IMPACTS OF HABITAT FRAGMENTATION ON THE ARBOREAL MAMMALS IN THE WET EVERGREEN FORESTS OF THE ANAMALAI HILLS IN THE WESTERN GHATS, SOUTH INDIA

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DEGREE OF DOCTOR OF PHILOSOPHY
in
ZOOLOGY

by
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CERTIFICATE

This is to certify that the thesis, entitled "**Impacts of habitat fragmentation on the arboreal mammals in the wet evergreen forests of the Anamalai Hills in the Western Ghats, South India**" is a record of original research work done by **Mr.G.Umapathy** in the Division of Conservation Biology, Salim Ali Centre for Ornithology and Natural History, as a full time Research Scholar during the period of study 1994 - 1998 under my guidance and supervision for the award of the Degree of Doctor of Philosophy in Zoology. I further certify that this research work has not previously formed the basis for the award of any other Degree or Diploma or Associateship or Fellowship or other similar title to any candidate of this or any other University.

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DECLARATION

I do hereby declare that the thesis entitled "**Impacts of habitat fragmentation on the arboreal mammals in the wet evergreen forests of the Anamalai Hills in the Western Ghats, South India**" submitted to the Bharathiar University, Coimbatore, for the award of the Degree of Doctor of Philosophy in Zoology, is a record of original and independent research work done by me during 1994 - 1998 under the supervision and guidance of **Dr.Ajith Kumar,** Principal Scientist, Salim Ali Centre for Ornithology and Natural History, Coimbatore, and it has not previously formed the basis for the award of any Degree, Diploma, Associateship, Fellowship or other similar title to any candidate of any University.

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SUMMARY

Habitat fragmentation is the most severe threat to biological diversity and is the primary cause of the present species extinction crisis. Small populations in fragments are highly prone to extinction due to demographic and environmental stochasticity, disease and catastrophes. Long term degeneration of habitat might also add to this extinction. In south India, wet evergreen (or rain) forest is confined to the Western Ghats mountains. Human activities such as plantations of tea, coffee, teak, *etc.*, and construction of roads, railways, and reservoirs during the last two centuries have led to extensive loss of these forests. More importantly, the remaining forest has been severely fragmented.

The impact of forest fragmentation is expected to be particularly severe among the arboreal mammals due to loss of arboreal connectivity between forest fragments. In this background, the objectives of this study were; 1) To assess the extent to which arboreal mammals disappear from wet evergreen forest fragments with respect to various landscape and habitat parameters associated with forest fragmentation; 2) To identify changes in their activity pattern and feeding ecology; 3) To examine changes in demographic parameters of these species in relation to habitat fragmentation; and 4) To examine species differences in their response to forest fragmentation and to suggest appropriate measures to enhance the survival of arboreal mammals in forest fragments.

Five species of arboreal mammals formed the subjects of this study. Two of these are diurnal primates (Order Primates; Family - Cercopithecidae) which are endemic to the Western Ghats; the lion-tailed macaque (*Macaca silenus*, Subfamily - Cercopithecinae) and the Nilgiri langur (*Trachypithecus johnii*, Subfamily - Colobinae). Three species were tree squirrels (Order Rodentia, Family Sciuridae), two of them are widely distributed in India, the Malabar giant squirrel (*Ratufa indica*, Subfamily - Sciurinae) and the large brown flying squirrel (*Petaurista philippensis*, Subfamily - Petauristinae). Only the small Travancore flying squirrel (*Petinomys fuscocapillus*, Subfamily - Petauristinae) is endemic to the Western Ghats.

The study was carried out in 1994-1996 in the wet evergreen forest fragments in the Indira Gandhi Wildlife Sanctuary and nearby privately owned forest fragments, in the Anamalai Hills, Tamil Nadu. The field studies included i) a survey of forest fragments to estimate the occurrence and abundance of arboreal mammals, and habitat status; ii) studies on the activity pattern and feeding ecology of the lion-tailed macaque, Nilgiri langur, and giant squirrel; iii) studies on demography of primates; and iv) monitoring of phenology of important plant food species.

Surveys were carried out to estimate the occurrence and abundance of five arboreal mammals in 25 forest fragments in relation to several habitat and landscape parameters. The occurrence and abundance of diurnal arboreal mammals were estimated from transects (400 km). The habitat parameters were estimated from 350 circular plots of 5 m radius. The wet evergreen forest fragments differed among themselves with

reference to various landscape and habitat parameters. Fragments which were small in size were most likely to be privately owned and had low tree density, basal area, canopy cover and canopy height. The large fragments were mostly owned by the Forest Department, and had better habitat quality. Among the five arboreal mammals, the lion-tailed macaque was the most affected, being absent from 15 of the 25 forest fragments, where as the Nilgiri langur and the giant squirrel were absent only from six and three fragments, respectively. The best predictor for the occurrence of lion-tailed macaque was canopy height, while it was tree density for the Nilgiri langur. The abundance of the lion-tailed macaque and the Nilgiri langur showed a high variability in the smaller fragments, while the density of the giant squirrel and flying squirrel increased with decreasing area and disturbance level. The increase in the densities of giant squirrels and flying squirrel may be due to their wide ecological amplitude and greater tolerance to disturbance. Area may be the best predictor of the occurrence of arboreal mammals only when area of the fragments is very small, the initial occurrence depending on the relative densities at which species occur. Once a species is initially present, its persistence is more likely to be related to other habitat parameters.

Activity pattern and feeding ecology were studied in three arboreal mammals (lion-tailed macaque, Nilgiri langur and giant squirrel) for one year in four forest fragments which varied in their area and level of disturbance. There were no consistent differences in the three species in the time that they spent on various activities between the four forest fragments. A significant change in the feeding ecology of the three species was a reduction in the number of food plant species used per day and a reduction in the use of lianas in the small and degraded fragments. The reduction of food abundance in small fragments was compensated by changes in vegetation. The vegetation that immediately surrounded the small fragments was of considerable food value to the arboreal mammals. Keystone species such as *Ficus* spp and *Cullinea exarillata* that have been left behind in small fragments probably have greater productivity due to increased penetration of solar radiation. The giant squirrel was the least affected.

The demographic parameters were estimated for the lion-tailed macaque from 11 groups in eight fragments, and for the Nilgiri langur from eight groups in four fragments. The major demographic effects on the lion-tailed macaque were a reduction in birth rate, population growth rate, and immatures survival, and increase in group size and a wide variation adult sex ratio in small fragments. The reduction in birth rate and survival may be due to reduction in the diet quality. The latter may be also due to fall from tree canopy and greater predation. For the Nilgiri langur there was a reduction in birth rate, population growth rate and immature survival and but not in adult sex ratio because they dispersed between fragments. The reduction in the birth rate may be to due to a reduction in diet quality, as in the lion-tailed macaque.

Dispersal between fragments might be limited in the lion-tailed macaque because of their inability to use treeless matrix and plantations (such as teak, eucalyptus, tea and coffee) and the female-bonded social system that prevents female dispersal. The giant squirrels are also unable

to disperse between forest fragments in the treeless matrix. In the Nilgiri langur, both male and female disperse between fragments across the landscape. Thus, the fragmented population of the lion-tailed macaque is unlikely to occur as a metapopulation that allows recolonisation, dampening of demographic stochasticity and genetic exchange. The squirrels might exist partially as a metapopulation, while most of the Nilgiri langur populations might form part of a metapopulation. Genetic consequences of population fragmentation and changes in the parasitic and pathogen profiles are two factors that could also influence the continued survival of the study animals.

Among the important steps to be taken to enhance the survival of arboreal mammals in a fragmented habitat are; 1) Retain the man made vegetation immediately around the small fragments which consists of *Coffee*, *Maesopsis eminii* and *Artocarpus heterophyllus*; 2) Retention of key-stone species such as *Ficus* spp, *Cullinea exarillata* and *Artocarpus heterophyllus* in the forest fragments; 3) Increase in the tree densities in small fragments through assisted regeneration, especially of food plants; 4) Retention and enhancement of canopy contiguity, especially across the roads; 5) Very strict control of even low level of poaching in the case of lion-tailed macaque; 6) Periodic monitoring of age/sex composition of small populations, for translocation of individuals if needed; and 7) Research especially of genetic and parasitic consequences.

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1. INTRODUCTION AND OBJECTIVES

1.1. INTRODUCTION

1.1.1. Loss of tropical forests

Tropical wet forests cover only 6% to 7% of the Earth's surface, but contain more than 50% and possibly as much as 90% of all species of plants and animals (WRI 1990). Tropical wet forests covered about 8 million km² in 1990 (Myers 1991). In 1989, the area deforested amounted to about 150,000 km², nearly 90% more than in 1979 (Whitmore 1997). World Resource Institute estimated an annual loss of 160,000 to 200,000 km² in 1991 which was double the 1980 annual loss (WRI 1990). It is predicted that at the current rate of loss, 90% of the remaining forest will be lost in 33 years (Terborgh 1992). It is also predicted that all five remaining extensively forested areas, Amazon, New Guinea, Sumatra, Borneo, and Zaire Basin, would be reduced and fragmented in the next few decades (Whitmore 1997). The tropical wet forests are disappearing more rapidly than any other biome. The destruction of tropical wet forest at the present rate could lead to the elimination of at least one-quarter and possibly one-third of all species, somewhere between half a million and several million species (Myers 1991).

Tropical forests were altered radically from around 1600 AD since the introduction of new crops and new methods of exploitation (Williams 1990). Forests began to be cleared extensively to raise or cultivate cash crops such as rubber in Malaysia and Indonesia, coffee in Brazil, tea in India and China, sugar in the Caribbean, tobacco and palm oil in Asia

(Whitmore 1986; Saunders and Hobbs 1991). The timber trade is also responsible for much of the destruction of the tropical forest (Whitmore 1986). Shifting cultivation has been a major factor, accounting for 70% of forest loss in Africa, 50% in Asia, and 35% in the South and Central Americas (Lanly 1982). Apart from these, human population explosion and introduction of domestic animals are also factors that led to the degradation of tropical wet forests (Whitmore 1986).

Tropical wet forests are characterized by high species diversity (Whitmore 1986). These species are highly susceptible to disturbances, due to their low rate of reproduction and dispersal, and a high degree of specialization. Such complex ecosystems with their many species and interactions are dynamically fragile (May 1975; Saunders *et al.* 1993).

Extensive removal of native vegetation for various purposes leads to fragmented forest patches across the landscapes, usually surrounded by a matrix of different vegetation and land use pattern. These patches are situated in different soil types, possess different vegetation types, and vary in the size, shape, isolation and type of ownership. The conservation of biota in many tropical regions depends entirely on the retention and management of these remnants (Saunders *et al.* 1987; Russell-Smith and Bowman 1992; Laurance 1993; Saunders *et al.* 1993; Lindenmayer and Possingham 1995; Turner and Corlett 1996). The management of fragmented forests becomes all the more important given the current and predicted loss of forests (Whitmore 1997), and the fact that most nations have less than 10% of their land designated as protected areas (Laurance and Gascon 1997). It is in this back-ground that Wilcox and Murphy (1985) stated "habitat fragmentation is the most serious threat to biological diversity and is the primary cause of the present extinction crisis".

1.1.2. Impacts of forest fragmentation

Habitat fragmentation has two primary consequences to species' survival. The first and immediate consequence is the isolation of a once contiguous and large population into several small isolated populations. The second and long-term consequence is the change in micro- and macro-climate and associated changes in flora and fauna of the forest fragments. The threats to small isolated populations of animals have been reviewed by Nitecki (1984), Soulé (1986, 1987), and Pimm *et al.* (1988). The long-term changes in fragments have been reviewed by Saunders *et al.* (1991), Fielder (1993) and Kozakiewicz (1993). The progressive loss of a species from a fragment occurs by one or more of the following pathways.

Species might disappear as a result of the direct impact of changes in micro- and macro-climate of the remnant forest and surrounding areas. These include changes in temperature, humidity, moisture, recruitment and water flux (Saunders *et al.* 1991; Fielder 1993). Changes in the structure and composition of vegetation follow immediately after fragmentation and continue to occur (Johns 1985, 1987; Johns and Skorupa 1987; Kapos 1989; Ferreira and Laurance 1997; Ganeshaiah *et al.* 1997). These can cause changes in the faunal species composition of the forest fragments through several pathways (Lovejoy *et al.* 1986; Saunders and Ingram 1987; Palik and Murphy 1990). Litter decomposition might change leading to changes in the invertebrate fauna (Kapos 1989). Greater tree mortality and physical damage from increased exposures to wind (Grace 1977; Lovejoy *et al.* 1986; Ferreira and Laurance 1997) could lead to resource depression for many animal species and cause changes in the faunal composition (Johns 1989).

Influx of fauna from surrounding secondary forests and other vegetation often displaces resident species. Species from secondary forest are more adapted to the changes in fragments than the residents (Lovejoy *et al.* 1986). Such influx of fauna could lead to increased predation (Johns 1985; Wilcove *et al.* 1986; Andrén 1992), and brood parasitism (Robinson *et al.* 1992; Haskell 1995). It is also being realised that pathogens and parasites, especially invading species or new strains, can pose a major threat to species in restricted environments such as forest fragments (Kozakiewicz 1993; McCallum and Dobson 1995; Loye and Carrol 1995; Combes 1996). Increased environmental stress increases susceptibility (Wauters *et al.* 1996) to parasites and pathogens, leading to new diseases and an increase in epidemics. Such diseases might also play a major role in interspecific competition among resident and invading species (Combes 1996).

In addition to the above factors, species would be lost inversely proportional to the area of fragment (Saunders *et al.* 1991) or population size of individual species. This is because small populations in remnants are more susceptible to demographic and environmental stochasticity, loss of genetic variability and diseases (Shaffer 1981, 1987; Gilpin and Soulé

1986; Quinn and Hastings 1987; Soulé 1987; Saltz 1996). Above effects are amplified by human impacts like fire, feral animals (Russell-Smith and Bowman 1992) and fire wood collection which are often greater on forest isolates.

Corridors (natural forest or plantations) play a major role in the retention of native species in the fragment through migration of species between fragments (Frankel and Soulé 1981; Saunders and Hobbs 1991). Dispersal through corridors increases persistence of fragmented populations as a metapopulation through recolonisation and genetic exchange (Levin 1969; Arnold *et al.* 1993). However, the use of corridors vary considerably among species depending on its diet and denning requirements, arboreality and social systems (Laurance 1990; Punttila 1996). Generally a few species use corridors, some being resident and others being passage species (Powell and Powell 1987; Bierragaard *et al.* 1992; Fahrig and Merriam 1994; Dunning *et al.* 1995; Hill 1995; Downes *et al.* 1997). The number and abundance of species in a fragment are also influenced by the surrounding modified landscape (Laurance 1990). Species that tolerate the matrix vegetation and edges are more successful in surviving in the fragments than forest interior species (Laurance 1990, 1991b; Newmark 1991; Opdam 1991; Stouffer and Bierregaard 1994; Mills 1995).

Following fragmentation species are lost from remnants but many, especially those with long life-span, continue to survive only to become extinct later (Soulé *et al.* 1988; Saunders *et al.* 1991; Andrén and Delin

1994). Thus, the presence of a species in a remnant does not guarantee its long-term survival (Saunders *et al.* 1987). Animals with large home ranges, ecological specialists and species with fluctuating populations that depend on patchy or unpredictable resources are especially prone to extinction from small isolated fragments (Terborgh and Winter 1980; Karr 1982; Laurance 1994).

The theory of Island Biogeography has been often applied to species extinction from forest fragments (MacArthur and Wilson 1967; Harris 1984). This predicts an initial faunal compression or compaction immediately following fragmentation. Soon there would be a faunal collapse but ultimately an equilibrium would be reached between extinction within the fragments and colonization from outside (Terborgh 1976). The number of species left at such an equilibrium would depend on the area of the fragment (which determines rate of species loss) and degree of isolation (which determines rate of colonization). The application of Island Biogeography theory to forest fragments is now considered premature and of no practical value for management (Gilbert 1980; Zimmerman and Bierregaard 1986; Kozakiewicz 1993).

Only a few of the several recent studies have found area as an important factor, either in predicting species richness or the survival of individual species; for birds (Wilson and Johns 1982); small mammals (Adler and Wilson 1985; Robinson *et al.* 1992); primates in Amazon (Bierregaard *et al.* 1992). In contrast, several studies have found that isolation mediated habitat variation is closely related to species richness in patches or to the survival of individual species; birds (Van Dorp and Opdam 1987; Knick and Rotenberry 1994; Martin *et al.* 1995), small mammals (Bierregaard *et al.* 1992; Bright and Morris 1996; Fitzgibbon 1997) and arthropods (Bierregaard *et al.* 1992; Abensperg-Traun *et al.* 1996). Other important factors are corridors, matrix or surrounding vegetation, social systems, and ecological features of the species.

