1978). Germination percentage of seeds that have been ingested by birds can be higher than those of non-ingested seeds (Tsutomu Yagihashi *et al.* 1999).

In temperate ecosystems, frugivores are omnivorous and fruit-frugivore interactions are supposed to be of diffuse evolutionary value, if any, to the evolution of fruit traits of fruiting plants (Johanna Honkavaara *et al.* 2007). However, frugivores may be of considerable aid in the colonization of new habitats. In addition to the effects on spatial

dispersal of seeds, ingestion by birds may also effect temporal dispersal, if germination is enhanced or delayed. (Traveset 1998 and Traveset *et al.* 2001b) Germination may also be reduced or remain unchanged after ingestion by birds (Crossland and Vander Kloet 1996). If dormancy of a seed is broken e.g. too early by abrasion, a seedling may be doomed to vanish in unsuitable conditions (Janzen 1983). Thus gut treatment by frugivores should be sufficient to enable seed germination, but gentle enough to prevent premature breaking of dormancy (Smith 1975).

Methodology

Seed germination experiment

Seed germination experiments were conducted to compare the germination efficiency of bird defecated seeds with that of control seeds. For the germination experiment, five fruit species namely *Syzygium densiflorum*, *Symplocos cochinchinensis, Ligustrum perrottetii, Eurya nitida*, *Neolitsea scrobiculata* were used. Three types of seeds were used for germination experiments. i. bird dispersed seeds collected from the nest middens, ii. pulp removed seeds and iii. seeds with pulp. Fresh ripe fruits were collected from the plants. Pulp of fresh fruits was hand-cleaned and the rest were kept intact for the experiment. Bird defecated seeds were collected from the nest-middens of Nilgiri Laughingthrush, *Garrulax cachinnans* a resident frugivore of the shola forest. During the breeding season, nests of Nilgiri Laughingthrush were located in the study site. Seeds from four nests were collected once in a week, analysed and identified. Seed species were identified by comparing with that of the seeds obtained from fresh fruits. For each category, 20 seeds were used. Seeds were sown in polythene bags filled with soil (upper layer of earth) and sand mixture and were placed in a nursery, which had an enclosure. The poly-bags were watered regularly and the height of the seedlings was recorded every week for four months from the date of sowing.

A comparison of germination percentage of various types of seeds was done and tested for statistical significance with One-Way ANOVA. Paired-Sample T-Test was used to know the statistical significance between each sample. The software SPSS 10.0 Windows was used.

Results

7.2.1 Seed germination

Five species with large/medium seeds were experimented. All the species showed enhanced germination (Fig. 5). According to One-Way Anova ($P=<0.05$) significant difference was observed between the germination percentage of bird defecated and control seeds experimented.

We paired the groups as seeds with pulp and pulp removed seeds, seeds with pulp and bird defecated seeds and pulp removed and bird defecated seeds. Each pair was tested for significant difference in germination percentage using Paired-Sample T-test. Seeds with pulp and pulp removed seeds (Paired Sample T-test $t = -21.113$, $p<0.05$), seeds with pulp and bird defecated seeds (Paired Sample T-test $t = -17.422$, $p<0.05$) and pulp removed seeds and bird defecated seeds (Paired-Sample T-test $t = -27.437$. $p<0.05$).

Seeds of all the five species experimented for germination study were found in the Nilgiri Laughingthrush nest sites. All the five species were medium sized which include, *Syzygium densiflorum*, *Symplocos cochinchinensis, Ligustrum perrottetii, Eurya nitida*, *Neolitsea scrobiculata.* In the case of bird defected seeds, seedling emergence was first recorded for *Syzygium densiflorum* after the first week of sowing. For the remaining species, seedling emergence was noticed during the 2nd and 3rd week.

In the case of control seeds, the percentage of germination was less than 30 percent for *Neolitsea scrobiculata, Ligustrum perrottetii* and *Symplocos foliosa.* While all the five plant species showed enhanced germination after defecation by Nilgiri Laughingthrush, *Syzygium densiflorum* showed 100% germination (Table 23). In the case of control seeds, *Eurya nitida* showed nil germination, other species showed low percentage of germination.

Table 23. Comparison of germination efficiency of seeds collected from the Nilgiri Laughingthrush droppings and control seeds

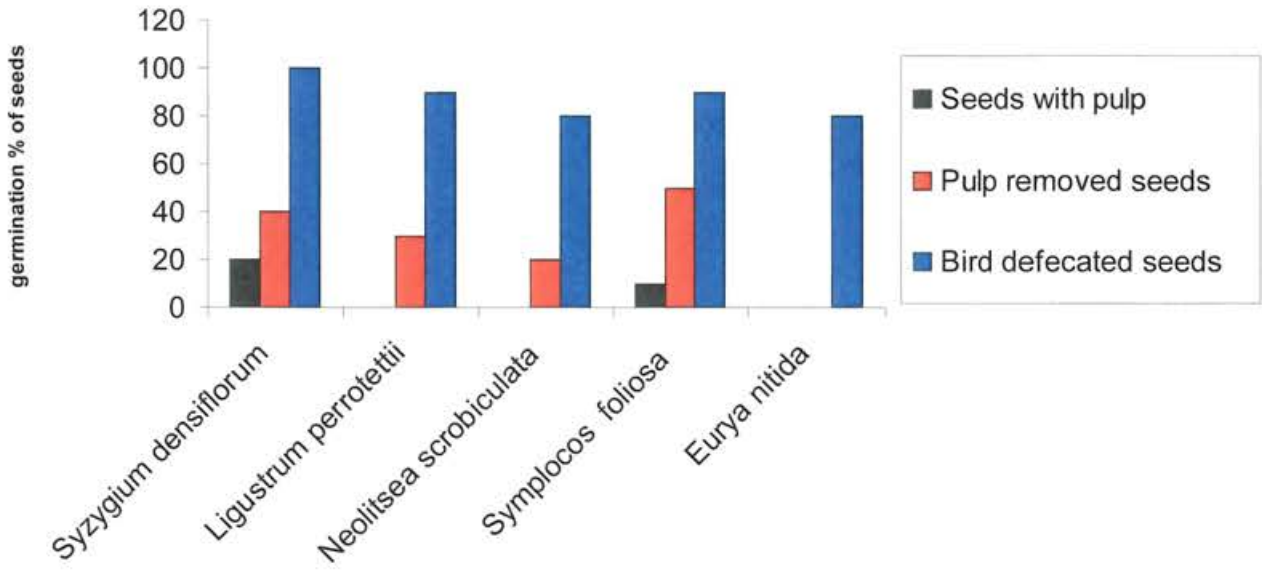
S.No	Name of the Plant species	Control seeds with pulp	Control seeds without pulp	Bird defecated seeds
		Germination %	Germination %	Germination %
1	*Syzygium densiflorum*	20	40	100
2	*Ligustrum perrotettii*	-	30	90
3	*Neolitsea scrobiculata*	-	20	80
4	*Symplocos foliosa*	10	50	90
5	*Eurya nitida*	-	-	80

-indicates nil germination

Of the five species experimented, seeds with pulp and pulp removed showed low percentage of germination compared to the bird defecated seeds which indicates the role of Nilgiri Laughingthrush in the scarification and deinhibition effect on seeds.

Species such as *Syzygium densiflorum*, *Ligustrum perrottetii* and *Symplocos foliosa* showed higher percentage of germination in bird defecated sample. Among the five bird defecated plant species, four species are endemic to the Western Ghats (Fig. 33). The results indicate that the Nilgiri Laughingthrush is an important seed disperser in the shola forests and play a major role in forest regeneration.

Fig. 33 Germination percentage of different plant species in the shola forest



7.2.2 Seed germination growth comparison (Friedman Rank Test –K-related samples)

Comparison of seed germination among various categories of seeds showed significant difference between control seeds with pulp, pulp removed and bird defecated seeds ($p=<0.05$, $df=2$, $N=796$).

Test Statistics[a]

N	796
Chi-Square	1039.241
df	2
Asymp. Sig.	.000

a. Friedman Test

Ranks

	Mean Rank
PULP	1.32
NONPULP	1.90
DEFECATE	2.78

Seed germination experiment

PLATE-26

Discussion

Germination trials during the present study showed that Nilgiri Laughingthrush gut passed seeds showed enhanced germination, which indicate that pulp removal after ingestion by birds strongly enhances seed germination. According to Santhoshkumar (2010) Indian Grey Hornbill gut passed seeds showed enhanced germination in the dry deciduous forest of Sathyamangalam Wildlife Sanctuary, Eastern Ghats, India. Seed dispersal by frugivorous animals is widely recognized as a crucial process in tropical forests (Stiles 1980; Willson 1992). Seed germination experiments on the seeds collected from middens of Malabar Grey Hornbill reported that hornbill dispersed seeds had higher germination potential, showed 75% enhanced germination than control seeds (Balasubramanian and Maheswaran 2002) in the Nilgiri Biosphere Reserve, India.

