STUDIES ON FRUGIVORY AND SEED DISPERSAL BY INDIAN GREY HORNBILL (*Ocyceros birostris*) IN SATHYAMANGALAM FOREST DIVISION, EASTERN GHATS

Thesis submitted to the

BHARATHIAR UNIVERSITY, COIMBATORE

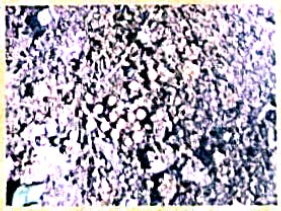
for the Degree of Doctor of Philosophy

In

BOTANY

By

E. SANTHOSH KUMAR



SACON **Division of Landscape Ecology**

Salim Ali Centre for Ornithology and Natural History

Coimbatore

May 2010

STUDIES ON FRUGIVORY AND SEED DISPERSAL BY INDIAN GREY HORNBILL (*Ocyceros birostris*) IN SATHYAMANGALAM FOREST DIVISION, EASTERN GHATS

Thesis submitted to the

BHARATHIAR UNIVERSITY, COIMBATORE

for the Degree of Doctor of Philosophy

In

BOTANY

By

E. SANTHOSH KUMAR

SACON

Division of Landscape Ecology

Sálim Ali Centre for Ornithology and Natural History

Coimbatore

May 2010

CERTIFICATE

This is to certify that the thesis, entitled "Studies on frugivory and seed dispersal by Indian Grey Hornbill (*Ocyceros birostris*) in Sathyamangalam Forest Division, Eastern Ghats" 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. E. Santhosh kumar during the period July 2006 to May 2010 of his research in the Department of Landscape Ecology at Sálim 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.

Countersigned

Director

डा. पी ए अजीज / Dr. P A Azeez
निदेशक / Director
सालिम अली पक्षीविज्ञान एवं प्राकृति विज्ञान केन्द्र
Sálim Ali Centre for Ornithology and Natural History
आनैकट्टी / Anaikatty (Post)
कोयम्बटूर / Coimbatore 641 108

Signature of the Guide

Dr. P. Balasubramanian M.Sc., Ph.D.
Principal Scientist
Salim Ali Centre for Ornithology
and Natural History
Anaikatty P.o, Coimbatore - 641 108.

DECLARATION

I, E. Santhosh kumar hereby declare that the thesis, entitled "Studies on frugivory and seed dispersal by Indian Grey Hornbill (*Ocyceros birostris*) in Sathyamangalam Forest Division, Eastern Ghats" 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 July 2006 to May 2010 under the supervision and guidance of Dr. P. Balasubramanian, Division of Landscape Ecology, Sálim 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

ACKNOWLEDGEMENTS

It is with great respect and devotion, I express my deep sense of gratitude and indebtedness to my research supervisor Dr. P. Balasubramanian, for his reverend guidance, constructive suggestions, unfailing patience, friendly approach, constant support and encouragement during the field work and preparation of this thesis. His kind stewardship throughout the course of study helped me to over come all the insurmountable obstacles.

I express my deep appreciation to late Dr. Ravi Sankaran, former Director, SACON. I extend my gratitude to Dr. P.A. Azeez, Director and other faculty at SACON, Drs. Lalitha Vijayan, S.N. Prasad, S. Bhupathy, S. Muralidharan, P. Pramod and Shrish Manchi for their encouragement and support during meetings and discussions. I am hugely indebted to all the administrative staff of SACON for their timely help throughout the course of my study.

My thanks are due to Tamil Nadu Forest Department for granting permission to carry out the field work. I thank the MoEF for providing grants.

Mr. S. Ramasubramanian, IFS., Divisional Forest Officer, Sathyamangalam Forest Division, himself spent number of hours with me in field and office discussing all about wildlife and conservation. He has been a source of constant support to complete the field work successfully. The forest personnel of Hasanur Range had been very supportive. The guards and watchers helped me a lot in maintaining the nursery put up for germination experiment.

People deserve special acknowledgement for their dedication in work, and the deserved one is J.J. Kumar, my tracker for the whole three year of my field study. His enthusiasm in field work made me to work more hard in the field. His knowledge on forest and field observation, made me admire. Many people in the field station had helped me a lot in fulfilling my daily requirements. I am incredibly grateful to all the kind hearts.

I express my sincere thanks to all friends at SACON for their kind help, support, encouragement, discussion throughout the course of my study. Special thanks to my colleagues who had helped me at field in assessing the vegetation of the study area. I extend my gratitude to all other friends for their encouragement throughout.

My family has been a great source of support and encouragement. I express my deep sense of appreciation to all my family members for their confidence in me and furthering my academic interest.

Upon all I bow my head before Almighty whose blessings are always with me to undertake any venture successfully.

.....Santhosh Kumar, E.

CONTENTS

List of Tables

List of Figures

List of Plates

CHAPTER I

GENERAL INTRODUCTION

1.1. Seed dispersal

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 & Traveset 2000). Seed dispersal refers the removal and deposition of seeds away from parent plants, 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).

Seed dispersal fundamentally influences a plant population's spatial structure and dynamics because it establishes the initial spatial template of offspring dispersion (Russo *et al.* 2006).

For many plant species, seed dispersal is one of the most important spatial demographic processes, directly influencing the colonization of new habitats,

population dynamics, genetic differentiation, and species interactions, as well as community structure and diversity (Nathan & Muller-Landau 2000).

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, where the seeds are attached to the outside of the animal's body or endozoochory, when the seeds are swallowed and ultimately dispersed by means of defecation (Stoner & Henry 2007).

Griz & Machado (2001) reported that among the four dispersal syndromes considered, zoochory was the most common dispersal mode represented by 36% followed by an anemochory 33%, ballistic dispersal 19% and barochory 12%.

Zoochory 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. A true mutualistic interaction only exists between a particular seed species and its disperser when both receive a benefit from the interaction.

Of the various seed dispersal mechanisms, endozoochory is the most important. Fruit eating mammals and birds are the most important vertebrate groups responsible for endozoochorous seed dispersal. Animals of all sorts and sizes

help plants to disperse their seeds. The method they use depends on the type of seed. To attract the mammals and birds and encourage them to be the seed carriers, plants often surround their seeds with a brightly-coloured pulp.

Seed dispersal consists of the removal of a fruit from a tree and the deposition of seeds in a particular area. The time required for seeds to pass through the digestive tract affects the fate of swallowed seeds. In that, seeds that spend more time in the digestive tract are generally deposited at greater distances from the mother plant and frequently consist of one species. Animals with short gut retention times more often deposit seeds closer to the mother plant and usually create mixed species seed shadows. Furthermore, the action that occurs in the gut may promote seed germination success or acids in the stomach make them viable. The distance that different animals move and their foraging pattern also affect the fate of dispersal. In general, animals that travel widely in a day will deposit seeds over a greater area than mammals that intensively exploit a smaller day range moving shorter distances. Finally, defecation patterns also affect seed dispersal, in that they may be deposited in high-density clumps, singly, or in low density clumps.

1.1.1. Fruit - frugivore interaction

Fruit - frugivore interactions play a pivotal role in maintaining the structural and functional integrity of natural ecosystems (Balasubramanian & Maheswaran 2002). Basic knowledge about fruit-frugivore interactions and especially the seed

dispersal process in forest ecosystems is essential for conservation of endangered animals and the forest itself (Corlett 1998; Da Silvaj & Tabarelli 2000). Avian seed dispersal mutualisms were once thought to be characterized by stable ecological relationships between birds and plants. It was argued that consistent bird–fruit interactions favoured the evolution of fruit characteristics to correspond with the foraging behaviour of fruit-eating birds (McKey 1975; Thompson & Willson 1979).

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 & Yumoto 1997), Hong Kong (Corlett 1996), Tamil Nadu state in India (Balasubramanian & Bole 1993; Balasubramanian 1996), North Negros Island in the Philippines (Hamann & Curio 1999; Heindl & Curio 1999), and Kutai National Park in Indonesia (Leighton & 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 & Traveset 2000), but also from changes to germination caused by the passage of a seed through the digestive tract of a vertebrates (Ketring 1973 and Van der Pijl 1982).

1.1.2. Seed dispersal by birds

Large frugivores are considered to be important seed dispersers for many tropical plant species (Kitamura *et al.* 2001). In the tropics up to 90% of tree species rely on frugivorous animals for the dispersal of their seeds (Howe & 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 & Smallwood 1982 and Stutchbury & Morton 2001).

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 and Wenny 2000) and take up a new habitat.

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 (Nasonj & Hamrick 1997 and Da Silvaj & Tabarelli 2000). At the same time, the presence of fruiting trees in fragmented habitats influences the maintenance of frugivorous bird communities (Whitney & 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 and Da Silvaj *et al.* 1996).

The capacity of seeds to germinate after ingestion by frugivores is important for the population dynamics of some plant species and significant for the evolution of plant-frugivore interactions (Traveset 1998). Frugivores functioning as seed dispersers have the necessary effects on the reproductive success of fruiting plants. The effectiveness of a seed disperser is the contribution it makes to the future reproduction of a plant, and has both quantitative and qualitative components. The quantity being the number of seeds dispersed and the quality is the probability that the seed survive and become an adult (Shupp 1993).

Avian seed ingestion increases, decreases, or has no influence on seed germination (Barnea *et al.* 1990). 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 & Heithaus 1981).

The effect that the ingestion of fruits by vertebrate frugivores has on seed germination has received considerable attention (Traveset & Verdu 2001). Many studies show that germination is more successful after seeds pass through the digestive tract of frugivores (mostly birds). Enhancement of germination occurs about twice as often as inhibition, and germination is more likely to be enhanced in trees and shrubs (Traveset 1998).

1.1.3. Seed dispersal by hornbills

Hornbills are all largely frugivorous (Kemp 1995). The larger species are the largest avian frugivores in the region and can handle fruits which are too big for any other bird (Leighton 1986; Kannan & James 1997 and Kemp 1995). Some species can also force open capsular fruits before they dehisce naturally (Leighton & Leighton 1983). Hornbills may be the only dispersal agents for some large, capsular fruits with lipid-rich arils, such as those produced by many Meliaceae and Myristicaceae (Leighton 1986), but most species also eat large amounts of smaller, mostly sugar-rich fruits. (Kemp 1995; Kinnaird & O'Brian 1999 and Suryadi *et al.* 1996). Surprisingly for such huge birds, only the smallest seeds are defecated and larger seeds are regurgitated intact (Kemp 1995). Fruit processing in the gut is slow, with both regurgitation and defecation occurring, on average, an hour or more after the fruit was swallowed (Kemp 1995). A large hornbill can carry up to 500 g of fruit (Kinnaird *et al.* 1996) and many species have large home ranges and long distances in the course of a day (Kemp 1995).

Figs are known to be eaten by all species of birds which also forms an important diet of Asian hornbills. Hornbills undertake long daily movements (13 km by *Aceros cassidix* ; Kinnaird *et al.* 1996; 14±4 km by *Buceros bicornis* ; Poonswad & Tsuji 1994) and may be capable of tracking the spatio-temporal availability of figs (Kinnaird *et al.* 1996). The large size of hornbills implies high levels of fruit and seed intake (*Buceros rhinoceros* consumed 27 *Ficus binnendykii* figs per

minute; Leighton 1986), and their wide gapes allow even large figs to be swallowed whole. Brockelman (1982) noted that hornbills were the only birds capable of eating *F. drupacea* figs whole. Although hornbills regurgitate large seeds, the small *Ficus* seeds are defecated ± gut transit times for fig seeds have been measured as 30 min (*Buceros bicornis*; Lambert 1989) and Whitney *et al.* (1998) showed that hornbills defecate fig seeds intact. Together, these observations suggest that hornbills are important dispersers of *Ficus* species. Hornbills have a potentially significant role in dispersal, germination and predation of seeds (Kemp 1995).

Few detailed studies on seed germination as influenced by hornbills have been done worldwide (Kolp *et al.* 2000; Balasubramanian & Maheswaran 2002; Cahill 2003; Poonswad 1995; Kinnaird 1998 and Kitamura *et al.* 2004a). Whitney *et al.* (1998) reported enhanced germination percentage after passing through hornbill guts.

The prominent role played by hornbills in the dispersal and regeneration of seeds of trees makes them important contributors to the maintenance of forest structure (Whitney *et al.* 1998; Whitney & Smith 1998; Holbrook & Smith 2000 and Poulsen *et al.* 2002).

1.2. The Hornbills

Class : Aves

Order : Coraciiformes

Sub order : Bucerotes

Family : Bucerotidae

The hornbills are one of the most recognizable groups among birds. The long decurved bill is their most obvious feature, this being surrounded by a casque that is unique among avian families. In many hornbill species, the casque is developed as a large imposing structure. Through both their active behaviour and loud calls, the hornbills form the most conspicuous birds wherever they occur. Hornbills are distributed in Sub-saharan Africa, Australia, South East Asia and India.

1.2.1. General habits

Hornbills are mostly birds of forests, depends on trees for fruit resources and nesting requirements. Hornbills are diurnal birds and begin their day at first light. They emerge from the roost to perch in the open for a while, calling, before they move off to forage. Those hornbills which feed on evenly dispersed food sources, like insects can begin to feed from the moment they leave the roost and continue feeding as they move about during the day. Other species which feed at patchy food sources such as fruiting trees may have to fly long distance before they can

stand to feed and they then have to spend period during the day in moving between different feeding sites. Usually, hornbills move around in pairs or in small family groups after the breeding season. But in the breeding season the male alone move, while the female stay in the nest.

Most hornbills return rightly to the same roost site, or have selection of regular sites within their territory amongst which they alternate at irregular intervals. Only a few species do not have regular roost site, they fly up in to a tree or to a cliff at whatever place they happen to end the day.

Loud calling can occur at any time of the day. It is usually most frequent in the early morning. The loud calls of most bucerotid species are among the most obvious of all animal sounds wherever these birds occur. The reasons for this are that hornbills tend to be conspicuous birds, and they need to make their presence known to one another. Calls are an especially useful means of communication, in dense habitats. Most hornbill species can be easily identified by their calls.

1.2.2. Food and feeding habits: Most hornbills are omnivorous, eating a combination of animal and vegetable foods, although there is a tendency for each species to eat mainly fruit or small animals. Each species of hornbill has specific food preferences, foraging techniques and within the forests, preferred foraging heights. Most of the predominantly frugivorous species live in forests, while the species with carnivorous tendencies live in Savanna habitats.

The proportions of different types of food in the diet vary during the year, depending mainly on availability (Kannan & James 1999). According to Kannan & James (1997), ripe fruits of three main categories are eaten by hornbills. These are figs, capsular fruits and juicy fruits. However, during nesting period the frugivorous species become carnivorous and include more animal protein in their diet. Most hornbills never drink water. Water must be obtained from the food, so some food may be selected more for its liquid than for its nutritional content.

Hornbills hunt for fleshy fruits in the forest patches and during this process, disperse the seeds of their food plants away from their parent plant, thus acting as mobile link in the tropical forest ecosystem (Kinnaird 1998 and Whitney *et al.* 1998).

1.2.3. Nesting and breeding: Hornbills are secondary cavity nesting birds. It is the nesting habits of hornbills that have most attracted the attention of naturalists, and in particular the unique habit of the female sealing herself into a nest cavity and leaving only a narrow slit through which the male passes her food. Even more interestingly, the female hornbill, often become flightless through a simultaneous moult of her main flight feathers and tail feathers. Furthermore, she and the chicks keep the nest clean by squirting their droppings out through the slit in the sealed nest entrance. The excreta are squirted out through the nest entrance by an elaborate and stereotyped behaviour. This involves turning away from the entrance and reversing up to the slit, positioning the anus, and then

defecating with considerable force. This results in a faecal shadow on the ground and on the vegetation below the nest, which is called as middens.

1.2.4. Seed dispersal: Hornbills, being primary frugivores of tropical forests, play a vital role in seed dispersal and germination (Kemp 1995). The method of selecting fruit also aids dispersion, such as opening fresh capsule before other seed predator can enter, selecting ripe and insect free fruits, dropping many fruits and not damaging seeds during ingestion. They are capable of dispersing over several kilometers, resulting in even spread of seedlings.

1.2.5. Status: A total of 54 species of hornbills are known world wide which are distributed from Sub-Saharan Africa through India and the islands of Malaysian archipelago, to as far as New Guinea and the Solomon Islands, among which 9 species are distributed in India (Kemp 1995).

Of the 54 species of hornbill, no fewer than 9 are currently considered threatened, all of them oriental region, 12 are near-threatened species. Seven of the threatened species are restricted to small oceanic islands. Apart from the habit alteration, the main threats to hornbills come from hunting for food and traditional medicines and robbing of nests for food or aviculture trade.

1.2.6. Hornbills in India: Nine species occur in India (Ali & Ripley 1987). Most species of hornbills in India are facing survival pressure due to fragmentation of habitats (Chattopadhyay 1985), poaching of adults as well as nestlings (Ali &

Ripley 1987). Off the nine species, four species, the Bar Pouched Wreathed Hornbill *Aceros undulates*, Oriental Pied Hornbill *Anthracoceros albirostris*, Indian Grey Hornbill *Ocyceros birostris* and Malabar Grey Hornbill *O. griseus* are known to be safe. While the Narcondam Hornbill *Aceros narcondami* and Rofous-necked Hornbill *A. nipalensis* have been recognized as vulnerable, Tickell's Brown Hornbill *Anorrhinus tickelli*, Malabar Pied Hornbill *Anthracoceros coronatus* and Great Hornbill *Buceros bicornis* are categorized as near threatened (BirdLife International 2001).

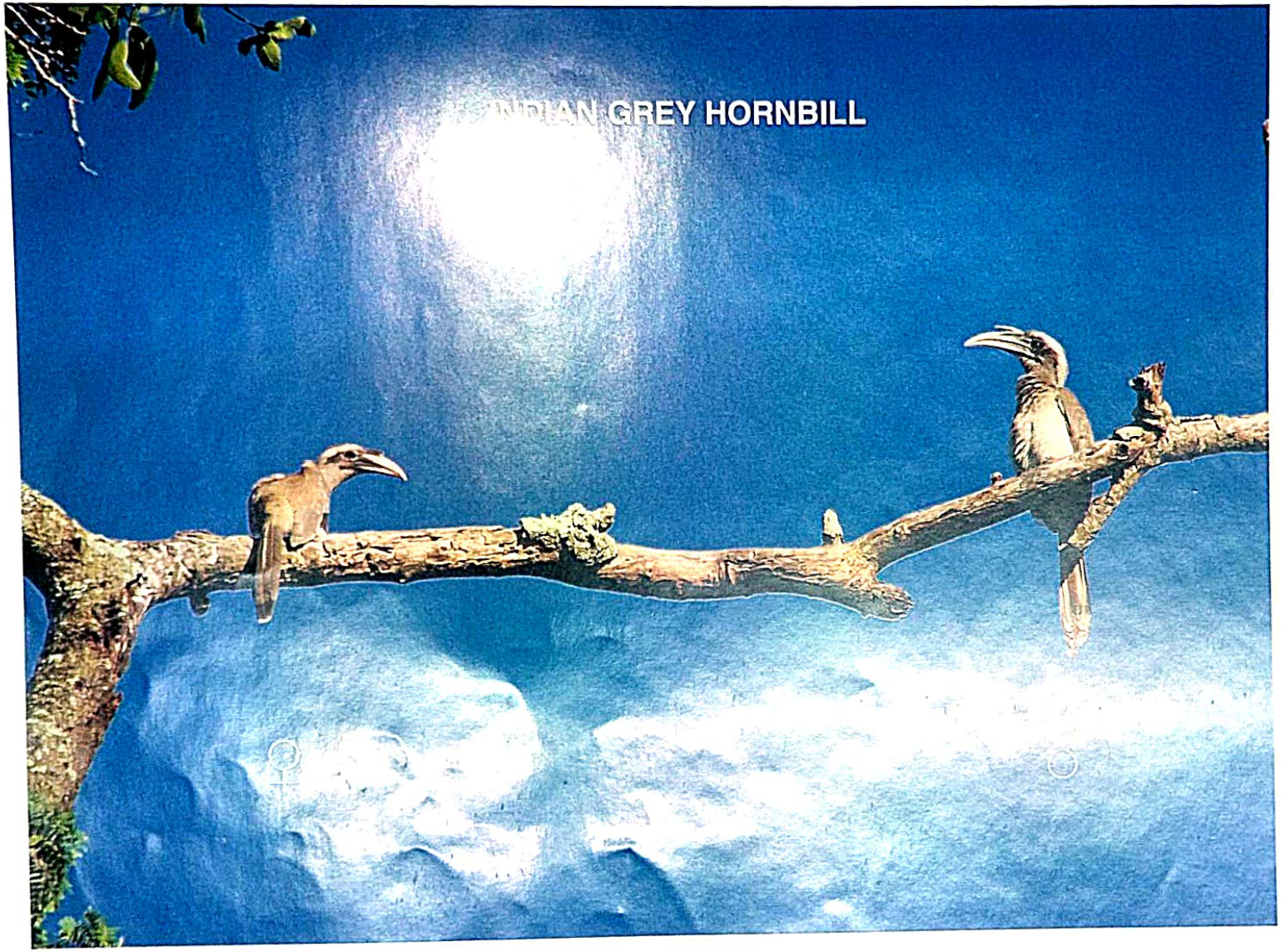
1.2.7. Study species: Indian Grey Hornbill (*Ocyceros birostris*)

Source: Ali & Ripley (1987)

Distribution: NE Pakistan, S. Nepal & NW Bangladesh, South though West of India (except SW & E Coasts).