1.2. THE WESTERN GHATS

1.2.1. Biodiversity

India is one of the 12 mega-diversity countries (Myers 1992), with about 126,000 species covering five major kingdoms namely Monera, Protista, Fungi, Animalia and Plantae. India has 8% of the global biodiversity, even though it covers only 2.4% of the land area of the world (Khoshoo 1995). The Eastern Himalayas and Western Ghats are also among the 18 biodiversity hot-spots in the world (Khoshoo 1995). The Western Ghats covers only 5% of the land area of India, but has 30% of India's species. The Western Ghats is one of the ten biogeographic zones of India (Rodgers and Panwar 1988). With about 45 protected areas (National parks and Wildlife Sanctuaries), Western Ghats has the highest protected area coverage among the ten zones. It extends over a distance of nearly 1,600 km north-south between 8° and 21° N, and covering an area of about 160,000 km^2. It is interrupted only once by the 40 km wide Palghat Gap at around 11° N. Running almost parallel to the west coast, mostly 30 km to 50 km inland, it traverses through the states of Kerala, Tamil Nadu, Karnataka, Goa, Maharashtra and Gujarat. The altitude ranges generally between 600 km to 1,000 m. There are 14 peaks above 2,000 m, Anaimudi in Kerala being the highest (2,695 m). The Western Ghats receives 80% of its rainfall during the south-west monsoon (June to September) and most of the remaining from the north-east monsoon (October and November). The Western Ghats is the source of more than 60 west-flowing and all three major east flowing rivers (Cauvery, Krishna and Godavary) in Peninsular India. These are the major sources of hydel power, drinking water, and irrigation for the peninsular India.

The geology of the Western Ghats is complex and does not conform to any specific geological formation (Krishnan 1982). Khondolites are found in the extreme south of the Western Ghats consisting of gneiss and schists with sillimanite and garnet. In the middle of the Western Ghats between 9° and 13°, Charnokites, consisting of granitoid gneiss dominate. Dharwar systems dominate in north (north of Coorg up to Goa) with metamorphic rocks, which are among the oldest in India.

Several forest types are represented in the Western Ghats (Champion and Seth 1968; Rodgers and Panwar 1988). The major types are the wet evergreen forests, often also called the rain forests, the dry and moist deciduous forests, and the montane shola-grassland vegetation at higher elevations of the southern Western Ghats. The Western Ghats especially wet evergreen forest is a very important distributional range for many plant families and genera. It has about 5,000 flowering plants of which 1,500 are endemic (Nair 1991). There are 58 endemic plant genera, of which 42 are monotypic. About 490 species of trees occur of which 308

(62.5%) species in 58 families are endemic. About 267 species of orchids occur here belonging to 72 genera, of which 130 species are endemic.

There are about 65 species of non-volant mammals in the Western Ghats, of which 11 are endemic. Endemism is not high among mammals compared to reptiles and amphibians. Among the endemics the Malabar civet (*Viverra civettina*) is the most endangered species. The lion-tailed macaque (*Macaca silenus*), Nilgiri langur (*Trachypithecus johnii*), Nilgiri marten (*Martes gwatkinsi*), brown palm civet (*Paradoxurus jerdoni*), Travancore flying squirrel (*Petinomys fuscocapillus*), jungle striped squirrel (*Funambulus tristriatus*), the spiny dormouse (*Platacanthomys lasiurus*) and Nilgiri tahr (*Hemitragus hylocrius*) are endemic at specific level. The brown mongoose (*Herpestes fuscus*), stripe-necked mongoose (*H. vitticollis*), grizzled giant squirrel (*Ratufa macroura*), Layardi's striped squirrel (*F. layardi*), and dusky striped squirrel (*F. sublineatus*) are endemic at sub-species level, being also found in Sri Lanka. The Western Ghats contain the largest population (15,000) of Asian elephant (*Elephas maximus*) and also have large populations of other large mammals that include gaur (*Bos gaurus*), sambar (*Cervus unicolor*), spotted deer (*Axis axis*), tiger (*Panthera tigris*), leopard (*Panthera pardus*) and Indian wild dog or dhole (*Cuon alpinus*). There are 508 species of birds, of which 15 are endemic (Ali and Ripley 1987; Daniels 1997). Among the lower vertebrates the amphibians and reptiles are species rich in the Western Ghats. A total of 120 species of amphibians have been reported from the Western Ghats of which 90 are endemic (Dutta 1997). There are 170 species of reptiles, of which more than 50% are endemic (CAMP 1997).

The large mammals of the Western Ghats have been studied in considerable detail; elephants (Sukumar 1985; Easa 1988; Desai 1991; Sivaganesan 1991; Baskaran and Desai 1996) gaur (Balakrishnan and Easa 1986; Easa and Vairavel *in prep.*), Nilgiri tahr (Rice 1984; Mishra and Johnsingh 1994; Sumithran *in prep.*), large carnivores (Johnsingh 1980, 1983; Karanth 1993; Karanth and Sunquist 1995). Considerable information also exist on their populations through annual census by the Forest Departments. In comparison, the smaller arboreal and terrestrial mammals have not been studied, with only a few exceptions. The lion-tailed macaque is the most studied with reference to its distribution, ecology, and behaviour (Sugiyama 1968; Green and Minkowski 1977; Kurup 1977; Karanth 1985; Kumar 1987, 1995a, 1995b; Ramachandran 1993; Kurup and Kumar 1994; Bhat 1993; Menon 1993; Menon and Poirier 1996; Easa *et al.* 1997; Singh *et al.* 1997a, 1997b). The Nilgiri langur has been studied in the Nilgiris (Poirier 1970), Kalakkad (Oates *et al.* 1980) and Mundanthurai (Sunderraj *in prep.*). Studies on small carnivores have been mostly surveys (Ashraf *et al.* 1993b; Rai and Kumar 1993; Yoganand and Kumar 1995; Mudappa *in press*). Among rodents, the giant squirrel has been studied in the Anamalais (Ramachandran 1988), and Bhimashankar in the northern Western Ghats (Borges 1989, 1993), and central India (Dutta and Goyal 1996). The terrestrial rodents have been studied in the shola-grasslands in the Nilgiris (Shankar 1997), in the

Anamalais (Chandrasekar-Rao and Sunquist 1996; Prabhakar *in prep.*) and in Kalakkad (Anon. 1997).

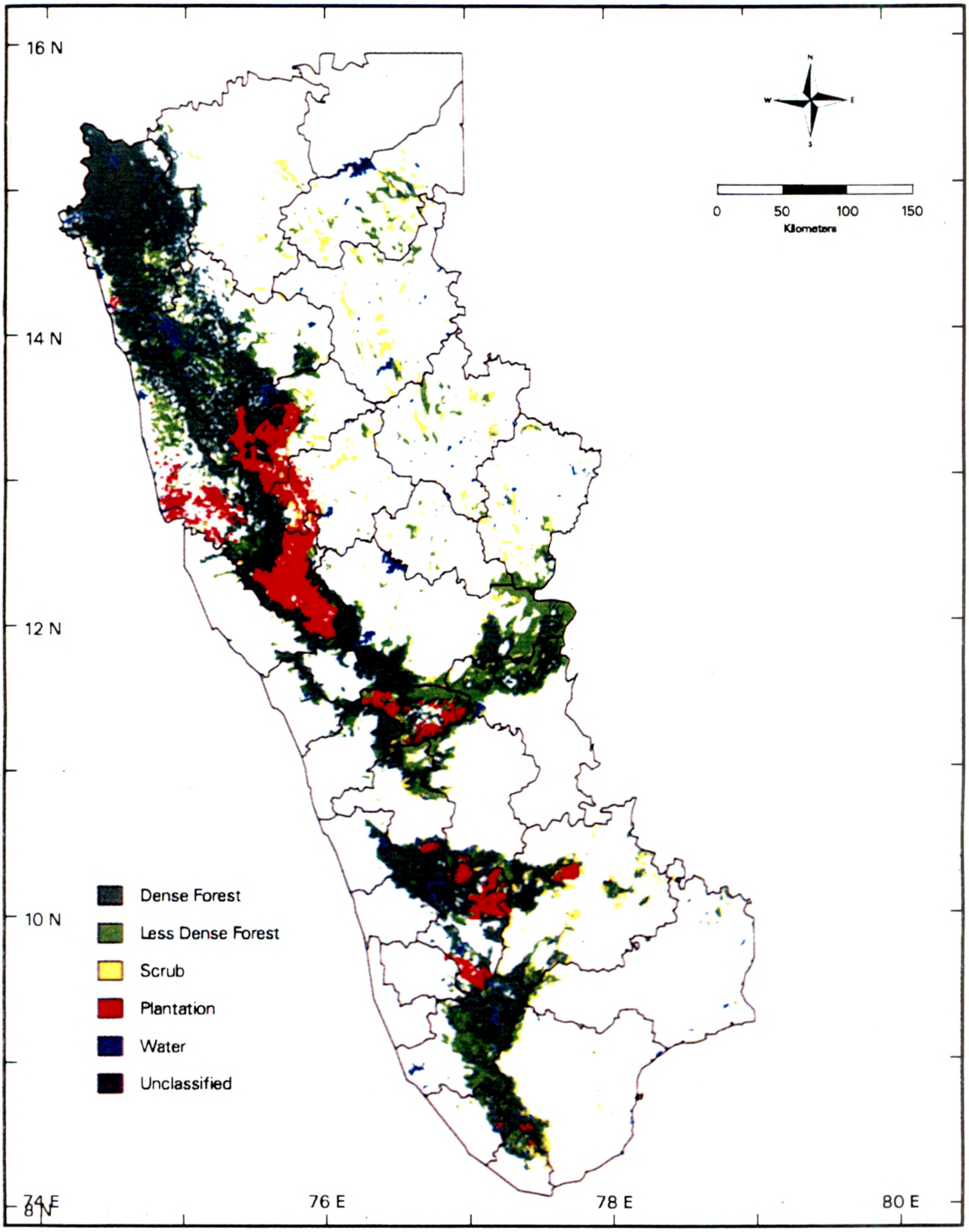
1.2.2. Loss and fragmentation of forests

Wet evergreen forest had a wide distribution, covering most of the peninsular India during the interglacial periods of Pleistocene (Gardiner 1984), when hot and humid conditions prevailed over these areas. The establishment of the monsoonal climate by the end of the Pleistocene about 25,000 years ago, resulted in the loss of wet evergreen forest from most of the peninsular India, except the heavy rainfall areas in the Western Ghats on west coast. Human occupation in the Western Ghats dates back to 10,000 years (Chandran 1997). However, even in the 1800s most of Western Ghats was covered with natural vegetation dominated by wet evergreen forests. The forests along the Western Ghats extended uninterrupted from the northern to the southern end. By the middle of the 19th century, the Palghat Gap had become the first major forest discontinuity in Western Ghats, with the laying of the arterial transportation system between eastern and western side of the Western Ghats by the British. Large scale deforestation in southern Western Ghats began in the mid 1850s, when British colonisers began plantations of tea, coffee and cardamom (Chattopadhyay 1985). This continued for nearly 50 years. After independence also, large scale clearing of forests continued for teak and eucalyptus plantations, agriculture (under the Grow More Food Programme), reservoirs, roads, rails and human settlements. These contributed substantially to the loss and fragmentation of the forests in

Western Ghats. In the northern Western Ghats, especially in Maharashtra and Goa, the loss was mostly due to agriculture.

In 1980s, India had a forest cover of 19.5% and only 11.7% had a canopy cover of more than 40% (Collins *et al.* 1991). The forest cover in Western Ghats was about 40,000 km² or nearly 25% of the land area of the Western Ghats in 1985-87 (Collins *et al.* 1991, based on Forest Survey of India 1989, Figure 1.1). Nearly 40% of the forest cover of the Western Ghats was lost between 1920 and 1990, to open cultivated lands, tea and coffee plantations, and hydro-electric projects (Menon and Bawa 1997). This loss was initially strongly correlated with altitude, roads, population centres and to a lesser extent, hydro-electric reservoirs (*op. cit.*). The rate of forest loss varied between regions and states within the Western Ghats. In Kerala, the annual forest loss between 1905 and 1965 has been estimated as 0.27% of the land area and 0.6% of the existing forest cover and between 1965 and 1973, as 1% and 4.8% respectively (Chattopadhyay 1985). The loss declined to 1.4% between 1972 and 1982 (Chattopadhyay 1985; Nair 1991). In Idukki District, Kerala, the loss of dense vegetation (mostly wet evergreen forest) was as much as 56% in an area of about 2,500 km², between 1973 and 1983 (Menon 1986). In Agasthyamalai, the annual loss was about 0.07% of the forest area between 1920 and 1960, and 0.33% between 1960 and 1990 (Menon and Bawa 1997).

The existing forests of the Western Ghats, especially wet evergreen forests, occur in a highly fragmented state. It has been estimated that between 1920 and 1990, when forest loss was nearly 40%, the number of



Source : Menon & Bawa 1997

Figure 1.1 Land-cover and land-use patterns in the Western Ghats ***circa*** *1990* forest patches increased nearly four fold, from 179 to 769, with an 83% reduction in average patch size (Menon and Bawa 1997). Moreover, there has also been an increase in perimeter to area ratio of the patches (*op. cit.*). Only a few areas have more than 200 km² of wet evergreen forests. These are Agasthyamalai Hills, Cardamom Hills, Silent Valley-New Amarambalam Forests, and southern parts of the South Kannada District in Karnataka State. Fragmentation and degradation have been so extensive north of Sharavathi river (northern Karnataka, Goa, Maharashtra and Gujarat) that the vegetation can no longer be classified as wet evergreen forests (Pascal 1988). There are several proposed hydel projects that could submerge some of the best remaining low land wet evergreen forests (*e.g.* Pooyamkutty Project), roads that could cut across the few remaining large rain forest areas (*e.g.* the proposed road from Papanasam in Tamil Nadu to Thiruvananthapuram in Kerala across the Agasthyamalai Hills), and railways (*e.g.* to Sabarimala temple in Kerala).

1.3. OBJECTIVES

Studies carried out in the recent years show that the changes brought about by habitat fragmentation (in area, isolation, connectivity, habitat variation, faunal and floral invasion, edge and matrix around fragments) have different impacts on the floral and faunal assemblages in the forest fragments. These impacts are often consistent with the biology, ecology, and social system of the species. In general however, rare, K-selected species, habitat specialists, and forest interior species are more prone to extinction, and that most of these are endemic species (Saunders *et al.* 1991; Bierregaard *et al.* 1992). The species-rich endemic flora and fauna of the wet evergreen forest in the Western Ghats are thus under serious threat of extinction from habitat fragmentation. The goal of this study was to assess the impact of fragmentation of wet evergreen forests of the Western Ghats on five species of arboreal mammals. These were two species of primates namely the lion-tailed macaque (*Macaca silenus*) and the Nilgiri langur (*Trachypithecus johnii*) and three species of squirrels namely Malabar giant squirrel (*Ratufa indica*), large brown flying squirrel (*Petaurista petaurista philippensis*) and small Travancore flying squirrel (*Petinomys fuscocapillus*).

Arboreal mammals were chosen for the study for several reasons. First, arboreal mammals are more likely to be affected by fragmentation of their habitat, given their arboreality and often specialised diet. In fact, primates, the most arboreal taxa among the mammals, are also the most threatened with 58% of the species in this category (IUCN 1996). Of the two primate species covered by this study, the lion-tailed macaque is endangered and the Nilgiri langur is vulnerable (IUCN 1996). Secondly, arboreal mammals show a high degree of endemism in the Western Ghats, with three of the five species in this study being endemic (lion-tailed macaque, Nilgiri langur and small Travancore flying squirrel). Finally, it is expected that management of forest fragments for the conservation of arboreal mammals would also ensure the survival of several other taxa of flora and fauna.

The objectives of the project were to:

a. assess the variation in the occurrence and abundance of five species of arboreal mammals in forest fragments in relation to several landscape and habitat parameters;

b. assess the responses of the arboreal mammals to habitat fragments in terms of changes in activity pattern and feeding ecology;

c. assess the changes in the demographic parameters of arboreal mammals due to habitat fragmentation; and

d. in the light of the findings from the study to suggest appropriate measures to enhance the survival of arboreal mammals in forest fragments.

The field studies were carried out in 1994-96 in the wet evergreen forest fragments in the Indira Gandhi Wildlife Sanctuary and nearby privately owned fragments in Tamil Nadu state. These fragments come within a 30 km radius of Valparai Town where the field station was based. This area was chosen because it typified the extent of fragmentation of wet evergreen forest in the Western Ghats. The forest fragments included only those that have been formed as a result of human activities. The naturally occurring forest fragments in the montane shola-grassland complex above 1,500 m were not covered by this study, because these are most likely not of human origin (Sukumar *et al.* 1993).

This thesis is divided into six chapters including this chapter. Chapter 2 is a description of the study area, animals and methods; Chapter 3 examines the occurrence of arboreal mammals in relation to habitat fragmentation; Chapter 4 examines the changes in activity pattern and feeding ecology; Chapter 5 examines demographic consequence of fragmentation; and Chapter 6 presents the conclusions, in the light of which management considerations are discussed.

2. STUDY AREA, ANIMALS AND METHODS

2.1. STUDY AREA

2.1.1. Geography and climate

The Indira Gandhi (formerly Anamalai) Wildlife Sanctuary (10°12' and 10°54' N and 76°44' and 77°48' E) in Tamil Nadu is one of the largest sanctuaries in south India (Figure 2.1). Created in 1976, it covers an area of about 987 km^2. It is located mainly in the Valparai Taluk, but extends to Pollachi and Udumalpet Taluks of Coimbatore district and Kodaikanal Taluk of Dindugal District. It extends 45 km north-south, and 25 km east-west. It is about 90 km from Coimbatore city. Three major public roads from Pollachi town passes through the Sanctuary - the Pollachi-Chalakudi road through Valparai, the Pollachi-Parambikulam road through Topslip and the Pollachi-Munnar road through Udumalpet range. A network of roads connect Valparai town to various estate settlements.