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All the five species experimented in the present study showed enhanced germination. Similarly out of 16 species, 15 showed enhanced germination in the dry deciduous forest of Eastern Ghats, India (Santhoshkumar 2010). Study on seed dispersal by *Ceratogymna* hornbills in Daj Reserve (Whitney *et al.* 1998) reported the role of hornbills in seed dispersal and enhancing germination potential of seeds. Of the 24 hornbill dispersed tree species tested, 23 germinated after gut passage. Among the 17 fruit species used as control, only 4 species germinated. The results of the present study have similar pattern as that of Whitney *et al.* (1998); Balasubramanian and Maheswaran (2002) and Balasubramanian and Santhoshkumar (2010) establishing the role of birds in enhancing the germination efficiency of the seed of their food plants.

Compared to seeds sowed with pulp or those manually extracted from fruits, seeds ingested by birds significantly increased their germinability for four of the five Mediterranean shrub species consumed by birds in sub-Andean landscape (Reid and Armesto 2011). Small birds are unable to swallow the large-sized fruits and hence bigger birds such as Nilgiri Laughingthrush seems to have an important role in dispersing the large seeded plant species in the shola forest.

CHAPTER VIII

SUMMARY AND CONCLUSION

A study on avian frugivory and seed dispersal in two shola forests of Nilgiri hills, Western Ghats was carried out from January 2009 to July 2011. Longwood shola is situated between 11°43.494'N and 076° 87.463'E) and Eppanadu shola between 11°29.151'N and 076° 47.223'E. The objectives of the present study were, i). study avian frugivory and find out major frugivores in the shola forests ii). assess the fruiting phenology of fleshy-fruited tree species and find out the fruiting seasonality, iii). establish the role of avian frugivores in seed dispersal and forest regeneration. Vegetation sampling was done in bothe the shola forests, Longwood and Eppanadu. One ha plot (50x20m) were laid in each of the above-mentioned two sholas. Data collected were analyzed to obtain quantitative structure and composition of plant communities. Fruiting periodicity was determined by monitoring tagged trees for 24 months.

Extended observations were carried out on fleshy fruited plants to record frugivory by birds. The observations were carried out mostly in the morning from 6 am to 9 am and in the evening between 3 pm and 6 pm, which is the active foraging time for frugivores. Data on frequency of bird visits and fruit handling behaviour were gathered. The distance traveled by each avian frugivore to the first perching site after leaving a fruiting tree was noted following. Number of fruits consumed per visit was recorded for various bird species. Seed germination experiments were conducted to compare the germination efficiency of bird defecated seeds with that of control seeds. Three types of seeds were used for germination experiments. i. bird dispersed seeds collected from the nest middens, ii. pulp removed seeds (manual removal) and iii. seeds with intact pulp. Seeds were sown in polythene bags filled with soil and sand mixture and were placed in a nursery, which had an enclosure.

In total, 874 individuals of 45 tree species belonging to 30 families were recorded in the Longwood shola. Highest number of individuals recorded include *Euonymus crenulatus* (n=93) followed by *Elaeocarpus oblongus* (n=89) and *Celtis tetrandra* (n=78). Of the 30 families recorded, Lauraceae (11.94%), Ulmaceae (9.50%), and Elaeocarpaceae (7.21%)

were represented by maximum number of individuals. Highest number of species was observed for Lauraceae (n=7 species). In the Longwood shola, major fruiting peak was observed in June. During the peak fruiting period of 2009, 2010, 87 individuals and 112 individuals were recorded with fruits. In the Longwood shola there was a peak in fruiting during south west monsoon (14 species). Post monsoon had 11 fruiting species, while summer showed 10 species and north-east monsoon was 11 species.

In the Longwood shola, 26 plant species were studied for avian frugivore visitation. A total of 1248 hrs of observations were made. Totally 27 avian frugivore species belonging to 10 families were recorded here. Maximum number of avian frugivore species belonged to Muscicapidae (8 species) followed by Pycnonotidae (5 species) and Corvidae, Columbidae (3 species each). Maximum number of foraging visits were made by the Nilgiri Laughingthrush (n=1233) followed by Red-whiskered Bulbul (n=886) and Blackbird (n=557). Nilgiri Laughing thrush and bulbuls formed major frugivores in the shola forest. Large proportion of fruit foraging visits were made by Muscicapidae (36%) followed by Pycnonotidae (30%) and Columbidae (12%). A total of 26 fleshy-fruited species belonging to 23 genera of 20 families were found to be dispersed by birds. Lauraceae (4 species) was found to be the predominant bird-dispersed family in the Longwood shola forest. Large proportion of avian frugivore visits was made on Lauraceae (n=11.01%) followed by Oleaceae (n=10.63%) and Sapotaceae (9.15%). Huge number of avian species were attracted by *Isonandra perrottetiana* (n=17) followed by *Myrsine wightiana* (n=11) and *Ilex wightiana* (n=10). Ivlev's Preference Index (PI) values showed *Viburnum punctatum* (PI=0.89) as the most preferred fruit species by avian frugivores followed by *Ternstroemia japonica, Litsea wightiana* (PI=0.86) and *Olea paniculata* (PI=0.84).

In the Eppanadu shola, a total of 1013 individuals belonging to 46 tree species of 30 families were recorded in the 1 ha sampling plot. Maximum number of individuals was represented by *Symplocos cochinchinensis* (n=176) followed by *Celtis tetrandra* (n=132) and *Actinodaphne bourneae* (n=60). Of the 30 families recorded, Symplocaceae (20.24%), Lauraceae (16.9%), Ulmaceae (13.92%), and Myrtaceae (9.28%) had higher number of individuals. Highest number of species was represented by Lauraceae (n=6)

followed by Myrtaceae (n=4). A total of 65 individuals of 11 species and 114 individuals of 14 species were recorded in the year of 2009 and 2010 respectively. Fruiting peak was noticed during June in the Eppanadu shola forest. Eppanadu shola had the fruiting peak (14 species) in southwest monsoon season. Post monsoon had 11 fruiting species, while summer showed 12 species, north-east monsoon with 11 species.

In the Eppanadu shola, 28 tree species was studied for avian frugivore visitation. A total of 1316 hrs of observations were made to record avian frugivore visits. In total, 29 avian frugivore species belonging to 11 families were recorded in the Eppanadu shola. Maximum number of avian frugivore species belonged to Muscicapidae (7 species) followed by Pycnonotidae (5 species) and Corvidae, Columbidae (3 species each). Totally, 5034 individuals belonging to 29 species of avian frugivores were recorded. Maximum number of fruit foraging visits was made by Red-whiskered Bulbul (n=1068) followed by Nilgiri Laughingthrush (n=682) and Nilgiri Wood-pigeon (n=527). Highest proportion of visits were made by Pycnonotidae (35%) followed by Muscicapidae (31%) and Columbidae (16%). In total 28 species of fleshy fruits belonging to 24 genera of 21 families were consumed by birds. Lauraceae (4 species) was found to be the predominant bird-dispersed family in the Eppanadu shola. Largest proportion of avian visits was recorded on Lauraceae (13.04%) followed by Ulmaceae (10.38%) and Myrtaceae (7.11%). Highest number of the frugivore species were attracted by *Ilex wightiana* (n=11) followed by *Daphniphyllum neilgherrense* (n=9). Ivlev's Preference Index (PI) showed *Viburnum punctatu*m (PI=0.89) as the most preferred fruit species by avian frugivores followed by *Ternstroemia japonica, Litsea wightiana* (PI=0.86) and *Olea paniculata* (PI=0.84).

A total of 47 species of avian frugivore food plants were observed in the study area. Out of 47 species, 40 were enumerated in the sample plots, of which 34 species were recorded in Eppanadu shola and 37 at Longwood shola. Eight types of fruit colours were recognized in the shola forests. Among the bird-dispersed species black (61%) followed by red (23%) were found to the predominant fruit colour in the shola forests. Among the 47 fleshy fruited species, 18 produced fruits measuring <10mm, 28 had 10-20 mm size and the remaining one species (*Elaeocarpus oblongus*) had >20 mm fruit diameter. In

total, four fruit types were utilized by birds in the shola forests. Berry (46.81%) formed the most used fruit type followed by drupe (42.55%) and others. The number of fruits consumed per visit by different bird species gives an idea of relative role each species in fruit consumption and likely removal of fruits from the parent plant. Highest number of fruits was consumed by Nilgiri Laughingthrush (3.12 ± 1.33) followed by Red-whiskered Bulbul (2.93± 1.09). The distance a bird traveled after leaving a fruiting tree was recorded as the distance to the first perching site. Among the 28 avian frugivores Laughingthrushes, bulbuls, Fairy Blue-bird and mynas dispersed seeds to a distance of >50 m. Other bird species traveled less than 50m distance.

Fruits of five tree species namely *Syzygium densiflorum*, *Symplocos cochinchinensis, Ligustrum perrottetii, Eurya nitida*, and *Neolitsea scrobiculata* consumed by the Nilgiri Laughingthrush during the breeding season were used for germination experiment. These included. Bird-defecated seeds and pulp removed seeds were experimented. In the case of bird defected seeds, early emergence (1st week) of seedling was noticed for *Syzygium densiflorum*. For the remaining species, seedling emergence was noticed during the 2nd and 3rd week only. In all the five species, bird defecated seeds showed enhanced germination. According to One-Way Anova (P=<0.05), significant difference was observed between the germination percentage of bird defecated and control seeds. It was inferred that birds enhance the germinability of seeds they consume.