Descriptive notes: Indian Grey Hornbill measures 50 cm long and mean mass of male bird is 375 g. It is a small silvery grey and white hornbill with long tail graduated with dark and light tip. Male has a blackish bill and narrow casque, later with protruding front edge, bill tip and lower mandible are pale yellow in colour. Female birds are considerably small with less prominent casque. Eyes reddish brown, juvenile with small pale yellow casqueless bill.

PLATE I



Habit: Deciduous wood land, park land and open thorn forest, especially among scattered fig trees and in areas of rural cultivation.

Food & Feeding: Mainly small fruits, especially figs also take various insects, lizards, mice and nestlings. Rarely flower petals. Flies from tree to tree in search of food, some time hop about ground or flies up to hawk insects.

Breeding: Lay eggs mainly in Feb or May to June at the end of dry season. Possibly co-operate at times, with additional male helpers. Nest in natural cavity. 3-13 m up in trees, lined with bark flake. Females seals the entrance with their own dropping, clutch 2-5 eggs, following pre laying period of 7-10 days. Incubation 21 days.

Movements: Generally resident, except for some local movements to keep track for fruiting trees.

Status: Not globally threatened. Wide spread, often common in broad range of habitats. Extensive range includes several reserve areas. Also co-exists well with humans at rural areas.

According to Ali and Ripley (1970), the Indian Grey Hornbill is reported to be a resident species, subjected to local movements depending on the fruit availability. This species is reported common in the Eastern Ghats (Balasubramanian *et.al.* 2005) particularly found in the dry deciduous forests.

CHAPTER II

STUDY AREA

The study was carried out in Sathyamangalam Forest Division, Eastern Ghats, India (Plate II).

2.1. Eastern Ghats

The Eastern Ghats is not a continuous range of mountains like that of Western Ghats but an assemblage of series of much broken hills because of the great rivers that cut across them. Eastern Ghats forms an important habitat for the diversified biota across the east coast of India traversing through the states of Tamil Nadu, Karnataka, Andhra Pradesh and Orissa. They are located between 11°30' and 22° N latitude and 76° 50' and 86°30 E longitude in a North-East to South-West strike. It covers a total area of around 75,000 sq. km. (Murthy et al. 1982), extending 1750 km in length with a width of about 100 km. The climate regime of the Eastern Ghats is tropical monsoon, with an average rainfall of 1000–1600 mm annually. The mean temperature ranges between 20-25°C during winter and 30-32°C in summer. The Eastern Ghats region has a special importance as an en-route for several major rivers, Mahanadi, Godavari, Krishna, Pennar and Cauvery, before they reach the Bay of Bengal (Murthy et al. 1982). Eastern Ghats carry a heap of ecological importance. This diversified topography has become a sanctuary for numerous plant and animal species in general and

endemic flora and fauna in particular. The Eastern Ghats flora and fauna are consistently subjected to threats from both natural and anthropogenic activities.

Eastern Ghats along the peninsular India can be divided in to Northern Eastern Ghats (Orissa), Middle Eastern Gahts (Andhra Pradesh) and Southern Eastern Ghats (Tamil Nadu and Karnataka).

Eastern Ghats of Orissa (Northern Eastern Ghats): This has a rich tropical forest cover which represents 45% of total geographical area. The diverse landscape includes sal dominant forests in the northern and central districts that cover 55.3% of the forest area. A total of 1173 angiosperms were reported here (Murthy *et al.* 2007).

Eastern Ghats of Andhra Pradesh (Middle Eastern Ghats): The total forest area in Eastern Ghats of Andhra Pradesh is 23,894 sq km, which occupies 24.2% of the total geographical area. The forests are broadly classified into dry deciduous, the moist deciduous and semi-evergreen types. The extent of anthropogenic pressure is more in Andhra Pradesh as evident from the larger spatial extent in the high disturbance regimes in the vegetated areas. About 1008 species of angiosperms were recorded from the State (Murthy *et al.* 2007).

Eastern Ghats of Tamil Nadu and Karnataka (Southern Eastern Ghats): Eastern Ghats of Tamil Nadu is broken in to several hills in Tamil Nadu, covers an area of 42,653 sq km. A total of 7,991.6 sq km or 18.7% of the total geographic area is

under forest cover. The Eastern Ghats also extend to two districts of Karnataka namely Chamrajnagar and Kolar, which are contiguous to Northwest borders of Tamil Nadu. These districts have a total of 2,902 sq km area (20.3%) under forest cover. Dry mixed deciduous forests followed by southern thorn forest and mixed moist forests dominate the region (Murthy *et al.* 2007).

2.2. Fauna of Eastern Ghats: The diversified ecological niches and environmental situation provide habitat for rich fauna. Eastern Ghats is home to largest number of Asiatic elephants (*Elephas maximus*) in the world. Other large animals such as Leopard (*Panthera pardus*), Gaur (*Bos gaurus*), Sambar (*Cervus unicolor*) and Tiger (*Panthera tigris*) abound the landscape. Apart from this, these ghats are known for the occurrence of wide variety of bird species. Avifauna of this region is highly diverse. About 470 species of birds are found in this region (Senapathi 2003).

2.3. Flora of Eastern Ghats: The Eastern Ghats is one of the nine floristic zones in India. In Eastern Ghats besides natural vegetation, there are numerous exotic species widely spread through out the Ghats (Pullaiah & Muralidhara Rao 2002). On the basis of dryness, Ahmedullah & Nayar (1986) divided Eastern Ghats in to two types namely northern zone of moist deciduous type with *Shorea robusta* and southern dry deciduous forest region with *Shorea tumbuggaia*, *Hardwickia binata* type.

The number of flowering plants and endemic taxa in the Eastern Ghats is about 3200 and 146 respectively (Reddy *et al.* 2003). According to the classification of Champion & Seth (1968), vegetation in Eastern Ghats can be broadly classified into evergreen forest, tropical semi-evergreen, tropical moist deciduous, southern tropical deciduous, northern mixed deciduous, dry Savannah, Scrub, tropical dry evergreen and tropical dry evergreen scrub.

2.4. Climate: The Eastern Ghats falls under tropical monsoon climate receiving rainfall from both south-west monsoon and north-east retreating monsoon. In the northern part, the annual rainfall ranges from 115 to 160 cm indicating the sub-humid climate. In the central and southern parts, the mean annual rainfall ranges from 60 to 105 cm exhibiting semi arid climate. Heavy winter rains coupled with cyclonic storms are the characteristics of the eastern portion, especially in the coastal plains. The maximum temperature shoots up to 43°C during hot season, and the night temperature goes down to 20°C during winter. The humidity is quite high in rainy season (70 – 75%). The diversity and distribution of plant and animal communities within the hill ecosystem of south India are influenced primarily by the number of rainy months and altitude (Murthy *et al.* 1982).

2.5. Southern Eastern Ghats: The low hilly area in the west south-west direction meeting the high mountain ranges of the Western Ghats in the Nilgiri belt, covering the Tamil Nadu districts of North Arcot (Javadi hills), South Arcot

(Gingee hills), Salem (hills of Shevaroy, Kalrayan), Namakkal (Kollimalai, Bodamalai, Nainamalai, Chitramalai), Dharmapuri (Melagiri hills), Tiruchirapalli (Pacchamalai hills), Coimbatore (Sathyamangalam range) and also Karnataka districts of Bellary (Sandoor hills) and Mysore (Biligirirangan hills) represents the southern Eastern Ghats.

Kolli hills of Eastern Ghats lie in Salem and Namakkal districts of Tamil Nadu between 11°19′ - 11°30′ N. latitude and 75°15′ - 75°30′ E. longitude. It forms the foot hill zone of the Eastern Ghats and extends to an area of 418 sq.km. with the elevation of the hill ranging between 600 and 1500 m above mean sea level. The Shevaroy hills come under Salem Forest Division. It is situated in the north east of Salem and forms the major hill range at the southern most point of the Eastern Ghats. It lies between 11°45′ and 11°55′ North latitude and 78°10′-78°20′ East longitude and covers an area of 470 sq.km. The altitude ranges from 400-700 m. The Pacchamalais is situated in the northwestern border of Tiruchirapalli and extends in to the adjoining Salem district. The hill is situated between 11°20′ N latitude and 78°35′-78°51′ E longitude with a total area of 450 sq.km. The boundary between Salem and Tiruchirapalli passes the plateau of Pachamalai leaving only the southern portion of the plateau in Tiruchirapalli Division. The Pacchamalais are separated from the Kollimalais by the narrow Thammampaty Valley.

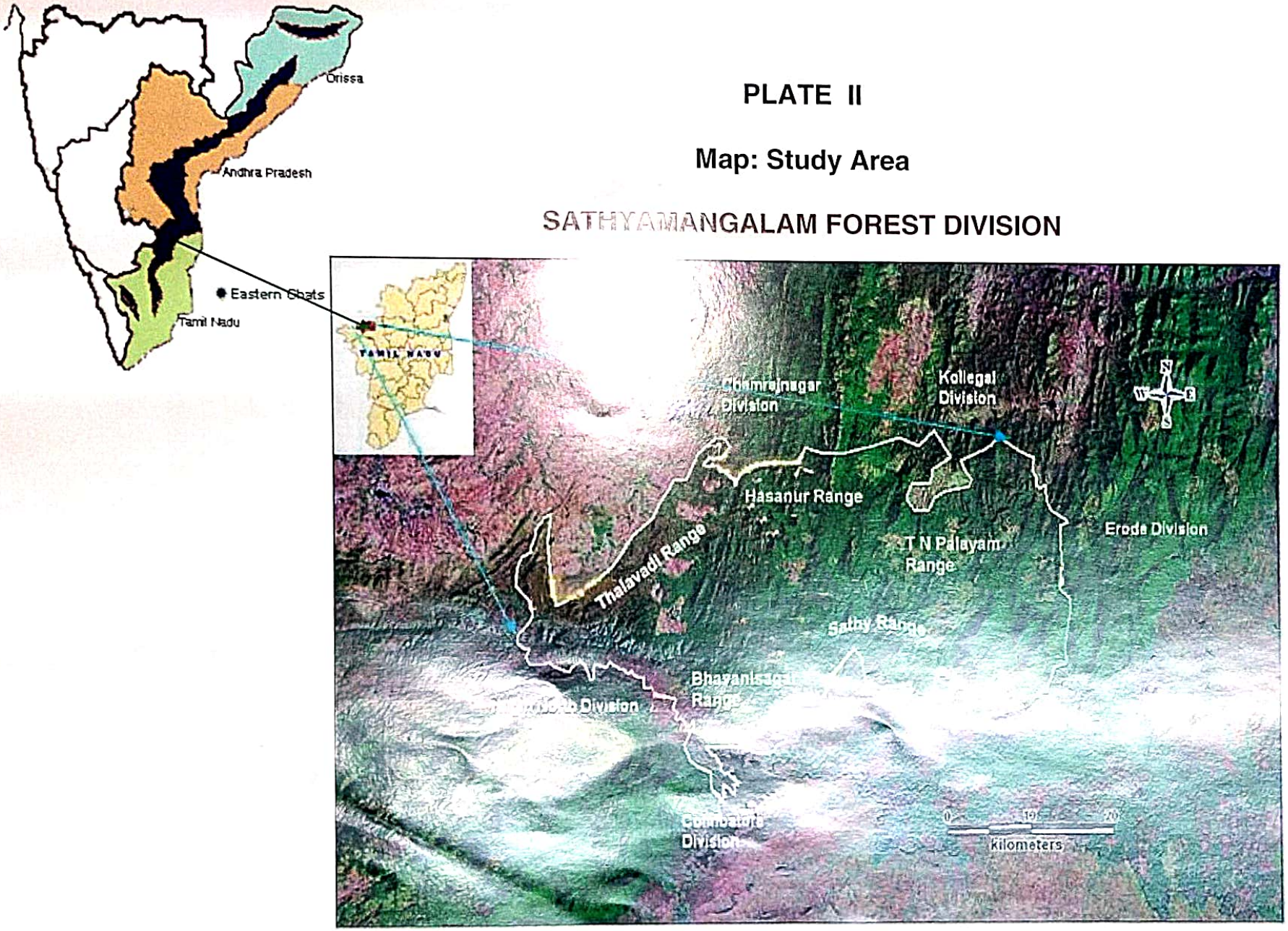
The Javadi hills form an interesting range of hills in North Arcot district, lying between 12°15′ -12°40′ North longitude and 78°2′ and 79° East latitude. The hills run approximately north east and south west towards Eastern portion of Alangayam and Thirupattur. It attains a maximum length of about 60 km and width of about 25 km. The Burgur hills lying in the north eastern side of Erode district has an area of 64729.6 ha. The Alagar hills come under the Alagar koil range in Dindugul Forest Division. It is about 22 km east of Madurai city and lies at 78°5′30′′ E. longitude and 9°55′10′′N latitude. It has a total area of 68.11sq.km. The hill is about 16 km long with three valleys. The Sirumalai/Chinnamalai group of hills spread in four districts of Tamil Nadu, namely, Tiruchirapalli, Dindugul, Karur and Sivagangai. It is situated between 77°33′ - 78°15′ E longitude and 10°39′ N latitude with a total area of 25 sq.km. The Piranmalai hill is located in Sivagangai district and it covers an area of 90 sq.km. Semmalai hills fall in Tiruchirapalli and Dindigul districts and reach a maximum elevation of 1031 m above msl.

2.6. Sathyamangalam Forest Division: The Dhimbam Ghats (Sathyamangalam Forest Division) is located in the Erode district of Tamil Nadu and it lies between 11° 29" - 11° 48" N latitude and 76° 50" - 77° 27" E longitude covering an area of 1455 sq.km. This division is the largest forest division in Tamil Nadu. It shares its border with Chamarajnagar and Kollegal Forest Division of Karnataka state in the northern side, Gobichettipalayam and Sathyamangalam

PLATE II

Map: Study Area

SATHYAMANGALAM FOREST DIVISION



towns in the southern side, Erode Forest Division in the eastern side and Bandipur and Nilgiri North Division in the west.

Elevation of this division varies from 280 to 1698 m above mean sea level. The annual rainfall varies from 600 – 850 mm; it has mosaic of habitats, from dry scrub to wet evergreen forest. This division is rich in biodiversity; the important large mammalian species found in this area are Asian Elephant (*Elephas maximus*), Gaur (*Bos gaurus*), Sambar Deer (*Cervus unicolor*), Spotted Deer (*Cervus axis*), Indian Wild Boar (*Sus scrofa*), Four-horned Antelope (*Tetraceros quadricornis*) etc. The important mammalian carnivores found in this division are Tiger (*Panthera tigris*), Leopard (*Panthera pardus*), Wild Dog (*Cuon alpinus*), Hyena (*Hyaena hyaena*) and Sloth Bear (*Melursus ursinus*). This division is a part of the Eastern Ghats and forms a part of project Elephant Range No.7, where the largest single population of elephants in Asia is found.

Sathyamangalam is one of the most disturbed forests among the forest divisions of Tamil Nadu, because of the presence of many villages in and around. This division is under heavy anthropogenic pressure due to cattle grazing and fuel wood collection. This division is a tropical dry forest straddled across three southern states - Tamil Nadu, Karnataka and Kerala. Spanning over an area of about 18,000 sq km, this division is contiguous with the Biligiri Rangaswamy Temple Wildlife Sanctuary. The vegetation comprises thorn forest, dry deciduous forest and tropical hill forest types. The height of forest decreases gradually

southwards into the arid Coimbatore plains. This division receives most of the rainfall during the southwest monsoon (June-September). Many tribal communities including the Mullu Kurumba and Soliga live in this forest. Dhimbam lies on the National Highway 209 between Bannari and Binakanahalli.

Sathyamangalam is also the name of a Reserve Forest under the Wildlife Protection Act, 1973. The Sathyamangalam Forest Division has been declared as a Wildlife Sanctuary on 3rd December 2008. It is contiguous with the Biligirirangan Temple Wildlife Sanctuary to the north in neighbouring Chamarajanagar District of Karnataka, and together forms a vital corridor for faunal movements, mainly elephants.

2.7. Hasanur range: Hasanur is a plateau whose elevation is about 940 msl. It is located between 11°40'-12.20' N latitude and 77°07'- 87° 7' E longitude. Dry deciduous forest is the principal vegetation type seen here. Riverine forest patches are seen along the stream running through, which ends in Mettur dam. The dry deciduous and riverine patches of the forest are utilized by the Indian Grey Hornbill for feeding and nesting.

CHAPTER – III

REVIEW OF LITERATURE

Extensive research works have been carried out world wide on different aspects of hornbills. Hornbills and their evolutionary history provide an important example for understanding the wonderful biological diversity that currently occupies in the planet earth. On the positive side, some researches have made considerable efforts to study and conserve hornbills.

Detailed study on Indian Grey Hornbill has not been made. Only anecdotal notes were available on Indian Grey Hornbill. Hall (1918) listed some food items consumed by Indian Grey Hornbill. Ali (1979) reported large insects and young mice are also a part of their food items apart from all the regular food. Food items consumed in Sanjay Gandhi National Park was enumerated by Patil *et al.* (1997).

3.1. Studies on hornbills: India

Though Indian hornbills are not completely studied, they have been researched to some extent. Major contributions are by Kannan & James (1997) on Great Pied Hornbill (*Buceros bicornis*), Mudappa (2000), Maheswaran & Balasubramanian (2003) on Malabar Grey Hornbill, Reddy & Basalingappa (1995), Balasubramanian *et al.* (2004) on Malabar Pied Hornbill (*Anthracoceros coronatus*) and Hussain (1984), Yahya & Zarri (2002) on Narcondam Hornbill (*Rhyticeros narcondami*).

Hussain (1984) studied the ecology and behaviour of Narcondam Hornbill in the Narcondam Island. Reddy & Basalingappa (1995) reported on some aspects of food and behaviour of Malabar Pied Hornbill in the North Kanara district of Western Ghats. Kannan & James (1997) documented the breeding biology of the Great Indian Hornbill in the Anamalai hills, Western Ghats. Mudappa (2000) recorded the breeding biology of the Malabar Grey Hornbill at the Indira Gandhi Wildlife Sanctuary in the Anamalai hills of Southern Western Ghats. Balasubramanian & Maheswaran (2002) investigated the food habits and nesting requirements of Malabar Grey Hornbill in the Nilgiri Biosphere Reserve, Western Ghats. Yahya & Zarri (2002) studied the ecology and behaviour of Narcondam Hornbill, *Rhyticeros narcondami* in the Narcondam Island. Datta & Rawat (2003) and (2004) reported the foraging patterns and nesting success of sympatric hornbills during non breeding season in Arunachal Pradesh. Balasubramanian *et al.* (2004) examined the fruit preferences of Malabar Pied hornbill in the Western Ghats.

3.2. Studies on hornbills: Overseas

Moreau & Moreau (1941) studied the breeding biology of Silvery cheeked hornbills, Africa. Poonswad *et al.* (1987) investigated the breeding biology of sympatric hornbill species in Thailand. Kalina (1989) reported the nesting and foraging behaviour of the Black-and-white Casqued Hornbill (*Bycanistes subcylindricus subquadratus*) in Kibale Forest, Uganda. Kinnaird & O' Brien

(1993) observed the breeding biology of endemic Sulawesi Red-knobbed Hornbill in the Indonesian islands. Suryadi *et al.* (1994) examined the food preferences of Sulawesi Red-knobbed Hornbill during the non-breeding season in North Sulawesi, Indonesia. Poonswad (1995) reported the nest site characteristics of four sympatric species of hornbills in Khao Yal National Park, Thailand.

Kinnaird *et al.* (1996) studied the importance of figs for Sulawesi Red-knobbed hornbills in North Sulawesi, Indonesia. Suryadi *et al.* (1996) reported on the home ranges and daily movements of the Sulawesi Red-knobbed Hornbill during the non-breeding season at the Tangkoko-Dua Sundara Nature Reserve, North Sulawesi, Indonesia. O'Brien (1997) investigated the ecology and behaviour of the North Sulawesi Tarictic Hornbill *Penelopides exarhatus exarhatus* during the breeding season in Tangkoko-Dua Sundara Nature Reserve, North Sulawesi, Indonesia. Whitney *et al.* (1998) observed seed dispersal by *Ceratogymna* hornbills in the Daj Reserve, Cameroon. Whitney & Smith (1998) studied the habitat use and resource tracking by African *Ceratogymna* hornbills and their implications for seed dispersal and forest conservation in the Daj Reserve, Cameroon.