Almost in the centre of the Sanctuary is nearly 180 km^2 of tea and coffee estates that are under private ownership, and in its centre is the Valparai Town. The Sanctuary is bordered in the south-west by Parambikulam Wildlife Sanctuary (287 km^2), in the south by the Reserve Forest of Chalakudi Forest Division and Eravikulam National Park (97 km^2), in south-east by Chinnar Wildlife Sanctuary (90 km^2) all in Kerala State, and in the east mostly by the cultivated plains. These sanctuaries along with the Reserve Forest of Nelliyampathi Hills form a large conservation area for large and wide ranging species such as elephant, gaur, and tiger.

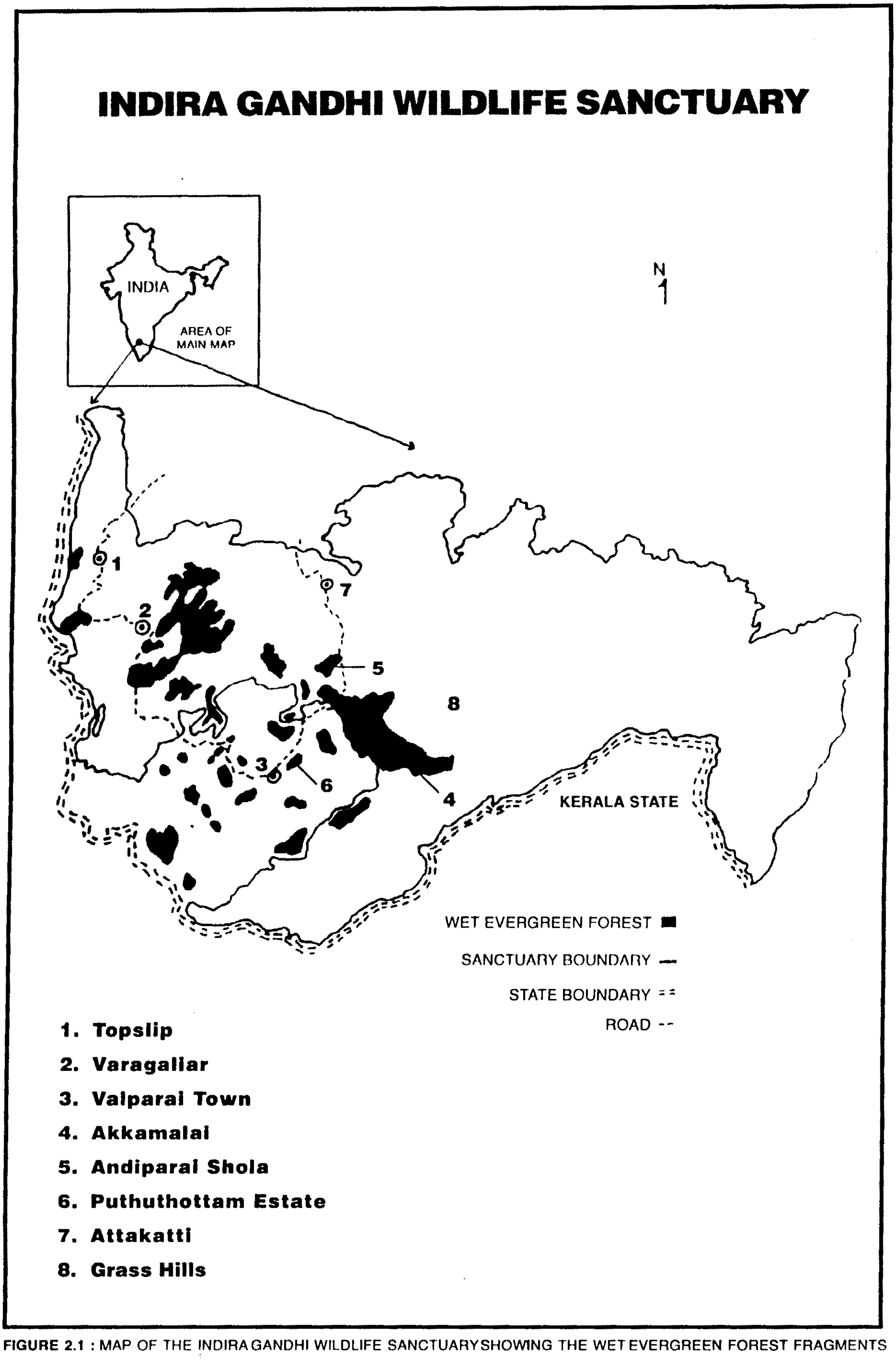


FIGURE 2.1 : MAP OF THE INDIRAGANDHI WILDLIFE SANCTUARYSHOWING THE WET EVERGREEN FOREST FRAGMENTS

The altitude of the Sanctuary ranges from 220 m in the plains at the foot hills in the east to 2,513 m atop Thanakkanmalai in the Grass Hills. Hilly tracts form over 90% of the total area, extending north-west to south-east with an elevation from 700 m at Topslip to 2,513 m at Thanakkanmalai. In the north, hills descend precipitously to the cultivated plains. The central portion around the Valparai Town, in an elevation of 900 m to 1,500 m, has been converted to tea and coffee plantations. In the south and south-east parts in the Udumalpet and Amaravathi ranges, the hills are elevated, steep and abruptly descend down to the plains.

The soil found in the Anamalai Hills is classified as lateritic soil (Krishnan 1982). It is a porous, pitted, clay-like rock with red, brown, grey and mottled colours depending on the composition. The rocks found here are classified into metamorphic and igneous types, and are estimated to be from the Pre-Cambrian period.

Rainfall varies considerably, ranging from 500 mm in the eastern slopes of the Sanctuary to 5,000 mm in the western slopes. The Sanctuary receives both south-west (June to September) and north-east (October and November) monsoons, with about 80% of the rainfall being during the former. The day time temperature varies considerably from 23°C to 40°C at the foot hills (200 to 350 m) to 20°C to 30°C at higher elevations (1,800 to 2,300 m). In the night, it ranges from 15°C to 25°C at the foot hills and from 10°C to 20°C at medium elevation of 900 m to 1,200 m. The temperature is lower at higher elevations, going down to 0°C in December and January at about 2,000 m. March to May are the hottest months.

According to rainfall and mean temperature for each month, I identified three distinct seasons; 1) Dry: low temperature and no or less rainfall (January to April); 2) First wet (South-west monsoon): moderate temperature and high rainfall (May to August); and 3) Second wet: moderate temperature and moderate rainfall (September to December).

2.1.2. History

The Anamalai (Elephant) Hills are called so, after the elephants which were once found in abundance there. It is a continuation of the Western Ghats immediately south of the Palghat Gap. In the early days of British rule, the forests in this area did not have any specific management nor were any of the forest properly surveyed. After the Bombay dockyard started construction of vessels of war (Sundararaju 1987), teak trees were required in large quantities. This demand was met from the forest of Anamalai Hills. British surveyors surveyed Anamalai Hills for the first time in 1820s and reported surpassing quantity and quality of teak trees. After the survey, the Bombay Marine Company started extraction of timber from this forest between Malabar border and north of Vengoli-Umayamalai ridge. During this time, most of the south division of Coimbatore was over exploited. The major tree species extracted were *Tectona grandis, Dalbergia latifolia, Pterocarpus marsupium, Terminalia tomentosa, T.bellerica, T. arjuna* and *T. indica.* Extraction declined considerably in 1862-63 when the construction of vessels of war in Bombay was given up. Reservation of forest in this tract commenced from 1883, after the enactment of Madras Forest Act in 1882. When the process of reservation was over, the

Government had set apart an area of 19,114.13 ha of virgin evergreen forest land in the Valparai area for raising tea, coffee, and cardamom plantations. This land was then leased to private companies for cultivation. The area to be opened up first was the Waterfall Estate in 1890, and was followed by other estates until 1930 (Congreve 1938). At present 18,032 ha of tea, coffee, and cardamom estates and 3,717 ha of cinchona plantation (half of which have been converted into tea plantation) are situated within the Sanctuary (Sundararaju 1987). The Forest Department continued logging in the northern side of the Sanctuary till 1976.

2.1.3. Vegetation

The natural vegetation in this area includes wet evergreen forest, montane shola-grassland, moist deciduous, dry deciduous and thorn forests. Tropical wet evergreen forest is found in an altitude of 600 m to 1,600 m, where *Cullenia-Mesua-Palaquium*, *Hopea-Mesua-Artocarpus*, and *Dipterocarpus -Anacolosa* associations occur (Pascal 1988). In this forest the trees obtain a height of about 30 m or more. In the higher elevations (>1,700 m), tropical montane forest occur with the following dominant tree species; *Gordonia obtusa, Michelia nilagirica, Ternstroemia japanica*, and *Eugenia* spp. Typically, these forests are interspersed with montane grassland, forming the shola-grassland complex. The lower elevations of the eastern slopes have mixed dry and moist deciduous forests, where *Tectona grandis, Terminalia bellerica, T. tomentosa, T. paniculata, Dillenia pentagyna* and *Lagerstroemia lanceolata* are the dominant tree species. The thorn forests occur mainly in the plains, east of the Sanctuary. The major tree species are *Acacia latronum*, *A. nilotica*, *A. ferruginea*, *A. leucophloea*, *Zizyphus jujuba* and *Albizzia amara*. An extensive area has been planted with teak, mostly between 600 m and 1,000 m altitude. Estimates of area under major vegetation types are not available. Forest Department statistics in 1980s showed that wet evergreen forests covered about 80 km^2.

2.1.4. Fauna

The faunal species richness and endemism are also expected to be very high and typical of Western Ghats, even though no comprehensive assessments have been made. The Sanctuary has substantial populations of the large mammals that include elephant (*Elephas maximus*), gaur (*Bos gaurus*), sambar (*Cervus unicolor*), chital (*Axis axis*), tiger (*Panthera tigris*), leopard (*P. pardus*), dhole or the Indian wild dog (*Cuon alpinus*), and sloth bear (*Melursus ursinus*). The shola-grassland in the Grass Hills and the adjoining Eravikulam National Park support the single largest population of the endemic mountain goat, the Nilgiri tahr (*Hemitragus hylocrius*), consisting of about 1,100 animals (Swengel 1991). The Sanctuary also has most other endemic non-volant mammals. These include the lion-tailed macaque, the Nilgiri langur, the Malabar spiny dormouse (*Platacanthomys lasiurus*), the Nilgiri marten (*Martes gwatkinsi*), the brown palm civet (*Paradoxurus jerdoni*), the dusky-striped squirrel (*Funambulus sublineatus*), the stripe-necked mongoose (*Herpestes vitticollis vitticollis*) and the brown mongoose (*H. fuscus fuscus*). The lower vertebrates and invertebrates have not been adequately surveyed.

In spite of its rich biodiversity, the Indira Gandhi Wildlife Sanctuary has received little research attention. Recent studies include the ecology, demography, and social behaviour of the lion-tailed macaque (Kumar 1987, 1995a, 1995b; Kumar and Kurup 1993; Menon 1993, Menon and Poirier 1996), loris (Singh *et al.* 1997a), primate community ecology (Singh *et al.* 1997b), rodents (Chandrasekar-Rao and Sunquist 1996), hornbills (Athreya 1993; Kannan 1994; Mudappa and Kannan 1997) and amphibians (Saravanakumar 1995). An ongoing study is examining the impact of rain forest fragmentation on the herpetofauna and small carnivores (Anon. 1997). In the adjoining Parambikulam Wildlife Sanctuary, there have been several studies on the large herbivores (Balakrishnan and Easa 1986; Vairavel *in prep.*) and giant squirrel (Ramachandran 1988).

2.1.5. People

About 200,000 people live in Valparai town and in the 54 estates within a radius of 30 km from it. About 15% to 20% of the inhabitants are labourers in the estates, the others being businessmen, dependents, *etc.* The tribal population is about 4,000, in 38 settlements, distributed through out the Sanctuary. Six major tribal communities have been identified within this area *viz*, the Kadars, Malasars, Malamalasars, Eravalars, Pulaiyars and Muduvars (Sundararaju 1987).

2.1.6. Water resources

A series of reservoirs and weirs have been constructed within and outside the Sanctuary under the Parambikulam-Aliyar Project. Of these, Aliyar, Upper Aliyar, Kadamparai, Upper and Lower Nirar, Thirumurthy and Parambikulam reservoirs come at least partly within the Sanctuary area. The Amaravathi reservoir, the largest in the area, is also partly inside the Sanctuary. These man-made reservoirs are now an important source of water to many animals especially during the summer. A few perennial and many seasonal streams also occur. The perennial rivers are Konalar in the Grass Hills, Varagaliar and Karuneerar in Ulandy range, and Chinnar and Amaravathi rivers in Udumalpet and Amaravathi ranges, respectively.

2.1.7. Forest fragments

Being at the 'T' junction of the northern end of the southern Western Ghats, the Anamalai Hills once had extensive wet evergreen forests. Between 1860 and 1930, extensive areas of wet evergreen forests were clear felled for planting tea, coffee, and teak. Some areas were also lost to reservoirs, roads and human settlements. Presently, privately owned tea and coffee estates cover more than 180 km^2 in the centre of the Sanctuary (Sundararaju 1987). Most of the wet evergreen forest fragments occur as islands in this landscape dominated by tea plantations, and are privately owned. Most of the fragments that come within the administrative control of the Sanctuary occur away from the tea estates, and are often surrounded by teak plantations.

2.2. STUDY ANIMALS

The arboreal mammals included in this study were two species of primates, the lion-tailed macaque (*Macaca silenus*) and the Nilgiri langur (*Trachypithecus johnii*), and three species of tree squirrels - the Malabar giant squirrel (*Ratufa indica maxima*), and the large brown (*Petaurista petaurista philippensis*) and small Travancore (*Petinomys fuscocapillus*) flying squirrels. A brief description of these species is given below.

2.2.1. Primates

2.2.1.1. *Taxonomy and distribution*

The mammalian Order Primates, with about 240 species (509 distinct taxa including subspecies; Anon. 1991), is distinguishable from other mammals by their prehensile hands and feet, opposable thumbs, flattened nails, forward looking eyes that have stereoscopic vision, and a relatively large brain exhibiting a high degree of cortical folding.

The Order Primates, is divided into 15 families. The Prosimian Families are Lemuridae (lemurs), Epilemuridae (sportive lemurs), Galagidae (galagos), Cheirogaleidae (mouse lemurs), Daubentoniidae (aye-aye), Lorisidae (lorises), Indriidae (short-tailed lemurs), and the Tarsiidae (tarsiers). The Anthropoid families include Callitrichidae (marmosets and tamarins), Callimiconidae (callimicos), Cebidae (cebids), Cercopithecidae (African and Asian monkeys), Hylobatidae (gibbons), Pongidae (orangutans, gorillas and chimpanzees) and Hominidae (man and his ancestors).

The major and distinct areas of primate distribution are Africa (including Madagascar), Asia, and South and Central Americas. Africa is the home of the Prosimians (lorises), Old World monkeys of the two Cercopithecid Subfamilies - Colobinae and Cercopithecinae, and two genera of great apes - the *Gorilla* (gorilla), and *Pan* (chimpanzee); 67 species in all. Madagascar is the only home for lemurs with 30 species. The primates in Asia comprise the Families, Hylobatidae and Tarsiidae along with Lorisidae, Cercopithecidae, and Pongidae, 63 species in all. In South and Central Americas, primates belong to the Families of Cebidae and Callitrichidae with 77 species. The only non-human primate in Europe is the Barbary ape (*Macaca sylvanus*), which is found in Gibraltar where it was probably introduced (Napier and Napier 1985).

Both the primate species selected for this study belong to the Family Cercopithecidae, the lion-tailed macaque (Subfamily Cercopithecinae) and the Nilgiri langur (Subfamily Colobinae). The differentiation of Cercopithecidae into the Subfamilies Cercopithecinae and Colobinae seems to have occurred by the middle Miocene epoch, 15-11 million years ago (Delson 1975). The Colobinae are specialized to an arboreal, folivorous habit, acquiring their characteristic dentition (Kay 1975), and sacculated, fermentative stomach (Delson 1975). The Cercopithecinae exploit more open habitats, retain a frugivorous/carnivorous (omnivorous) diet, and with it a generalized dentition and simple stomach (Delson and Andrew 1975).

Most of the Colobines (about 28 species in 7 genera) that occur in tropical Africa (7 species in 2 genera) and Asia (21 species in 5 genera) are primarily adapted to a rain forest habitat, with the exception of *Colobus guereza* in Africa and *Semnopithecus entellus* in India which occur in drier habitats, the Proboscis monkey (*Nasalis larvatus*) which inhabits the mangrove swamps in south-east Asia, and the golden snub-nosed monkey

(*Rhinopithecus roxellanae*) which is found in relatively high altitudes in China (Napier and Napier 1985).

The subfamily Cercopithecinae is comprised of eight genera, with only one genus (*Macaca*) in Asia and seven in Africa (*Cercocebus, Cercopithecus, Erythrocebus, Papio, Miopithecus, Allenopithecus*, and *Theropithecus*). *Macaca* is the most widely distributed primate genus. Its geographic range includes southern and eastern Asia, and extends up to north-western Africa. The extant 19 species of macaques can be divided into four subgroups; *Silenus-sylvanus*, *Sinica*, *Fasicularis* and *Arctoides* (Fooden 1980). The geographic ranges of these sub-groups partly overlap in the Indochinese peninsula. However, ranges of the species within each subgroup do not overlap (Fooden 1982). Macaques are adapted to live in almost any ecological niche ranging from tropical rain forest, cedar forest, mangrove swamps, montane forest and woodlands to towns, temples and other man made habitats (Napier and Napier 1985).