Encroachment of forest areas for agricultural activities is prevalent in the study area. This leads to the loss of habitat. Livestock grazing and collection of non-timber forest products are also noticed in the study area. Tourism activity also recorded inside of the shola forest. Exotic species pose a threat to this high altitude ecosystem. Blue wattle (*Acacia mearnsii*) and Bluegum (*Eucalyptus globulus*) are the consequence of commercial plantation and afforestation drives. Other fast spreading invasives include *Lantana camara* and *Solanum erianthum*. All these factors lead to the degradation of shola forest habitat.

Encroachment of forest lands for agriculture need to be prevented. Poaching of avian frugivoress need to be stopped and wood cutting should be stopped. It is suggested to

include bird-dispersed tree species in the afforestation programmes. This would help to sustain the population of avian frugivores and other frugivorous vertebrates. Manual removal of weeds is suggested before flowering and local villagers could be encouraged to use them after removal. *Lantana camara* forms a useful source in basketary and *Solanum erianthum* is a good firewood.

REFERENCES

ANGGRAINI, K., KINNAIRD, M., and O' BRIEN, T. 2000. The effect of fruit availability and habit disturbance on an assemblage of Sumatran hornbills. *Bird Conservational* 10: 189-202.

APPANAH, S. 1985. General flowering in climax rainforest of south-east Asia; *J. Trop. Ecol.* 1 225-240.

ARAVIND, DINESH, N.A., RAO, K.N., GANESHAIAH, R., UMA SHAANKER and POULSEN, J.G. 2010. Impact of the invasive plant, *Lantana camara*, on bird assemblages at Malé Mahadeshwara Reserve Forest, South India. *Tropical Ecology* 51: 325-338

ARUNA, R., BALASUBRAMANIAN, P. and RADHAKARISHNAN, P. 2011. Role of frugivorous birds in seed dispersal in the mixed dry deciduous forests of Attappady and Anaikatty, Western Ghats, *Indian Forester* 135 (10) : 1308-1316.

ASHTON, P.S. 1988. A global network of plots for understanding tree species diversity in tropical forests. pp. 47-62. *In*: F. Dallmeier and J. A. Comiskey (eds.) *Forest Biodiversity Research, Monitoring and Modeling: Conceptual Background and Old World Case Studies*. Paris: UNESCO, Parthenon Publishing, Pearl River, NY.

AUGSPURGER, C.K. 1981. Reproductive synchrony of a tropical shrub: experimental studies on effects of pollinator and seed predators on *Hybanthus prunifolius* (Vioraceae). *Ecology* 62:775–788

AUGSPURGER, C. K. 1983. Seed dispersal of the tropical tree, Platypodium elegans, and the escape of its seedlings from fungal pathogens. *Journal of Ecology* 71: 759-771.

AUGSPURGER, C. K. 1984a. Seedling survival of tropical tree species: interactions of dispersal distance, light-gaps, and pathogens. *Ecology* 65: 1705-1712.

AUGSPURGER., C. K. and KELLY, C. K., 1984b. Pathogen mortality of tropical tree seedlings: experimental studies of the effects of dispersal distance, seedling density, and light conditions. *Oecologia* 61: 211-217.

BALASUBRAMANIAN, P. and BOLE, P.V. 1993a. Fruiting phenology and seasonality in tropical dry evergreen forest in Point Calimere Wildlife Sanctuary. *J. Bombay nat. Hist. Society*. 90: 163-177.

BALASUBRAMANIAN,P and P.V. BOLE 1993b. Seed dispersal by mammals at Point Calimere Wildlife Sanctuary. *J. Bombay nat. Hist. Soc.* 90(1): 33-44

BALASUBRAMANIAN, P. 1996. Interaction between fruit-eating birds and bird-dispersed plants in the tropical dry evergreen forest in Point Calimere, South India, *J.Bom.Nat. Hist. Soc.*, 93(3): 428-441.

BALASUBRAMANIAN, P. NARENDRA PRASAD, S. and KANDAVEL, K. 1998. Role of birds in seed dispersal and natural regeneration of forest plants in Tamil Nadu. Technical Report No: 7, SACON. pp. 43.

BALASUBRAMANIAN, P. and B. MAHESWARAN 2002: Hornbill-tree interactions with special reference to identification and conservation of "keystone mutualists" in the Nilgiri Biosphere Reserve Pp. 109-113. *In*: Biosphere Reserves in India and their management (Eds: Sharma, J.K., P.S. Easa, C.Mohan, N. Sasidharan and R.K. Rai), 254 pp. MoEF, New Delhi and KFRI, Peechi.

BALASUBRAMANIAN, P., and MAHESWARAN, B. 2003a. Frugivory, seed dispersal and regeneration by birds in south Indian forests. *Journal of Bombay Natural History Scoiety* 100: 411-431.

BALASUBRAMANIAN, P., SARAVANAN, R. and MAHESWARAN, B. 2003b. Habitat utilization by Malabar Pied Hornbill in Athikadavu Valley, Western Ghats. Project Report. Salim Ali Centre for Ornithology and Natural History. pp-26.

BALASUBRAMANIAN, P., SARAVANAN, R., and MAHESWARAN, B. 2004. Fruit preferences of Malabar Pied Hornbill *Anthracoceros coronatus* in Western Ghats, India. *Bird Conservation International* 14: 69-79.

BALSSUBRAMANIAN, P. and E. SANTHOSHKUMAR. 2009. Ecology of Indian Grey Hornbill (*Ocyceros birostris*) with special reference to its role in seed dispersal in Southern Eastern Ghats. Final report, Salim Ali Centre for Ornithology and Natural History and Tamil Nadu Forest Department pp-72.

BALSSUBRAMANIAN, P., ARUNA, R., ANBARASU, C. and SANTHOSHKUMAR, E. 2011. Avian frugivory and seed dispersal of Indian Sandalwood *Santalum album* in Tamil Nadu, India. *Journal of Threatened Taxa* 3(5): 1775–1777.

BARBEL, B. and BOHNING-GAESE, K. 2001. Consequences of frugivore diversity for seed dispersal, seedling establishment and the spatial pattern of seedlings and trees. Oecologia 129: 385 – 394.

BARNEA, A., YOM-TOV, Y., and FRIEDMAN, J. 1990. Differential germination of two closely related species of *Solanum* is response to bird ingestion. *Oikos* 57: 222-228.

BARNEA, A., YOM-TOW, Y. and FRIEDMAN, J. 1991. Does ingetion by birds affect seed germination? *Func. Ecol.* 5: 394-402.

BASCOMPTE, J. and JORDANO, P. 2007. Plant-animal mutualistic networks: the architecture of biodiversity. Annual Review of Ecology, Evolution and Systematics, 38, 567–93.

BirdLife International. 2011. Species factsheet: *Columba elphinstonii*. Downloaded from http://www.birdlife.org on 13/03/2011.

BHAT, D.M. 1992. Phenology of tree species of tropical moist forest of Uttara Kannada district, Karnataka, *India. J.Biosci.*, 17: 325-352.

BHAT, D. M. and MURALI, K. S. 2001. Phenology of understorey species of tropical moist forest of Western Ghats region of Uttara Kannada district in south India. *Current Science*, 81(7): 799-805.

BLAKE, J. G., LOISELLE, B. A., MOERMOND, T. C., LEVEY, D. J. and DENSLOW J. S. 1990. Quantifying abundance of fruits for birds in tropical habitats. *Stud Avian Biol*, 13: 71–77

BLASCO, F. 1970. Aspects of the flora and ecology aof savannas of the south Indian hills *J.Bom.Nat. Hist. Soc.* 67: 522-534.

BOND, W. J. 1995. Assessing the risk of plant extinction due to pollinator and disperser failure. Pp. 131-146 in Lawton, J. H. and May, R. M. eds. Extinction rates. Oxford.

BORCHERT, R., S. A.MEYER, R. S. FELGER and PORTER-BOLLAND, L. 2004. Environmental control of flowering periodicity in Costa Rican andMexican tropical dry forests. *Glob. Ecol. Biogeogr.* 13: 409–425.

BRADBEER, J.W., 1988. Seed Dormancy and Germination.. CHAPMAN and HALL, New York.

BUSTAMANTE, R.O., REZ, A., SIMONETII, J.A., VASQUEZ, R.A. and WALKOWIAK, A.M. 1993. Antagonistic effects of frugivores on seeds of *Cryptocarya alba* (Mol.) Looser (Lauraceae): consequences on seedling recruitment. *Acta Oecologica* 14, 739–745.

CARLO, T.A., AUKEMA, J.E. and MORALES, J.M. 2007. Plant–frugivore interactions as spatially explicit networks: integrating animal foraging and fruiting plant spatial patterns. Seed Dispersal: Theory and its Application in a Changing World(eds A. Dennis, E. Schupp and D. Wescott), pp. 369–390. CABI, Oxon, UK.

CHAMPION, H.G. and SETH, S.K. 1968. A Revised Survey of the Forest Types of India. Manager of Publications. Government of India, New Delhi.

CHAPMAN, C.A., 1995. Survival without dispersers: Seedling recruitment under parents. *Conservation Biology* 9 : 675-678.

CHARLES-DOMINIQUE, P., ATRAMENTOWICZ, M., CHARLES-DOMINIQUE, M., GERARD, H., HLADIK, A., HLADIK, C. M. and PREVOST, M. F. 1981. Les mammiferes frugivores arboridoles nocturne d'une forest guyanaise: interrelations plantes-animaux. *Revue d'Ecologie (Terre et Vie)* 35:341- 436.