Kinnaird (1998) evidenced Sulawesi Red-knobbed Hornbill for effective seed dispersal in the Indonesian island of Sulawesi. Klop *et al.* (2000) documented the breeding biology, nest site characteristics and nest spacing of the Visayan Tarictic Hornbill *Penelopides panini panini* in Philippines. Anggraini *et al.* (2000)

reported on the effect of fruit availability and habitat disturbance on an assemblage of Sumatran hornbills in Bukit Barisan Selatan National Park, Sumatra. Holbrook & Smith (2000) observed the seed dispersal and movement patterns in two species of *Ceratogymna* hornbills in a West African tropical lowland forest. Holbrook *et al.* (2002) reported the implications of long-distance movements of the Black-casqued Hornbill and White-thighed Hornbill in the lowland tropical forests of Cameroon. Cahill (2003) investigated the nest-site characteristics of the Red-knobbed Hornbill *Aceros cassidix* and Sulawesi Dwarf Hornbill *Penelopides exarhatus* in Sulawesi. Kitamura *et al.* (2004a) studied the pattern and impact of hornbill seed dispersal at nest trees in a moist evergreen forest in Thailand. Kitamura *et al.* (2004b) observed the characteristics of hornbill-dispersed fruits in a tropical seasonal forest of Thailand. Hadiprakarsa & Kinnaird (2004) observed the foraging characteristics of an assemblage of four Sumatran hornbill species. Siriporn (2005) investigated the ecology of Wrinkled Hornbill *Aceros* (*Rhyticeros*) *corrugatus* in Bala forest, Bangkok. Thiensongrusamee *et al.* (2005) reported the characteristics of Helmeted Hornbill nests in Thailand. Hulley & Craig (2007) assessed the status of the Southern Ground-Hornbill in the Grahamstown region, Eastern Cape, South Africa. Kitamura *et al.* (2008) observed aggregated seed dispersal by Wreathed hornbills at a roost site in a moist evergreen forest of Thailand.

Information on the role of Indian Grey Hornbill in seed dispersal was lacking. Hence, the present study was undertaken with the following objectives,

I. Determine the frugivorous habit of Indian Grey Hornbill.

II. Establish the role of Indian Grey Hornbill in seed dispersal.

CHAPTER IV

VEGETATION IN HORNBILL HABITATS

Tropical forests are the richest terrestrial ecosystems on the planet. Habitat loss and modifications are considered as the primary threats to the species throughout the world (Heywood 1995). Degradation of forest habitats due to anthropogenic disturbances is the major causes of decline in global biodiversity. A sound knowledge of floristic component is required for appropriate conservation of the biological diversity. Floristic inventory and the monitoring of vegetation form an essential component for the management of wildlife areas, as changes in vegetation influence the distribution and abundance of animal species. Determination of habitat association of species is fundamental for the maintenance of biodiversity and provides baseline data vital to management and conservation (Krusic *et al.* 1996).

Habitat utilization by birds has a long-standing history that dates back to the time of Darwin (1859). The composition of plant species in fragmented landscapes may be influenced by the pattern of visitation by birds to fruiting trees and by the movement of seeds among and within fragments.

The old growth forests in peninsular India have been subjected to various human disturbances which directly affect the survival of frugivorous birds such as hornbills and other vertebrate frugivores. As information on habitat features of

hornbills are essential for conserving the species, vegetation assessment was done in the study area.

4.1. Methods

In the study area, two habitats namely, dry deciduous and riverine forests were found to be used by the Indian Grey Hornbill. Vegetation assessment was done in the above-mentioned habitats and also in a disturbed dry deciduous forest site to assess the loss of food plants by anthropogenic interventions. Disturbed habitat includes dry deciduous forest site which is closer to human settlements, where activities such as fuel wood collection, livestock grazing etc are noticed. Two 1 ha plots (100 X100m) were laid one in each of the disturbed and undisturbed habitats. In each of the habitat, the 1 ha plot was subdivided into 100 sub-plots (10x10m). In each of the 10x10 m plot, number of individuals of trees and GBH (Girth at Breast Height) were noted. To enumerate the riverine forest vegetation, belt transect was located along the river bank. The 1 ha belt transect was divided in to 100 (10 m X 10 m) square plots (used as alternate for 1 ha square plot). All the trees within the belt transect, with Girth at Breast Height (GBH) more than 20 cm were recorded. Data collected were analyzed to obtain quantitative structure and composition of plant communities. Density value was calculated for each species following Curtis & McIntosh (1950). Density is defined as the number of individuals of a species in a unit area. It is an expression of the numerical strength of a species in a community from the

sampling data and was calculated as the total number of individuals divided by the total number of quadrats studied. The relative value of density was determined as per Philips (1959). Relative density (RD) is the study of numerical strength of a species in relation to total number of all species and is calculated as the number of individuals of a species divided by number of individuals of all species, and multiplied by 100. Species diversity of the sampling site was calculated by Shannon Weaver Index (Shannon-Weaver 1949) as given below:

$H' = -\Sigma\, pi \ln pi$

Where H' is the measure of diversity, pi is the proportion of individuals found in the i^{th} species and ln is the natural logarithm.

4.2. Results

4.2.1. Species richness, diversity of trees

The present study shows that the Indian Grey Hornbill's prime habitats in Eastern Ghats include riverine forests and the dry deciduous forests. While the dry deciduous forest is used for foraging, the riverine forests for foraging and nesting. Vegetation assessment indicated the occurrence of 30 tree species in the dry deciduous forests and 64 species in the riverine habitat. While the dry deciduous forests harbour 43% of Indian Grey hornbill's food plant species, riverine forests harbour 38%. Due to anthropogenic activities, the hornbill habitats have become degraded. A comparison of vegetation features of the undisturbed dry deciduous

forest with that of the degraded forest site revealed the loss of 53% of tree species and 65% food plant species in the degraded site.

4.2.2. Dry deciduous forest

A total of 322 trees belonging to 30 species, 28 genera and 17 families were recorded in the 1 ha plot of the dry deciduous forest. Family Rutaceae represented by 5 species followed by Rubiaceae (4 species) were the dominant families. Maximum number of individuals were encountered by *Vitex altissima* (n=69) followed by *Erythroxylum monogynum* (n=62) and *Bambusa arundinacea* (n=34). Mean girth size of tree species ranged from 22 cm to 321 cm and the mean girth size of all trees was 122.95 cm. Maximum relative density values were recorded for *Vitex altissima* (21.43) followed by *Erythroxylum monogynum* (19.25) and *Bambusa arundinacea* (10.56). Highest basal area values were recorded for *Anogeissus latifolia* 1907.93 m^2, *Phyllanthus emblica* 1756.27m^2 and *Butea monosperma* 1596.69 m^2. Most dominant tree species include *Ficus benghalensis* (IVI 46.53), *Bambusa arundinacea* (IVI 39.00) and *Vitex altissima* (IVI 39.00). Shannon's species diversity was worked out to be 2.64.

4.2.3. Riverine forest

A total of 588 trees belonging to 64 tree species, 49 genera and 25 families were recorded in the riverine forests. Moraceae (fig family) represented by 7 species followed by Mimosaceae (6 species) and Fabaceae (5 species) were the

dominant families. Maximum number of individuals were encountered by *Pongamia pinnata* (n=90) followed by *Terminalia arjuna* (n=64) and *Mangifera indica* (n=37). Mean girth size of tree species ranged from 25 cm to 713 cm and the mean girth size of all trees was 203.70 cm. Maximum density was recorded for *Terminalia arjuna* (0.64), *Mangifera indica* (0.37) and *Capparis grandis* (0.35). Highest relative density was recorded for *Pongamia pinnata* (15.31) followed by *Terminalia arjuna* (10.88) and *Mangifera indica* (6.29). Basal area values indicate the predominance of *Terminalia arjuna* (3045269.46m²) followed by *Bambusa arundinacea* (2956863.14 m²) and *Pongamia pinnata* (1008763.43 m²). Dominant tree species in the riverine habitat include *Terminalia arjuna* (IVI 52.35) followed by *Bambusa arundinacea* (IVI 37.69) and *Pongamia pinnata* (IVI 37.55). Shannon's species diversity for tree flora was worked out to be 3.40.

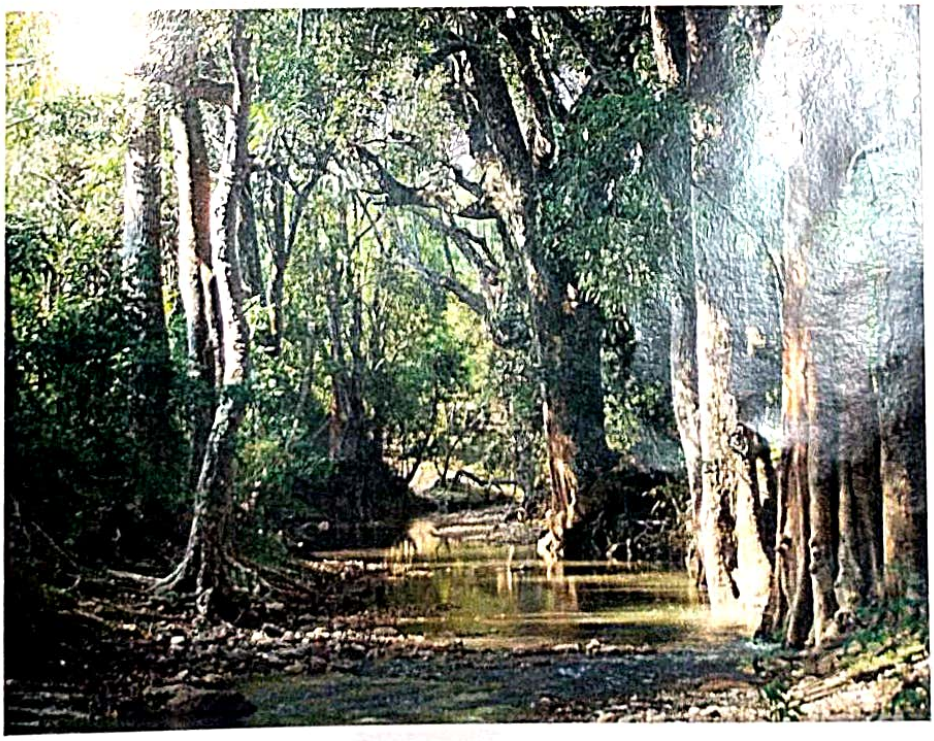
A comparison of tree community parameters of dry deciduous forest with the riverine forests indicates the presence of higher number of trees, species, genera, and family in the later habitat. Occurrence of just 30 tree species and 17 families in the dry deciduous forests indicates it's relatively less diverse nature.

Tree species richness and diversity were found to be higher in the riverine habitat, than in the dry deciduous forest (Table 1). Maximum number of observations on hornbill's feeding, roosting, perching and other activities were recorded in the riverine habitat. The Shannon's diversity index value for riverine habitat (3.40) is greater than the dry deciduous habitat (2.64) (Table 1).

PLATE III

Indian Grey Hornbill habitats in Eastern Ghats

Dry deciduous forest



Riverine Forest

Table 1. Tree community parameters in hornbill habitats

Parameters	Riverine forest	Dry deciduous forest
# Families	25	17
# Genera	49	28
# Species	64	30
# individuals	588	322
Shannon's diversity index	3.40	2.64

4.2.4. Food and nest plant distribution

Among the 41 species of Indian Grey hornbill's food plants, 22 plant species were recorded in the sample plots. Of the 22 food plant species, 20 food plants were recorded in the riverine habitat and 14 in the dry deciduous habitat. Comparison of food plant distribution among two habitats indicates that the riverine habitat is very rich in food plant abundance (Table 2). Indian Grey Hornbill used six tree species for nesting. While only two nest tree species were recorded in the dry deciduous habitat and all the six species were found in the riverine habitat. Nest trees included *Melia dubia*, *Syzygium cumini*, *Mangifera indica* and *Albizzia odoratissima*, *Terminalia arjuna* and *Terminalia bellirica*. Majority (44%) of the nest trees used were *Melia dubia*. All the nests identified were found in the riverine habitat where there are huge trees with several

cavities. The results of the vegetation studies reveal that the density of trees preferred by hornbills for nesting is more in the riverine habitat than in the dry deciduous habitat. *Ficus* spp., *Vitex altissima*, *Diospyros montana*, *Santalum album*, *Melia dubia*, *Mangifera indica*, *Syzygium cumini* and *Terminalia* spp. are some of the important tree species of riverine habitat, highly utilized by Indian Grey Hornbill for feeding and nesting.

4.2.5. Human impacts on vegetation in hornbill habitat

Comparison of vegetation features of a primary forest patch with that of a disturbed site of dry deciduous forest is shown in Table 3. Thirty five per cent families, 56% genera, 53% of the species and 83% of the trees were lost in the disturbed site. Tree species diversity (2.12) was also found to be lower in the human impacted site, as compared to the undisturbed/ primary forest site (2.64).

The riverine forests are subjected to various sorts of human disturbances. Agricultural practices alongside the rivers by local tribals, livestock grazing and non-timber forest produces collection formed the major disturbances. As a result of these activities, nest and food tree species are lost. Livestock grazing open up the shrub stratum where fast spreading exotic weeds such *Solanum erianthum*, *Lantana camara*, and *Cassia siamea* colonize. These exotics suppress the emerging native tree saplings which lead to the decline of native tree populations whom the hornbill depends upon for nesting and feeding.

Table 2. Distribution of hornbill food plants in the riverine and dry deciduous forests

Plant species	Riverine Forest			Dry Deciduous Forest		
	# of individuals	Density	Relative density	# of individuals	Density	Relative density
Atalantia monophylla	1	0.01	0.17	5	0.05	1.55
Bridelia crenulata	-	-	-	1	0.01	0.31
Canthium dicoccum	3	0.03	0.51	12	0.12	3.73
Capparis grandis	35	0.35	5.95	16	0.16	4.97
Celtis tetrandra	3	0.03	0.51	-	-	-
Clausena dentate	1	0.01	0.17	2	0.02	0.62
Diospyros montana	20	0.20	3.40	23	0.23	7.14
Drypetes roxburghii	1	0.01	0.17	-	-	-
Erythroxylum monogynum	3	0.03	0.51	62	0.62	19.25
Ficus benghalensis	11	0.11	1.87	8	0.08	2.48
Ficus drupacea	2	0.02	0.34	-	-	-
Ficus microcarpa	4	0.04	0.68	-	-	-
Ficus racemosa	9	0.09	1.53	-	-	-
Ixora pavetta	8	0.08	1.36	5	0.05	1.55
Mimusops elengi	-	-	-	2	0.02	0.62
Naringi crenulata	1	0.01	0.17	8	0.08	2.48
Premna tomentosa	3	0.03	0.51	5	0.05	1.55
Santalum album	4	0.04	0.68	-	-	-
Schelichera oleosa	6	0.06	1.02	-	-	-
Syzygium cumini	15	0.15	2.55	-	-	-
Vitex altissima	19	0.19	3.23	69	0.69	21.43
Zizyphus mauritiana	18	0.18	3.06	9	0.09	2.80

Table 3. Comparison of tree community parameters in undisturbed and disturbed dry deciduous forest sites

Parameters	Undisturbed forest	Disturbed forest
# Families	17	11
# Genera	28	13
# Species	30	14
# individuals	322	56
Shannon's diversity index	2.64	2.12

Sixty five per cent of the food plant species were not found in the disturbed site. Nine species that were recorded in the primary forest were completely absent in the human impacted site, thus showing 100% loss. Four food plant species namely *Capparis grandis*, *Diospyros montana*, *Ficus benghalensis* and *Ixora pavetta* showed lesser values in the human impacted site, indicating moderate loss. Only one species, *Canthium dicoccum* (+25) had slightly higher number of individuals indicating slight gain. Two species *Santalum album* and *Zizyphus oenoplia* were found only in the disturbed site (Table 4).

Table 4. Loss of hornbill food plants in the dry deciduous forests

Plant species	Family	Trees/ha.		
		Undisturbed Site	Disturbed site	Loss/gain (%)
Atalantia monophylla	Rutaceae	5	-	-100
Bridelia crenulata	Euphorbiaceae	1	-	-100
Canthium dicoccum	Rubiaceae	12	15	+25
Capparis grandis	Capparidaceae	16	12	-25
Clausena dentate	Rutaceae	2	-	-100
Diospyros montana	Ebenaceae	23	10	-56.5
Erythroxylum monogynum	Erythroxylaceae	62	-	-100
Ficus benghalensis	Moraceae	8	1	-87.5
Ixora pavetta	Rubiaceae	5	2	-60
Mimusops elengi	Sapotaceae	2	-	-100
Naringi crenulata	Rutaceae	8	-	-100
Premna tomentosa	Verbenaceae	5	-	-100
Santalum album	Santalaceae	-	2	+100
Vitex altissima	Verbenaceae	69	-	-100
Ziziphus mauritiana	Rhamanceae	9	-	-100
Ziziphus oenoplia	Rhamnaceae	-	2	+100

4.3. Discussion

Johns (1987) observed the greatest diversity and abundance of hornbill species in undisturbed forest. He recorded the loss of a high proportion of food resources in selectively logged forests. Anggraini *et al.* (2000) found that the Sumatran hornbills preferring undisturbed forests and avoiding highly disturbed areas. Population decline of Bushy-crested, Rhinoceros and Helmeted hornbills were observed in the fire affected areas of Bukit Barisan Selatan National Park, Sumatra (Anggraini *et al.* 2000). Datta (1998) related the habitat features with the abundance of various hornbill species in Arunachal Pradesh, India. She observed that hornbill abundance was not correlated with fig tree density. Balasubramanian *et al.* (2004) mentioned that the lowland riparian forests in Western Ghats, India that harbour Malabar Pied hornbills have higher fig density and tall, large-girthed nest trees than the adjoining vegetation types.

CHAPTER V

FRUITING PHENOLOGY

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. Pattern of phenological events are variously used for characterization of vegetation type (Opler *et al.* 1980 and Shimwell 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 birds. Hence, phenological studies on the fleshy fruit bearing plants were carried out in the study area, an important bird habitat.

Research on fruiting phenology of tropical forests has initiated the concept of pivotal and keystone plant resources (Howe 1977; Leighton & Leighton 1983; Terborgh 1986). These species are important in conserving frugivore populations. Identifying these fruiting species have important conservation implications for the entire food web, as frugivores act as key dispersal agents and thus play vital role in forest dynamics (Gilbertt 1980 and Kinnaird 1998).

5.1. Method

Fruiting periodicity was monitored by tagging 210 plants belonging to 21 fleshy-fruited species for two years from July 2006 to June 2008 in the study site. All the 210 individuals were nailed with aluminum tags and were numbered with paint. 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. Botanical names were determined based on Gamble & Fischer (1967). 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 and Balasubramanian *et al.* 2004).

5.2. Results

The phenology data indicates the seasonal variations of fruiting in the hornbill habitat. Fruit production occurs year round in the dry deciduous forest. Number of species and the number of individuals in fruits varied in different months (Fig. 1 & 2). In the study area, a major fruiting peak was recorded in May and July of both the years. During the fruiting peak in July 2006 and 2007, 96 individuals belonging to 12 species and 103 individuals belonging to 12 species were recorded in fruits respectively. During the fruiting peak in May 2007 and 2008, 98 individuals of 13 species and 95 individuals of 12 species were recorded with

fruits respectively. A dip in fruiting was recorded during January - March in both the years. This shows the occurrence of definite seasonality of fruiting in the dry deciduous forests. The food preferences of Indian Grey Hornbill in the breeding and non breeding season closely associate with the fruiting seasonality of the food plant species (Table 5). Fruits of *Ficus* spp., *Premna tomentosa*, *Diospyros montana*, *Syzygium cumini*, *Santalum album* and few other fleshy fruited species in the study area which were not tagged for phenology provided food to Indian Grey hornbills during the breeding season.

Of the 21 plant species belonging to 14 families tagged for phenological studies, four species of Moraceae (*Ficus benghalensis*, *Ficus drupacea*, *Ficus microcarpa* and *Ficus racemosa*) fruited throughout the year. Though the exotic shrub *Lantana camara* was fruiting all round the year, it was not preferred by hornbills. All other species showed seasonal fruiting activity (Table 6). Fruit abundance had fluctuation between the years. *Vitex altissima* fruits were available from July to September. *Santalum album* showed peak during September-October and also fruited in March and April. *Ficus* fruits, which were available year round, formed an important source of food for hornbills both in breeding and non-breeding season.