There are 15 species of non-human primates in India. The slender loris (*Loris tardigradus*) inhabits the dry deciduous and scrub forests of peninsular India, while the slow loris (*Nycticebus coucang*) occurs in the tropical rain forest of north-east India. Among the macaques, the rhesus macaque (*Macaca mulatta*) is widely distributed, occurring in northern India (except in deserts) south to the Godavari river, and in north-east India (Fooden 1989). It inhabits a variety of habitats including cities, villages, forests, and high mountains. It also occurs in Pakistan. The Assamese (*M. assamensis*), pig-tailed (*M. nemestrina*) and stump-tailed

(*M. arctoides*) macaques occur in north-east India. The crab-eating macaque (*M. fasicularis*) inhabits only the forests of Nicobar Islands. The bonnet macaque (*M. radiata*) occurs through out peninsular India, up to Satara and Godavari rivers (Fooden 1989). The lion-tailed macaque (*M. silenus*), one of the most endangered species in India, is restricted to the wet evergreen forest of the Western Ghats. The golden langur (*Trachypithecus geei*) is known only from north of the Manas river in Assam and Bhutan. The Phayre's leaf monkey (*T. phayrei*) and the capped langur (*T. pileatus*) occur only in the tropical rain forest of north-east India. The most common species of primate in India is the Hanuman langur (*Semnopithecus entellus*), which occurs through out the country in all sorts of habitats from sea level up to 3,600 m. The Nilgiri langur (*Trachypithecus johnii*) is endemic to Western Ghats, south of Kodagu. The only ape found in India is the hoolock gibbon, *Hylobates hoolock* which occurs in the rain forests of north-east India. Even though as many as ten species of primates are found in north-east India, none of them are endemic, since all of them are also found in one or more of the neighbouring countries of Bangladesh, Myanmar, China, Bhutan, and Nepal.

Six species of primates occur in the Western Ghats: the slender loris, lion-tailed macaque, bonnet macaque, rhesus macaque, common langur and the Nilgiri langur. The lion-tailed macaque and the Nilgiri langur are endemic to the Western Ghats. The former occurs only in the wet evergreen forest and the latter in both the wet evergreen and moist deciduous forests.

2.2.1.2. *Lion-tailed macaque*

The lion-tailed macaque (*Macaca silenus*) is an endangered primate (IUCN 1996), and is listed in Schedule I of the Indian Wildlife (Protection) Act, 1972. It is endemic to the wet evergreen forest of the Western Ghats in south India. There have been several studies on the population and ecology of lion-tailed macaques in the wild (Sugiyama 1968; Green and Minkowski 1977; Kurup 1978, 1988; Karanth 1985; Kumar 1987; Ramachandran 1993; Menon 1993; Bhat 1993; Kumar *et al.* 1995a; Kumar and Kurup 1993; Kumar 1995a, 1995b; Menon and Poirier 1996; Singh *et al.* 1997a). Its distribution ranges from Agasthyamalai Hills in the south to a few kilometres north of Sharavathi river in the north (Kumar 1995a), in an elevation ranging from 150 m to 1,500 m.

Lion-tailed macaques live in groups of 8 to 40 animals, with an average of about 18 animals (Kumar 1995a). The number of adult males (>8 years of age) in a group varies from 1 to 4. Most of the groups have only one adult male, one sub-adult male, 5-7 adult females, the remaining being juveniles and infants. Larger groups often have more than one adult male. The average adult sex ratio is about five females to an adult male. Births occur through out the year with a peak between December and February (Kumar 1987; Kumar and Kurup 1993). Female gives birth first at an age of 6.6 years (Kumar 1987). The inter-birth interval is about 2.5 years, and the average birth rate is about 0.31 infants/female/year, which is considerably lower than that of other macaques (Kumar 1995b). The mortality rate of all age/sex classes together is about 0.045/year

(Kumar 1987; Kumar and Kurup 1993), which is considerably lower than in other macaques. The delayed age at first birth and the low birth rate indicate the low population growth rate which the species can achieve. The species is able to survive because of its high survival rate, remarkable for a wild animal (Kumar 1995b).

The lion-tailed macaque feeds on a variety of food items that include seeds, fruits, flowers, nectar, invertebrates and rarely small vertebrates such as infants of giant squirrel, flying squirrel, lizards, and bird eggs. In Indira Gandhi Wildlife Sanctuary, fruits and seeds from about 100 species formed 57.5% of the diet and invertebrates about 37.5% (Kumar 1987). In Kalakkad about 67 species were used (Green and Minkowski 1977) while in Puthuthottam (Indira Gandhi Wildlife Sanctuary) about 42 species were used contributing to 96.5% of the annual diet (Menon 1993).

The lion-tailed macaque gets its food mainly from upper canopy, but it also eats flowers and fruits of vines, small trees and shrubs. In southern Western Ghats, *Cullenia exarillata* and *Artocarpus* spp. are the main food plants (Green and Minkowski 1977), whereas in the *Dipterocarp* forest of Karnataka its main food plants are *Artocarpus* spp., *Mangifera indica*, *Ficus* spp., *Euginea* spp. and *Caryota urens* (Bhat 1993). In Indira Gandhi Wildlife Sanctuary, *Ficus* spp., *Artocarpus* spp., and *Diospyros* spp. formed the major food plants (Kumar 1987). When compared to other macaques, the lion-tailed macaque feeds more on animal food probably to compensate for the protein deficient diet of fruits and seeds (Kumar 1987).

In a small and degraded fragment, the lion-tailed macaque fed on poor quality food and had a low dietary diversity (Menon 1993). Number of food species eaten per day and the time spent feeding were also significantly low when compared to continuous forest (Menon 1993). They also fed on fruits and flowers of pioneer and cultivated species in the fragments (Menon 1993). Green and Minkowski (1977) estimated an annual home range of 5 km² in Kalakkad, whereas Kumar (1987) reported a smaller home range of about 1.5 km² in Anamalai Hills.

Plant species richness which ensure a constant supply of fruits, seeds, and foliage invertebrates through out the year is a major factor influencing the natural distribution of lion-tailed macaques (Kumar 1995a). In the recent past, its distribution was contiguous from southern most Western Ghats up to the state of Maharashtra (Kumar 1995b). The severe loss and fragmentation of wet evergreen forests resulted in the local extinction of the lion-tailed macaque populations by 1950s in Goa and Maharashtra. The lowland wet evergreen forest in Kerala has also been wiped out, confining the population to higher elevations (Kumar 1995a). At present the species is restricted to three states, of which Kerala has about 2,000 animals, and Tamil Nadu and Karnataka have about 1,000 animals each (Kumar 1995a). The current population is fragmented into many sub populations, only five are large with more than 10 groups each (Mookambika-Someshwara, Kodagu, Silent Valley-Amarambalam, Cardamom Hills, and Agasthyamalai) and the remaining are highly fragmented with 1 - 5 groups forming isolated populations (Kumar 1995a).

2.2.1.3. *Nilgiri langur*

Nilgiri langur (*Trachypithecus johnii*) is a vulnerable (IUCN 1996) primate endemic to the Western Ghats. Unlike the lion-tailed macaque, it also occurs in a variety of forest types such as moist deciduous, riverine and montane wet evergreen. Compared to the lion-tailed macaque, there have been only few studies on the distribution and population of the Nilgiri langur (Ryley and Shortridge 1913; Daniel and Kannan 1967; Krishnan 1971; Kurup 1973, 1975, 1977; Oates 1979), and its ecology and behaviour (Tanaka 1965; Poirier 1969, 1970; Horwich 1972; Oates 1979; Oates *et al.* 1980; Srivastava *et al.* 1996). With the exception of Poirier (1969) and Sunderraj (*in prep.*), most of them were short-term studies.

Nilgiri langur is restricted to the Western Ghats between 8° to 12° N from Agasthyamalai in Kerala in the south, to Kodagu in Karnataka in the north. Due to habitat destruction and hunting for medicinal purpose, it had been wiped out in some areas by the late 1960s (Kurup 1973). Following Wildlife (Protection) Act, 1972, there has been a recovery of populations in most areas. At present it is confined only to the relatively undisturbed areas of the Western Ghats, extending over a range of elevation from 150 m to 2,500 m. In the Mundanthurai plateau in Tirunelveli district, Tamil Nadu, it is found at the foot hills of the Western Ghats, along the riverine forest (Oates 1979).

Nilgiri langur lives in groups of 3 to 25 animals (Srivastava *et al.* 1996), with an average of 8 to 9 animals (Prater 1980). Most groups consist of one adult male, 4 to 5 adult females, and the rest are infants and juveniles. Adult females form one third of a group (Srivastava *et al.* 1996).

The Nilgiri langur ranges within an area of 0.65 to 2.0 km² (Prater 1980). It feeds on young and mature leaves, flowers, fruits, seeds, petiole, resin, and bark. In Agasthyamalai they used 115 plant species in a year, with fibre and condensed tannin content characterising foliage selection (Oates *et al.* 1980). Social interactions are infrequent, often without physical contact and for short durations (Poirier 1970).

2.2.2. Squirrels

2.2.2.1. *Taxonomy and distribution*

Squirrels belong to the Family Sciuridae, in the Order Rodentia. This Order with nearly 1,000 species, is the most speciose among mammals and also the most widely distributed. The Family Sciuridae, is classified into two Subfamilies, Sciurinae comprising the tree and ground squirrels which are diurnal, and Petauristinae comprising the flying squirrels which are nocturnal. About 121 species of tree and ground squirrels occur in the world, of which about 56 species (in 16 genera) occur in the Oriental region (Ellerman 1961). Squirrels occur world wide in a variety of habitats including the forests, deserts, plains and the tundra.

India has 18 species of squirrels in six genera. There are eight species (4 genera) of squirrels in the Western Ghats. These are the Malabar giant (*Ratufa indica*), grizzled giant (*R. macroura*), dusky-striped (*Funambulus sublineatus*), Western Ghats striped (*F. tristriatus*), Layard's striped (*F. layardi*), and three-striped palm (*F. palmarum*) squirrels, all of which are diurnal, and the large brown (*Petaurista petaurista philippensis*) and small Travancore (*Petinomys fuscocapillus*) flying squirrels both of which are nocturnal.

The genus *Ratufa* with four species occurs in the peninsular and Indo-Malayan regions. The Malayan giant squirrel *R. affinis* occurs in the Malayan forests. The Malayan black squirrel *R. bicolor* inhabits the Malayan region, north-east India and Myanmar. The grizzled giant squirrel *R. macroura* is found in Sri Lanka, and in isolated pockets of riverine forest in the eastern slopes of Western Ghats at Srivilliputhur Grizzled giant squirrel Sanctuary and Chinnar Wildlife Sanctuaries.

2.2.2.2. *Malabar giant squirrel*

The Malabar giant squirrel *R. indica* has a wide distribution in the Western Ghats (Agasthyamalai to Surat-Dangs), Eastern Ghats (Billgirirangan Hills to Chaibhassa in Orissa) and in Central India west of Hoshangabad in Madhya Pradesh (Abdulali and Daniel 1952). Abdulali and Daniel (1952) and Prater (1980) have identified eight races of giant squirrels from India with seven races in the Western Ghats. They inhabit dry deciduous to wet evergreen forests with an altitude range of 150 m to 2,000 m (Prater 1980; Borges 1989).

The Malabar giant squirrel is a solitary, diurnal tree squirrel. Even though it is nucivorous (seed predator), it also feeds on flowers, fruits, leaves and bark (Ramachandran 1988). The home range of the female giant squirrel was estimated to be about 13.4 ha in the moist deciduous forest of Parambikulam Wildlife Sanctuary in Kerala (Ramachandran 1988). Borges

(1989) reported a home range of about one hectare in the wet evergreen forest of Bhimashankar, Maharashtra, in northern Western Ghats. The giant squirrel builds several nests or dreys in their territory for breeding and nursing pups (Ramachandran 1988). The males which range adjacent to female territories, enter the sexually receptive female's territory and compete for reproduction (Ramachandran 1988). Females give birth to one pup per litter and breeds between December and January (Ramachandran 1988). Adult males do not show parental care (Ramachandran 1988; Borges 1989).

2.2.2.3. *Flying squirrels*

Flying squirrels belong to the Subfamily Petauristinae. There are 12 genera and 35 species of flying squirrels in the world. Two species occur in North America, one in eastern Europe, and the rest in Asia. The flying squirrels have a wing-like extension on either side of the body, forming a patagium between the hind- and fore-limbs, which enable them to glide. There are four species of large flying squirrels (Genera *Petaurista* and *Eupetaurus*) and four species of small flying squirrels (Genera *Petinomys*, *Belomys* and *Hylopetes*) in India. Only two, the large brown flying squirrel (*Petaurista petaurista philippensis*) and the small Travancore flying squirrel (*Petinomys fuscocapillus*) occur in the Western Ghats. The former occurs through out peninsular India, whereas the latter is endemic to the Western Ghats (Prater 1980).

The flying squirrels are nocturnal and nest in tree cavities. They feed on fruits, nuts, flowers, leaves, and bark, like the Malabar giant squirrel

(Prater 1980). Only short term studies have been conducted on flying squirrels (Kurup 1989; Ashraf *et al.* 1993a). *P. petaurista* is more abundant in deciduous forests and cardamom plantations than in wet evergreen forests, and *Petinomys fuscocapillus* is not as rare as it was thought to be (Ashraf *et al.* 1993a).

2.3. METHODS

The field studies were carried out in the Indira Gandhi Wildlife Sanctuary and private forests in the area, in Tamil Nadu, from January 1994 to July 1996. The field studies included i) a survey of forest fragments to estimate the occurrence and abundance of arboreal mammals, and assess the status of the habitat; ii) observations on the ecology and behaviour; and iii) studies on demography. Detailed methods are given in the respective chapters, and only a brief description is given below.

2.3.1. Survey

Between January and March 1994, I identified and surveyed 25 fragments of wet evergreen forests (ranging from <10 ha to >2,000 ha in area) to assess the occurrence and abundance of lion-tailed macaque, Nilgiri langur and giant squirrel and to characterize the fragments with reference to various landscape and habitat parameters. A total of 400 km was surveyed on foot. All sightings of arboreal mammals were recorded with age/sex composition, and sighting distance and angle. Several habitat parameters were recorded from 5 m radius circular plots, at an interval of 100 strides, on either side of the transect. Several landscape parameters such as the presence of corridor, location of the fragment in the landscape and surrounding vegetation were also recorded for each fragment. Estimation of densities of flying squirrels (large brown and the small Travancore flying squirrels) was done using transect surveys between 1900 hrs to 2100 hrs using spot lights.

2.3.2. Intensive ecological studies

The changes in ecology and behaviour due to forest fragmentation were studied in the lion-tailed macaque, Nilgiri langur and giant squirrel in four fragments differing in area (from <25 to 2,000 ha) and disturbance levels. Time budget, diet composition and ranging distance were estimated using group scan sampling (Altmann 1974) in the case of lion-tailed macaque and Nilgiri langur, and focal animal sampling in the case of giant squirrel. The data was collected from dawn to dusk for five days per species in each fragment, in each of the three seasons (dry, first wet and second wet) from January to December 1995. A total of 2,160 hours of data have been collected on the three species together. This data is analyzed to examine a) changes in time budget due to fragmentation, especially time spent on feeding, ranging and resting; and b) changes in diet quality, with reference to time spent on feeding on various plant parts.

2.3.3. Demographic studies

The demographic parameters estimated for the lion-tailed macaque and Nilgiri langur were, group size, age/sex composition, birth rate and growth rate of groups. Due to poor visibility of infants and the lack of sexual dimorphism in colour and size, no data is available on age/sex composition and birth rate of the giant squirrel. The demographic data is used to examine changes in birth rate, percentage of immature, adult sex ratio and group size due to habitat fragmentation.

2.3.4. Analysis of data

Data on habitat parameters, animal abundance, activity pattern and demography were analyzed using mostly non-parametric statistics (Siegel and Castellan 1988) because the primary level of measurement was often nominal, or conditions of normality and homogeneity of variance were unlikely to be met. Differences between two independent samples were tested using Mann-Whitney U test (M-W); difference among more than two were tested using Kruskal-Wallis test (K-W), association between two variables was estimated using Spearman rank correlation (r_s); the frequencies were tested using Chi-square test (χ^2) or Fisher exact probability test when sample size was low. The significance level decided *a priori* was 0.05 two tailed. Most of the analyses were done using SPSS package (Norusis 1990) on a UNIX Operating System.

4. ACTIVITY PATTERN AND FEEDING ECOLOGY

4.1. INTRODUCTION

As shown in Chapter 3, fragmentation brings about substantial changes in the habitat of the arboreal mammals. The changes include, a reduction in area of the habitat, isolation from other habitats, and changes in resource abundance and distribution as indicated by the changes in tree density, basal area, canopy cover, canopy height, and matrix that surrounds the fragments. Some of the changes immediately follow fragmentation (*e.g.* area and associated disturbances such as reduction in tree density due to logging), while others occur in the long term (*e.g.* absence of regeneration, wind falls and firewood collection). Other long-term changes include increased predation from invading predators (Johns 1985; Saunders *et al.* 1991; Andrén 1992; Fahrig and Merriam 1994), and inter-specific competition especially with generalist and often invading species (Fahrig and Merriam 1994).