CIPOLLINI, M.L. and LEVEY, D.J. 1997. Secondary metabolites of fleshy vertebrate-dispersed fruits; adaptive hypotheses and implications for seed dispersal. *Am. Nat.* 150: 346-372.

COATES-ESTRADA, R., and ESTRADA, A. 1986. Fruiting and frugivores at a strangler fig in the tropical rain forest of Los Tuxtlas, Mexico. *Journal of Tropical Ecology* 2: 349-357.

CONNELL, J. H. 1971. On the role of natural enemies in preventing competitive exclusion in some marine animals and in rain forest trees. Pp. 298-310 in PJ Den Boer and GR Gradwell, eds. Dynamics of populations. Centre for Agricultural Publishing and Documentation, Wageningen

CORLETT, R. T. 1996. Characteristics of vertebrate-dispersed fruits in Hong Kong. *J. Trop. Ecol.* 12: 819-833.

CORLETT, R.T. 1998a. Frugivory and seed dispersal by vertebrates in the Oriental (Indomalayan) region. *Biological Review* 73: 413-448.

CORLETT, R.T. 1998b. Characteristics of vertebrate-dispersed fruits in Hong Kong. *Journal of Tropical Ecology* 12: 829-833.

CORLETT, R.T. 2005. Interactions between birds, fruit bats and exotic plants in urban Hong Kong, South China. Urban Ecosystems 8: 275-283

CRONK, C. B. and FULLER, J. L. 1995. Plant invaders: the threat to natural ecosystems. Chapman and Hall, London

CROSSLAND, D.R. and VANDER KLOET, S.P. 1996. Berry consumption by the American robin, *Turdus migratorius*, and the subsequent effect on seed germination, plant vigour, and dispersal of the lowbush blueberry, *Vaccinium angu*stifolium- *Can.Field.Nat.* 110: 303-309.

CURTIS, J.T. and MCINTOSH, R.P. 1950. The interrelations of certain analytic and synthetic phytosociological characters, *Ecology*, 31: 434-455.

DANIELS, R.J.R. 1997. A field guide to the birds of southwestern India. Oxford University Press, New Delhi.

DARWIN. 1859. . On the origin of species. Murray, London.

DA SIVAJ, M.C. and TABARELLI. M. 2000. Tree species impoverishment and the future of flora of the Atlantic Forest of northeast Brasil. *Nature* 404: 72-74.

DAVIDAR, P., MOHANDAS, D. and . VIJAYAN, L. 2007. Floristic inventory of woody plants in a tropical montane (shola) forest in the Palni hills of the Western Ghats, India. *Tropical Ecology* 48(1): 15-25.

DAVID, P. J. SENTHIL MURUGAN, B. and RANJIT. M. 2011. Frugivory by birds and mammals in Sriharikota Island, southern India. J.B.N.H.S. 108(1). 24-40.

DENSLOW, J.S. and MOERMOND, T.C. 1982. The effect of accessibility on rates of fruit removal from tropical shrubs: an experimental study. *Oecologia* 54: 170-176

DIAMOND, I. M. 1973. Distributional ecology of New Guinea birds. *Science* 179:759-769.

DIAZ, M., and E. GRANADILLO. 2005. The significance of episodic rains for reproductive phenology and productivity of trees in semiarid regions of northwestern Venezuela. Trees-Struct. Funct. 19: 336–348.

DOWSETT-LEMAIRE. 1988. Fruit-Choice and seed dissemination by birds and mammals in the evergreen forests of upland. *Malawai. Rev Ecol.* Vol. 43: 251-285.

EMMONS, L. H., GAUTIER-HION, A. and DUBOST, G. 1983. Community structure of the frugivore-folivore forest mammals of Gabon. *Journal of Zoology* 199:209-222.

ENGEL, VERA LEX. and FERNANDO ROBERTO MARTINS. 2005. Reproductive phenology of Atlantic forest tree species in Brazil: an eleven year study. *Tropical Ecology* 46: 1-16.

EVENARI, M. 1949. Germination inhibitors. *Bot. Rev.,* 15:153–194.

FIGUEIREDO, R. A., MOTTA JUNIOR, J.C. and VASCONCELLOS, LAS. 1995. Pollination, seed dispersal, seed germination and establishment of seedlings of *Ficus microcarpa*, Moraceae, in southeastern Brazil. Revista Brasileira de *Biologia* 55:233–239.

FISHER, K. E. and CHAPMAN, C. A. 1993. Frugivores and fruit syndromes - Differences in patterns atthe genus and species level. *Oikos.* 66:472-482

FLEMING, T. H., and HEITHAUS, E. R. 1981. Frugivorous bats, seed shadows, and the structure of tropical forests. *Reproductive Botany*: 45-53.

FLEMING, T. H., BREITWISCH, R. and WHITESIDES, G. H. 1987. Patterns of tropical vertebrate frugivore diversity. *Annual Review of Ecology and Systematics* 19:91-109.

FOSTER, R. B. 1982. The seasonal rhythm of fruit fall on Barro Colorado Island. Pp. 151±172 in Leigh, E. G., Rand, A. S. and Windsor, D. M. (eds.). *The ecology of a*

tropical forest: seasonal rhythms and long-term changes. Smithsonian Institution Press, Washington, D.C.

FRANKIE, G.W., BAKER, H.G. and OPLER, P.A. 1974. Comparative phenological studies of trees in tropical wet and dry forests in the lowlands of Costa Rica. *Journal of Ecology* 62: 881–913.

FUNCH, L.S., FUNCH, R. and BARROSO, G. M. 2002. Phenology 10. of gallery and montane forest in the Chapada Diamanina, Bahia, Brazil. *Biotropica* 34: 40 –50.

GANESH, T. and DAVIDAR, P. 2001. Dispersal modes of tree species in the wet forests of southern Western Ghats. *Current Science* 80: 394-399.

GARWOOD, N.C. 1983. Seed germination in a seasonal tropical forest in Panama: a community study. *Ecol. Monogr.* 53:159–181

GAUTIER HION, A., DUPLANTIER, J. M., QURIS, F., FEER, F., SOURD, C., DECOUX, J.P., DUBOST, G., EMMONS, L., ERARD, C., HECKETSWEILER, P., MOUNGAZI, A., ROUSSILHON, C. and THIOLLAY, J. M. 1985. Fruit characteristics as a basis for fruit choice and seed dispersal in a tropical forest vertebrate community. *Oecologia* 65:324-337.

GRAZIELE, D., ANTONIO GOMES, J.R., ANA CAROLINA, C. and LEANDRO, B. 2010. The role of avian frugivores on germination and potential seed dispersal of the Brazilian Pepper *Schinus terebinthifolius*. *Biota Neotrop.,* Vol. 10: 45-51.

GRIZ, L.M.S., MACHADO, I.C.S., 2001. Fruiting phenology and seed dispersal syndromes in caatinga, a tropical dry forest in the northeast of Brazil. *J. Trop. Ecol.* 17, 303– 321.

GUNTER, S., STIMM., B., CABRERA, M., DIAZ, M. L., LOJAN, M., ORDONEZ, E., RICHTER, M. and WEBER, M. 2008. Tree phenology in montane forests of southern Ecuador can be explained by precipitation, radiation and photoperiodic control. *J Trop Ecol*, 24: 247–258.

HAJRA, P.K., NAIR, V.J. and Daniel, P. 1997. Flora of India. IV: 1 – 561.

HAMANN, A. and CURIO, E. 1999. Interactions among frugivores and fleshy fruit trees in a Philippine submontane rainforest. *Conservation Biology* 13: 766-773.

HAMANN, A. 2004. Flowering and fruiting phenology of a Philippine submontane rain forest: climatic factors as proximate and ultimate causes. *J. Ecol.* 92:24–31

HENRY, A.N., KUMARI, G.R. and CHITRA. 1987. *Flora of Tamil Nadu, India*, Ser I. Analysis,Vol.2. Botanical Survey of India, Coimbatore.

HEINDL, M. and CURIO. E. 1999. Observations of frugivorous birds at ruit-bearing plants in the northe Negros Forest Reserve, Philippines. *Ecotropica* 5: 167-181.

HERRERA, C. M., 1985 Determinants of Plant-Animal Coevolution - the Case of Mutualistic Dispersal of Seeds by Vertebrates. *Oikos* 44:132-141

HERRERA, C. M. 1986. Plant adaptations for vertebrate dispersal: what should they do and what they actually do. Pages 5-18 in A. ESTRADA and FLEMING, T.H. eds. Frugivores and seed dispersal. Junk, Dordrecht, The Netherlands.

HERRERA, C. M. 1992. Interspecific variation in fruit shape: allometry, phylogeny, and adaptation to dispersal agents. Ecology 73:1832-1841

HERRERA, C. M., JORDANO, P., LOPEZ-SORIA, L. and AMAT, J.A. 1994. Recruitment of a mast-fruiting, bird-dispersed tree: bridging frugivore activity and seedling establishment. *Ecological Monographs* 64, 315–344.