Table 5. Fruiting period of fleshy-fruited species in the study area

S. No	Species	Family	Fruiting months
1.	*Canthium dicoccum*	Rubiaceae	12, 1
2.	*Capparis grandis*	Capparidaceae	7, 8, 9
3.	*Celtis tetrandra*	Ulmaceae	2, 3, 4
4.	*Diospyros montana*	Ebenaceae	11, 12, 1
5.	*Erythroxylum monogynum*	Erythroxylaceae	6, 7
6.	*Ficus benghalensis*	Moraceae	1-12
7.	*Ficus drupacea*	Moraceae	1-12
8.	*Ficus microcarpa*	Moraceae	1-12
9.	*Ficus racemosa*	Moraceae	1-12
10.	*Flacourtia indica*	Flacourtiaceae	12, 1
11.	*Grewia tiliifolia*	Tiliaceae	5, 6
12.	*Ixora pavetta*	Rubiaceae	3, 4
13.	*Lantana camara*	Verbenaceae	1-12
14.	*Melia dubia*	Meliaceae	1-12
15.	*Premna tomentosa*	Verbenaceae	5, 6, 7
16.	*Santalum album*	Santalaceae	3,4, 8, 9, 10
17.	*Schelichera oleosa*	Sapindaceae	5, 6, 7
18.	*Scutia myrtina*	Rhamnaceae	4, 5, 6, 7
19.	*Syzygium cumini*	Myrtaceae	4, 5, 6
20.	*Vitex altissima*	Verbenaceae	7, 8, 9
21.	*Zizyphus mauritiana*	Rhamnaceae	10, 11, 12, 1

Fig. 1. Phenology of fruiting trees (# of species in fruiting) (n=21)

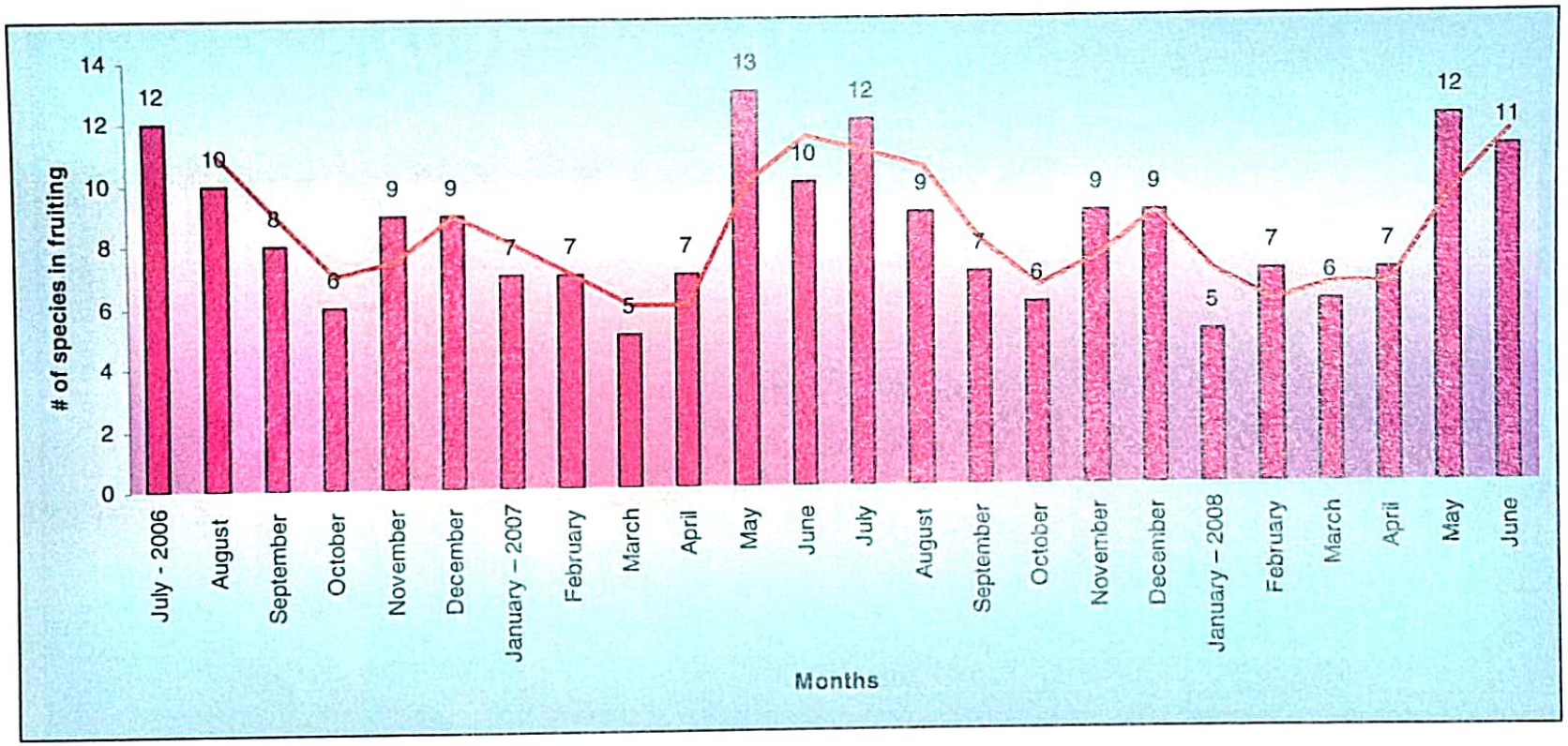
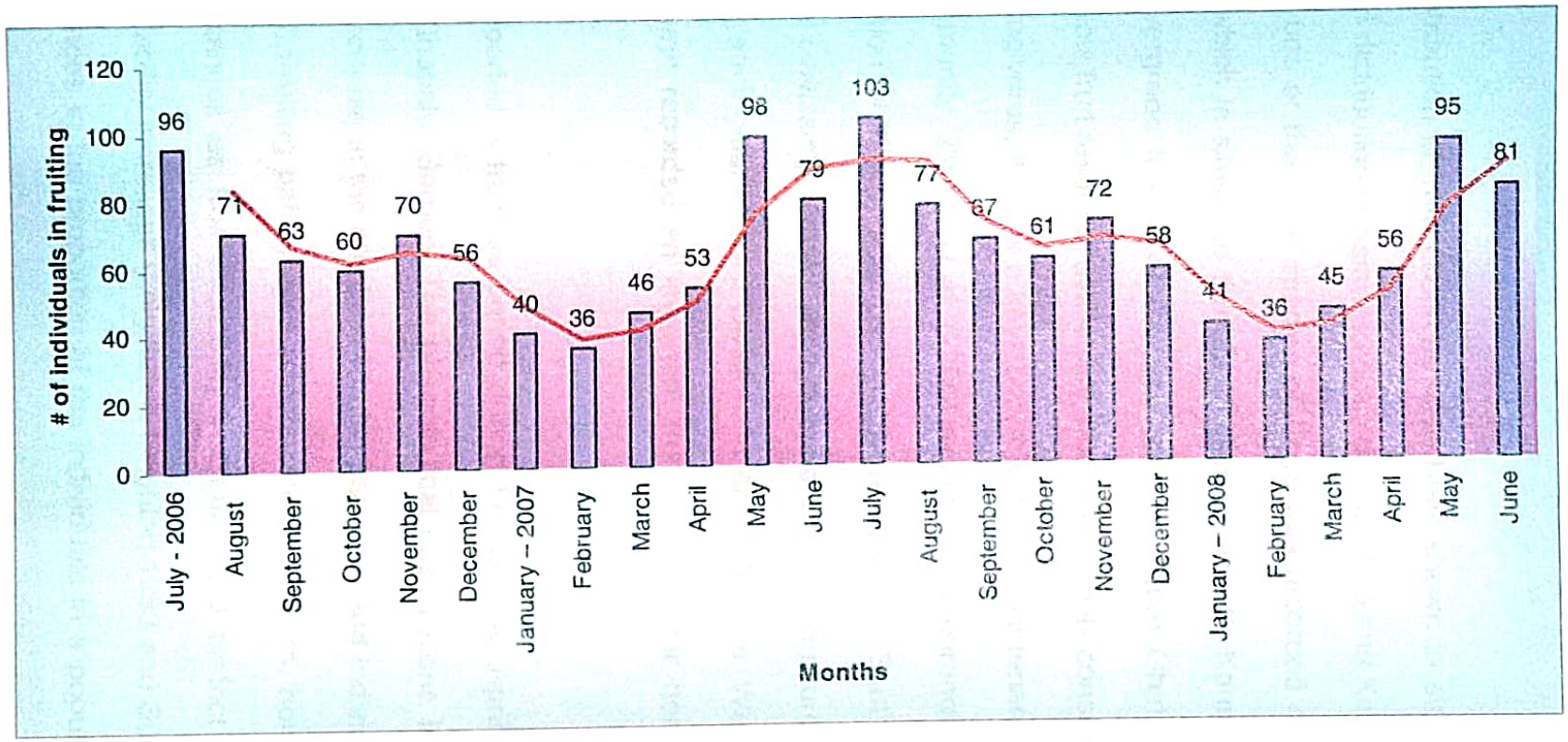


Fig. 2. Phenology of fruiting trees (# of individuals in fruiting) (n=210)



5.3. Discussion

The abundance and distribution of fruit resources have been shown to strongly influence the density and distribution of Asian Hornbills (Kemp 1995 and Kinnaird *et al.* 1996). Fruiting of one or the other species of *Ficus* was recorded during each month in a year, which is similar to the observations made by Kannan & James (1999) in the evergreen forests of Anamalai hills, Western Ghats. As *Ficus* fruited at times of low fruit resource availability, and was heavily consumed by hornbills and other frugivores, it plays a keystone role in the maintenance of the avian frugivore community. Zhang *et al.* (2006) reported asynchronous fig production at a population of *Ficus racemosa* in Xishuangbanna, Southwest China. The fruits of *Vitex altissima* formed another important fruit resource for avian frugivores in Sathyamangalam Forest Division. In Anamalai hills, Western Ghats also *Vitex altissima* recorded an important fruit resource for hornbills (Kannan & James 1999).

Kimura *et al.* (2001) reported a fruitless period during February to April in a hornbill habitat in Mt. Kinabalu, Borneo. The phenological observations in the present study show a decrease in the number of fruiting species and individuals during February to April. Fruiting pattern also affects ranging pattern, hornbills tend to travel long distances as fruit availability decrease and restrict their movements as fruit availability increases (Leighton & Leighton 1983 and Suryadi *et al.* 1998). These changes in the proportion of the individuals in a population

fruiting and in the abundance of fruit produced may be linked to climate change (Chapman *et al.* 2005).

The overall fruiting pattern of the dry deciduous forest suggested that figs fruited aseasonally and formed an important fruit resource for Indian Grey hornbills. All the other seasonal fruits aided hornbills in time of their availability. Fruit availability in the study area is very closely associated with that of the breeding and non breeding season of the Indian Grey Hornbill, providing a good resource of food year round.

Table 6. Month wise fruiting profile of the fleshy fruited plants in the study area

Plant species	June (2006)	July	August	September	October	November	December	January (2007)	February	March	April	May	June	July	August	September	October	November	December	January (2008)	February	March	April	May
Canthium dicoccum							✓	✓											✓	✓				
Capparis grandis		✓	✓	✓										✓	✓	✓								
Celtis tetrandra									✓	✓	✓										✓	✓	✓	
Diospyros montana						✓	✓	✓										✓	✓	✓				
Erythroxylum monogynum	✓	✓											✓	✓										
Ficus benghalensis	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Ficus drupacea	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Ficus microcarpa	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Ficus racemosa	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Flacourtia indica							✓	✓											✓	✓				
Grewia tiliifolia	✓											✓	✓											✓
Ixora pavetta										✓	✓											✓	✓	
Lantana camara	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Melia dubia	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Premna tomentosa	✓	✓										✓	✓	✓										✓
Santalum album			✓	✓	✓			✓	✓						✓	✓	✓			✓	✓			
Schleichera oleosa	✓	✓										✓	✓	✓										✓
Scutia myrtina	✓	✓									✓	✓	✓	✓									✓	✓
Syzygium cumini	✓										✓	✓	✓										✓	✓
Vitex altissima		✓	✓	✓										✓	✓	✓								
Ziziphus mauritiana					✓	✓	✓	✓									✓	✓	✓	✓				

CHAPTER VI

FOOD HABITS OF INDIAN GREY HORNBILL

Asian hornbills are generally frugivorous, but become omnivorous in the breeding season. Proportions of animal food in the diet may vary by species and perhaps by season (Poonswad *et al.* 1998). A study on the diet of Asian hornbills has been reported by Poonswad *et al.* (1998). Understanding fruit preference patterns of frugivorous animals is of special ecological importance when it is linked to the dispersal of seeds (Carlo *et al.* 2003). Hornbill studies in southern India revealed their predominantly frugivorous habits and their probable role in seed dispersal of forest trees (Kannan & James 1997; Balasubramanian & Maheswaran 2002 and Balasubramanian *et al.* 2005). Some notes on the food of Indian Grey Hornbill in the breeding season were made by Patil *et al.* (1997). In this chapter food habits of Indian Grey Hornbill and food preferences during the breeding and non breeding season are discussed.

6.1. Methods

Data were gathered in two breeding and non breeding seasons during 2006-2008. In the breeding season that extends around 90 days, active cavities of trees were identified by following the breeding pair of hornbills and breeding male carrying fruit to the nest. Remains of food items consumed by nest inmates are generally squirted out through the nest slit which get deposited beneath the nest

tree as middens. Midden deposits include seeds, undigested parts of plant and animal food. Middens of 10 nests were collected once in a week during the nesting period. Items collected from the 10 nest middens were analyzed, quantified and recorded. We excluded minute seeds in the nest middens, which were not included in the seed count owing to their very small size. Seed species were identified by comparing with that of the seeds taken from fresh fruits. The middens under the nest were cleaned after each collection. In addition, a total of 720 hours were spent at the hides made aside the nests for monitoring the fruit deliveries by males to the nest inmates. A total of 10 nests were studied. Focal observations were carried out from 06:00 AM to 06:00 PM. During nest monitoring, details such as number of visits made by the male, food items delivered, number of items delivered per visit was recorded from an observation hide situated 10–20 m away from the nest, using a pair of 10×50 binoculars. The breeding season of Indian Grey Hornbill was divided into two phases namely pre-hatching and post-hatching. The percentage proportion of plant and animal food delivered to the nest inmates was determined for both the phases of breeding period.

Diet during non-breeding was assessed by scan sampling and focal animal sampling method (Altman 1974). Observations were done along select transects, mostly done from 06:00 to 10:00 AM and 04:00 to 06:00 PM when the feeding activity of hornbills was high. During the transect walk, hornbills foraging within

50 m of either side of transects were recorded. During each observation, food item consumed and the tree species in which they were feeding were recorded.

Fruits being the major diet, efforts were made to find out hornbill's preferred fruit species. Preference index (PI) was calculated 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, the individuals were counted and recorded. Utilization of the species was driven from the number of feeding observations recorded. Values of Preference Index (PI) range between -1 and +1. Where -1 indicates avoidance while +1 indicates highest preference. The difference in food items consumed between the pre-hatching and post-hatching phases of nesting period was tested for statistical significance using T-Test and the difference in food items consumed within the pre-hatching and post-hatching phases was tested for statistical significance with One-way ANOVA, using SPSS 11.0 for Windows.

6.2. Results

In the breeding season, the food items delivered to the nest inmates (female and chicks) include both vegetable (63.65%) and animal matter (36.35%). Fleshy fruits of 26 species belonging to 16 families were delivered at the nest during the breeding season. The animal matter delivered comprised mainly insects (99.60%). Seeds collected from the nest middens were analyzed, identified and

recorded. Seeds of all the 26 fleshy fruited species consumed by hornbills in the breeding season were recorded in the nest middens. Food habits during non-breeding season were assessed by walking along transects and observing foraging activities of hornbills. Of the 3086 feeding observations made, 82.98% were on fruits and the remaining included leaves (8.82%), insects (7.70%) and flowers (0.50%). Of the 38 fruit species belonging to 21 families consumed, *Ficus* constituted 25.26% of the non-breeding season diet. In all, fruits of 41 species belonging to 22 families were consumed by Indian Grey Hornbill in the study area. Both figs and non-figs found to be important for Indian Grey Hornbill.

6.2.1. Breeding season diet

Breeding season of hornbills is the duration between the day of complete nest sealing and the day on which the hatchlings break out of the nest. The nesting period of Indian Grey Hornbill lasted for about three months from March to May. The nesting period averaged 87 days, with the female sealed in the nest cavity for an average of 76 days and the nestlings fledging an average of 13 days after the female emerged. Here the nesting period was divided in to two phases namely pre-hatching and post hatching. The mean duration of nesting period was 87 days, the young ones hatched in an average of 30 days (pre-hatching phase) from the date of incarceration of the female. The post-hatching phase was 57 days on an average.

PLATE IV

Indian Grey Hornbill foraging on fleshy-fruited plants

6.2.2. Nest monitoring

During nest monitoring, a total of 13,680 food items were delivered to the nest inmates of 10 focal nests. The incarcerated female and chicks were fed by loads of food items by the male in the initial phase and at the later stage of the breeding cycle, the chicks were fed by both male and female. Food items delivered at the nest comprised both vegetable (63.65%) and animal matter (36.35%) (Table 9). The animal diet mainly constituted insects (99.60%) besides lizards, snakes and rats. The vegetable diet included mainly fruits (98.30%) and a small proportion of *Melia dubia* leaves. Fruits of 26 plant species belonging to 16 families were consumed during the breeding season among which 14 species were identified while monitoring the nests and 12 species from the nest middens. Among the fruits delivered, figs (Moraceae) formed the majority (26%) (Fig. 3).

PLATE V

Male Indian Grey Hornbill delivering food to the nest inmates

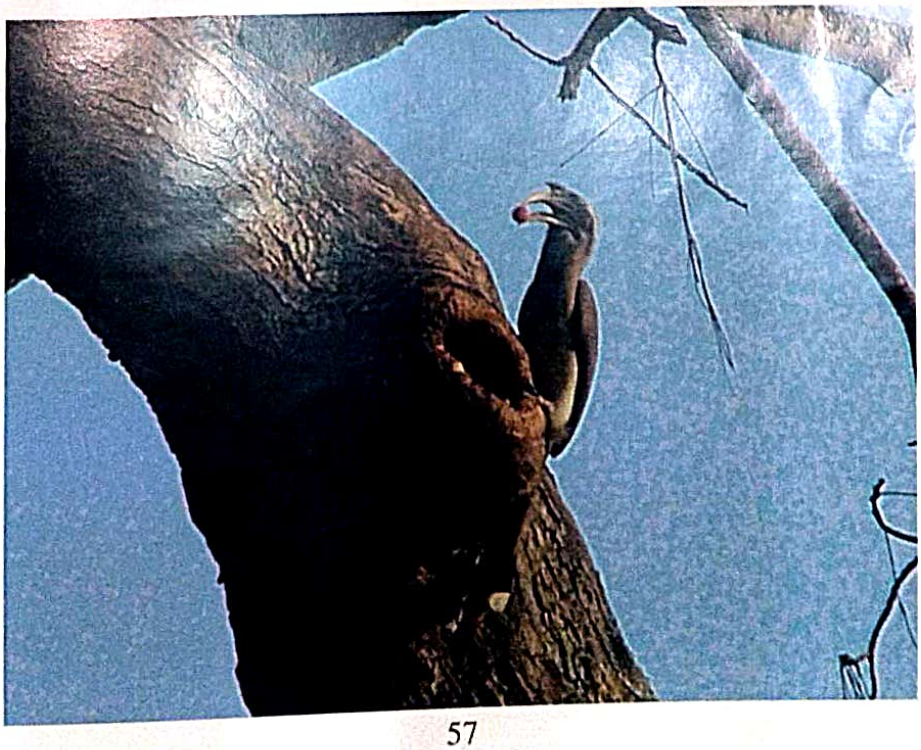
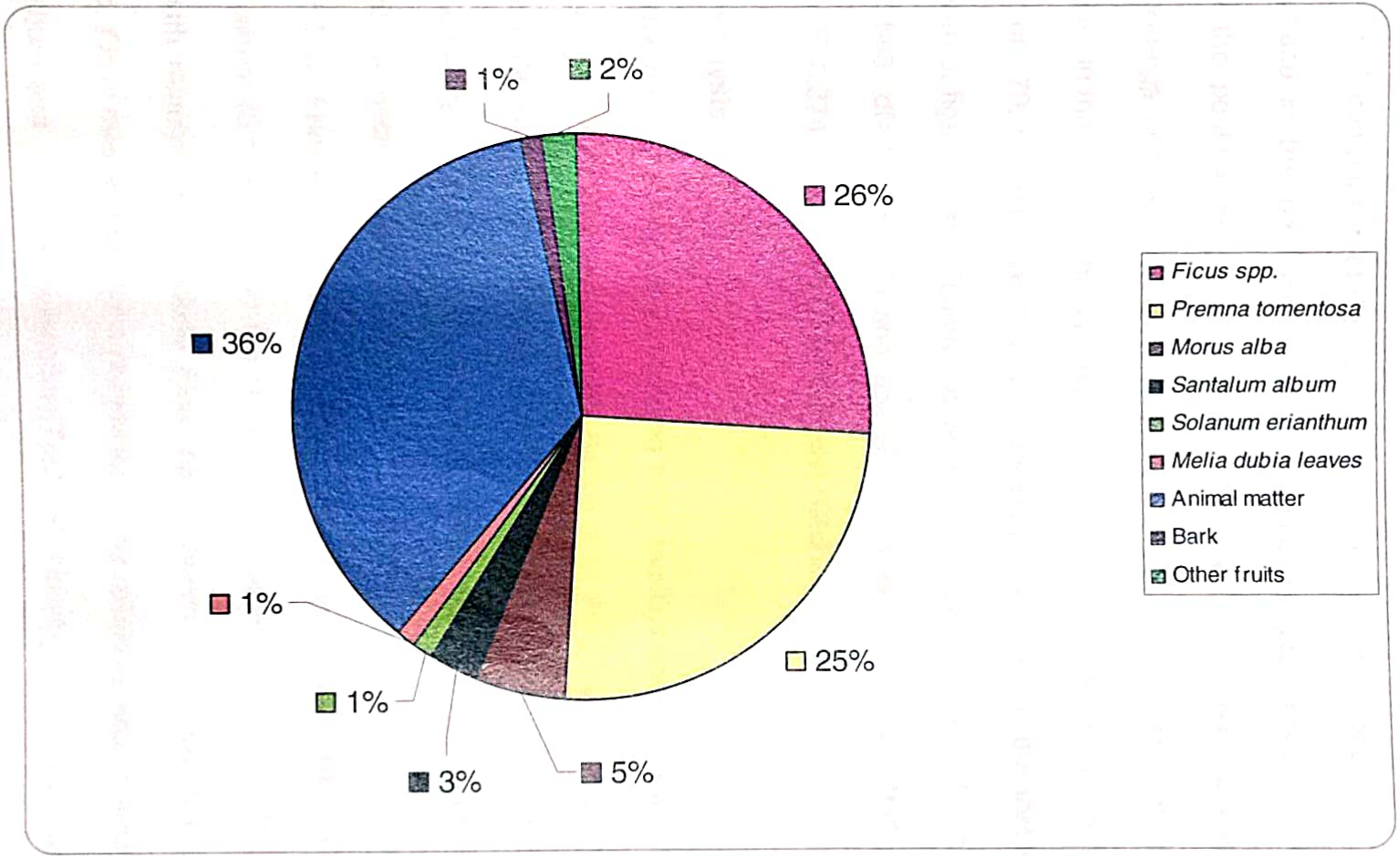


Fig. 3. Breeding season diet of Indian Grey Hornbill



The food items delivered to the nest inmates were classified in to figs, non-figs and animal matter. A comparison of diet composition of pre-hatching phase and post-hatching phase in the breeding season indicates the predominance of animal food in the post-hatching phase and figs in the pre-hatching phase (Fig. 4). The non-figs and animal matter delivered to the nest inmates were significantly higher in the post-hatching phase (T-Test, $t = -3.508$, $df = 57$, $p<0.01$ and $t = -4.133$, $df = 79$, $p<0.01$) than the pre-hatching phase. Among the three food items delivered, figs was significantly higher during the pre-hatching phase, (ANOVA, $F=26.683$, $df=2$, $p <0.01$) and animal food was found significantly higher (ANOVA, $F=8.374$, $df = 2$, $p <0.01$) in the post-hatching phase.