The first response of animals to fragmentation of their habitat and associated disturbances are changes in their activity pattern and feeding ecology (Johns 1985; Johns and Skorupa 1987; Marsh *et al.* 1987; Decker 1994). Through such changes the animals would attempt to maximize their survival and reproduction within the constraints of the changes in their habitat. The demographic consequences discussed in Chapter 5 are the results of such changes in activity pattern and feeding ecology.

Only a few studies have examined the changes in activity pattern, ranging and feeding ecology due to habitat fragmentation in mammals in general, and arboreal mammals in particular. Strier (1991) did not find a substantial change in the activity pattern of a group of woolly spider monkeys (*Brachyteles arachnoides*) in a forest fragment in Brazil. Menon and Poirier (1996) found that the lion-tailed macaque in a forest fragment fed on fewer species and had a low quality diet, compared to those in contiguous forest. Among rodents, a reduction of home range and its overlap has been reported in bank voles (*Clethrionomys glareolus*) in forest fragments in Poland (Kozakiewicz 1985). An increase in home range in fragments has been reported in Eurasian red squirrel, *Sciurus vulgaris* (Wauters *et al.* 1994; Yahner and Mahan 1997). In chipmunks (*Tamias striatus*) there was an increase in foraging and pausing in fragments (Mahan 1996; Yahner and Mahan 1997). The increased abundance of red-backed voles (*Clethrionomys californicus*) in large fragments was related to greater abundance of mycorhizal fungi which were sensitive to edge effects (Mills 1995). It has also been reported that the abundance of plant and animal foods (*e.g.* insects) change within and around fragments, to which animals often respond. Forest humming birds that exploit food resource in the secondary forest survive better than insectivorous birds that are unable to do so (Bierregaard *et al.* 1992). In Brazil, canopy insect abundance decreased and understorey insects increased in forest fragments (Malcom 1991), to which insectivorous birds responded differentially.

Several studies have examined the changes in activity pattern, ranging and feeding ecology of arboreal and terrestrial mammals, following disturbance due to selective logging of tropical rainforest, which may be similar to those following fragmentation. Immediately following selective logging, most primates showed a reduction in ranging and home range, and faced a reduction in food availability and increased predation risk and hunting by humans (Marsh 1981; Marsh and Wilson 1981; Johns 1983; Marsh *et al.* 1987; Johns and Skorupa 1987; Decker 1994). The long-term impacts on activity pattern, feeding and ultimately demography, depended on the ecology, especially, diet of the species. Primate vulnerability to habitat disturbance could be predicted from fruits and seeds in the diet and home range size (Wilson and Wilson 1975; Oates 1977; Skorupa 1986; Johns and Skorupa 1987). The energetic constraints resulting from a low quality diet might limit ranging as in some primates (*e.g.* Milton 1980; Raemakers 1980; Johns 1985) or increase ranging as in some birds (Johns 1985). Heydon and Bulloh (1997) found that two species of mouse deer in Borneo were more severely affected than arboreal mammals by selective logging and that strangler figs were critical to their survival in logged forests. However, because of their low density, figs may not be key stone species to relatively sedentary animals such as the Malabar giant squirrel (Borges 1993).

Thus the limited information that we have indicates that the ecological response to fragmentation and associated habitat disturbance varies considerably among species. The response is related to the nature of changes that occur in and around the fragments on the one hand and to the ecology of the species, especially its diet on the other. In this Chapter I examine the changes in activity pattern and feeding ecology of the three diurnal arboreal mammals (lion-tailed macaque, Nilgiri langur and giant squirrel) with reference to habitat fragmentation. The objectives are;

1. To assess changes in the activity pattern with reference to area and vegetation status of the fragments; and
2. To assess changes in the feeding ecology with reference to area and vegetation status of fragments.

4.2. STUDY SITES

4.2.1. Selection of study sites and groups

The changes in activity pattern and feeding ecology of the lion-tailed macaque, Nilgiri langur and giant squirrel due to fragmentation were studied in four fragments for each species. Since all three arboreal mammals did not occur within four fragments, five fragments were chosen for intensive ecological studies, which varied in size and degradation level. The Akkamalai shola (>2,000 ha) and the Tata Estate fragment (24 ha) were selected as large and small fragments, respectively, for all the three species. The Andiparai shola (large, 185 ha) and Puthuthottam Estate (65 ha) were selected for the lion-tailed macaque; Andiparai and Korangumudi (35 ha) for Nilgiri langur and, Puthuthottam and Korangumudi for giant squirrel. A description of these fragments is given below (see also Figure 2.1).

4.2.1.1. *Tata Estate*

The Tata Coffee Estate (10° 20'N 76° 56'E), the smallest fragment selected for the intensive ecological study, is 10 km from Valparai Town, by the side of the Valparai-Chalakkudy Road. It is owned by Tata Tea Estate (Pvt) Ltd., and covers an area of about 24 ha, and is surrounded by plantations of tea and coffee, Upper Sholaiyar reservoir and human settlements. This patch was isolated in 1914, the nearest forest being about 1.5 km away. It has no connectivity or corridor with other forests. Most of the forest is under natural vegetation, with one hectare under-planted with coffee, leaving the big emergents intact. This fragment has one group of lion-tailed macaque, 6 to 7 groups of Nilgiri langur, many giant squirrels, flying squirrels and other small mammals including civets and mongooses. It is also a temporary refuge for elephant, gaur and sambar while they move between the fragments in the landscape. At present it has a relatively good forest cover (see Table 3.2). However firewood collection is degrading it rapidly.

4.2.1.2. *Korangumudi Estate*

It is another small fragment (10° 18'N and 76° 54'E) about 9 km southwest of Valparai Town, with an area of about 35 ha. It is a highly degraded fragment. About half of the area has been clear-felled and the remaining area is left with a very thin forest cover under cardamom cultivation. This patch was isolated in 1906, and is surrounded on three sides by coffee and on one side by tea plantation. There is a human settlement in one corner of the fragment. The nearest forest, a small fragment, is about 2 km away. This fragment has been selectively logged repeatedly, the last time in 1987. There is no regeneration or recruitment of trees because of cardamom cultivation. The fragment is under intense pressure from both the planters and workers for its timber and firewood, respectively. One group of lion-tailed macaque and two groups of Nilgiri langur and other arboreal mammals occur in this fragment. Elephant, gaur and sambar use it temporarily while moving between the forest areas. Man-elephant conflict is common in this fragment during dry periods of the year, with three human deaths in the last two years.

4.2.1.3. *Puthuthottam Estate*

It is about 65 ha in area (10° 20'N 76° 56'E), and about 1.5 km from Valparai Town on the Pollachi-Valparai Road. It is also a privately owned fragment surrounded on three sides by tea and on one side by coffee plantation. The heavily used Pollachi-Valparai road passes through the fragment. This fragment was isolated in 1906 and it has been selectively logged many times, the last one being in 1991. About half the area is under-planted with cardamom, which is presently not being maintained. The adjoining coffee plantation has been planted with *Maesopsis eminii* as a shade tree. This fragment is heavily exploited for firewood and small timber by the local people. About 20 families depend on the fragment for their livelihood by selling firewood to tea shops and small hotels in the town. This fragment is a permanent refuge for two groups of lion-tailed macaque, many giant squirrels, flying squirrel, civet and mongoose, and a temporary refuge for larger mammals (elephant, gaur, tiger and leopard). There were no Nilgiri langur in this fragment.

4.2.1.4. *Andiparai Shola*

This is a medium-sized fragment (10° 24'N 76°59'E), located 17 km from Valparai town, on the Valparai-Pollachi Road. It covers an area of about 185 ha, and is within the Indira Gandhi Wildlife Sanctuary. Isolated in 1896 and privately owned, the Forest Department acquired this area about 50 years back. This fragment is surrounded by tea estates on three sides, but has a narrow one km long and 50 m wide corridor of eucalyptus plantation to the adjoining contiguous forest. It is located on the slope of Waverly mountain, the altitude ranging from 1,200 to 1,500 m. It has a better vegetation cover than the smaller fragments but is under pressure from the local people for firewood and small timber. This fragment provides refuge for a wide variety of wildlife throughout the year. Elephants use this area during the summer season. There was one group of lion-tailed macaque, several groups of Nilgiri langur and several giant squirrel in this fragment.

4.2.1.5. *Akkamalai Shola*

This is a large fragment, with an area of about 2,000 ha. The altitude ranges from 1,200 to 2,500 m. In the higher elevations (>1,800 m) it is contiguous with shola-grassland of the Grass Hills about 50 km^2 in area). It comes within the Sanctuary and provides a good habitat to almost all wildlife in the Anamalai Hills. One small town (Iyerpadi), and several estate labour settlements are present along its border in the lower elevation. The vegetation is moderately degraded in areas adjoining such settlements. Moreover, about 50 ha of forest at the lower elevation has been under planted with cardamom by the Forest Department. At higher elevation (>1,500 m), the forest is relatively undisturbed. There were more than two groups of lion-tailed macaque, several groups of Nilgiri langur, several giant squirrel and other arboreal mammals in this fragment.

4.3. METHODS

4.3.1. Ecology and Behaviour

The changes in ecology and behaviour were studied with reference to time budget, diet composition and ranging. These were estimated using group scan sampling (Altmann 1974) in the case of the lion-tailed macaque and Nilgiri langur, and focal animal sampling in the case of the giant squirrel. The groups of lion-tailed macaque and Nilgiri langur selected for study were habituated for two to three months before starting regular data collection. For giant squirrel, individual identification was not possible, therefore, an individual in the same area within the fragment was selected for each day. The data was collected from dawn to dusk for five days in each fragment in each season between January and December 1995. The three seasons were dry season (January to April), first wet season (May to August) and second wet season (September to December). Due to heavy rains during the first wet season, data was collected from only two fragments for each species.

For the lion-tailed macaque and Nilgiri langur group scan was done at an interval of 15 minutes, and in the case of giant squirrel the focal animal sampling was done at two minute interval. In each group scan, activities of all visible individuals were recorded within a five minute period. The data recorded are given in (Table 4.1).

Table 4.1. Data recorded during scan sampling of lion-tailed macaque, Nilgiri langur and giant squirrel.

S.No	Variable
1	Date and Time
2	Weather (sunny, cloudy and rainy)
3	Individual (age/sex class)
4	Activity of the individual
5	Height of the canopy (height of the canopy above and below the individual)
6	Number of individuals in the same tree
7	Nearest neighbour
8	Distance travelled by the group or individual since previous scan
9	Presence of other arboreal mammals nearby
10	Group dispersion

Activities were recorded in considerable detail initially but for analysis were grouped into the following classes.

1. Plant feeding: Feeding on foods of plant origin.
2. Animal feeding: Feeding on foods of animal origin or actual handling of such a resource.
3. Ranging: It included two categories of movement.
    a. Travel: Movement without searching for food resources
    b. Foraging: Moving while also searching for food resources

4. Resting: Sitting, sleeping or inactivity.
5. Other activities: All social interactions and alarm behaviour.

The number of records made in a scan varied from 4 to 10 for lion-tailed macaque, and from 7 to 14 for Nilgiri langur. The number of scans made in a day varied from 40 to 50. For giant squirrel about 30 records were made in an hour at two minute interval. A total of about 15,400 records were made for the lion-tailed macaque, 14,800 for the Nilgiri langur and 14,200 for the giant squirrel. Percent of time spent on an activity in a day was calculated by the equation:

$$P_a = \frac{n_a}{N} \times 100$$

where,

P_a = percent time spent on activity a

n_a = number of records when activity was a

N = total number of activity records in that day

For each activity the mean of five days in each fragment in each season was considered as the seasonal mean time spent on that activity.

The relative time spent on different food items such as different plant species or parts was calculated using the above formula, but with P_a=percent time spent on food item 'a' out of total feeding time; n_a=number of feeding records of food item 'a' and N=total number of feeding records.

The distance travelled in a day, or day range length, was estimated as the sum of the distance the group (or individual giant squirrel) travelled between successive scans. The latter was visually estimated and recorded during each scan.

4.3.2. Vegetation

Phenology was recorded for 5 to 10 trees for each major food plant species in each fragment once in a fortnight. The percentages of crown covered by the vegetative (leaves) and reproductive (flowers and fruits) phases were visually estimated, each phase having a maximum coverage of 100%. The abundance of major plant food species was estimated from several 100 m X 5 m plots. In each plot the number of plant species, number of food species, number of individuals of each species, and basal area of food trees (>30 GBH) were recorded.

4.4. RESULTS

4.4.1. Lion-tailed macaque

4.4.1.1. *Time budget: Time spent on various activities*

Activity bouts

In general, the diurnal activity of a group of lion-tailed macaque began at dawn between 0530 and 0630 hrs, depending on the season, with a short distance travel to a major food tree. This major bout of feeding was followed by ranging when the group spread out searching for and feeding on invertebrates, and widely dispersed small clumps of fruits. The group often took rest between 1200 and 1400 hrs, when most of the social interactions such as grooming and play took place. Following resting, once again they searched for and fed on invertebrates, while moving towards a large food tree for another major bout of feeding. This ended at dusk

(1800 to 1830 hrs) with resting or sleeping on a clump of trees not far from the major food tree to which the group went to the next morning.

The timing of bouts of major activities and their duration varied with season, and food abundance and distribution. During the dry months, the activities started earlier, and there was a pronounced bout of resting during the afternoon. In the cooler months of December to February, the activities started often later after a bout of sun basking. In the monsoon season, activities such as feeding and ranging were often held up during heavy rain. When food abundance was low, the resting bouts were shorter or even absent, whereas ranging increased. When the food was widely dispersed, major feeding bouts were replaced by several short bouts. Thus, the activity bout was a function of season and food abundance and distribution.

In all three seasons ranging was the dominant activity followed by feeding. These two together formed 80% to 85% of day time activity in all seasons (Table 4.2) Since there were considerable differences in the time spent on various activities among seasons within a fragment, comparisons of time budget among fragments is made separately for each season.

Feeding

The feeding time in a day ranged from 19.01% to 46.60%. The seasonal mean for a fragment ranged from 19.70% to 43.60%, both lowest and highest were during the first wet season (Table 4.2). The largest difference among the fragments was during the first wet season (when only two fragments were studied), 19.70% in the small fragment (Puthuthottam)

Table 4.2. The percentage of day time spent on various activities and day range length in the lion-tailed macaque groups in four forest fragments in three seasons.

Season	Fragment	% feeding	% ranging	% resting	% play	% other activities	Day range length (m)
Dry (Jan-Apr)	Tata	40.54	44.35	11.59	2.64	0.92	1252.0
	Puthuthottam	36.31	45.22	12.29	2.40	3.03	974.0
	Andiparai	40.21	41.52	15.90	0.88	1.41	1267.0
	Akkamalai	35.86	45.58	17.13	0.52	0.84	2036.0
Ist wet (May-Aug)	Puthuthottam	19.70	63.57	14.52	0.77	1.46	1142.3
	Akkamalai	43.60	33.41	17.12	2.99	2.80	1383.0
IInd wet (Sep-Dec)	Tata	32.53	52.50	12.41	0.21	2.27	650.0
	Puthuthottam	33.03	48.08	14.16	2.71	2.05	666.0
	Andiparai	25.77	64.44	6.40	1.09	2.34	1058.3
	Akkamalai	38.43	47.91	11.88	0.84	0.96	1235.0

and 43.60% in the large fragment (Akkamalai), the difference being statistically significant (M-W U=1, *P*=0.04). During the second wet season mean feeding time ranged from 25.77% to 38.43% but there was no significant difference (K-W χ^2=7.53, *P*=0.056). In the dry season feeding time ranged only from 35.86% to 40.54% (K-W χ^2=1.75, *P*=0.62).

Ranging

Ranging is the movement of individuals while searching for food (foraging) or moving between food or resting trees. Ranging was the most dominant activity recorded, and was mostly followed by a major feeding bout. Time spent on ranging varied from 33.41% to 64.44% (Table 4.2).

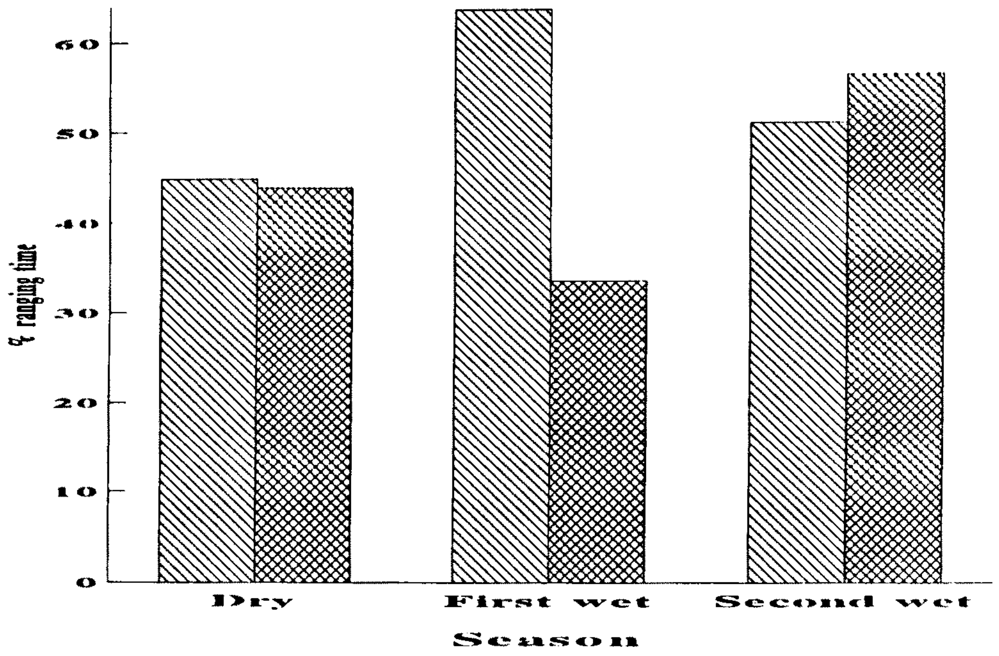
During the first wet season it was significantly higher (63.57%, Figure 4.1a) in the small fragments (<100 ha) than large (33.41%, M-W U=24, $P<0.05$). In second wet season also there was a significant difference in ranging among the fragments (K-W $\chi^2=8.0$, $P=0.04$) but not between the large and small fragments (M-W U=34, $P=0.51$). Ranging did not vary significantly between fragments during the dry season, even between large (>100 ha) and small fragments (M-W U=30, $P=0.13$).