HERRERA, C. M. 2002. Seed dispersal by vertebrates. In C. M. HERRERA and O. PELLMYR (Eds.). Plant–animal interactions: An evolutionary approach, pp. 185–208. Blackwell, Oxford, UK.

HESPENHEIDE, H. A. 1973. Ecological inferences from morphological data. Annu. Rev. Ecol. Syst. 4: 213-229.

HILTY, S. L. 1980. Flowering and fruiting periodicity in a premontane rain forest in Paci®c Colombia. *Biotropica* 12:292-306.

HOLL, K.D. 2002. Effect of shrubs on tree seedling establishment in an abandoned tropical pasture. *Journal of Ecology* 90, 179–187.

HOPPES, W. G. 1987. Pre and post-foraging movements of frugivorous birds in an eastern deciduous forest woodland, USA. *Oikos* 49: 281-290.

HOULE, G. 1998. Seed dispersal and seedling recruitment of *Betula alleghaniensis*: spatial inconsistency in time. *Ecology* 79, 807–818.

HOWE, H. F. and G.F. ESTABROOK 1977. On intra-specific competition for avian dispersers in tropical trees. *Am.Nat.* 3:817-832.

HOWE, H. F. and VANDE KERCKHOVE, G. A. 1980. Nutmeg dispersal by tropical birds. *Science* 210:925-927

HOWE, H. F. and SMALLWOOD, J. 1982. Ecology of seed dispersal. *Annual Review of Ecology and Systematics* 13: 201–228.

HOWE, H. F. 1984. Implications of seed dispersal by animals for tropical reserve management. *Biological Conservation* 30: 261-281.

HOWE, H. F., SCHUPP, E.W. and WESTLEY, L.C. 1985. Early consequences of seed dispersal for a neotropical tree (*Virola surinamensis*). *Ecology* 66: 781-791.

HOWE, H. F. 1986. Seed dispersal by fruit-eating birds and mammals. Pp. 123-189 in DR Murray, ed. Seed dispersal. Academic Press, Australia.

HOWE, H. F. and WESTLEY, L. C. 1988. Ecological relationships of plants and animals. Oxford University Press.

HUBBELL, S. P. 1979. Tree dispersion, abundance, and diversity in a tropical dry forest. *Science* 203: 1299-1309.

IVLEV, V.S. 1961. Experimental ecology of feeding of fishes. Yale University Press, New Haven, Connecticut, USA.

JACKSON, P. S. W., CRONK, Q. C. B. and PARNELL. J. A. N. 1988. Notes on the regeneration of two rare Mauritian endemic trees. *Trop. Ecol.,* 29:98–106.

JACOBS, G. H. 1981. Comparative color vision. Academic Press, New York.

JANSON, C. H. 1983. Adaptation offruit morphology to dispersal agents in neotropical Co-rests. *Science* 219: 187-189.

JANZEN, D. H. 1967. Synchronization of sexual reproduction of trees within the dry season in Central America. *Evolution* 21:620-637.

JANZEN, D.H. 1970. Herbivores and the number of tree species in tropical forests. Am. Nat., 104: 501-528.

JANZEN, D.H. 1972. Escape in space *by sterculia ape*tala seeds from the bug *Dysdercus fasciatus* in a Costa Rican deciduous forest. *Ecology* 53: 3. 50-61.

JANZEN, D. H., 1980 When is it coevolution? *Evolution* 34:611-612

JANZEN, D. H. 1983. Dispersal of seeds by vertebrate guts. Pages 232-262 in D. J. Futuyma and M. Slatkin, eds. Coevolution. Sinauer, Sunderland, Mass.

JENKINS, R. 1969. Ecology of three species of saltators with special reference to their frugivorous diet. Ph.D. diss. Harvard University, Cambridge, Mass

JOHANNA HONKAVAARA, HELI SIITARI, VIIPI SALORANTA. and JUSSI VIITALA. 2007. Avian seed ingestion changes germination pattern of bilberry, Vaccinium myrtillus. *Ann. Bot. Fennici* 44: 8-17.

JORDANO, P. 1995. Angiosperm fleshy fruits and seed dispersers: a comparative analysis of adaptation and constraints in plant-animal interactions *American Naturalist* 145: 163-191.

JORDANO, P. and SCHUPP, E.W. 2000. Seed disperser effectiveness: the quantity component and patterns of seed rain for *Prunus mahaleb*. *Ecological Monographs* 70, 591-615.

JORDAN KARUBIAN, LUKE BROWNE , CARLOS BOSQUE, TOMAS CARLO, MAURO GALETTI , BETTE, A., LOISELLE, JOHN, G. BLAKE, DOMINGO CABRERA, RENATA DURAES, FABIO, M. LABECCA, KIMBERLY, M., HOLBROOK, RICHARD HOLLAND, WATRE JETZ, FRANZ KUMMETH, JORGE OLIVO, KYM OTTEWELL, GIANNI PAPADAKIS, GONZALO RIVAS, SILKE STEIGER, BRYSON VOIRIN and MARTIN WIKELSKI. 2012. Seed dispersal by Neotropical birds : Emerging patterns and underlying processes. Ornithologia Neotropical 23: 9-24.

JOSEPH, M.B., PERE PONS and CRISANTO GOMEZ. 2005. Exclusive frugivory and seed dispersal of *Rhamnus alaternus* in the bird breeding season. *Plant Ecology*.

KALKO, E. K. V., HERRE, E. A. and HANDLEY, C. O. 1996. Relation of fig fruit characteristics to fruit-eating bats in the New and Old World tropics. *Journal of Biogeography* 23:565-576

KANNAN, R. and JAMES, D.A. 1999. Fruiting phenology and the conservation of the Great Pied Hornbill (*Buceros bicornis*) in the Western Ghats of Southern India. *Biotropica*, 31: 167-177.

KANTAK, G. E. 1979. Observations on some fruit-eating birds. Auk. 96: 183-186.

KITAMURA, TAKAKAZU YUMOTO and KIHACHIRO KIKUZAWA. 2001. Fruiting phenology of fleshy-fruited plants and seasonal dynamics of frugivorous birds in four vegetation zones on Mt. Kinabalu, Borneo *Journal of Tropical Ecology* 17:833-858.

KELLY, D., LADLEY, J.J. and ROBERTSON, A. W. 2004. Is dispersal easier than pollination? Two tests in New Zealand Loranthaceae. *New Zealand J Bot* 42:89–103

KETRING, D.L. 1973. Germination inhibitors. *Seed Science and Technology* 1: 305-324.

KING, G. 1996. *Reptiles and Herbivory*. Chapman and Hall, London.

KNIGHT, R. S. and SIEGFRIED, W.R. 1983. Inter-relationships between type, size and colour of fruits and dispersal in Southern African trees. *Oecologia* 56 : 405-412

KOPTUR, S., HERBERT, W. A., FRANKIE, G. W. and Baker H. G. 12. 1988. Phenological studies of shrubs and treelet species in tropical cloud forests of Costa Rica. *Journal Tropical Ecology* 4: 323–346.

KORINE, C., KALKO, E.K.V., and HERRE, E.A., 2000. Fruit characteristics and factors affecting fruit removal in a Panamanian community of strangler figs. *Oecologia* 123:560-568

KUMAR, S. 1993. Survey and Mapping of Shola Forests and Grasslands in the Upper Nilgiri Plateau and Assessment of Human Utilization of the Vegetation. Report submitted to World Wild Fund for Nature- India.

KUMAR, A., KONSTANT, W.R., and MITTERMEIER, R.A. 1999. Western Ghats and Sri Lanka. Pages 354-365 in R.A. MITTERMEIER, N. MYERS and C.G. MITTERMEIER, (Eds) Hotspots: Earth's biologically richest and most endangered terrestrial ecoregions. CEMEX Conservation International, Mexico.

KURT, P.M and MORAG, A. M. 2005. Seasonal Patterns of Flowering and Fruiting in a Dry Tropical Forest in Jamaica. *Biotropica* 37(4): 584-590 2005.

LAKSHMINARAYANA, K.V., YAZDANI, G.M. and RADHAKRISHNAN, C. 2002. Western Ghats. In Ecosystems of India. (Eds.) ALFRED, J.R.B., DAS A.K., and SANYAL A.K. Zool. Surv. India, Kolkata. Pp. 349-369.

LECK, C. F. 1971. Overlap in 1:he diet of some neotropical birds. *Living Bird* 10:89-106

LEIGHTON, M. 1982. Fruit resources and patterns of feeding, spacing and grouping among sympatric Bornean hornbills (Bucerotidae). Ph.D., University of California

LEIGHTON, M. and LEIGHTON, D. R. 1983. Vertebrate responses to fruiting seasonality within a Bornean rain forest. In: Sutton SL, Whitmore TC, CHADWICK AC (eds). Tropical rain forest: ecology and management. Blackwell, London, pp 181-196.

LEVEY, D.L., SILVA, W. R. and GALETTI, M. (eds) 2002. *Seed dispersal and frugivory: ecology, evolution and conservation*. CAB. Pub. 511 p

LIEBERMAN, D. 1982. Seasonality and phenology in a dry tropical forest in Ghana. *Journal of Ecology* 70: 791- 806.

LIEBERMAN, M. and LIEBERMAN, D. 1986. An experimental study of seed ingestion and germination. *Ecological Monograph*. 19: 269-286.