6.2.3. Midden analysis

Fruits of 26 fleshy fruited plant species belonging to 16 families were consumed by Indian Grey Hornbill in the breeding season. Seeds of all the 26 species were found in middens. Of the 26 species dispersed, 17 had large/medium seeds and nine had minute seeds. A total of 3,303 large/medium seeds were recorded in the middens of 10 nests. Seeds of *Premna tomentosa* (38.66%), *Drypetes roxburghii* (19.59%), *Filicium decipiens* (12.75%), *Diospyros montana* (9.87%) and *Santalum album* (6.18%) formed the predominant species (Table 7). The nine species with minute seeds include *Ficus benghalensis*, *Ficus drupacea*, *Ficus infectoria*, *Ficus microcarpa*, *Ficus racemosa*, *Ficus religiosa*, *Morus alba*, *Solanum erianthum* and *Solanum violaceum* (Table 8). No physical injury was noticed in the seeds defecated by the Indian Grey hornbills.

Fig. 4. Percentage proportion of food delivered to the nest inmates

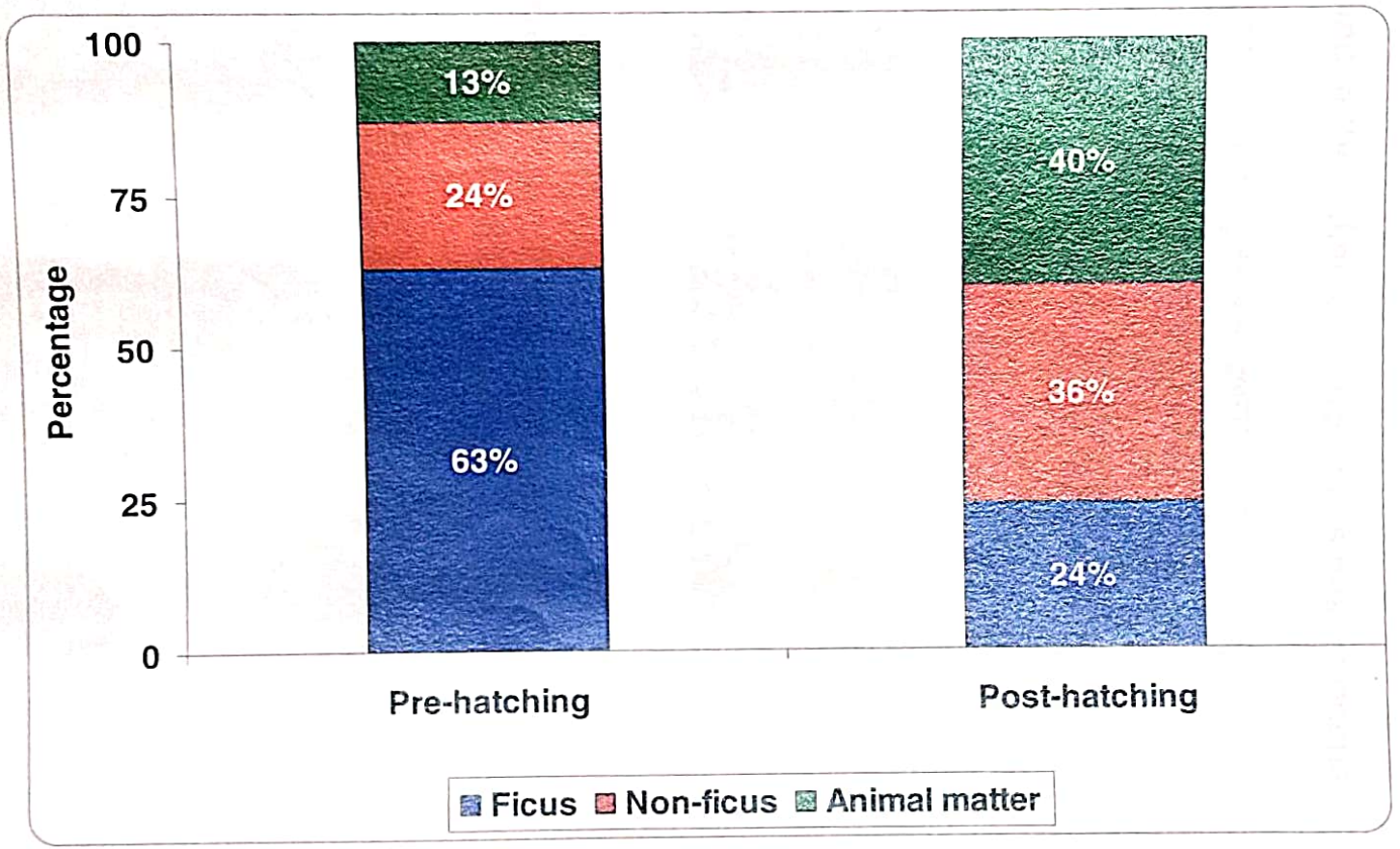
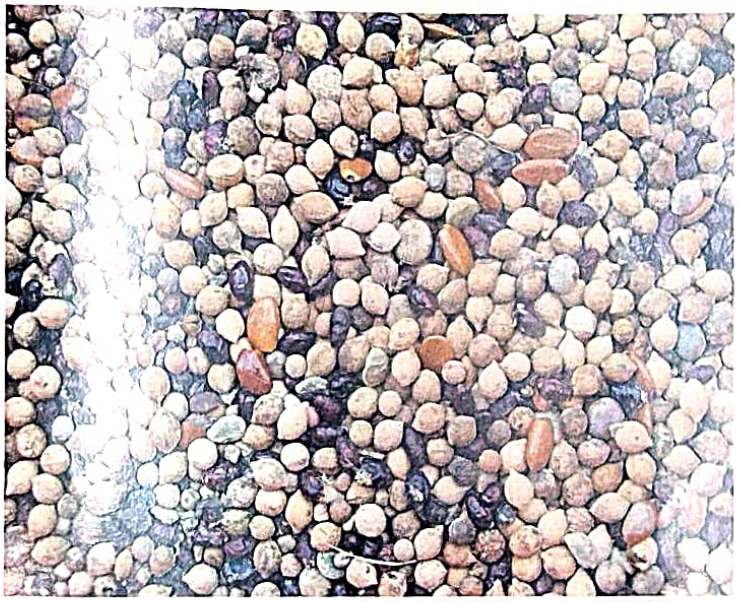


PLATE VI

Seeds found in the Indian Grey Hornbill's nest middens



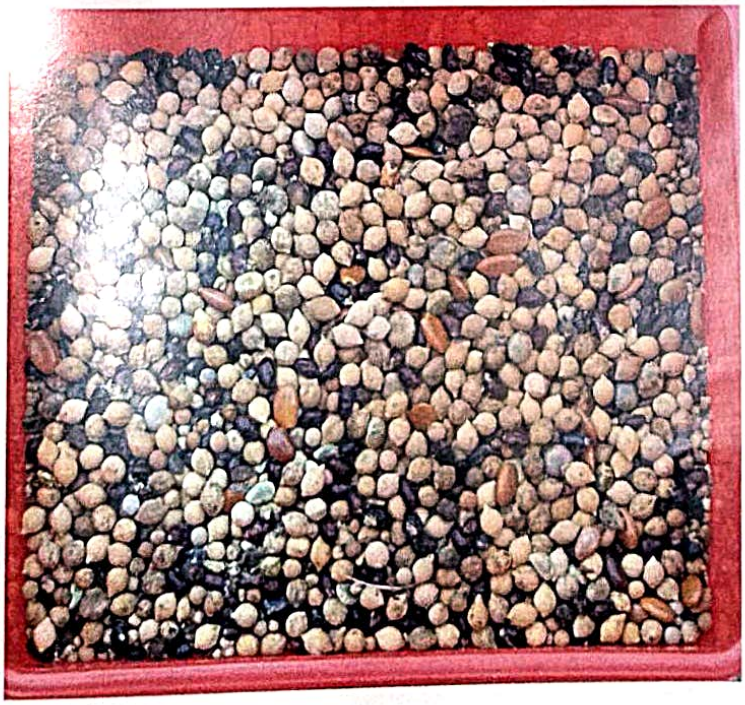


Table 7. Percentage proportion of various seed species in hornbill middens

S. No.	Plant species	Family	# of seeds	%
1.	*Atalantia monophylla*	Rutaceae	45	1.36
2.	*Capparis grandis*	Capparidaceae	55	1.67
3.	*Celtis tetrandra*	Ulmaceae	12	0.36
4.	*Cordia monoica*	Boraginaceae	21	0.64
5.	*Cordia oblique*	Boraginaceae	23	0.70
6.	*Diospyros montana*	Ebenaceae	326	9.87
7.	*Drypetes roxburghii*	Euphorbiaceae	647	19.59
8.	*Filicium decipiens*	Sapindaceae	421	12.75
9.	*Lantana camara*	Verbenaceae	44	1.33
10.	*Mimusops elengi*	Sapotaceae	51	1.54
11.	*Pithecellobium dulce*	Caesalpiniaceae	9	0.27
12.	*Premna tomentosa*	Verbenaceae	1277	38.66
13.	*Santalum album*	Santalaceae	225	6.81
14.	*Strychnos potatorum*	Loganiaceae	38	1.15
15.	*Syzygium cumini*	Myrtaceae	45	1.36
16.	*Vitex altissima*	Verbenaceae	40	1.21
17.	*Zizyphus mauritiana*	Rhamnaceae	24	0.73
Total			**3303**	**100.00**

Table 8. Minute seeds recorded in middens

S. No.	Plant species	Family
1.	*Ficus benghalensis*	Moraceae
2.	*Ficus drupacea*	Moraceae
3.	*Ficus infectoria*	Moraceae
4.	*Ficus microcarpa*	Moraceae
5.	*Ficus racemosa*	Moraceae
6.	*Ficus religiosa*	Moraceae
7.	*Morus alba*	Moraceae
8.	*Solanum erianthum*	Solanaceae
9.	*Solanum violaceum*	Solanaceae

6.2.4. Non breeding season diet

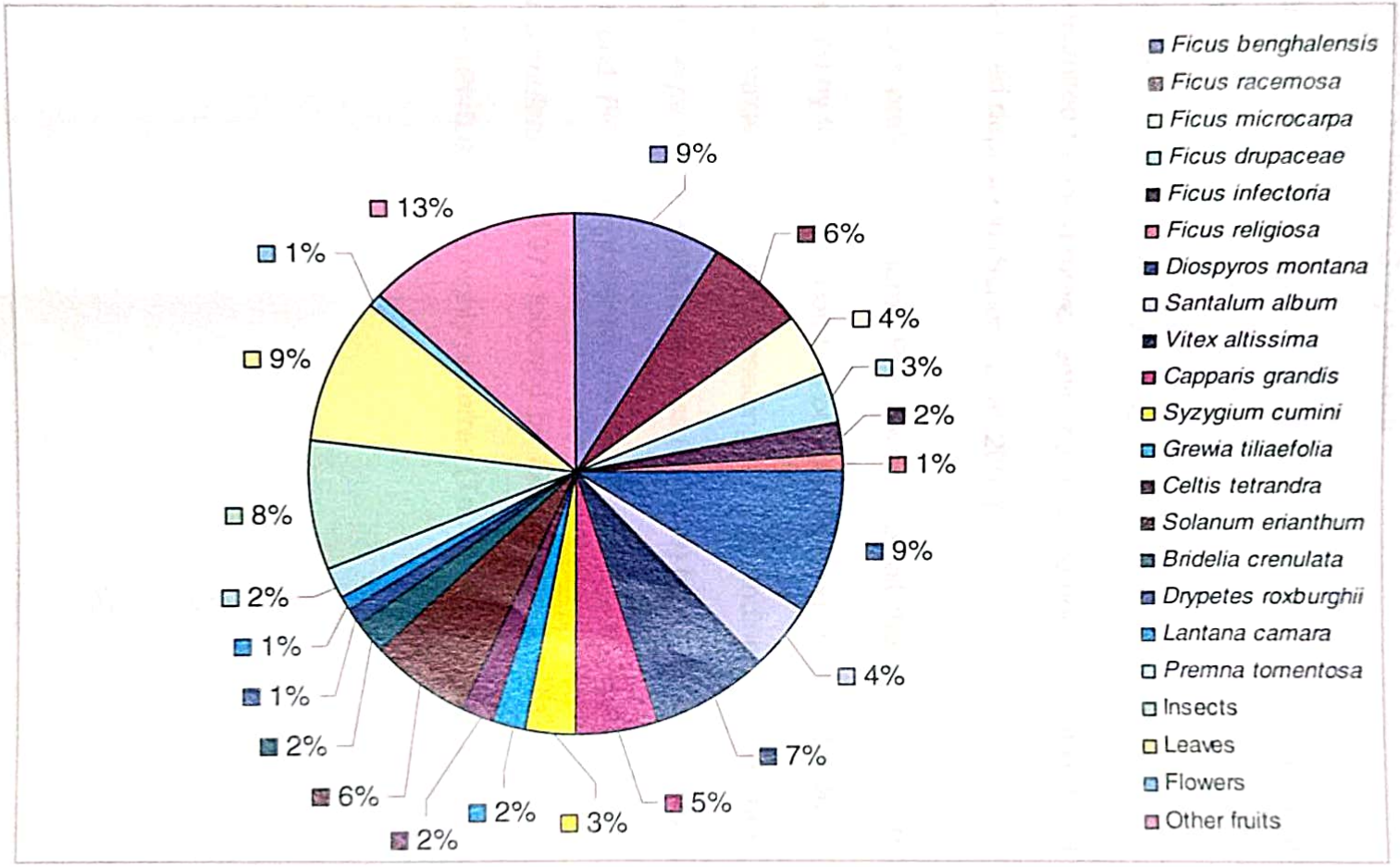
Non-breeding season is the intervening period between two successive breeding seasons and for Indian Grey Hornbill it is June – February in the study area. A total of 3,086 feeding observations were made during the non-breeding season. Indian Grey Hornbill ate fruits (82.98%), leaves (8.83%), flowers (0.50%) and insects (7.70%) (Table 9). A total of 38 fruit species belonging to 21 families were consumed. Of the 38 plant species, six species of *Ficus* (*Ficus benghalensis*, *F. drupacea*, *F. infectoria*, *F. microcarpa*, *F. racemosa*, *F. religiosa*) constituted 25%. Non-figs such as *Diospyros montana* (9%) and *Vitex altissima* (7%) also formed major food (Fig. 5). Indian Grey Hornbill was also feeding on leaves of *Melia dubia* and *Ailanthus excelsa*. A few feeding observations included flower feeding on *Vitex altissima*. Cultivated fruit species such as *Pithecellobium dulce*, *Carica papaya*, *Morus alba*, *Psidium guajava* and *Muntingia calabura* also comprised hornbills' food (4%). During non-breeding season, the Indian Grey Hornbill was found spending longer hours on fruiting figs. Highest number of hornbills (n=22) were feeding on a *Ficus microcarpa* for more than an hour. Twelve hornbills spent 52 minutes on a *Ficus microcarpa* tree. On a *Ficus benghalensis* tree, 10 individuals were feeding for 67 minutes.

Fruits formed majority of the diet. In all, fleshy fruits of 41 species belonging to 22 families were eaten by Indian Grey hornbills during breeding and non-breeding season. (Appendix 1).

Table 9. Proportion of vegetable and animal matter consumed by Indian Grey Hornbill

	Breeding season	Non-breeding season
	% utilized	% utilized
I. Vegetable matter		
1. Fruits		
a. Figs	25.90	25.26
b. Non-figs	36.66	57.72
2. Leaves	1.10	8.83
3. Flowers	-	0.50
II. Animal matter		
1. Insects	36.10	7.70
2. Eggs	0.13	-
3. Lizards	0.09	-
4. Others (chicks,snakes, rodents)	0.03	-

Fig. 5. Non-breeding season diet of Indian Grey Hornbill



6.2.5. Fruit preference by Indian Grey Hornbill

Understanding fruit preference patterns of frugivorous animals is of special ecological importance when it is linked to the effective removal and dispersal of seeds. Once animals operate as seed dispersal agents, patterns of preference can couple with delimited foraging movements and produce non-random or focal spatial patterns of seed deposition (Schupp *et al.* 2002).

The results of Ivlev's preference index (PI) showed that all the six *Ficus* spp. were highly preferred by Indian Grey hornbills both in breeding and non-breeding season with the PI value >0.9. During breeding season, Indian Grey Hornbill prefers *Ficus microcarpa* and *Premna tomentosa* (PI=0.99) followed by *Santalum album* (PI=0.98) and *Ficus benghalensis* (PI=0.97). During the non-breeding season, *Bridelia crenulata* (PI=0.97) followed by *Ficus religiosa* (PI=0.95) and *Solanum erianthum* (PI=0.95) were highly preferred (Table 10).

Table 10. Preference index of the fruit species consumed by Indian Grey Hornbill in Sathyamangalam Forest Division

S.No	Plant species	Preference Index PI=(U-A)/(U+A)	
		Non-breeding season	Breeding season
1.	*Bridelia crenulata*	0.97	-
2.	*Canthium dicoccum*	-0.11	-
3.	*Capparis grandis*	0.50	-
4.	*Capparis sepiaria*	-0.61	-
5.	*Celtis tetrandra*	0.91	-
6.	*Clausena dentate*	0.70	-
7.	*Diospyros montana*	0.73	0.06
8.	*Drypetes roxburghii*	0.94	-
9.	*Erythroxylum monogynum*	-0.83	-
10.	*Ficus benghalensis*	0.90	0.97
11.	*Ficus drupacea*	0.94	0.78
12.	*Ficus infectoria*	0.96	0.92
13.	*Ficus microcarpa*	0.93	0.99
14.	*Ficus racemosa*	0.91	0.96
15.	*Ficus religiosa*	0.95	0.93
16.	*Ixora pavetta*	-0.30	-
17.	*Lantana camara*	-0.97	-0.95

18.	*Mimusops elengi*	0.83	-
19.	*Naringi crenulata*	-0.50	-
20.	*Premna tomentosa*	0.71	0.99
21.	*Santalum album*	0.93	0.98
22.	*Schelichera oleosa*	0.67	-
23.	*Solanum erianthum*	0.95	0.96
24.	*Syzygium cumini*	0.71	-
25.	*Vitex altissima*	0.45	-
26.	*Zizyphus mauritiana*	-0.05	-
27.	*Zizyphus oenoplia*	0.81	-

U= utilization, A= availability

.