Day range length is the distance travelled by a group during the course of the day. It was estimated as the sum of the distance travelled between consecutive scans. Overall, the distance travelled in a day by a group ranged from 650 m in Tata Estate (second wet season) to 2,036 m in Akkamalai (dry season, Table 4.2). During dry and second wet seasons it varied significantly among the fragments (K-W $\chi^2=11.03$, $P=0.012$ and $\chi^2=12.33$, $P=0.006$ respectively, Figure 4.1b) and was greater in the larger fragments than the smaller. In the first wet season also it was greater in the large fragments, but not significantly so (M-W U=3, $P=0.51$).

Resting

Resting mostly followed a long feeding bout. Groups took rest mostly between 1200 hrs to 1500 hrs, with a peak between 1300 hrs and 1400 hrs. Most of the social interactions such as grooming and play took place during resting. The duration of resting in day time varied from half an hour to two hours at a stretch. The overall time spent on resting in a day ranged from 6.40% to 17.13% (Table 4.2). During the second wet season it differed significantly among fragments (K-W $\chi^2=9.31$, $P=0.026$), being greater in the

(a) Ranging



(b) Day range length

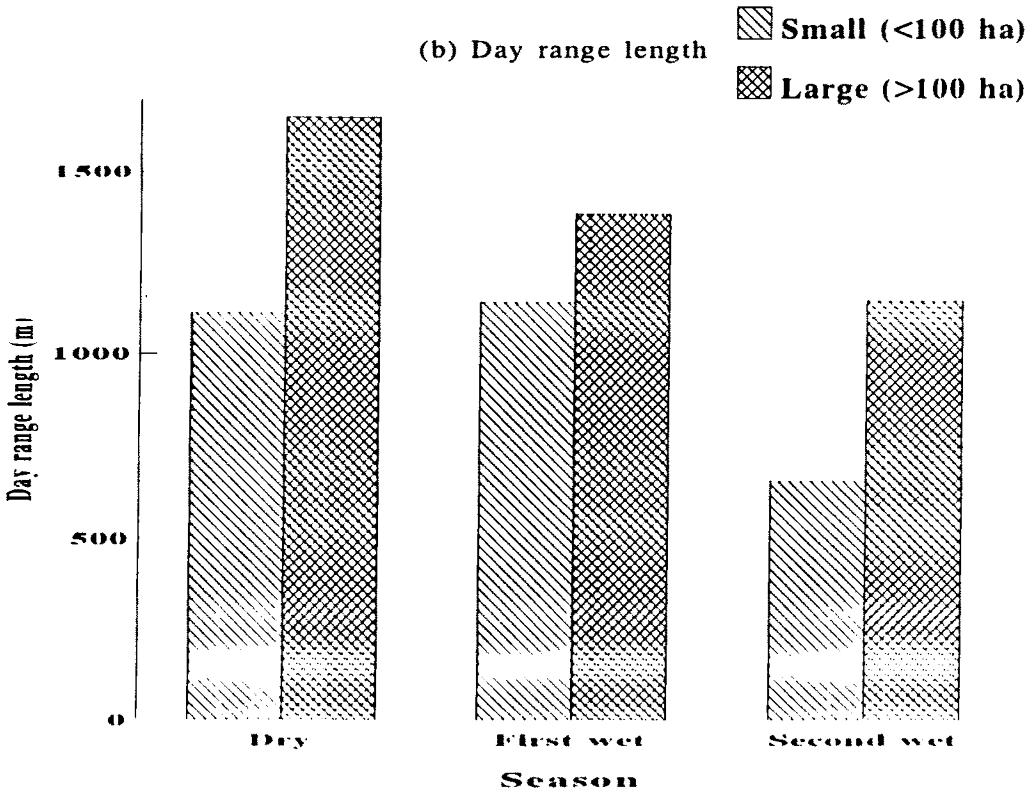


Figure 4.1 Percentage on day time spent of ranging (a) and day range length (b) by the lion-tailed macaque in large and small fragments in three seasons (Dry: Jan-Apr; Ist wet: May-Aug; IInd wet: Sep-Dec).

smaller fragments. Resting time was significantly greater in the larger fragments (>100 ha) during dry (M-W U=17.5, *P*=0.014) and first wet season (M-W U=1, *P*=0.02), and lower in second wet season (M-W U=17, *P*=0.041, Figure 4.2).

Play

Play occurred mostly during resting, among the infants, juveniles and sub-adults. Play activity included biting each other, chasing, clinging and jumping between branches. Only very little time was spent on play, there being no difference among seasons, the lowest being (0.52%) in the dry season and the highest (3.71%) in the second wet season (Table 4.2).

Other activities

Very little time was spent on other activities (Table 4.2) which included grooming, agnostic interactions, alarm behaviour, *etc*. Therefore, further analysis of this was not done.

4.4.1.2. *Feeding ecology*

Plant vs Animal food

The major feeding bouts were usually on large food trees, to which all animals of a group converged. It was only during such occasions that the entire group could be seen on one tree, or a few neighbouring trees. At other times the group was widely spread out. Typical of such large feeding trees were *Ficus* spp and *Elaeocarpus ferrugineus*. Some of the major food trees were medium sized, but often found in relatively large numbers either together (*e.g. Cullinea exarillata*) or apart (*e.g. Macaranga peltata*). While

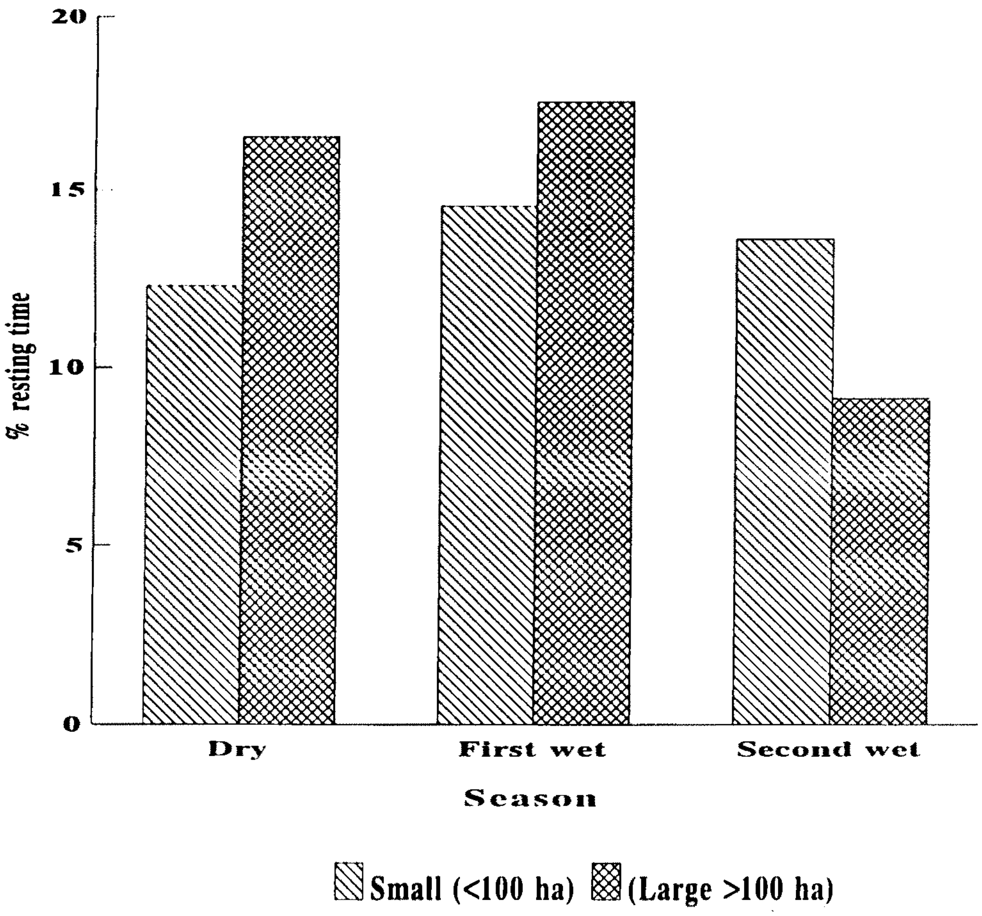


Figure 4.2 Percentage of day time spent on resting by the lion-tailed macaque in large and small fragments in three seasons.

feeding on such trees the group, especially if it was large, split into two or more subgroups. It was when the monkeys came together on such feeding trees that most of the social interactions especially grooming, play and agonistic interactions, such as displacement and aggression, occurred.

The lion-tailed macaque fed on plant parts (mostly fruits, flowers and seeds), animals (mostly invertebrates), and other items (mushroom and lichens). Feeding in a day usually included two major feeding bouts often on large food trees, between 0800 and 1100 hrs in forenoon and between 1500 and 1800 hrs in the afternoon. The time spent on plant parts out of total feeding time varied from 74.74% to 94.74%. It differed among the fragments in the dry season more than in the other seasons (Table 4.3), and was highest (90.62%) in Puthuthottam and lowest in the Andiparai shola (74.74%). In this season in the large fragment (>100 ha) groups spent significantly less time (77.90%) feeding on plants out of total feeding time than small fragments (89.20%, M-W U=6, *P*=0.001, Figure 4.3). Conversely, this meant that in the large fragments the groups spent more time on invertebrates. A similar trend was seen in the second wet season also, when the relative time spent on plant foods was lower (86.50%) in the large fragments (M-W U=19, *P*=0.034) than small fragments (92.46%), whereas in the first wet season it did not vary significantly (M-W U=34, *P*=0.40). Thus, while there was no difference in total feeding time among the fragments in dry and second wet seasons, groups in the large fragments spent less time on plant foods and more time on invertebrates, compared to groups in the small fragments which spent more time on plant foods. In the first wet season when total feeding was significantly greater in the large fragment, there was no difference between large and small fragments in feeding on plant and animal parts.

Table 4.3. Percentage of time spent on plant and animal foods out of total feeding time and mean number of plant food species used in a day by lion-tailed macaque groups in four forest fragments in three seasons.

Season	Fragment	% plant parts	% animal food	Mean number of plant species used per day
Dry (Jan-Apr)	Tata	87.80	11.88	2.40
	Puthuthottam	90.62	9.76	3.40
	Andiparai	74.74	24.68	4.20
	Akkamalai	81.20	17.34	3.40
Ist wet (May-Aug)	Puthuthottam	88.25	11.75	3.67
	Akkamalai	90.04	9.74	5.00
IInd wet (Sep-Dec)	Tata	94.74	5.24	2.80
	Puthuthottam	90.18	9.09	5.00
	Andiparai	89.88	10.87	6.00
	Akkamalai	85.60	14.33	5.80

Number of food plant species used

A total of 62 species were used as food plants by all four study groups lion-tailed macaque together (Appendix 1). Of these 39 were trees, 12 were shrubs, 9 were lianas and the rest included a few species of lichens and mushrooms. There was considerable difference among the

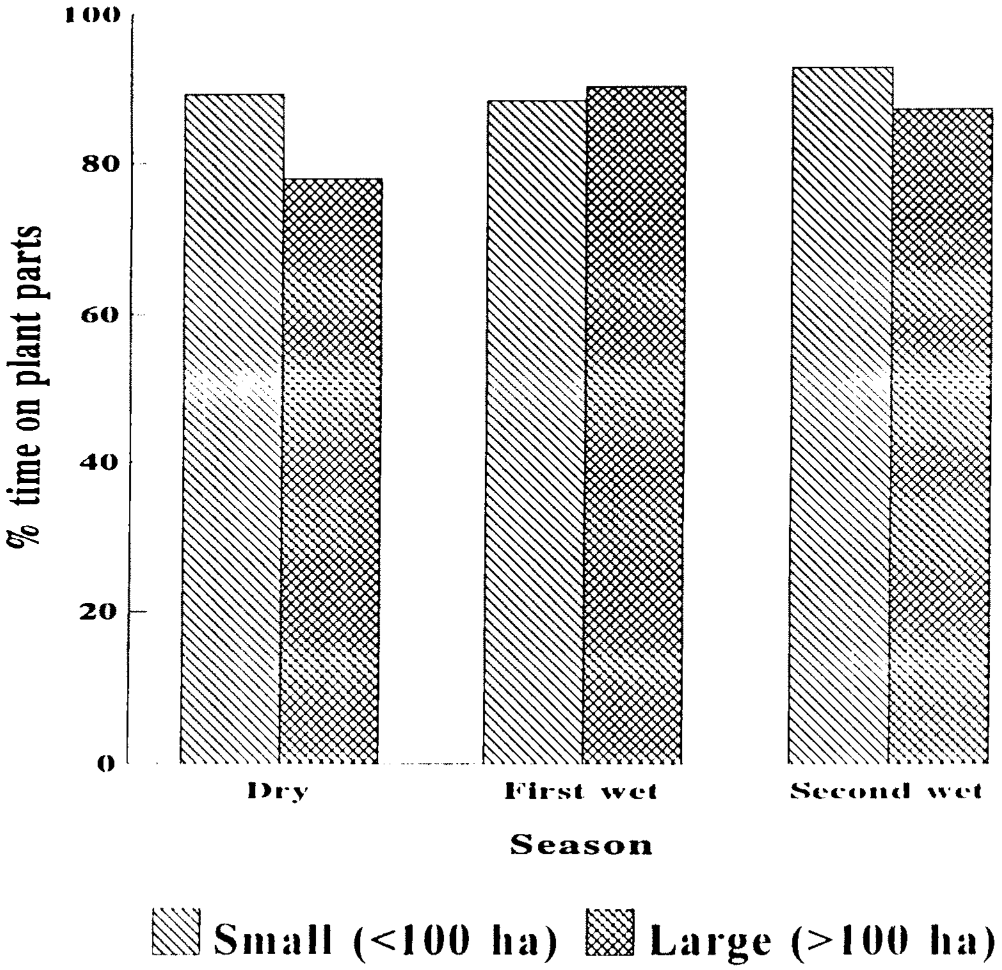


Figure 4.3 Percentage time spent on plant parts out of total feeding time by the lion-tailed macaque in small and large forest fragments.

fragments in the relative composition of food trees, shrubs and lianas. Lianas formed more than 20% of the food species in the two larger and less disturbed forests (Figure 4.4), compared to less than 7% in the smaller more degraded forests. In contrast, maximum food species belonged to trees and shrubs in the smaller fragments. Among the most important food trees in all fragments were *Cullinea exarillata*, several species of *Ficus* and *Artocarpus heterophyllus*. *Maesopsis eminii,* an exotic, was an important food tree in Puthuthottam Estate. The major lianas in the larger less disturbed fragments were *Elaeagnus kologa* and *Cayratia pedata*. Among the important shrubs or understorey trees were *Antidesma menasu* and *Maesa indica* in all fragments, and *Coffea arabica* and *Lantana camera* in the small disturbed fragments.

Overall, the number of plant species used in a day varied from 2 to 12 species. The seasonal mean for a fragment ranged from 2.4 to 6 species/day (Table 4.3). In the second wet season it was significantly greater (mean=5.9 species/day) in the large fragments (<100 ha) than small fragments (3.9 species per day, M-W U=15, *P*=0.012). In the dry and first wet seasons it did not vary significantly among the fragments even though it was greater in the large fragments (Table 4.3). Across the seasons, the number of plant species used in a day was significantly greater (mean=5.0 species/day) in the larger fragments (>100 ha) than in the small fragments (mean=3.4 species/day, M-W U=126, *P*=0.003).