LINNEBJERG, J.F., HANSEN, D.F. and OLESEN, J.F. 2009. Gut passage effect of the introduced red-whiskered bulbul (Pycnonotus jocosus) on germination of invasive plant species in Mauritius. *Austral Ecol* 34:272–277

LOISELLE, B. A. and BLAKE. J.G. 2002. Potential consequences of extinction of frugivorous birds for shrubs of a tropical wet forest, in LEVEY, D. J., SILVA, W. R., and GALETTI, M. editors. *Seed Dispersal and Frugivory: Ecology, Evolution and Conservation*. CABI Publishing, Oxford, UK.

LORD, J. M., MARKEY, A. S., MARSHALL, J. 2002. Have frugivores influenced the evolution of fruit traits in New Zealand? In: LEVEY. D. J., SILVA, W. R., GALETII, M.,(eds) Seed dispersal and frugivory: Ecology, Evolution and Conservation. CABI

Publishing, Wallingford, pp 55-68

MAHESWARAN, B. 2002. Habitat utilization by Malabar Grey Hornbill at Mudumalai Wildlife Sanctuary, Western Ghats. Ph.D thesis. Bharathiar University, Coimbatore

MALHI, Y., AND J. WRIGHT. 2004. Spatial patterns and recent trends in the climate of tropical rainforest regions. Philos. Trans. R. Soc. Lond. B 359: 311–329.

MARTIN, T.E. 1985. Resource selection by tropical frugivorous birds; integrating multiple interactions. *Oecologia* 66: 563-573.

MAYER, A. M. and A. POLJAKOFF-MAYBER. 1989. The germination of seeds. Pergamon Press, New York. 270 p.

MCCONKEY, K.R., DRAKE, D.R., 2002. Extinct pigeons and declining bat populations: are large seeds still being dispersed in the tropical pacific? In: Levey, D.J., Silva, W.R., Galetti, M. (Eds.), Seed Dispersal and Frugivory: Ecology, Evolution and Conservation. CAB International, Wallingford, pp. 381–395.

MCDONNELL, M. J. and STILES, E. W. 1983. The structural complexity of old field vegetation and the recruitment of bird-dispersed plant species. *Oecologia.* 56: 109-116

MCKEY, D. 1975. The ecology of coevolved seed dispersal systems. Pp. 159–191. In: Gilbert, L.E. and Raven, P.H. (eds) *Coevolution of animals and plants*. University of Texas Press: Austin.

MEDHAVI, D., TADWALKAR, AMRUTA, M., JOGLEKAR, MONALI HASKAR, RADHIKA, B., KANADE, BHANUDAS CHAVAN, APARNA, V., WATVE4, K. N., ANESHAIAH, and ANKUR PATWARDHAN. 2012. Dispersal modes of woody species from the northern Western Ghats, India. *Tropical Ecology* 53(1): 53-67

MEHER-HOMJI, V. M. 1967. Phytogeography of south Indian hill stations. *Bulletin of the Torrey Botanical Club* 94: 230-242.

MEHER-HOMJI, V. M. 1987. Ecological diversity in the Nilgiri district. *Journal of Palynology* 23-24: 159-166.

MISHRA, R.K., UPADHYAY, V.P., MOHAPATRAL, S.B. and MOHANTY, R.C. 2006. Phenology of species of moist deciduous forest sites of Similipal biosphere reserve. *Lyonia.* 11(1): 5-17.

MOERMOND, T. C. and DENSLOW, J. S. 1983. Fruit choice In Neotropical birds: effects of fruit type and accessibility on selectivity. *Journal of Animal Ecology* 52:407-420

MOHANDASS, D. and Davidar. P. 2009. Floristic sturucture and diversity of a tropical montane evergreen forest (shola) of the Nilgiri Mountains, Southern India. *Trop. Ecol.* 50: 219-229.

MOLES, A.T. and DRAKE, D.R. 1999. Post-dispersal seed predation on eleven large-seeded species from the New Zealand flora: a preliminary study in secondary forest. *N Z J Bot* 37: 679–685.

MOORE, P.D. 2001. Ecology: The guts of seed dispersal. *Nature* 414: 406-407.

MORDEN-MOORE, A. L. and WILLSON, M. F.1982. On the ecological significance of fruit color in *Prunus* and *Rubus*: field experiments. *Can. J. Bot.* 60:1554-1560.

MORTON, E. S. 1973. On the evolutionary advantages and disadvantages of fruit eating in tropical birds. *American Naturalis*t 107: 8-22.

MURALI, K.S 1992. Vegetative and reproductive phenology of a tropical dry deciduous forest, Southern India. Ph.D. thesis. Centre for Ecological Sciences, Indian Institute of Science, Bangalore

MURALI, K.S. AND SUKUMAR, R. 1994. Reproductive phenology of a tropical dry forest in Mudumalai, southern India. *Journal of Ecology* 82: 759-767.

MURRAY, K.G., RUSSELL, S., PICONE, C.M., WINNETTMURRAY, K., SHERWOOD, W. and KUHLMANN, M.L. 1994. Fruit laxatives and seed passage rates in frugivores: consequences for plant reproductive success. *Ecology* 75:989–994

NARENDRAN, K., MURTHY., I. K., SURESH, H.S., DATTARAJA, H.S., RAVINDRANATH, N.H. and SUKUMAR, R. 2001. Non timber forest product extraction utilization and valuation: A case study from the Nilgiri Biosphere Reserve, southern India. *Economic Botany* 55: 528-538.

NAIR, N.G. 1986. Endemic Trees of Western Ghats: Their Importance and Conservation. Proceedings of Seminar on Ecodevelopment of Western Ghats. KFRI Publication. 41-44.

NASON, J. D., P. R. ALDRICH, and J. L. HAMRICK. 1997. Dispersal and the dynamics of genetic structure in fragmented tropical tree populations. Pages 304–320 *in* W. L. Laurance and R. O. Bierregaard, Jr., editors. Tropical forest remnants: ecology, management, and conservation of fragmented communities. University of Chicago Press, Chicago, Illinois, USA.

NEWBERY, D. M., SONGWE, N. C. and CHUYONG, G. B. 1998. Phenology and dynamics of an African rainforest at Korup, Cameroon. Pp. 267±308 in Newbery, D. M., Prins, H. H. T. and Brown, N. D. (eds). *Dynamics of tropical communities*. Blackwell Science, Oxford.

NEWSTROM, L. E., FRANKIE, G. W., BAKER, H. G. and COLWELL, R. 1994. Diversity of long term flowering patterns. Pp. 142-160 in MCDADE, L. A., BAWA, K. S., HESPENHEIDE, H. A. and HARTSHORM, G. S. (eds). LA SELVA*: ecology and natural history of a neotropical rain forest*. University of Chicago Press, Chicago.

NINA, R. and INGLE. 2003. Seed dispersal by wind, birds, and bats between Philippine montane rainforest and successional vegetation. *Oecologia*. 134: 251-261.

NG, F. S. P. 1983. Ecological principles of tropical lowland rain forest conservation, p. 359–375. *In*: S L. Sutton, T. C. Whitmore and A. C. Chadwick (eds.). Tropical Rain Forest: Ecology and Management. Blackwell, Oxford.

NOMA, N., and YUMOTO, T. 1997. Fruiting phenology animal-dispersed plants in replnse to winter migration of frugivores in warm temperate forest on Yakushima Island, Japan. *Ecological Research* 12: 119-129.

NYSTRAND, O and GRANSTROM, A. 1997. Post-dispersal predation on *Pinus sylvestris* seeds by *Fringilla* spp: ground substrate affects selection for seed color. *Oecologia* 110:353–359

OPLER, P. A., FRANKIE, G. W. and BAKER, H. G. 1976. Rainfall as a factor in the release, timing, and synchronization of anthesis by tropical trees and shrubs. *Journal of Biogeography* 3:231-236.

ORR SPIEGEL and RAN NATHAN. 2007. Incorporating dispersal distance into the disperser effectiveness framework: frugivorous birds provide complementary dispersal to plants in a patchy environment. *Ecology Letters*:10: 718–728

PARCIAK, W. 2002. Environmental variation in seed number, size, and dispersal of a fleshy-fruited plant. *Ecology*, 83, 780–793.

PASCAL, J.P. 1988. Wet evergreen forests of the Western Ghats of India: ecology, sturucture, floristic composition and succession. French Institute, Pondicherry, India.

PHILLIPSs, E.A. 1959. Methods of Vegetation Study. A HoltDryden Book. Henry Holt and Co.

PIZO, M. A. 1997. Seed dispersal and predation in two populations of Cabralea canjerana (Meliaceae) in the Atlantic Forest of southeastern Brazil. *Journal of Tropical Ecology* 13: 559-578.

POULIN, B., WRIGHT, S. J. and LEFEBVRE, G. 1999. Interspecific synchrony and

asynchrony in the fruiting phenologies of congeneric bird-dispersed plants in Panama. *J. Trop. Ecol.* 15: 213-227

PRASAD, S. N. and HEDGE, M. 1986. Phenology and seasonality in the tropical deciduous forest of Bhandipur, South India. Proc Indian Acad Sci *Plant Sci,* 96:121–133

PREMALATHA S., SANIL R. and FRANKLIN CHARLES JOSE. 2009. Shola trees in the upper Nilgiris of Western Ghats. *Journal of Basic and Applied Biology* 3(3and4), 97-102

PUTZ, F.E. 1979. Aseasonality in Malaysian tree phenology. *Malaysian Forester* 42:1-24.