PLATE VII

Food plants of Indian Grey Hornbill

Ficus drupacea

Ficus benghalensis

Ficus religiosa

Ficus racemosa

Ficus microcarpa

Ficus infectoria

PLATE VIII

Food plants of Indian Grey Hornbill

Santalum album

Diospyros montana

Filicium decipiens

Premna tomentosa

Vitex altissima

Syzygium cumini

PLATE IX

Food plants of Indian Grey Hornbill

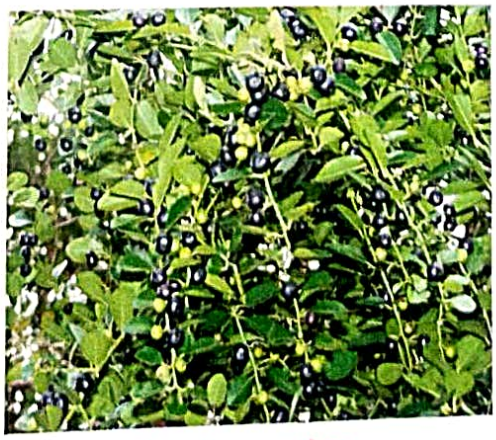
Drypetes roxburghii

Capparis grandis

Zizyphus mauritiana

Cordia monoica

Mimusops elengi



Scutia myrtina

6.3. Discussion

Majority of the diet of Indian Grey Hornbill comprised vegetable matter, especially fruits. Six species of figs were consumed by the hornbill in the study area. As there are no published literature on the food preferences of Indian Grey Hornbill, food habits of this species is compared with that of other hornbill species. The food habit studies on other hornbills highlight the importance of fruits, especially figs for hornbills. Balasubramanian *et al.* (2004) reported that the Malabar Pied Hornbill, *Anthracoceros coronatus* mainly consumed fruits both in the breeding season and non-breeding season; figs alone formed 60% in non-breeding season and 75% in the breeding season. In the case of Malabar Grey Hornbill, *Ocyceros griseus* in Anamalai hills of Western Ghats, India Mudappa (2000) reported that fruits comprised 63% of diet during breeding season in which figs alone formed 26%. Balasubramanian & Maheswaran (2002) reported that two species of figs, *Ficus tsjahela* and *F. drupacea* forming major food to the Malabar Grey Hornbill in Mudumalai Wildlife Sanctuary, Western Ghats. Datta & Rawat (2003) in Arunachal Pradesh, North-east India recorded the consumption 100% vegetable diet by the Wreathed Hornbill *Anthracoceros undulatus* in which 35% were figs. In the case of Oriental Pied Hornbill *Anthracoceros albirostris*, 96% of the diet was vegetable matter among which 47% was figs (Datta & Rawat 2003). According to O'Brien (1997) fruits of 34 species belonging to 13 families were delivered at the nest of North Sulawesi Traictic Hornbill *Penelopides exarhatus exarhatus* among which one-third was figs. Sulawesi Red-knobbed Hornbill

Aceros cassidix consumed fruits of 52 plant species in the breeding season (Kinnaird & O'Brien 1993). Kannan & James (1997) in India and Poonswad *et al.* (1987) in Thailand reported 72.9% and 57% of the food delivered at Great Hornbill, *Buceros bicornis* nests were figs respectively. Kannan & James (1997) considered figs as keystone resource for Great Hornbill in the Western Ghats. Suryadi *et al.* (1994) reported figs were continuously available and were preferred by Sulawesi Red-knobbed Hornbill in the non-breeding season in the Tangkoko-Dua Sudara Reserve, North Sulawesi, Indonesia. Kitamura *et al.* (2004b) reported that the family Moraceae (figs) was the most common family among the 73 hornbill fruit species in a tropical seasonal forest in Thailand. Fig fruiting occurs all-round the year, which could make them indispensable resource for tropical frugivores, especially hornbills.

Patil *et al.* (1997) reported that fruits form the major diet of Indian Grey hornbills during the breeding season. As hornbills do not take water directly, they prefer fleshy fruits for their nutrients and water content (Reddy & Basalingappa 1995; Balasubramanian *et al.* 2004 and Chapman *et al.* 2005). The results of the present study reveal similar results; hornbills were never seen drinking water and fleshy fruits formed the major diet.

Indian Grey hornbills consumed higher proportion of animal diet during the post-hatching phase. According to Mudappa (2000), the supplementation of animal matter in the post-hatching phase that coincides with the hatching of the chicks

could be to provide the growing chicks with high quality food that comprises essential nutrients (Mudappa 2000). Kannan & James (1997) opined that the differences in various food items delivered during the nesting period could be related to the availability of fruits.

CHAPTER VII

SEED DISPERSAL BY INDIAN GREY HORNBILL

Frugivores disperse the seeds of the majority of woody plant species worldwide. Thus, insights on how frugivores influence the dispersal of plants and the variability of this process are crucial for understanding plant population dynamics in a rapidly changing world (Carlo & Morales 2008). Avian fruit consumption may ensure plant reproductive success when frugivores show consistent preference patterns, effectively remove pulp and disperse seeds (Carlo *et al.* 2003). Being major frugivores, hornbills have an important role to play in the seed dissemination and regeneration of several forest tree species. Hornbills are known to travel long distances in a day in search of fruits and hence capable of moving viable seeds to distance locations. Hornbills are the principal frugivores in many of the forests which they occupy and their role in seed dispersal, germination and predation of seeds is notable (Kemp 1995, Kinnaird 1998, Whitney *et al.* 1998). Their ability compared with other avian forest frugivores to break up and swallow large fruits and their regurgitation of seeds undamaged make them ideal disperses (Holbrook & Smith 2000).

The quality of treatment by the disperser can be assessed by measuring the germination success of seeds (Roxburgh 2007). Birds help in determining the structure of their habitats, as a major proportion of fleshy fruit species are consumed and dispersed by them (Balasubramanian & Maheswaran 2002).

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 & Heithaus 1981). This chapter addresses the role of Indian Grey Hornbill as a seed disperser in the study area.

7.1. Methods

Diet of Indian Grey Hornbill during the breeding season was determined by direct observations at the nest and analyzing the seeds deposited in the nest middens. Due to their specialized breeding habits, hornbills need to bring large load of food to the nesting site to feed the incarcerated female and chicks through out the nesting period. Nesting period lasts for about three months. Seeds of the fruits consumed by nest inmates are squirted out through the nest slit. These seeds and fruit remains are deposited under the nest cavity and are known as nest midden. Seeds from 10 active nest middens were collected once in a week, analyzed, identified and recorded. Minute seeds in the nest middens were excluded, owing to their small size. Seed species were identified by comparing with that of the seeds obtained from fresh fruits. Seeds collected from nest middens were examined for visible physical damage.

Role of Hornbill in regeneration of its food plants was assessed by monitoring the seedling abundance in front and behind 10 nest trees. The plot behind the nest was used as control. A total of 20 quadrats were laid for sampling seedling

abundance. Two 3X3 m quadrats, one each in the front and behind the nest tree were laid. All the seedlings in the 3X3 m quadrats were recorded and identified. The plots were monitored weekly for seedling emergence. After the rainy season, in the first week of August, all seedlings in the 3 m plots were counted and identified.

Seed germination experiments were conducted to compare the germination efficiency of bird defecated seeds with that of control seeds. For the germination experiment, 16 seed species were used. Fresh ripe fruits were collected from the study site. Pulp of few fresh fruits was hand-cleaned and the rest were kept intact for the experiment. 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. For each type, 10 seeds were used. Seeds were sown in polythene bags. The bags were 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 and for comparison of the seedlings in front and behind the nest cavities. The software SPSS 10.0 Windows was used.

7.2. Results

A total of 26 seed species belonging to 16 families were dispersed by the Indian Grey Hornbill in the breeding season. Of the 2082 seedlings belonging to 44 species recorded under the nests, 55 percent of the seedlings were hornbill's diet species. Seeds of *Premna tomentosa*, *Diospyros montana*, *Drypetes roxburghii*, *Santalum album* and *Filicium decipiens* formed the predominant species in the middens. Germination studies on hornbill's diet species indicated that the Indian Grey Hornbill enhance the germination efficiency of seeds which they regurgitate/defecate. Of the 16 seed species tested, 15 showed enhanced germination. Hornbills' preferred diet species such as *Syzygium cumini*, *Premna tomentosa*, *Diospyros montana* and *Drypetes roxburghii* showed 100 percent germination in the case of bird defecated sample.

7.2.1. Regeneration of food plants at the nest site

Regeneration of hornbill's food plants under the nest trees were recorded for 10 nests. Twenty quadrats of 3X3 m were laid in front and behind the nest trees for comparison. A total of 44 species of seedlings were recorded among which 24 species (54.5%) were found to be food plant species of Indian Grey Hornbill. The number of seedlings of the diet species in front of the nest was higher and showed significant difference (Paired-Sample T-Test $t = 3.630$, df = 38 $P < 0.01$). There was no significant difference for non-diet species in front and behind the nest (Paired-Sample T-Test $t = 0.412$, df = 24 $P > 0.05$).

Predominant diet species found in front of the nest trees were *Diospyros montana* (23.97%), *Drypetes roxburghii*, (17.47%), *Capparis grandis* (5.49%) *Premna tomentosa* (5.49%) and *Filicium decipiens* (5.11%). The number of diet species seedlings recorded in front of the nests dominated by *Diospyros montana* (n=209) followed by *Drypetes roxburghii* (n=153) and *Lantana camara* (n=140). Behind the nest trees, maximum number of diet species seedlings were encountered by *Lantana camara* (n=115) followed by *Diospyros montana* (n=28) and *Syzygium cumini* (n=20) (Table 12). The number of seedlings of hornbill food plant species in front of the nests was higher than that of non-diet species (Fig. 6). The number of seedlings of non-diet species was higher behind the nest, indicating that the nest inmates spray out their droppings through the nest hole, which falls in front of the nest tree. The results of the phytosociological analysis of the seedlings recorded under the nest trees showed that the abundance of the food plants were found higher in front of the nest trees than behind the nest trees. The number of seedlings in front of the nest trees was nearly four times more than the seedlings behind the nests. This clearly represents that the density of hornbill food plants is higher in front of the nest, which conform that Indian Grey Hornbill plays an important role in the regeneration of its food plants.

Regular roost sites of Indian Grey Hornbill could not be identified. A few unusual roost locations were located in the study site. Regeneration of hornbill's food plant species under the roost trees was studied by enumerating the seedlings.

Seedlings of 9 species were recorded. Predominant seedling species include *Syzygium cumini* (25%), *Diospyros montana* (20%) and *Drypetes roxburghii* (16%) (Table 11).

Table 11. Number of seedlings of food plant species recorded at the roost sites of Indian Grey Hornbill

S.No.	Species	#	%
1.	Capparis grandis	12	8
2.	Celtis tetrandra	8	5
3.	Diospyros montana	32	20
4.	Drypetes roxburghii	27	16
5.	Lantana camara	12	8
6.	Morus alba	9	6
7.	Santalum album	12	8
8.	Solanum erianthum	7	4
9.	Syzygium cumini	40	25

PLATE X

Natural regeneration of food plants below hornbill nest tree

Natural regeneration of food plants below hornbill roost tree

Fig. 6. Seedlings of diet and non-diet species in front and behind the nest trees

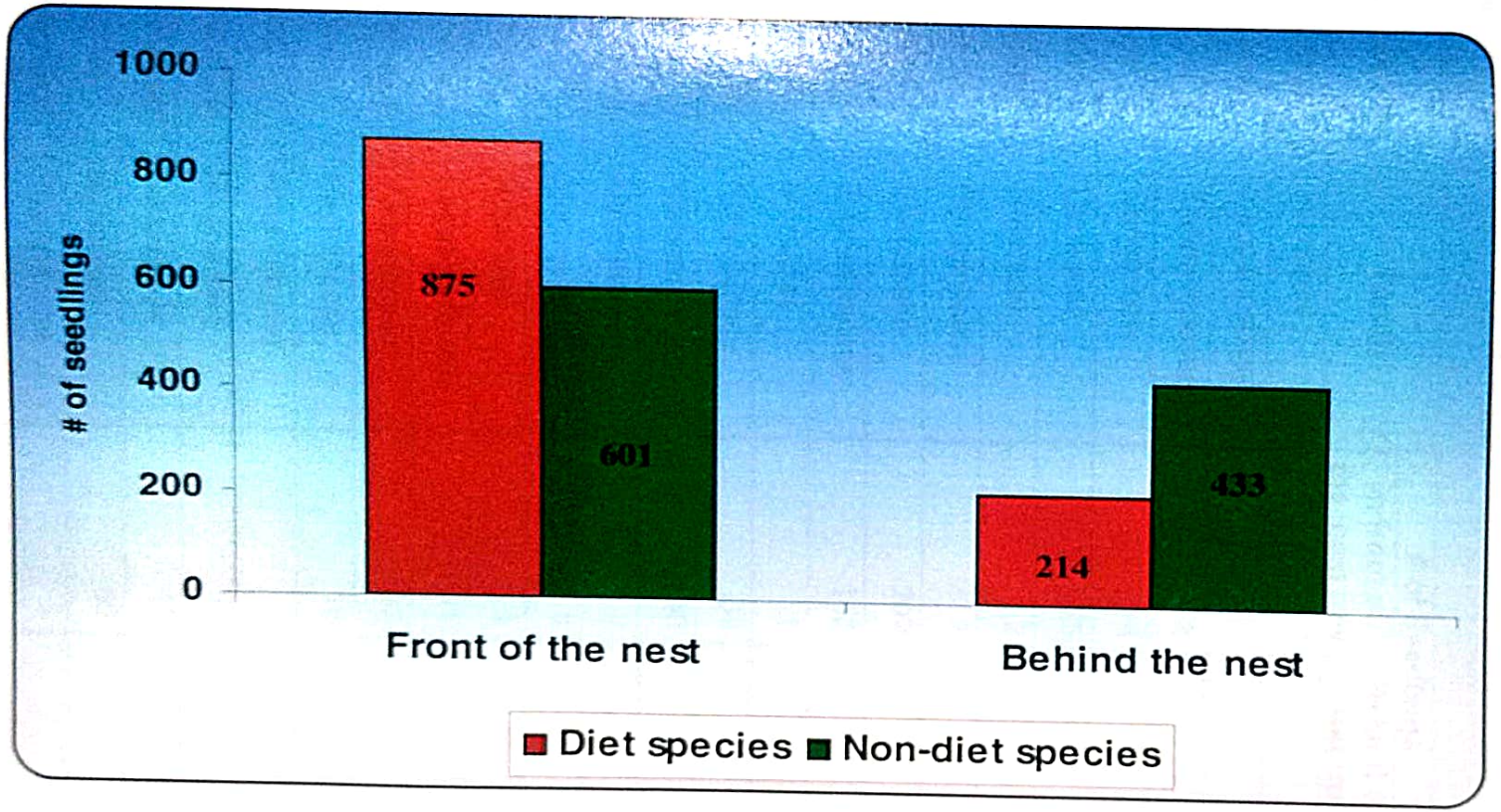


Table 12. Number of seedlings of food plant species in front and behind the nest trees of Indian Grey Hornbill

S.No.	Plant species	Family	# of Seedlings	
			In front of the nest tree	Behind the nest tree
1.	*Atalantia monophylla*	Rutaceae	1	-
2.	*Capparis grandis*	Capparidaceae	41	6
3.	*Capparis sepiaria*	Capparidaceae	8	-
4.	*Carica papaya*	Caricaceae	4	-
5.	*Celtis tetrandra*	Ulmaceae	25	2
6.	*Clausena dentata*	Rutaceae	2	-
7.	*Cordia monoica*	Boraginaceae	1	-
8.	*Diospyros montana*	Ebenaceae	209	28
9.	*Drypetes roxburghii*	Euphorbiaceae	153	7
10.	*Ficus racemosa*	Moraceae	1	-
11.	*Filicium decipiens*	Sapindaceae	38	5
12.	*Lantana camara*	Verbenaceae	140	115
13.	*Mimusops elengi*	Sapotaceae	2	-
14.	*Morus alba*	Moraceae	8	-
15.	*Naringi crenulata*	Rutaceae	1	-
16.	*Pithecellobium dulce*	Caesalpiniaceae	11	1
17.	*Premna tomentosa*	Verbenaceae	39	5
18.	*Santalum album*	Santalaceae	18	2
19.	*Scutia myrtina*	Rhamnaceae	3	-
20.	*Solanum erianthum*	Solanaceae	81	17
21.	*Solanum violaceum*	Solanaceae	18	5
22.	*Syzygium cumini*	Myrtaceae	62	20
23.	*Zizyphus mauritiana*	Rhamnaceae	5	1
24.	*Zizyphus oenoplia*	Rhamnaceae	4	-

7.2.2. Seed germination experiment

Seeds of all the 26 species dispersed by hornbills were found in the middens. Of the 26 species dispersed, 17 had large/medium seeds and six had minute seeds. Of the 3303 large/medium seeds were recorded in the middens, seeds of *Premna tomentosa* (38.66%), *Drypetes roxburghii* (19.59%), *Filicium decipiens* (12.75%), *Diospyros montana* (9.87%) and *Santalum album* (6.18%) formed the predominant species. Species with minute seeds include *Ficus benghalensis*, *Ficus drupacea*, *Ficus infectoria*, *Ficus microcarpa*, *Ficus racemosa*, *Ficus religiosa*, *Morus alba*, *Solanum erianthum* and *Solanum violaceum*. No physical injury was noticed in the seeds dispersed by hornbills.

Sixteen species with large / medium seeds were experimented. Of the 16 seed subjected for germination experiment, 15 species showed enhanced germination (Fig. 7). According to One-Way ANOVA (F = 6.142, P = <0.05), significant difference was observed between the germination percentage of bird defecated and control seeds experimented. We paired the groups as seed with pulp and pulp removed seeds, seed 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 = -5.555, df = 3 P< 0.05), seeds with pulp and bird defecated seeds (Paired-Sample T-Test t = -5.555, df = 3, P< 0.05)

and pulp removed seeds and bird defecated seeds (Paired-Sample T-Test t = -6.058, df = 8 P< 0.05).

In the case of bird defecated seeds, seedling emergence was first recorded for *Syzygium cumini* after the first week of sowing. Later in the second and third week, seedling emergence was noted for all the other species except *Santalum album*, in which seedlings emerged only after the fourth week. *Syzygium cumini*, *Premna tomentosa*, *Diospyros montana* and *Drypetes roxburghii* showed 100 percent germination. The percentage of germination was less than 30 percent for *Zizyphus mauritiana* and *Filicium decipiens* and more than 60 percent for the remaining species. *Vitex altissima* was the single species that did not germinate after defecation by hornbills (Table 13). Of the 16 species experimented as control, nine species of pulp removed and four species of intact fruit categories alone germinated, that too in lower percentage, indicating the importance of hornbill's scarification and deinhibition effect on seeds. In all, the germination trials indicate that seeds dispersed by the Indian Grey hornbill show enhanced germination.

Species such as *Syzygium cumini*, *Premna tomentosa*, *Diospyros montana*, *Drypetes roxburghii* and *Santalum album* showed 100 percent germination in bird defecated sample and seedlings of all the above species were higher in number in front of the nests. A few native plant species, *Santalum album*, *Drypetes roxburghii*, with hard seed coat needs the help of hornbills for their dispersal and

regeneration. The results indicate that the Indian Grey Hornbill is an important seed disperser in Eastern Ghats and play a major role in regeneration of its food plants.

Table 13. Comparison of germination efficiency of seeds collected from the Indian Grey Hornbill droppings and control (from trees)

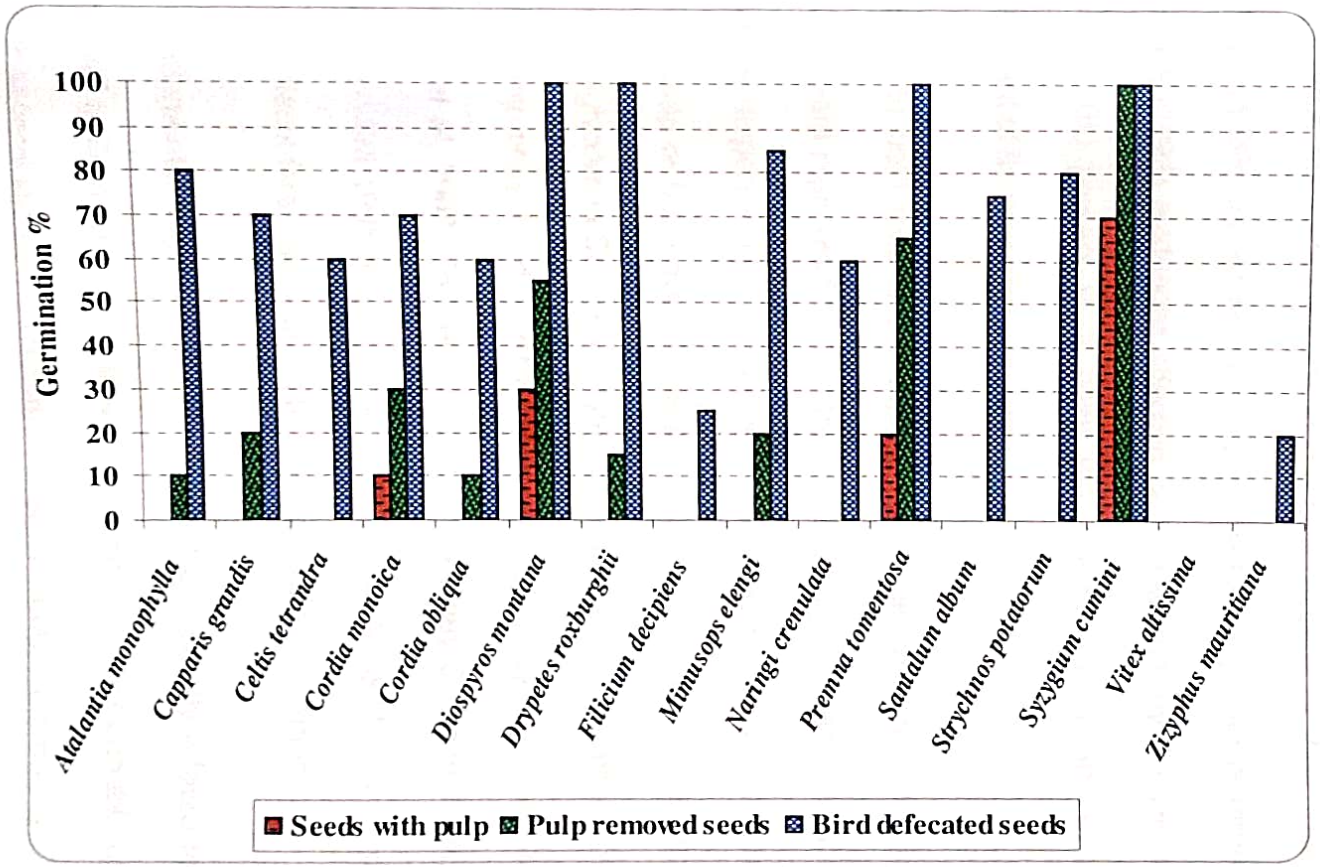
S.No.	Plant species	% of germination		
		Seeds with pulp	Pulp removed Seeds	Bird defecated seeds
1.	*Atalantia monophylla*	-	10	80
2.	*Capparis grandis*	-	20	70
3.	*Celtis tetrandra*	-	-	60
4.	*Cordia monoica*	10	30	70
5.	*Cordia obliqua*	-	10	60
6.	*Diospyros montana*	30	55	100
7.	*Drypetes roxburghii*	-	15	100
8.	*Filicium decipiens*	-	-	25
9.	*Mimusops elengi*	-	20	85
10.	*Naringi crenulata*	-	-	60
11.	*Premna tomentosa*	20	65	100
12.	*Santalum album*	-	-	75
13.	*Strychnos potatorum*	-	-	80
14.	*Syzygium cumini*	70	100	100
15.	*Vitex altissima*	-	-	-
16.	*Zizyphus mauritiana*	-	-	20

- indicates nil germination

PLATE XI

Seed germination study: experimental plot

Fig. 7. Comparison of germination efficiency of seeds (bird defecated *vs* control)



7.3. Discussion

Although, the importance of hornbills as seed dispersers is well known, only a few studies have reported their effectiveness in dispersing seeds of their food plants. Becker & Wong (1985) studied Malay Black Hornbill as disperser of large seeded fruits. Kinnaird (1998) evidenced effective seed dispersal by Sulawesi Red-knobbed Hornbill. The present study deals with the role of Indian Grey Hornbill in seed dispersal of its food plant species.