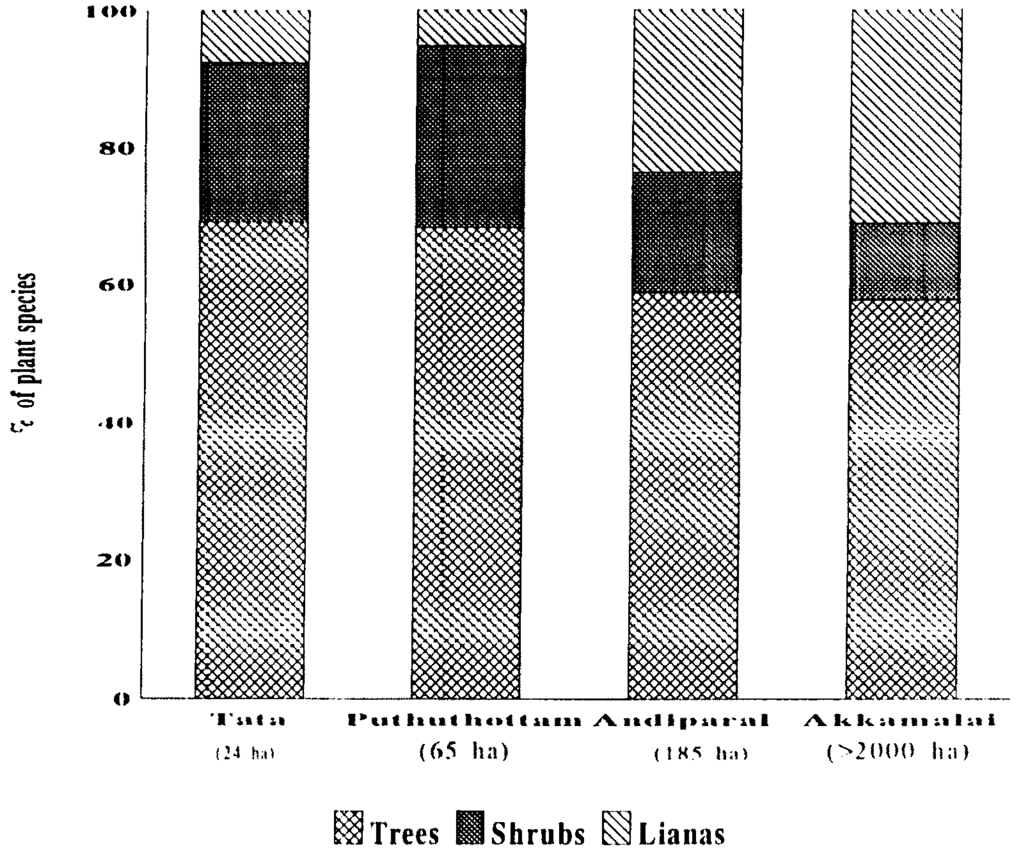


Figure 4.4 Percentage of lianas, shrubs and trees in the plant food species of the lion-tailed macaque in four forest fragments.

Use of plant parts

Flowers

Flowers of three species were eaten, the seasonal mean time spent on them out of total feeding time varying from 0.60% to as high as 84.58% (Table 4.4). The most eaten flowers were that of *Cullinea exarillata* which formed up to a maximum of 85% of the plant diet in a fragment. Flowers were eaten in all three seasons but mostly in the dry season. Even though flower feeding was weakly correlated with percent of monitored trees in flower (r_s= 0.40, n=10, P>0.05), the mean feeding time on flowers was

Table 4.4. Percentage of time spent on flowers, fruits and seeds out of total plant feeding time by lion-tailed macaque groups in four forest fragments in three seasons.

Season	Fragment	% flowers	% fruits	% seeds
Dry (Jan-Apr)	Tata	84.58	8.66	6.74
	Puthuthottam	28.45	34.37	37.20
	Andiparai	8.82	37.37	53.78
	Akkamalai	21.12	8.60	70.18
Ist wet (May-Aug)	Puthuthottam	7.33	88.27	4.40
	Akkamalai	1.30	93.33	5.33
IInd wet (Sep-Dec)	Tata	6.76	15.86	77.36
	Puthuthottam	0.60	65.86	33.52
	Andiparai	2.10	77.76	20.13
	Akkamalai	2.84	45.18	51.98

greater than 20% in only three (all in dry season) of the 10 observations sessions, being less than 10% in the other sessions (Table 4.4). Thus, flowers formed an important component of the diet only in the dry season, when *Cullinea exarillata* was in flower. In the other two seasons, *Macaranga peltata* and *Mallotus tetracocus* formed a minor component of the diet. In the dry season, the percentage of flowers in the diet was significantly higher (56.52%) in the small fragments (<100 ha) than large (14.62%, M-W U=6, *P*=0.0009), there being no difference in the other two seasons (M-W U=9, *P*=0.36 for dry season; M-W U=37, *P*=0.48 for second wet season Figure 4.5a).

Fruits

A total of 33 species were used for feeding on fruits (the fleshy or pulpy layer around the seed, sometimes including seed coat) most often at the ripe stage. Of these, four were drupes (fleshy outer covering with one stone which may have more than one seed) either large to medium (*e.g. Mangifera indica* and *Palaquium elipticum*) or small (*Syzygium* spp). More than 20 species were berries (any multi seeded or stoned fleshy fruit). The major berries were several species of *Ficus, Bischofia javanica, Elaeagnus kologa* and *Cayratia pedata. Artocarpus heterophyllus*, the fruits and seeds of which were eaten, is included in fruits. There was no difference among the forest fragments in the relative number of food species belonging to different types of fruits (χ^2=2.4, df=3 *P*=0.24).

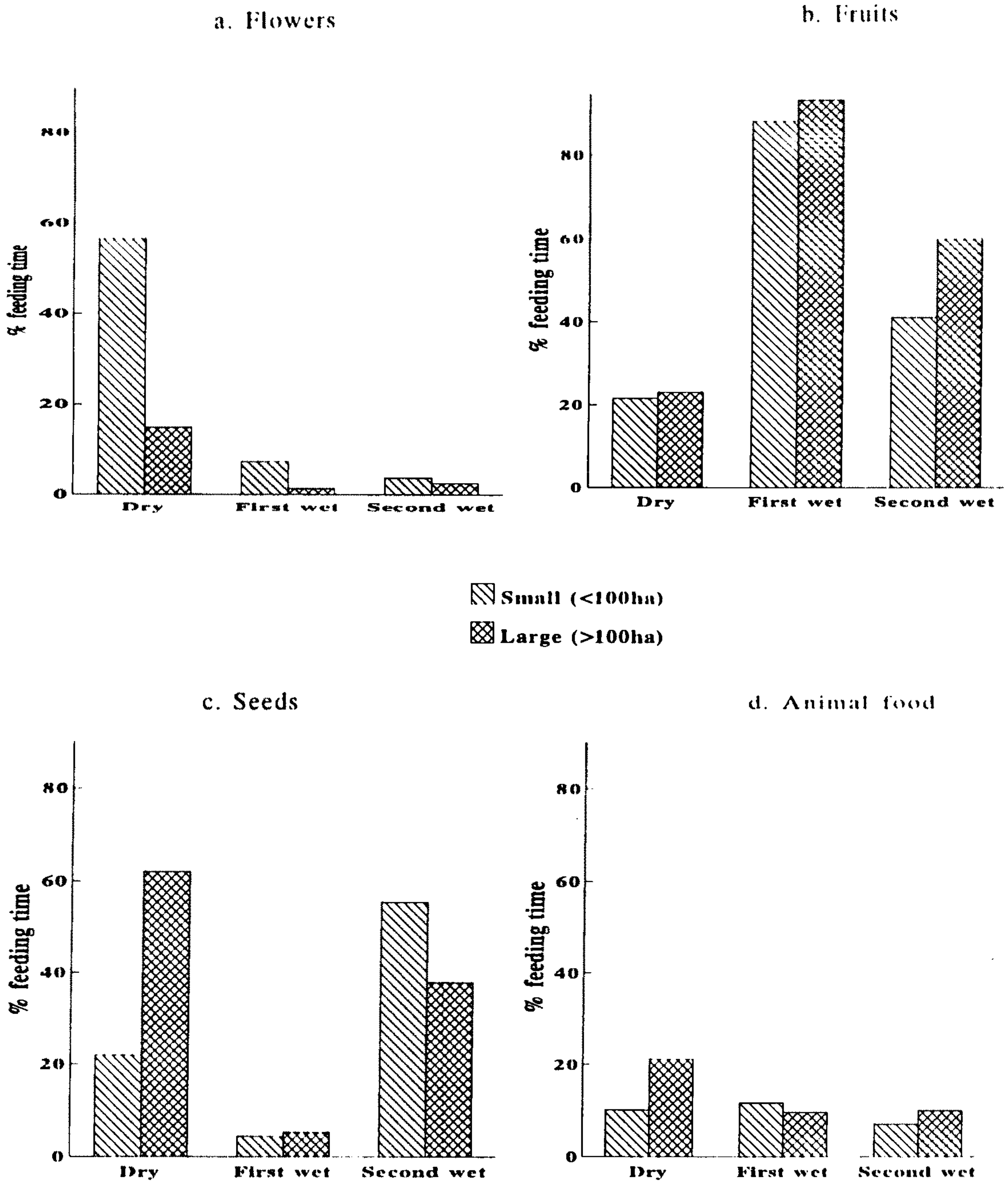


Figure 4.5. Time spent on various plant parts and animal food in the small and large forest fragments by the lion-tailed macaque in three seasons.

The feeding time on fruits out of total plant feeding varied from 8.66% to 93.33% (Table 4.4). In all seasons the percentage of fruits in the diet was higher in the large fragments (>100 ha) than small fragments (Figure 4.5b), but not significantly so (M-W U=47, *P*=0.82 for dry season; U=8, *P*=0.35 for first wet season; and U=28, *P*=0.16 for second wet season).

Seeds

In 15 species only seeds were eaten which included *Cullinea exarillata*, *Diospyros sylvatica* and *Coffea arabica*, in a few other species the seeds were eaten along with the mesocarp (*e.g. Artocarpus heterophyllus*). The time spent on seeds varied from 4.40% to 70.18% out of total plant feeding time (Table 4.4). It was greater in the dry and second wet seasons compared to the first wet season. In the dry season,it was significantly higher (61.98%) in the large fragments (>100 ha) than small (21.97%, M-W U=9, *P*=0.001, Figure 4.5c). In contrast, it was higher (55.44%) in the small fragments than large (37.82%) during the second wet season, but not significantly so (M-W U=30, *P*=0.22). In the first wet season the time spent on seeds was low in both large and small fragments, with no significant difference between them (M-W U=8, *P*=0.34).

Abundance of plant foods

The abundance of plant food species was estimated as the mean number of such species in 100 m X 5 m plots. The number of all plant species, food plant species, and basal area of food trees (>30 cm in GBH) were greater in the larger fragments than in the smaller fragments (Figure 4.6), the difference being greatest in total number of plant species. There

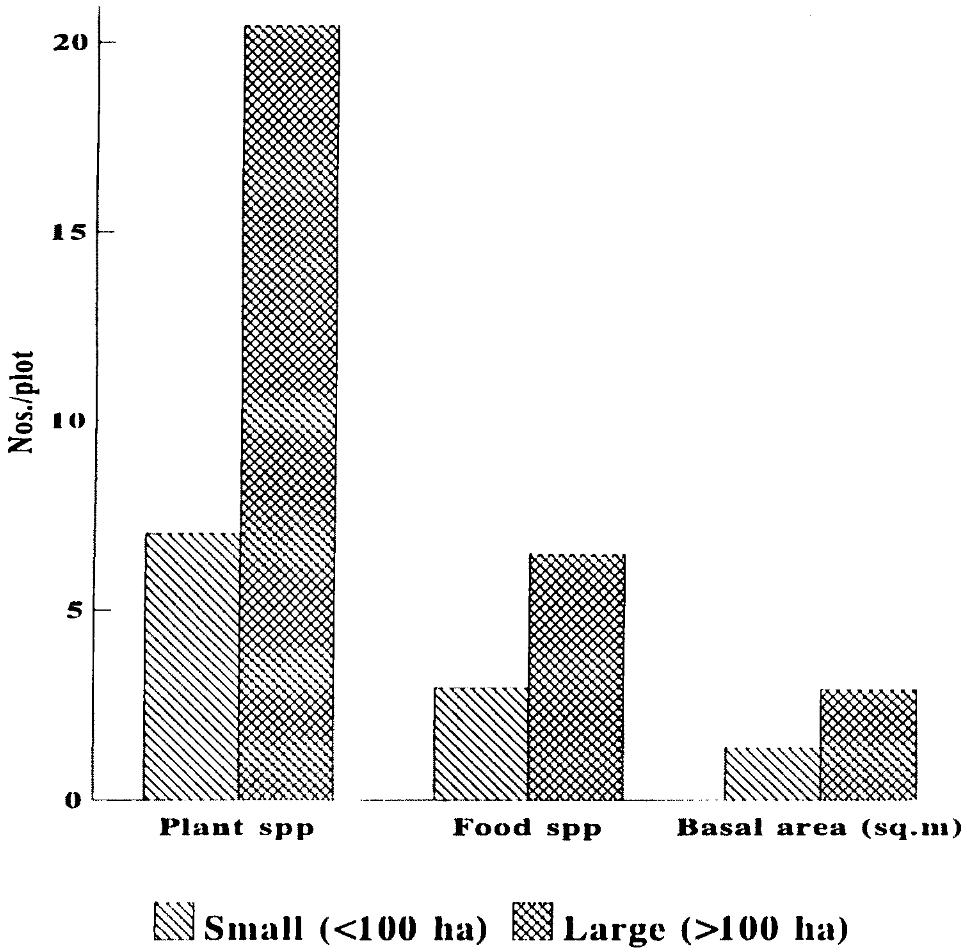


Figure 4.6 The mean number of woody plants and woody food species, and total basal area of woody food species of lion-tailed macaque in 5 m X 100 m plots in large and small forest fragments.

also was an effect of disturbance; thus among the smaller fragments (<100 ha), Tata Estate which was least disturbed had greater abundance of plant and food plant species and greater basal area (Table 4.5). Among the two larger fragments (>100 ha), the least disturbed, Akkamalai shola, had greater abundance.

Table 4.5. The mean number of total tree species and food tree species of the lion-tailed macaque and basal area of food tree species in 100 X 5 m plots in four forest fragments.

Fragment	Plant species/ plot	Food species/ plot	Total basal area of food trees m^2/plot	Number of plots (100 m X 5 m)
Tata	7.25	3.00	1.70	11
Puthuthottam	6.73	2.91	1.06	17
Andiparai	19.63	5.50	2.20	22
Akkamalai	21.25	7.44	3.61	25

A total of 550 trees of 20 species were monitored for phenological changes, especially the abundance of edible flowers, fruits and seeds. Even though I attempted to assess abundance, it was difficult to visually assess stage of ripeness of fruits, and to compare fruits of different sizes, *e.g.* large *Artocarpus heterophyllus* with small *Ficus* fruits. Hence, the phenology data was used only to estimate the percentage of trees that had edible flowers and fruits in each season.

The percent of monitored food trees in flowers varied from 0 to 29.41% (Table 4.6) and was greater in the smaller fragments in all seasons (Figure 4.7). Similarly the food trees in fruit, also was greater in the smaller

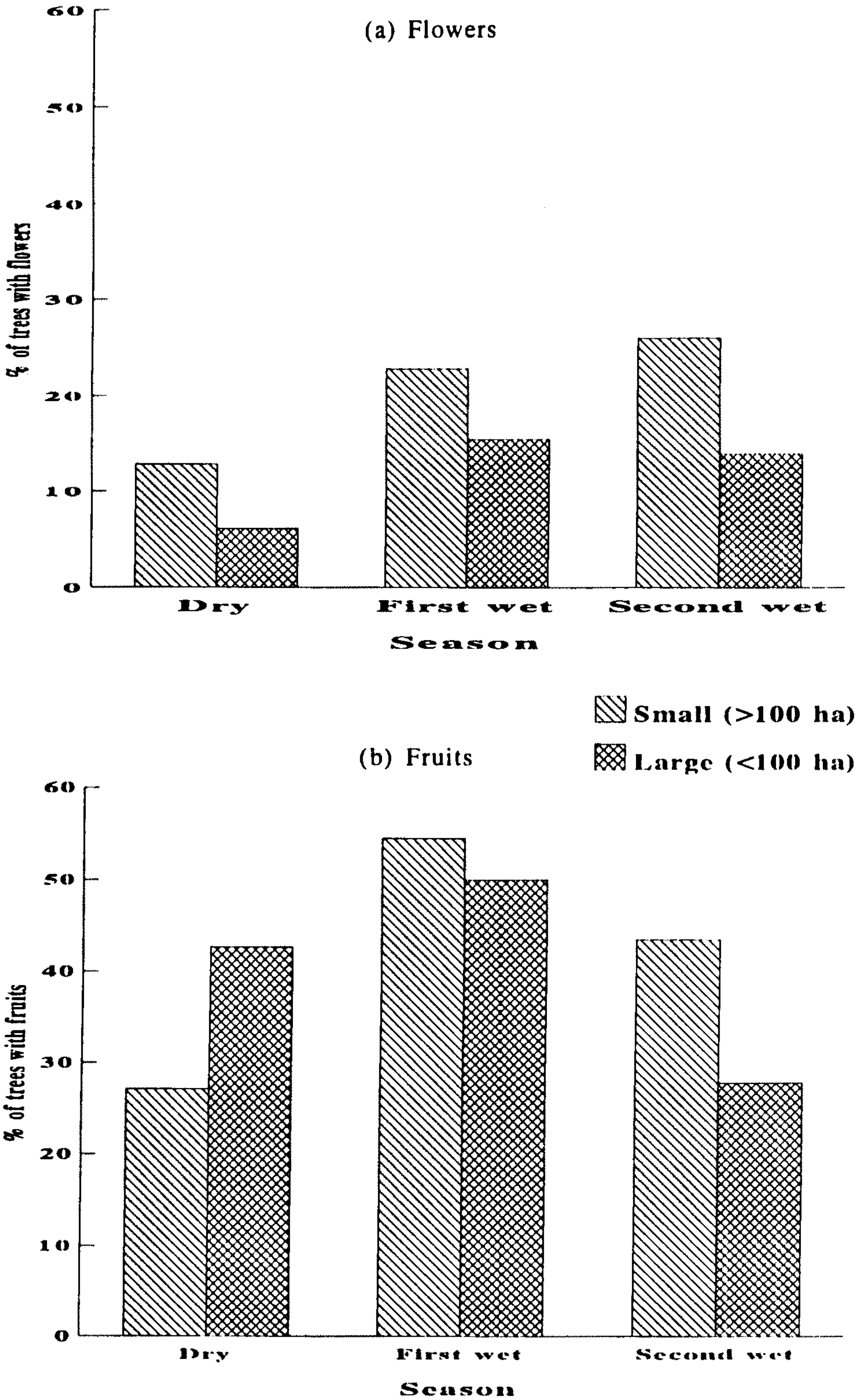


Figure 4.7 Percentage of trees with flowers and fruits out of total monitored trees in three seasons.

fragments in two seasons. This greater abundance of trees in flower and fruit in the smaller fragments was due to two reasons. First, more flower species were used as food trees in the smaller fragments (Section 4.4.2.2). Secondly, these few species had prolonged flowering and fruiting periods.