RATHKE, B. and LACEY, E. P. 1985. Phenological patterns of terrestrial plants. *Annual Review of Ecology and Systematics* 16:179-214.

RAWAT, G.S, P.V. KARUNAKARAN, and V.K UNIYAL. 2003. Shola grasslands of the Western Ghats: conservation status and management needs. *ENVIS Bulletin on Grassland Ecosystems and Agroforestry* 1(1):57-64.

REID, S. and ARMESTO, J.J. 2011. Interaction dynamics of avian frugivores and plants in a Chilean Mediterranean shrubland. *Journal of Arid Environments* 75: 221-230

REY, P. J., GUTIERRE, J. E. ALCANTARA, J.and VALERA, F. 1997. Fruit size in wild olives: implications for avian seed dispersal. *Functional Ecology* 11:611–618.

REY, P.J. and ALCANTARA, J.M. 2000. Recruitment dynamics of a fleshy fruited plant (*Olea europaea*): connecting patterns of seed dispersal to seedling establishment. *Journal of Ecology* 88, 622–633.

RICHARDS, P. W. 1952. The Tropical Rainforest. Cambridge University Press, Cambridge.

RICHARDS, P. W. 1996. *The tropical rain forest.* (Second edition.) Cambridge University Press, Cambridge. 575 pp.

RIDELY, H.N. 1930. The dispersal of plants throughout the world. Reeve and Co., Ltd., Ashford, UK. 744 pp.

RIVERA, G., ELLIOTT, L. S. CALDAS, G. NICOLOSSI, V. T. R. CORADIN and BORCHERT. R. 2002. Increasing day-length induces spring flushing of tropical dry forest trees in the absence of rain. *Trees-Struct. Funct.* 16: 445–456.

ROBBINS, C.T. 1993. *Wildlife Feeding and Nutrition.* Academic Press, San Diego, CA, USA.

RODGERS, W.A., PANWAR, H.S. and MATHUR, V.B. 2000. Wildlife Protected Area Network in India. An review. Wildlife Institute of India. Dehra Dun, India.

SAMUELS, J.A. and LEVEY, D.J. 2005. Effects of gut passage on seed germination: do experiments answer the questions they ask? *Funct. Ecol* 19: 365-368.

SANJAPPA, M.1991. endemic Legumes of Western Ghats: 31-43, in KARUNAKARAN C.K. (ed.), Proceedings of the Symposium on Rare, Endangered and Endemic Plants of Western Ghats. Kerala Forest Department, Thiruvananthapuram.

SANTHOSHKUMAR, E. 2010. Studies on frugivory and seed dispersal by Indian Grey Hornbill (*Ocyceros birostris*) in Sathyamangalam Forests Division. Eastern Ghats. Ph.D thesis, Bharathiar University pp.124.

SANTHOSHKUMAR, E. and BALASUBRAMANIAN, P. 2011. Seed dispersal by the Indian Grey Hornbill Ocyceros birostris in Eastern Ghats, India. *Ecotropica.* 17: 71-77.

SANDRA FREITAL DE VASCONCELOS, FRANCISEA DE ARAIIJO, ARIADNA VALENTINA LOPES. 2010. Phenology and dispersal modes of wood species in the Carraco, a tropical deciduous shrubland in the Brazilian semiarid. *Biodiversity and Conservation* 19: 2263-2289.

SCHUPP, E.W. 1993. Quantity, quality and the effectiveness of seed dispersal by animals. *Vegetatio* 107/108: 15-29.

SCHUPP, E.W. 1995. Seed–seedling conflicts, habitat choice, and patterns of plant recruitment. *American Journal of Botany* 82, 399–409.

SEKERCIOGLU, C.H., DAILY, G.C., EHRLICH, P.R., 2004. Ecosystem consequences of bird declines. PNAS 101, 18042–18047.

SHARMA, B.D. 1977. Studies on the flora of Nilgiris, Tamil Nadu. *Angiosperm Taxonomy. Biol. Memoirs* 1-2: 2- 286.

SHARMA, S. K., EORGE, M. and PRASAD K.G. 1983. Forest vegetation survey and classification with special reference to South India-Vegetation survey and quadrat analysis. *Indian Forester* 384-393.

SHIBU JOSE, A., SREEPATHY, B. MOHAN KUMAR, V.K. and VENUGOPAL. 1994. "Structural, floristic and edaphic attributes of the grassland-shola forests of Eravikulam in peninsular India". *Forest Ecology and Management* 65 (2and3): 279–291.

SHIMWELL, D.W. 1972. The Description and Classification of Vegetation. University of Washington Press. Seattle.

SINGH, J.S. and SINGH, V.K. 1992. Phenology of seasonally dry tropical forest. *Current Science*, 63(11): 684-689.

SINGH, K. P. and KUSHWAHA. C.P. 2006. Diversity of flowering and fruiting phenology of trees in a tropical deciduous forest in India. *Ann. Bot.* 97: 265–276.

SKATE S. T. 1987. Interactions between birds and fruits in a northern Florida hammock community. *Ecology* 68: 297-309.

SMITH, A.J. 1975. Invasion and ecesis of bird-disseminated woody plants in a temperate forest sere. *Ecology*, 56, 19–34

SMYTHE, N. 1970. Relationships between fruiting seasons and seed dispersal methods in a neotropical forest. *American Naturalist* 104: 25-35.

SNOW, D. W. 1965. A possible selective factor in the evolution of fruiting seasons in tropical forest. *Oikos* 15:274±281.

SNOW, B. K. 1970. A field study of the Bearded Bellbird in Trinidad. *Ibis* 112:299-329.

SNOW, D. W. 1971 Evolutionary aspects of fruit-eating by birds. *Ibis* 113 194-202.

SNOW, D. W. 1981. Tropical frugivorous birds and their food plants: A world survey. *Biotropica* 13: 1–14.

SOMASUNDARAM, S. 2006. Status and Ecology of the Nilgiri Wood Pigeon in the Western Ghats. Ph.D. thesis, Bharathiar University, Coimbatore

SOMASUNDARAM, S. and VIJAYAN L. 2010a. Foraging cology of the globally threatened Nilgiri Wood Pigeon (*Columba elphinstonii*) in the Western Ghats, India. *Chinese Birds.* 1(1): 9-21.

SOMASUNDARAM, S. and VIJAYAN, L. 2010b. Plant diversity and phenological pattern in the montane wet temperate forests of the southern Western Ghats, India *For. Stud. China*, 12(3): 116–125

SORENSEN, A. E. 1983. Taste aversion and frugivore preference. *Oecologia* (Berlin) 56:117-120.

SORENSON, A.E. 1984. Nutrition, energy and passage times: experiments with fruit preference in European black birds. *J.of. Ani. Ecol.* 53: 545-557.

STATTERSFIELD, A.J., CROSBY, M.J., LONG, A.J., and WEGE, D.C., 1998. Endemic bird areas of the world: priorities for biodiversity conservation. Birdlife International, Cambridge, United Kingdom. *Conservation Series* No. 7. pp 400-402.

STEVENS, C.E. 1988. Comparative Physiology of the Vertebrate Digestive System. Cambridge University Press, Cambridge, UK.

STILES, E.W. 1980. Patterns of fruit presentation and seed dispersal in bird-disseminated woody plants in the eastern deciduous forest. American Naturalist 116: 670-688.

STILES, E. W. 1982. Fruit flags: two hypotheses. *Am. Nat.* 120:500-509

STILES, E.W. 2000. Animals as seed dispersers. In: Fenner, M. (Ed.), Seeds: The Ecology of Regeneration in Plant Communities. CABI Publishing, Wallingford, UK, pp. 111e124.

STONER, K.E., and HENRY, M. 2007. Seed dispersal and frugivry in tropical ecosystems. Encyclopedia of Life Support System. UNESCO-EOLSS.

STUTCHBURY, B.J.M., and MORTON, E.S. 2001. Behavioral Ecology of Tropical Birds. Academic Press, London.

SUN, C., KAPLIN, B. A., KRISTENSEN, K. A., MUNYALIGOGA, V., MVUKIYUMWAMI, J., KAJONDO, K.K. and MOERMOND, T. C. 1996. Tree phenology in a tropical montane forest in Rwanda. *Biotropica* 28:668-681.

SUNDARAPANDIAN, S.M., CHANDERASEKARAN, S., SWAMY, P.S., 2005. Phenological behavior of selected tree species in tropical forests at Kodayan in the Western Ghats, Tamil Nadu, India. *Current Science*. 88: 805-810.

SVEN GUNTER, BERND STIMM, MANUEL CABRERA, MARIA LUISA DIAZ, MANUE LOJAN, EDURDO ORDONEZ, MICHAEL RICHTER and MICHAEL

WEBER. 2008. Tree phenology in montane forests of southern Ecuador can be explained by precipitation, radiation and photoperiodic control. *Journal of Tropical Ecology.* 24:247–258.

TABERRELLI, M., VICENTE, A., BARBSA, DCA. 2003. Variation of seed dispersal spectrum of woody plants across a rainfall gradient in north-eastern Brazil, *J. Arid Environ* 53: 197-210.