Forests are subjected to both natural and anthropogenic disturbances, which disrupt the process of plant regeneration (Teketay 2005). However, certain fruits and their seeds can be dispersed by many different vertebrates. But, fruits with large seeds need the help of large avian frugivores such as hornbills. Hornbills are the largest avian frugivores in Southeast Asia and are important members of the seed disperser community (Corlett 1998). Recent studies by Holbrook & Smith 2000; Holbrook *et al.* 2002; Poulsen *et al.* 2002; Whitney & Smith 1998; Whitney *et al.* 1998; Kinnaird 1998 and Kitamura *et al.* 2004a suggest that seed dispersal by hornbills affects forest structure in the African and Asian tropics.

Movements are a fundamental feature of vertebrates and are directly related to frugivore-seed dispersal patterns (Holbrook *et al.* 2002). Hornbills are capable of dispersing seeds over several kilometers (Holbrook & Smith 2000; Holbrook *et al.* 2002 and Whitney *et al.* 1998), resulting in an even spread of seeds in the forest. Large-scale movements by frugivores may have important conservation

implications as they provide an opportunity for long-distance seed dispersal. *Ceratogymna* hornbills make movements up to 290 km (Holbrook *et al.*, 2002). Non-breeding hornbills and juveniles do not deposit seeds in a limited area, but scatter throughout the forest (Kinnaird 1998). Seed dispersal ability of hornbills is greater in non-breeding season than in the breeding season (Datta & Rawat 2003 and Poonswad & Tsuji 1994). As Indian Grey Hornbill consumed fruits of several species in the non-breeding season, it is likely to be an important seed disperser of its food plant species. The pattern of hornbill seed dispersal at the nest site in the breeding season is very different from that of the non-breeding season.

The effective dispersal of seeds deposited beneath hornbill nests ultimately depends on whether the seedlings mature and reproduce (Kinnaird 1998). Regeneration status of food plants under the nest trees was quantified by evaluating the effectiveness of hornbill seed dispersal at nest trees, on the basis of seedling survival. The seedlings in the adjacent quadrats were also monitored (behind the nest) for comparison. Methods described by Kinnaird (1998) and Kitamura *et al.* (2004a) were followed and the results are compared with those studies. Large number of seeds is wasted due to unknown mortality factors; even then there was high density and diversity of seedlings of the food plants in the quadrats laid in front of the nest tree. These seedlings under the nest trees may obtain some nutrients from hornbill faeces (Kannan & James 1997). Considering both quantitative and qualitative components of seed dispersal, Nogales *et al.*

(2005) concluded that native birds are the most important seed dispersers in this multi-disperser system. The present study reveals that Indian Grey hornbills play an important role in the regeneration of their food plants in this landscape.

It was observed that bird defecated seeds showed higher regeneration potential than control seeds. 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 & Heithaus 1981). Naranjo *et al.* (2003) reported the effect of ingestion by birds on seed germination of cactus species in Venezuela. Robertson *et al.* (2006) assessed the benefits of frugivory for seed germination in New Zealand. Germination studies on *Ficus benghalensis* and *Azadirachta indica* by Midya & Brahmachary (1991) and Misra *et al.* (1987) also reported enhanced germination for bird defecated seeds.

Smaller birds are unable to swallow the large-sized fruits and hence bigger birds such as hornbills are very effective in dispersing the large seeded plant species. Germination trials during the present study showed that hornbill gut passed seeds showed enhanced germination. Seed dispersal by frugivorous animals is widely recognized as a crucial process in tropical forests (Stiles 1980 and 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 & Maheswaran 2002). 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 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 a similar pattern as that of Whitney *et al.* (1998) and Balasubramanian & Maheswaran (2002) establishing the role of Indian Grey Hornbill in enhancing the germination efficiency of the seeds of their food plants.

CHAPTER VIII

SUMMARY

Seed dispersal refers the removal and deposition of seeds away from parent plants, by which a plant scatter its offspring away from their source of origin 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. Basic knowledge about fruit-frugivore interactions and especially the seed dispersal process in forest ecosystems is essential for conservation of endangered animals and the forest itself. Fruit consumption by birds is an important species interaction that contributes to seed dispersal in forests.

Hornbills, being primary frugivores of the tropical forest, play an important role in seed dispersal and regeneration of forest trees. Their ability to open and swallow large, ripe fruits and their defecation and regurgitation of undamaged viable seeds make them ideal dispersers. Hornbills are one of the most recognizable groups among birds. They are distributed in Sub-saharan Africa, Australia, South-east Asia and India. Among the 54 species of hornbills in the world, 9 species occur in India. Indian Grey Hornbill (*Ocyceros birostris*) also known as Common Grey Hornbill is distributed in India, Pakistan, Nepal and North-west Bangladesh. Hornbills have specific food preferences and foraging techniques. A review of literature revealed the absence of detailed research on Indian Grey Hornbill. Hence, a study was undertaken with the following objectives, i. assess

frugivory by Indian Grey Hornbill and ii. establish its role in seed dispersal and regeneration of its food plants. The study was carried out in Sathyamangalam Forest Division (11° 29" - 11° 48" N latitude and 76° 50" - 77° 27" E longitude), Eastern Ghats, India.

In the study area, two habitats namely, dry deciduous and riverine forests were found to be used by the Indian Grey Hornbill. Vegetation assessment was done in the above-mentioned habitats and also in a disturbed dry deciduous forest site to assess the loss of food plants by anthropogenic interventions. One ha plots (100 X 100 m) were laid in each of the above-mentioned three habitats. Data collected were analyzed to obtain quantitative structure and composition of plant communities. Fruiting periodicity was monitored by tagging 210 plants belonging to 21 fleshy-fruited species for two years from July 2006 to June 2008 in the study site. Tagged plants were monitored once in a fortnight for fruit availability.

Fruit use by the hornbills was determined in the breeding and non-breeding season. During non-breeding season hornbills mostly forage on fruit trees. In the breeding season, the female and chicks that are confined to the nest holes are fed by the male. Data were gathered in two breeding and non breeding seasons during 2006-2008. In the breeding season, active cavities of trees were identified by following the breeding pair of hornbills and breeding male carrying fruit to the nest. Middens of nests were collected once in a week during the nesting period. Items collected from the 10 nest middens were analyzed, quantified and

frugivory by Indian Grey Hornbill and ii. establish its role in seed dispersal and regeneration of its food plants. The study was carried out in Sathyamangalam Forest Division (11° 29" - 11° 48" N latitude and 76° 50" - 77° 27" E longitude), Eastern Ghats, India.

In the study area, two habitats namely, dry deciduous and riverine forests were found to be used by the Indian Grey Hornbill. Vegetation assessment was done in the above-mentioned habitats and also in a disturbed dry deciduous forest site to assess the loss of food plants by anthropogenic interventions. One ha plots (100 X 100 m) were laid in each of the above-mentioned three habitats. Data collected were analyzed to obtain quantitative structure and composition of plant communities. Fruiting periodicity was monitored by tagging 210 plants belonging to 21 fleshy-fruited species for two years from July 2006 to June 2008 in the study site. Tagged plants were monitored once in a fortnight for fruit availability.

Fruit use by the hornbills was determined in the breeding and non-breeding season. During non-breeding season hornbills mostly forage on fruit trees. In the breeding season, the female and chicks that are confined to the nest holes are fed by the male. Data were gathered in two breeding and non breeding seasons during 2006-2008. In the breeding season, active cavities of trees were identified by following the breeding pair of hornbills and breeding male carrying fruit to the nest. Middens of nests were collected once in a week during the nesting period. Items collected from the 10 nest middens were analyzed, quantified and

recorded. In addition, a total of 720 hours were spent at the hides made aside the nests for monitoring the fruit deliveries by males to the nest inmates. Focal observations were carried out from 06:00 AM to 06:00 PM at 10 nests. Diet during non-breeding was assessed by scan sampling and focal animal sampling method. Observations were done along selected transects, mostly done from 06:00 to 10:00 AM and 04:00 to 06:00 PM when the feeding activity of hornbills was high. During the transect walk, hornbills foraging within 50 m of either side of transects were recorded. During each observation, food item consumed and the tree species in which they were feeding were recorded. Fruits being the major diet, efforts were made to find out hornbill's preferred fruit species. Preference index (PI) was calculated using Ivlev's Index of Selectivity.

Role of Indian Grey Hornbill in regeneration of its food plants was assessed by monitoring the seedling abundance in front and behind 10 nest trees. A total of 20 quadrats were laid for sampling seedling abundance. Two 3x3 m quadrats, one each in the front and behind the nest trees were laid. All the seedlings in the 3x3m quadrats were recorded and identified. The plots were monitored weekly for seedling emergence. All seedlings in the 3 m plots were identified and counted.

Seed germination experiments were conducted to compare the germination efficiency of bird defecated seeds with that of control seeds. For the germination experiment, 16 seed species were used. Three categories of seed samples were

used for germination experiments, i. bird dispersed seeds collected from the nest middens, ii. pulp removed seeds and iii. seed with pulp. For each category, 10 seeds were used. Seeds were sown in polythene bags. The bags were filled with soil and sand mixture. The poly-bags were watered regularly and the height of the seedlings was recorded every week for four months from the date of sowing.

In the 1 ha plot of the dry deciduous forest, 322 trees belonging to 30 species, 28 genera and 17 families were recorded. Shannon's species diversity was worked out to be 2.64. A total of 588 trees belonging to 64 tree species, 49 genera and 25 families were recorded in the riverine forests. Shannon's species diversity for tree flora was worked out to be 3.40. Among the 41 species of Indian Grey hornbill's food plants recorded in the study area, 22 species were recorded in the sample plots. Of the 22 food plant species, 20 were recorded in the riverine habitat and 14 in the dry deciduous habitat. Tree species diversity (2.12) was found to be lower in the human impacted site, as compared to the undisturbed forest site.

Fruit production occurs year round in the dry deciduous forest. A fruiting peak was recorded in May and July of both the years, indicating the occurrence of seasonality. Of the 21 plant species tagged for phenological studies, four species of Moraceae (*Ficus benghalensis, Ficus drupacea, Ficus microcarpa* and *Ficus racemosa*) fruited throughout the year. All other species showed seasonal fruiting activity. Fruit abundance also had fluctuation between the years.

The nesting period of Indian Grey Hornbill lasted for about three months from March to May. The nesting period averaged 87 days. In the breeding season, the food items delivered to the nest inmates (female and chicks) include both vegetable (63.65%) and animal matter (36.35%). During nest monitoring, a total of 13,680 food items were delivered to the nest inmates. The vegetable diet included mainly fruits (98.30%) and a small proportion of *Melia dubia* leaves. Fruits of 26 plant species belonging to 16 families were consumed during the breeding season among which 14 species were identified by monitoring the nests and 12 species from the nest middens. Seeds of all the 26 species were found in middens. A total of 3,303 large/medium seeds were recorded in the middens of 10 nests. Seeds of *Premna tomentosa* (38.66%), *Drypetes roxburghii* (19.59%), *Filicium decipiens* (12.75%), *Diospyros montana* (9.87%) and *Santalum album* (6.18%) formed the predominant species. The nine species with minute seeds include *Ficus* spp (6), *Solanum* spp (2) and *Morus alba*. No physical injury was noticed in the seeds dispersed by Indian Grey hornbills.

Food habits during non-breeding season were assessed by walking along transects and observing foraging activities of hornbills. Of the 3086 feeding observations made, 82.98% were on fruits and the remaining included leaves (8.82%), insects (7.70%) and flowers (0.50%). Of the 38 fruit species belonging to 21 families consumed, *Ficus* constituted 25.26% of the non-breeding season diet. In all, fruits of 41 species belonging to 22 families were consumed by Indian

Grey Hornbill. Both figs and non-figs formed the diet of Indian Grey Hornbill in Eastern Ghats.

Ivlev's preference index (PI) showed that all the six *Ficus* spp. were preferred by Indian Grey hornbills both in breeding and non-breeding season with the PI value >0.9. During breeding season, hornbill prefers *Ficus microcarpa* and *Premna tomentosa* (PI=0.99) followed by *Santalum album* (PI=0.98) and *Ficus benghalensis* (PI=0.97). During the non-breeding season, *Bridelia crenulata* (PI=0.97) followed by *Ficus religiosa* (PI=0.95) and *Solanum erianthum* (PI=0.95) were preferred.

Regeneration of hornbill's food plants under the nest trees were recorded for 10 nests. Twenty 3X3 m quadrats were laid in front and behind the nest trees for comparison. A total of 44 species of seedlings were recorded among which 24 species (54.5%) were found to be food plant species of Indian Grey Hornbill.

Predominant diet species found in front of the nest trees were *Diospyros montana* (23.97%) and *Drypetes roxburghii* (17.47%). The number of seedlings of hornbill diet species (plants) was higher than that of non-diet species in front of the nests. Quantification of seedlings under the nest trees showed that the abundance of the hornbill's food plants were higher in front of the nest trees than behind the nest trees. The number of seedlings in front of the nest trees was nearly four times more than the seedlings behind the nests. Regeneration of hornbill's food plant species was also quantified under the roost trees. Prominent

seedlings include *Syzygium cumini*, *Diospyros montana*, *Drypetes roxburghii*, *Premna tomentosa, Santalum album* and *Filicium decipiens.*

Of the 16 seed species subjected for germination experiment, 15 species of bird defecated seeds showed enhanced germination. Species such as *Syzygium cumini, Premna tomentosa, Diospyros montana* and *Drypetes roxburghii* showed 100 percent germination. The percentage of germination was less than 30 percent for *Zizyphus mauritiana* and *Filicium decipiens* and more than 60 percent for the remaining species. Of the 16 control species experimented, nine species of pulp removed seeds and four species of intact fruit alone germinated, indicating the importance of hornbill's scarification and deinhibition effect on seeds. Germination trials indicated that majority of the seeds dispersed by the Indian Grey hornbill show enhanced germination.

Study shows that Indian Grey Hornbill is mainly a frugivorous bird, 64% of the breeding season diet and 92% of the non-breeding season diet constituted fruits. In all, Indian Grey Hornbill consumed 41 fleshy fruited species belonging to 22 plant families. Seed germination trials showed enhanced germination percentage of hornbill defecated seeds. Food habits and regeneration of hornbill's food plants at the nest and roost sites point out that Indian Grey Hornbill plays an important role in seed dispersal.

CHAPTER IX

CONCLUSION

Indian Grey hornbills are primarily frugivorous, 64% of the breeding season diet and 92% of the non-breeding season diet constituted fruits. Twenty six fruit species belonging to 16 families, 38 fruit species belonging to 21 families were consumed during the non-breeding and breeding season respectively. In all 41 fruit species of 22 families were eaten by hornbills in the study area.

Indian Grey Hornbill's preferred fruits include *Ficus microcarpa* and *Premna tomentosa* (PI=0.99) followed by *Santalum album* (PI=0.98) and *Ficus benghalensis* (PI=0.97) during breeding season and *Bridelia crenulata* (PI=0.97), *Ficus religiosa* (PI=0.95) and *Solanum erianthum* (PI=0.95) in the non-breeding season.

During the breeding season, seeds of 26 plant species belonging to 16 families were dispersed by Indian Grey Hornbill. A total of 3,303 large/medium seeds were recorded in the middens of 10 nests. Predominant species found in the middens were *Premna tomentosa* (38%), *Drypetes roxburghii* (19%), and *Filicium decipiens* (12%).

Regeneration of food plants were recorded under the nest trees. Of the 44 species of seedlings recorded, 24 species (54.5%) were found to be food plant

species of Indian Grey Hornbill. The number of seedlings of the diet species in front of the nest tree was higher than at behind the nest tree.

Seedlings of nine species were recorded under the hornbill roost sites. Predominant seedling species include *Syzygium cumini* (25%), *Diospyros montana* (20%) and *Drypetes roxburghii* (17%).

Seeds of sixteen fleshy fruited species were subjected for germination experiments. Of the 16 species experimented, 15 species showed enhanced germination. Seeds of *Syzygium cumini*, *Premna tomentosa*, *Diospyros montana* and *Drypetes roxburghii* showed 100 percent germination.

Seed germination trials showed enhanced germination percentage for hornbill defecated seeds. Regeneration studies of hornbill's food plants at the nest sites point out that Indian Grey Hornbill plays an important role in seed dispersal. Economically important trees benefited by Indian Grey Hornbill included *Santalum album, Drypetes roxburghii, Diospyros montana, Strychnos potatorum, Vitex altissima, Celtis tetrandra* and *Syzygium cumini.*

Threats

Encroachment of forest areas for agricultural activities is prevalent in the study area. This leads to the loss of habitat. Forest fire, livestock grazing and collection of non-timber forest products are also noticed in the study area. Predation was

recorded in two nests of Indian Grey Hornbill. Poaching of hornbills though not recorded in the study area, reported in other areas.

Conservation measures

Encroachments of forest lands for agriculture need to be prevented. Preventive measures may be taken to stop the occurrence of forest fires. Poaching of hornbills need to be stopped. It is suggested to plant hornbill's preferred food and nest tree species in the restoration programmes. This would help to sustain the population of hornbills and other frugivorous birds.

LITERATURE CITED

Ahmedullah, M., and Nayar, M.P. 1986. Endemic plants of the Indian Region. Botanical Survey of India, Calcutta.

Ali, S., 1979. *The book of Indian Birds*. Bombay Natural History Society, Mumbai.

Ali, S. and Ripley, S.D. 1970. *Handbook of the Birds of India and Pakistan.* Compact edition. Oxford University Press, Oxford, New York.

Ali, S., and Ripley, S.D. 1987. *Compact Handbook of the Birds of India and Pakistan.* Oxford University Press, New Delhi.

Altman, J.C. 1974. Observational study of behaviour – sampling method. *Behaviour* 49: 227-285.

Anggraini, K., Kinnaird, M., and O'Brien, T. 2000. The effect of fruit availability and habit disturbance on an assemblage of Sumatran hornbills. *Bird Conservation International* 10: 189-202.

Balasubramanian, P. 1996. Interactions between fruit-eating birds and bird-dispersed plants in the tropical dry evergreen forest of Point Calimere, South India. *Journal of Bombay Natural History Society* 93:428- 441.

Balasubramanian, P., and Bole, P.V. 1993. Seed dispersal by mammals at Point Calimere Wildlife Sanctuary, Tamil Nadu. *Journal of Bombay Natural History Society* 90:33-44.

Balasubramanian, P., and Maheswaran, B. 2002. Frugivory, seed dispersal and regeneration by birds in south Indian forests. *Journal of Bombay Natural History Society* 100: 411- 431.

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.

Balasubramanian, P., Ravi, R., Venkitachalam, R., Maheswaran, B., Krishnakumar, N., Vijayan, V.S., and Prasad, S.N. 2005. Status and conservation of the hornbills in southern India. In: Kemp, A.C., and Kemp, M.I. (ed). *The Active Management of Hornbills and their Habitats for Conservation.* pp. 143-153. CD-ROM Proceedings of the 4th International Hornbill Conference, Mabula Game Lodge, Bela-Bela, South Africa. Naturalists and Nomads, Pretoria.

Barnea, A., Yom-Tov, Y., and Friedman, J. 1990. Differential germination of two closely related species of *Solanum* in response to bird ingestion. *Oikos* 57: 222–228.