TERBORGH, J.W. and DIAMOND, J.M. 1970. Niche overlap in feeding assemblages of New Guinea birds. *Willson Bull.* 82: 29-52.

TERBORGH, J. 1986. Community aspects of frugivory in tropical forests. Pp. 371±384 in Estrada, A. and Fleming, T. H. (eds.). *Frugivores and seed dispersal*. W. Junk Publishers, Dordrecht, The Netherlands.

TERBORGH, J. and VAN SCHAIK, C. P. 1987. Convergence vs. nonconvergence in primate communities. Pp. 205±226 in Gee, J. H. R. and Giller, P.S. (eds). *Organization of communities, past and present*. Blackwell Scientific Publications, Oxford.

THOMPSON, J. N. and WILLSON, M. F. 1978. Disturbance and the dispersal of feshy fruits. *Science* 200:1161-1163.

THOMPSON, J.N., and WILLSON, M.F. 1979. Evolution of temperate fruit/bird interactions: phonological strategies. *Evolution* 33: 973-982.

THOMAS, S. M. THOMAS and PALMER, M. W. 2007. "The montane grasslands of the Western Ghats, India: Community ecology and conservation". *Community Ecology* 8 (1): 67–73

TILMAN, D., LEHMAN, C. L. and KAREIVA, P. 1997. Population dynamics in spatial habitats. Pp. 3-20 in TILMAN, D. and KAREIVA, P. eds. Spatial ecology. The role of space in population dynamics and interspecific interactions. Princeton University Press, Princeton, New Jersey.

TRAVESET, A. 1998. Effect of seed passage through vertebrate frugivores' guts on germination: a review. *Perspectives in Plant Ecology, Evolution and Systematics* 1/2, 151–190.

TRAVESET, A., RIERA, N and MAS, R.E. 2001b. Passage through bird guts causes interspecific differences in seed germination characteristics *Functional Ecology* 15, 669–675.

TRAVESET, A and VERDU, M. 2001a. A meta-analysis of the effect of gut treatment on seed germination. In: Levey DJ, Silva WR, Galetti M (eds) Seed dispersal and frugivory: ecology, evolution and conservation. CAB International, Wallingford, pp 339–350

TRAVESET, A. and VERDU, M. 2002. A meta-analysis of the effect of gut treatment on seed germination. In: LEVEY D.J., SILVA W.R., GALETTI, M. (eds) Seed dispersal and frugivory: ecology, evolution and conservation. CABI Publishing, Wallingford, UK, pp 78-101.

TRAVESET, A., GULIAS, J., RIERA, N. and MUS, M. 2003. Transition probabilities from pollination to establishment in a rare deciduous shrub species (*Rhamnus ludovici-salvatoris*) in two type of habitats. *Journal of Ecology* 91, 427–437

TRAVESET, A., ROBERTSON, A.W. and RODRI GUEZ-PEREZ, J. 2007. A review on the role of endozoochory in seed germination. In: DENNIS, A.J., SCHUPP, E.W., GREEN, R.J., WESTCOTT, D.W. (eds) Seed dispersal: theory and its application in a changing world. CABI Publishing, Wallingford, UK, pp 78–101.

TRAVESET, A., RODRIGUEZ-PEREZ, J. and PIAS, B. 2008. Seed trait changes in dispersers' guts and consequences for germination and seedling growth. *Ecology* 89:95-106

TSUTOMU YAGIHASHI, MIYSIHIRA HAYASIDA and TOSHIZUMI MIYAMOTA 1999. "Effect of bird ingestion on seed germination of two Prunus species with different fruit-ripening seasons. *Ecological Research*. 14:71-76.

TUTIN, C. E. G. and FERNANDEZ, M. 1993. Relationships between minimum temperature and fruit production in some tropical forest trees in Gabon. *Journal of Tropical Ecology* 9:241-248.

VAN DER PIJL, L. 1957. The Dispersal of Plants by Bats (Chiropterochory). *Acta Bot. Nederland*. 6: 291-315.

VAN DER PIJIl, L. 1969. Principles of dispersal in higher plants. Springer-Verlag, New York.

VANDER PIJL, L. 1982. Principles of dispersal in higher plants. Springer-Verlag: Berlin 136: 790–809.

VAN SCHAIK, C. P. 1986. Phenological changes in a Sumatran rain forest. *Journal of Tropical Ecology* 2:327±347.

VANSCHAIK, C.P., TERBORGH, J.W. AND WRIGHT, S.J., 1993. The phenology of tropical forests adaptive significance and consequences for primary consumers. *Annu. Rev. Ecol. Syst.* 24, 353–377.

VENKATEWWARALU, V.L. 1982. External morphology of Angiosperms. S. Chand and Co. Ltd., New Delhi.

VIVIAN-SMITH, G., GOSPER, C.R., WILSON, A. and HOAD, K. 2006. *Lantana camara* and the fruit- and seed-damaging fly, *Ophiomyia lantanae* (Agromyzidae): Seed predator, recruitment promoter or dispersal disrupter? Biological Control 36:247—257

WASER, N. M. and PRICE, M. V. 1991. Out crossing distance effects in *Delphinium nelsonii*: Pollen loads, pollen tubes and seed set. *Ecology*, 72: 171–179..

WENNY, DG. and LEVEY, DJ., 1998. Directed seed dispersal by bellbirds in a tropical cloud forest. Proc. Natl. Acad. Sci. USA, vol. 95, p. 6204-6207.

WENNEY, D.G. 2000. Seed dispersal, seed predation, and seedling recruitment of neotropical montane tree. *Ecological Monographs* 70: 331-335.

WHEELWRIGHT, N. T., and ORIANS, G.H. 1982. Seed dispersal by animals: contrasts with pollen dispersal, problems of terminology, and constraints on coevolution. *Am. Nat.* 119:402-413.

WHEELWRIGHT, N. T. 1983. Fruits and the ecology of Resplendent Quetzals (Pharomachrus mocinno). Auk 100:286–301.

WHEELWRIGHT, N. T., and JANSON. C. H. 1985a. Colors of fruit displays of bird-dispersed plants in two tropical forests. *Am. Nat.* 126:777-799.

WHEELWRIGHT, N.T. 1985b. Competition for dispersers and the timing of flowering and fruiting in a guild of tropical trees. *Oikos* 44: 564-477

WHITE, L. J. T. 1994. Patterns of fruit-fall phenology in the LopeÂ Reserve, Gabon. *Journal of Tropical Ecology* 10:289-312.

WHITNEY, K.D., and SMITH, T.B. 1998. Habitat use and resource tracking by African Ceratogymna hornbill: implications for seed dispersal and forest conservation. *Animal Conservation* 1: 107-117.

WHITTAKAR, R.J. and JONES, S.H. 1994. The role of frugivorous batas and birds in the rebuilding of a tropical forest Ecosystem, Krakattu, Indonesia. *J. of Biogeo.* 21: 245-258.

WILLIAMS-LINERA, G. 1997. Phenology of deciduous and broadleaved-evergreen tree species in a Mexican tropical lower montane forests. Global *Ecol Biogeogr Lett* 6:115–127.

WILSON, D. S. 1975. The adequacy of body size as a niche difference. *American Naturalist* 109:769-784.

WILLSON, M. F., and THOMPSON, J. N. 1982. Phenology and ecology of color in bird-dispersed fruits. *Can. J. Bot.* 60:701-713.

WILLSON, M.F., A. K. IRVINE and N.G. WALSH 1989. Vertebrate dispersal syndromes in some Australian and New Zealand plant communities with geographic comparisons. *Biotropica*, 21(2): 133-147.

WILLSON, M.F. 1992. Biodiversity and ecological processes. In Szaro, R.C. and D.W. JOHNSON (eds.). Biodiversity in managed landscapes, pp. 96-107. Oxford University Press, New York.

WILLSON, M.F., and TRAVESET, A. 2000. The ecology of seed dispersal. Pp. 85-110. In: Seeds: The ecology of regeneration in plant communities. 2nd Edition. M. FENNER (ed.). CAB International, Walllingfore, UK.

WITMER, M.C. and CHEKE, A.S. 1991. The Dodo and the Tambalacoque tree: an obligate mutualism reconsidered. *Oikos* 61: 133–137.

WRIGHT, J. S., and CORNEJO. F. H. 1990. Seasonal drought and the timing of flowering and leaf fall in a Neotropical forest. *In* K. Bawa and M. Hadley (Eds.). Reproductive ecology of tropical forest plants, pp. 49–61. Parthenon, Park Ridge, New Jersey.

WRIGHT, S. J. and CALDERON, O. 1995. Phylogenetic patterns among tropical flowering phenologies. *Journal of Ecology* 83:937– 948.

YAGIHASHI, T., HAYASHIDA, M. and MIYAMOTO, T. 1998. Effects of bird ingestion on seed germination of Sorbus commixta. *Oecologia.* 114: 209–212.

ZAFER-UL ESLAM and RAHMANI, A. R. 2004. Important Bird areas of India priority sites for conservation. Bombay Natural History Society.

ZHANG, G. SONG, Q. and YANG, D. 2006. Phenology of *Ficus racemosa* in Xishuangbanna, Southwest China. *Biotropica* 38(3): 334-341.