Becker, P., and Wong, M. 1985. Seed dispersal, seed predation and juvenile mortality of *Aglaia* sp. (Meliaceae) in lowland dipterocarp rain forest. *Biotropica* 17: 230-237.

BirdLife International. 2001. *Threatened birds of the world.* Lynx Edicions and BirdLife International, Baracelona and Cambridge.

Brockelman, W.Y. 1982. Observations of animals feeding in a strangler fig, *Ficus drupacea*, in southeast Thailand. *Natural History Bulletin of the Siam Society* 30: 33-44.

Cahill, A.J. 2003. Nest-site characteristics of the Red-knobbed Hornbill *Aceros cassidix* and Sulawesi Dwarf Hornbill *Penelopides exarhatus. Ibis* 145: 97-113.

Carlo, T.A., and Morales, J.M. 2008. Inequalities in fruit-removal and seed dispersal: consequences of bird behaviour, neighbourhood density and landscape aggregation. *Journal of Ecology* 96: 609-618.

Carlo, T.A., Collazo, J.A., and Groom, M.J. 2003. Avian fruit preferences across a Puerto Rican forested landscape: pattern consistency and implications for seed removal. *Oecologia* 134:119–131.

Champion, H.G., and Seth, S.K. 1968. *A Revised Survey of the Forest Types of India*. Govt. of India Press, New Delhi.

Chapman, C.A., Chapman, L.J., Strahsaker, T.T., Zanne, A.E., Clark, C.J., and Poulsen, J.R. 2005. A long term evaluation of fruiting phenology: importance of climate change. *Journal of Tropical Ecology* 21: 31-45.

Chattopadhyay, S. 1985. Deforestation in parts of Western Ghats region (Kerala), India. *Journal of Environment Management* 20: 219-230.

Corlett, R.T. 1996. Characteristics of vertebrate-dispersed fruits in Hong Kong. *Journal of Tropical Ecology* 12: 819-833.

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

Curtis, J.T., and McIntosh, R.P. 1950. The interactions of certain analytic and synthetic phytosociological characters. *Ecology* 31: 434-455.

Da Silvaj, 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.

Da Silvaj, M.C., Uhl, C., and Murray, G. 1996. Plant succession, landscape management, and the ecology of frugivorous birds in abandoned Amazonian pastures. *Conservation Biology* 10: 491-503.

Darvin, C. 1859. *On the Origin of Species by Means of Natural Selection or the Preservation of Favoured Races in the Struggle for Life.* Murray. London, U.K.

Datta, A. 1998. Hornbill abundance in unlogged forest, selectively logged forest and a forest plantation in Arunachal Pradesh, India. *Oryx* 32(4): 285-294.

Datta, A., and Rawat, G.S. 2003. Foraging patterns of sympatric hornbills during the nonbreeding season in Arunachal Pradesh, northeast India. *Biotropica* 35:208-218.

Datta, A., and Rawat, G.S. 2004. Nest-site selection and nesting success of three hornbill species in Arunachal Pradesh, north-east India: Great Hornbill *Buceros bicornis*, Wreathed Hornbill *Aceros undulatus* and Oriental Pied Hornbill *Anthracoceros albirostris*. *Bird Conservation International* 14: 39-52.

Flemming, T.H., and Heithaus, E.R. 1981. Frugivorous bats, seed shadows and the structure of tropical forests. *Biotropica* 13: 45-53.

Gamble, J.S., and Fischer, C.E.C. 1967. *Flora of the Presidency of Madras*. Reprinted Edition, Vol. I – III, Botanical Survey of India, Calcutta.

Gilbert, L.E. 1980. Food web organization and the conservation of neotropical diversity. *In* M.E. Soule and B.A. Wilcox (eds.). *Conservation Biology: an Evolutionary – Ecological Perspective*. Sinauer, Sunderland, MA. pp. 11-33.

Griz, L.M.S., and Machado, I.C.S. 2001. Fruiting phenology and seed dispersal syndromes in Caatinga, a tropical dry forest in the northeast of Brazil. *Journal of Tropical Ecology* 17: 303-321.

Hadiprakarsa, Y.Y., and Kinnaird, M.F. 2004. Foraging characteristics of an assemblage of four Sumatran hornbill species. *Bird Conservation International* 14:S53-S62.

Hall, E.F. 1918. Notes on the nidification of the Common Grey Hornbill (*Lophoceros birostris*). *Journal of Bombay Natural History Society* 94: 408-411.

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

Heindl, M., and Curio. E. 1999. Observations of frugivorous birds at fruit-bearing plants in the north Negros Forest Reserve, Philippines. *Ecotropica* 5: 167-181.

Heywood, V.H. 1995. *Global biodiversity assessment*. Cambridge University Press. Cambridge, UK.

Holbrook, K.M., and Smith, T.B. 2000. Seed dispersal and movement patterns in two species of *Ceratogymna* hornbills in West African tropical lowland forest. *Oecologia* 125: 249–257

Holbrook, K.M., Smith, T.B., and Hardesty, B.D. 2002. Implications of long-distance movements of frugivorous rain forest hornbills. *Ecography* 25: 745-749.

Howe, H.F. 1977. Bird activity and seed dispersal of a tropical wet forest tree. *Ecology* 58: 539-550.

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

Howe, H.F. and Smallwood, J., 1982. Ecology of seed dispersal. *Annual Review of Ecology and Systematics* 13:201-228.

Hulley, P.E., and Craig, A. 2007. The status of the Southern Ground-Hornbill in the Grahamstown region, Eastern Cape, South Africa. *Ostrich* 78:89-92.

Hussain, S.A. 1984. Some aspects of the biology and ecology of Narcondam Hornbill (*Rhyticeros narcondami*). *Journal of Bombay Natural History Society* 81: 1-18.

Ivlev, V.S. 1961. *Experimental ecology of the feeding fishes.* New Haven, CN: Yale University Press.

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

Johns, A.D. 1987. The use of primary and selectively logged rainforest by Malaysian hornbills (Bucerotidae) and implications for their conservation. *Biological Conservation* 40: 179-190.

Kalina, J. 1989. Nest intruders, nest defense and foraging behavior in the black-and-white casqued hornbill *Bycanistes subcylindricus*. *Ibis* 131:567-571.

Kannan, R., and James, D.A. 1997. Breeding biology of Great Pied Hornbill (*Buceros bicornis*) in the Western Ghats of South India. *Journal of Bombay Natural History Society* 94:(3) 451-465.

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.

Kemp, A .C. 1995. *The Hornbills*. Oxford University Press, Oxford.

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

Kimura, K., Yumoto, T., and Kikuzawa, K. 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.

Kinnaird, M.F. 1998. Evidences for effective seed dispersal by the Sulawesi Red-knobbed Hornbill *Aceros cassidix*. *Biotropica* 30: 50-55.

Kinnaird, M.F., and O'Brien, T.G. 1993. Preliminary observation on the breeding biology of the endemic Sulawesi Red-knobbed Hornbill (*Rhyticeros cassidix*). *Tropical Biodiversity* 1:107-112.

Kinnaird, M.F., and O'Brien, T.G. 1999. Breeding ecology of Sulawesi Red-knobbed Hornbill *Aceros cassidix. Ibis* 141: 60-69.

Kinnaird, M.F., O'Brien, T.G., and Suryadi, S. 1996. Population fluctuation in Sulawesi Red-knobbed Hornbill *Aceros cassidix* : tracking figs in space and time. *Auk* 113, 43-440.

Kitamura, S., Yumoto, T., Poonswad, P., Chulailua, P., Plongmai, K., Maruhashi T., and Noma, N. 2001. Interactions between fleshy fruits and frugivores in the tropical seasonal forest in Thailand. *Oecologia* 133: 559-572.

Kitamura, S., Yumoto, T., Poonswad, P., Noma, N., Chuailua, P., Plongmai, K., Maruhashi T., and Suckasam, C. 2004a. Pattern and impact of hornbill seed dispersal at nest trees in a moist evergreen forest in Thailand. *Journal of Tropical Ecology* 20: 545-553.

Kitamura, S., Yumoto, T., Poonswad, P., Chulailua, P., and Plongmai, K. 2004b. Characteristics of hornbill-dispersed fruits in a tropical seasonal forest in Thailand. *Bird Conservation International* 14: 581-588.

Kitamura, S., Yumoto, T., Noma, N., Chuailua, P., Maruhashi, T., Wohandee, P., and Poonswad, P. 2008. Aggregated seed dispersal by wreathed hornbills at a roost site in a moist evergreen forest of Thailand. *Ecological Research* 23:943-952.

Klop, E., Curio, E., and Lastimoza, L.L. 2000. Breeding biology, nest site characteristics and nest spacing of the Visayan Tarictic Hornbill *Penelopides panini panini* on Panny, Philippines. *Bird Conservation. International* 10: 17-27.

Kursic, R.A., Yamasaki, M., Neefus, C.D., and Pekins, P.J. 1996. Bat habitat use in White Mountain National Forest. *Journal of Wildlife Management* 60 (3): 625-631.

Lambert, F.R. 1989. Fig-eating by birds in a Malaysian lowland forest. *Journal of Tropical Ecology* 5: 401-412.

Leighton, M. 1986. Hornbill social Dispersion: variations on a monogamous theme. *In* D.I. Rubesnstein and R.W. Wrangham (eds.). *Ecological aspects of social evolution*, Princeton University Press, Princeton, New Jersey. pp. 108-30.

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.

Maheswaran, B., and Balasubramanian, P. 2003. Nest tree utilization by the Malabar Grey Hornbill *Ocyceros griseus* in the semi-evergreen forest of Mudumalai Wildlife Sanctuary (S India). *Acta Ornithologica* 38:33-37.

McKey, D. 1975. The ecology of coevolved seed dispersal systems. *Co-evolution of animals and plants* (eds. L.E. Gilbert and P.H. Raven), pp. 159–191. University of Texas Press, Austin, USA.

Midya, S., and Bramachary, R.L. 1991. The effect of birds upon germination of Banyan (*Ficus benghalensis*) seeds. *Journal of Tropical Ecology* 7: 537-538.

Mishra, R.M., Bhatnagar, S., and Sharma. M. 1987. Studies on dispersal ecology of *Azadirachta indica* Juss. *Geobios* 14: 112-116.

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

Moreau, R.E., and Moreau, W.M. 1941. Breeding biology of Silvery cheeked hornbills. *Auk* 58: 13-27.

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

Mudappa, D. 2000. Breeding biology of the Malabar Grey Hornbill (*Ocyceros griseus*) in Southern Western Ghats, India. *Journal of Bombay Natural History Society* 97: 15-24.

Murthy, M.R.S., Sudhakar, S., Jha, C.S., Sudhakar Reddy Ch., Pujar, G.S., Roy, A., Rajasekharan, G., Trevedi, S., Pattanaik, C., Sudha, K., Ambastha, K., Joseph S., and Roj, P.S. 2007. Vegetation, land cover and phytodiversity characterization at landscape level using satellite remort sensing and Geographic informantion system in Eastern Ghats, India. *EPTRI-ENVIS Newsletter* 13: (1). 2-12.

Murthy, R.S., Pofali, R.M., Sitaram, R., and Swaminathan, M. 1982. Environs of Eastern Ghats—their problems, potentials and priorities for development. *Proc. National Seminar on Resources, Development and Environment of Eastern Ghats.* Waltair. pp. 39-143.

Naranjo, M.E., Rengifo, C., and Soriano, J. 2003. Effect of ingestion by bats and birds on seed germination of *Stenocereus griseus* and *Subpilocereus repandus* (Cactaceae). *Journal of Tropical Ecology* 19: 19-25.

Nasonj, D., and. Hamrick, J. L. 1997. Reproductive and genetic consequences of forest fragmentation: Two case studies of Neotropical canopy trees. *The Journal of Heredity* 88: 264-276.

Nathan, R., and Muller-Landau, H.C. 2000. Spatial patterns of seed dispersal, their determinants and consequences for recruitment. *Trends in Ecology and Evolution* 15:278–285.

Nogales, M., Nieves, C., Illera, J.C., Padilla, D.P., Traveset, A. 2005. Effect of native and alien vertebrate frugivores on seed viability and germination patterns of *Rubia fruticosa* (Rubiaceae) in the eastern Canary Islands. *Functional Ecology* 19:3. 429-436.

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

O'Brien, T.G. 1997. Behavioural ecology of the North Sulawesi Tarictic Hornbill *Penelopides exarhatus exarhatus* during the breeding season. *Ibis* 139:97-101.

Opler, P.A., Frankie, G.W., and Baker, H.G. 1980. Comparative phenological studies of treelet and shrubs species in tropical wet and dry forests in the lowlands of Costa Rica. *Journal of Ecology* 68: 167-188.

Patil, N., Chaturvedi, N., and Hedge, V. 1997. Food of Common Grey Hornbill *Tockus birostris* (Scopoli). *Journal of Bombay Natural History Society* 94: 408-411.

Philips, E.A. 1959. Methods of vegetation study. Henry Holt and Co. New York.

Poonswad, P. 1995. Nest site characteristics of four sympatric species of hornbills in Khao Yal National Park, Thailand. *Ibis* 137: 183-191.

Poonswad, P., and Tsuji, A. 1994. Ranges of males of the Great Hornbill *Buceros bicornis*, Brown Hornbill *Ptilolaemus tickelli* and Wreathed Hornbill *Rhyticeros undulatus* in Khao Yai National Park, Thailand. *Ibis* 136: 79-86.

Poonswad, P., Tsuji, A., and Ngarmpongsai, C. 1987. A comparative study on breeding biology of sympatric hornbill species (Bucerotidae) in Thailand with implications for breeding in captivity. In Proceedings 1987 Jean Delacour/IFCB *Symposium on Breeding Birds in Captivity*, pp. 250-277. International Foundation for the Conservation of Birds, North Hollywood, California, U.S.A.

Poonswad, P., Tsuji, A., Jirawatkavi, N., and Chimchome, V. 1998. Some aspects of food and feeding ecology of sympatric hornbill species in Khao Yai National Park, Thailand. pp. 137-157 in Poonswad, P. (ed.). *The Asian hornbills: ecology and conservation*, *Thai Studies in Biodiversity* 2. BIOTEC, NSTDA, Bangkok.

Poulsen, J.R., Clark, C.J., Conner, E.F, and Smith, T.B. 2002. Differential resources use by primates and hornbills: implications for seed dispersal. *Ecology* 83: 228-240.

Pullaiah, T., and Muralidhar Rao, D. 2002. Flora of Eastern Ghats: hill ranges of Southeast Asia.

Reddy, M.S., and Basalingappa, S. 1995. The food of Malabar Pied Hornbill. *Journal of Ecological Society* 8: 23-28.

Reddy, S., Reddy, K.N., Prasad, P.R.C., and Raju, V.S. 2003. Threatened endemic plants from Eastern Ghats, India. EPTRI – ENVIS Newsletter 9(2): 3-7.

Robertson, A.W., Trass, A., Ladley, J.J., and Kelly, D. 2006. Assessing the benefits of frugivory for seed germination: the importance of deinhibition effect. *Functional Ecology* 20: 58-66.

Roxburgh, L. 2007. The effect of gut processing on the quality on mistletoe seed dispersal. *Journal of Tropical Ecology* 23: 377-380.

Russo, S.E., Portnoy, S., and Augspurger, C.K. 2006. Incorporating animal behavior into seed dispersal models: implications for seed shadows. *Ecology* 87: 3160-3174.

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

Senapathi, S.K. 2003. Bird and plant propagation with special reference to Eastern Ghats, Orissa. *The Eastern Ghats. EPTRI-ENVIS Newsletter.* 9(3): 6-7.

Shannon, C.E., and Weiner, W. 1949. *The mathematical theory of communication*. University of Illinnos Press. Urbana.

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

Siriporn, T.A. 2005. Ecology of Wrinkled Hornbill *Aceros* (*Rhyticeros*) *corrugatus* in Bala forest. Hala Bala Wildlife Research Station, Bangkok.

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

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.

Stoner, K.E., and Henry, M. 2007. Seed dispersal and frugivory 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.

Suryadi, S., Kinnaird, M.F., O'Brien, T.G., Supriatna, J., and Somadikarta, S. 1994. Food preferences of the Sulawesi red-knobbed hornbill during the non-breeding season. *Tropical Biodiversity* 2:377-384.

Suryadi, S., Kinnaird, M.F., and O'Brien, T.G. 1996. Home ranges and daily movements of the Sulawesi Red-knobbed Hornbill during the non-breeding season. In: Proceedings of the *Second International Asian Hornbill Workshop*, Bangkok, Thailand.

Suryadi, S., Kinnaird, M.F., and O'Brien, T.G. 1998. Home ranges and daily movements of the Sulawesi Red-knobbed Hornbill during the non-breeding season. pp. 159-170 *In* P. Poonswad, (ed.). *The Asian hornbills: ecology and conservation.* Bangkok: Thai Studies in Biodiversity 2.

Teketay. D. 2005. Seed and regeneration ecology in dry afromontane forests of Ethiopia: I. Seed production – population structures. *Tropical Ecology* 46: (1) 29-44.

Terborgh, J. 1986. Keystone plant resources in tropical forest. *In* M. Soule (ed.). *Conservation Biology: the science of scarcity and diversity*, Sinauer Associates, Sunderland, Massachusetts. pp. 33-44.

Thiensongrusamee, P., Poonswad, P., and Hayeemuida, S. 2005. Characteristics of Helmeted Hornbill nests in Thailand. pp. 51-54 in Lum, S., and Poonswad, P. (eds.) *The ecology of hornbills: reproduction and populations.* Pimdee Karnpim Co. Ltd., Bangkok, Thailand. long-distance movements of frugivorous rain forest hornbills. *Ecography* 25:745-749.

Thompson, J.N., and Willson, M.F. 1979 Evolution of temperate fruit/bird interactions: phenological strategies. *Evolution* 33: 973–982.

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., and Verdu. M. 2001. A meta-analysis of gut treatment on seed germination. *Frugivores and Seed Dispersal: Ecological, Evolutionary and Conservation Issues* (eds. D. Levey, M. Galetti and W. Silva). CAB International, Wallingford, UK.

Van der Pijl, L. 1957. *Seed dispersal mechanisms*. Springer-Verlag. Berlin.

Van der Pijl, L. 1982. *Principles of Dispersal in Higher Plants*. Springer Verlag, Berllin.

Wenny, D.G. 2000. Seed dispersal, seed predation, and seedling recruitment of neotropical montane tree. *Ecological Monographs* 70: 331–355.

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.

Whitney, K.D., Fogiel, M.K., Lamperti, A.M., Holbrook, K.M., Stauffer, D.J., Hardesty, B.D., Parker, V.T., and Smith, T.B. 1998. Seed dispersal by *Ceratogymna hornbills* in the Dja reserve, Cameroon. *Journal of Tropical Ecology 14*, 351-371.

Willson M.F. 1992. Biodiversity and ecological processes. *In* Szaro, R.C. and D.W. Johnston (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, Wallingford, UK.

Yahya, H.S.A., and Zarri, A.A. 2002. Status, ecology and behaviour of Narcondam Hornbill, Andaman and Nicobar Islands, India. *Journal of Bombay Natural History Society* 99(3): 434-445.

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

APPENDIX 1

Fruits consumed by Indian Grey Hornbill in Eastern Ghats, India

S. No	Family	Botanical Name
1	Boraginaceae	*Cordia monoica*
2	Boraginaceae	*Cordia obliqua*
3	Caesalpiniaceae	*Pithecellobium dulce*
4	Capparidaceae	*Capparis grandis*
5	Capparidaceae	*Capparis sepiaria*
6	Caricaceae	*Carica papaya*
7	Celastraceae	*Euonymus indica*
8	Ebenaceae	*Diospyros montana*
9	Erythroxylaceae	*Erythroxylum monogynum*
10	Euphorbiaceae	*Bridelia crenulata*
11	Euphorbiaceae	*Drypetes roxburghii*
12	Loganiaceae	*Strychnos potatorum*
13	Moraceae	*Ficus benghalensis*
14	Moraceae	*Ficus drupacea*
15	Moraceae	*Ficus infectoria*
16	Moraceae	*Ficus microcarpa*
17	Moraceae	*Ficus racemosa*
18	Moraceae	*Ficus religiosa*
19	Moraceae	*Morus alba*
20	Myrtaceae	*Psidium guajava*
21	Myrtaceae	*Syzygium cumini*
22	Rhamnaceae	*Scutia myrtina*
23	Rhamnaceae	*Zizyphus mauritiana*
24	Rhamnaceae	*Zizyphus oenoplia*

25	Rubiaceae	*Canthium dicoccum*
26	Rubiaceae	*Ixora pavetta*
27	Rutaceae	*Atalantia monophylla*
28	Rutaceae	*Naringi crenulata*
29	Rutaceae	*Clausena dentata*
30	Sapindaceae	*Filicium decipiens*
31	Sapindaceae	*Schleichera oleosa*
32	Sapotaceae	*Mimusops elengi*
33	Santalaceae	*Santalum album*
34	Solanaceae	*Solanum erianthum*
35	Solanaceae	*Solanum violaceum*
36	Tiliaceae	*Grewia tiliaefolia*
37	Tiliaceae	*Muntingia calabura*
38	Ulmaceae	*Celtis tetrandra*
39	Verbenaceae	*Lantana camara*
40	Verbenaceae	*Premna tomentosa*
41	Verbenaceae	*Vitex altissima*