Table 4.6. Percentage of trees with flowers and fruits out of total monitored food trees of lion-tailed macaque (500 trees of 20 species in each season).

Season	Fragment	% with flowers	% with fruits/seeds
Dry (Jan-Apr)	Tata	17.78	20.00
	Puthuthottam	07.89	34.20
	Andiparai	00.00	38.89
	Akkamalai	12.20	46.34
Ist wet (May-Aug)	Puthuthottam	22.72	54.54
	Akkamalai	15.38	50.00
IInd wet (Sep-Dec)	Tata	22.22	32.35
	Puthuthottam	29.41	54.55
	Andiparai	12.50	28.12
	Akkamalai	15.15	27.27

The major food trees in the smaller fragments with a prolonged flowering and fruiting periods were *Artocarpus heterophyllus*, *Cullinea exarillata*, and several *Ficus* spp. In the larger fragments, the total number of food plant species and hence monitored species were greater. Even though these included the above three species, many other species with short flowering and fruiting periods were also included. Thus, food availability in the smaller fragments was dependent on three or four species which had prolonged fruiting period. In contrast, fruits availability in the larger fragments, in addition to the above species, was also influenced by several other species that have relatively short fruiting period (*e.g. Mangifera indica* and *Palaquium elipticum*).

Use of animal foods

Animal food comprised of invertebrates, juveniles of flying and giant squirrels, bird eggs, lizards (*Calotes* spp), and tree frogs. Invertebrates formed the major component (>95% of the time spent on animal food), and were eaten from green and dry foliage, bark, dead wood, fruits and seeds. Flying squirrels were twice seen being eaten from tree holes and giant squirrel juvenile once from a nest. Feeding time on animal foods out of total feeding time varied, ranging from 8.57% to 24.68% (Table 4.3). It was shown earlier that the time spent on animal foods out of total feeding was significantly more in the larger fragments in the dry and second wet seasons (M-W U=5.5, *P*=0.008 for dry season; U=5, *P*=0.04 for second wet season, Figure 4.5d).

Thus the major differences in diet composition in the lion-tailed macaque are; a) greater total feeding time in the large fragments in the first wet season; b) greater time spent feeding on insects in the large fragments in the dry and second wet seasons and c) greater time spent on fruits and seeds in the large fragments, and flowers in the small fragments in the dry season.

4.4.2. Nilgiri langur

4.4.2.1. *Time budget: Time spent on various activities*

Activity bouts

The diurnal activity of Nilgiri langur began at dawn when they moved up to the top of the sleeping tree for basking for about an hour, depending on the time of sunrise and intensity of sunlight. Following basking, langurs moved into major food trees mostly within 50 m, for a feeding bout of about 2 to 3 hours. During this time they fed on one or several species in the same area. After this long feeding bout langurs took rest on the same or neighbouring trees for the next 3 to 4 hours continuously (between 1100 hrs and 1500 hrs). During this period most of the interactions such as grooming, play and other social activities took place. After resting, once again the groups moved into other food trees for another feeding bout. This feeding bout ended with resting in the evening between 1800 hrs and 1830 hrs. Langurs in the small fragments often moved into adjacent coffee plantations to feed on the young leaves of exotic and non-native species such as *Erythrina subumbrans, Spathodia campanulata* and *Maesopsis eminii*. During the summer the activity began early and ended late in the evening. Overall, feeding and resting constituted 85% to 90% of the total diurnal activity (Table 4.7).

Feeding

The mean feeding time did not vary much among the seasons, the highest (37.91%) was during first wet season and the lowest (28.94%) in the second wet season (Table 4.7). In the dry season it did not vary much between large and small fragments compared to the other seasons (M-W U=33, *P*=0.32). In the first wet season, it spent more time on feeding (37.91%) in the small fragment than large fragment (31.92%), but not significantly so (M-W U=2, *P*=0.27). During the second wet season, the highest (39.06%) was in the large fragment and the lowest (28.94%) in a small fragments, the difference being not significant (M W U 31, *P* 0.42, Figure 4.8). Thus, overall there was no significant difference among fragments in the time spent on feeding.

Table 4.7. The percentage of day time spent on various activities and day range length in Nilgiri langur groups in the four forest fragments in three seasons.

Season	Fragment	% feeding	% ranging	% resting	% other activities	Day range length (m)
Dry (Jan-Apr)	Tata	29.44	9.97	56.12	4.45	407
	Korangumudi	31.34	14.04	53.07	1.55	281
	Andiparai	34.06	11.17	53.27	1.48	270
	Akkamalai	32.46	14.31	51.39	1.78	321
Ist wet (May-Aug)	Korangumudi	37.91	20.17	39.32	2.59	460
	Akkamalai	31.92	6.27	57.78	4.62	112
IInd wet (Sep-Dec)	Tata	28.94	14.22	53.44	3.39	381
	Korangumudi	33.98	17.44	44.54	4.04	235
	Andiparai	39.06	17.22	40.84	2.91	343
	Akkamalai	31.61	18.33	48.41	1.58	301

Ranging

The Nilgiri langur spent only very little time in ranging, from 6.27% to 20.15% of the diurnal activity (Table 4.7). Ranging occurred while

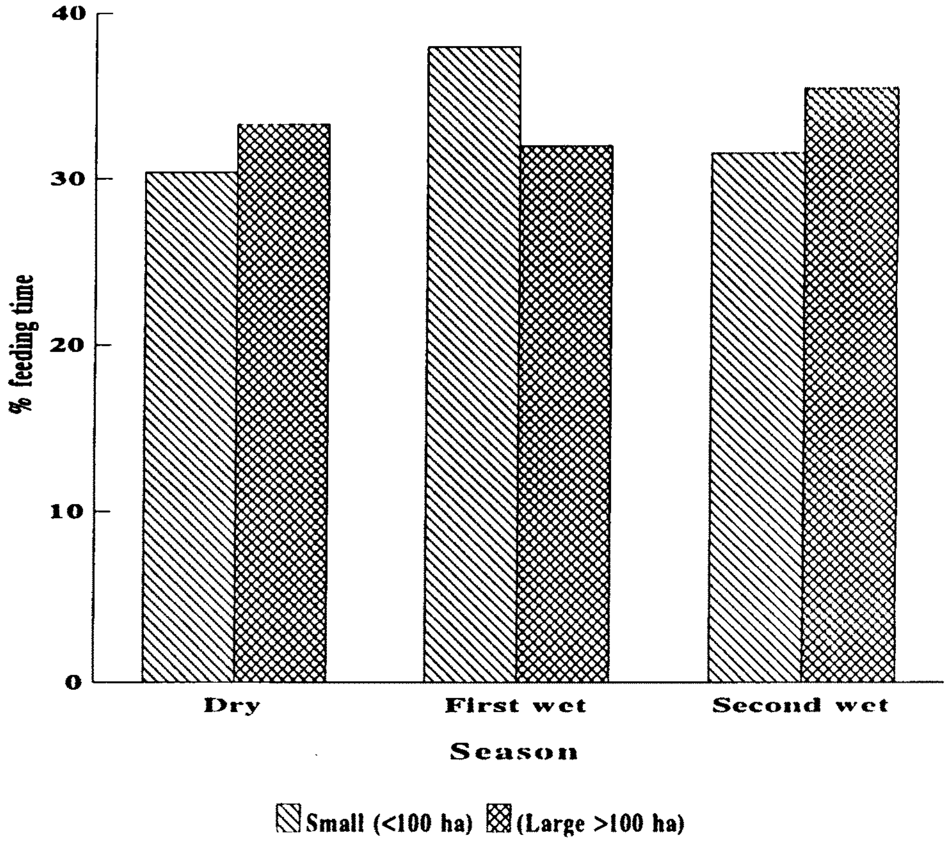


Figure 4.8 Percentage of day time spent on feeding by the Nilgiri langur in small and large fragments in three seasons.

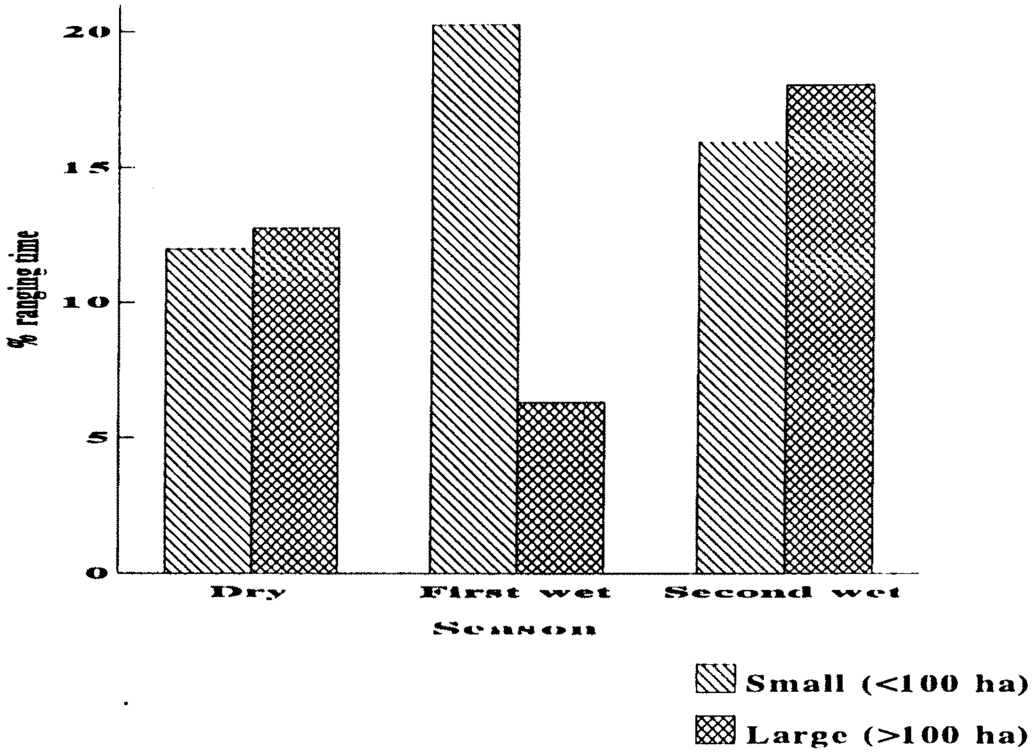
feeding (moving between trees in same area) and while searching for major food trees. Ranging did not occur continuously and was an infrequent activity. There was no major differences among the fragments in the time spent ranging, except in first wet season when it was greater in the small fragments (20.17%) than the large fragment (6.27%, M-W U=1, P=0.05, Figure 4.9a).

As expected from the time spent ranging, Nilgiri langurs did not travel much compared to the lion-tailed macaque (Table 4.7). Travel occurred mostly immediately before feeding activity. In the small fragments langur moved often into the surrounding plantations (where *Erythrina subumbrans* had been planted as shade for coffee plantation) for feeding. The day range length varied from 112 m to 460 m, and did not show any seasonal variation (Table 4.7). In the dry season it did not differ significantly among the fragments (K-W χ^2=7.17, P=0.06), even though it was greater in the small fragments (344 m), than in the larger fragments (295.5 m, M-W U=27.5, P=0.15). In the first wet season it was significantly greater in the small fragment than the large fragment (M-W U=1, P=0.046, Figure 4.9b). There were no major difference among the fragments in the second wet season (K-W χ^2=2.8, P=0.07), even between the larger and small fragments (M-W U=22, P=0.27).

Resting

Compared to the lion-tailed macaque, the Nilgiri langur spent considerably more time on resting, the seasonal means ranging from 39.21% to 57.78% (Table 4.7). Langurs normally rested continuously for

(a) Ranging



(b) Day range length

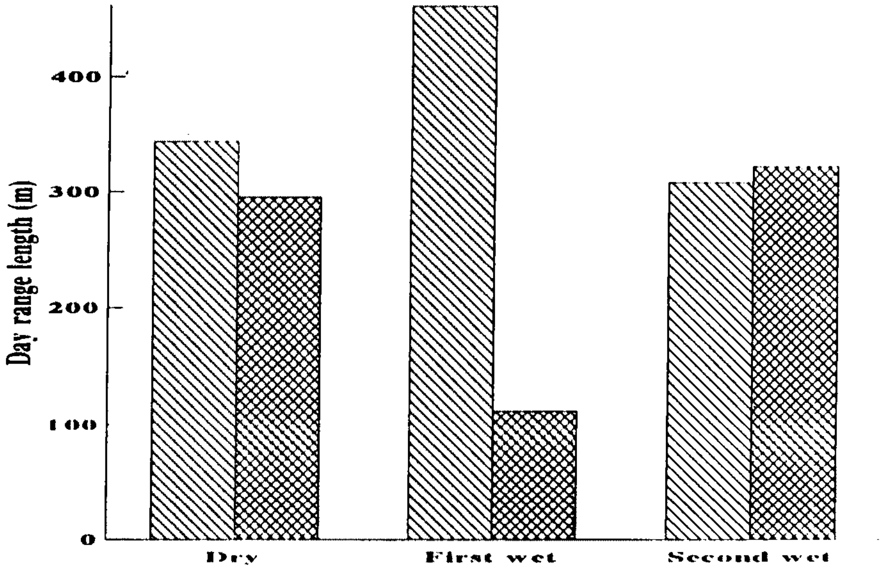


Figure 4.9 Percentage of time spent on ranging (a) and day range length (b) in the Nilgiri langur in the small and large fragments in three seasons.

2 to 4 hrs after the morning feeding bout. During resting the adults often slept or were involved in social activities, especially grooming, while the immatures often played. The time spent on resting was similar among the fragments in the dry season (between 51.39% to 56.12%), and in the second wet season (between 40.84% and 53.44%). Only in the first wet season a significantly greater (57.78%) time was spent in the larger fragments than small (39.32%, M-W U=0, *P*=0.04).

Other activities

Less than 5% of the time was spent on other activities. There was no significant difference among the fragments in the time spent on other activities, even when the fragments were grouped into small and large (Table 4.7).

4.4.2.2. *Feeding ecology*

Number of plant species used

Nilgiri langur fed on a variety of plant parts, that included sprouting leaves, young leaves, mature leaves, petioles, flowers, fruits, seeds and bark. A total of 55 plant species were used by all study groups together (Appendix II). Of these, 39 species were trees, 4 were shrubs, and 12 were lianas. The major food trees were *Mesua ferrea*, *Antidesma menasu*, *Gomphandra coriacea*, *Syzygium* spp, and *Myristica dactyloides*. In the small fragments (Korangumudi and Tata Estates) the exotic and non-native tree species *Maesopsis eminii*, *Spathodia campanulata* and *Erythrina subumbrans* formed major food species.

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Overall, the number of food plant species used in a day ranged from 4 to 16. Seasonal mean ranged from 5 to 14, the lowest and highest were during the second wet season, in Tata Estate and Andiparai shola fragments, respectively (Table 4.8). In the dry and second wet seasons, the number of food plant species used differed significantly among the fragments, being greater in the larger fragments (K-W χ^2=13.2, P=0.005 for dry season, K-W χ^2=11, P=0.012 for second wet season, Figure 4.10). More species were used in the larger fragment during the first wet season also, the difference however not being significant (M-W U=25, *P*=0.10).

Use of plant parts

Young leaves

Young leaves and fruits together formed more than 75% of the feeding time in all fragments in most of the observation sessions. A total of 40 species were used for feeding on young leaves, the major species being *Mesua ferrea, Gomphandra coriacea, Antidesma menasu, Symploccos cochinchinensis,* and *Syzygium laetum* in most fragments. In the small fragments even exotic and non-native species like *Maesopsis eminii* and *Erythrina subumbrans* also formed major food species. The seasonal mean time spent feeding on young leaves (out of total feeding time) was highest (73.69%) and lowest (27.30%) in the second wet season (Table 4.8). In the dry season it varied from 41.69% to 73.54% in Akkamalai shola and Korangumudi Estate fragments respectively, but not significantly so (K-W χ^2=4.16, *P*=0.24), and there was no significant difference between the small (<100 ha) and large fragments (M-W U=1, *P*=0.12, Figure 4.11a). During

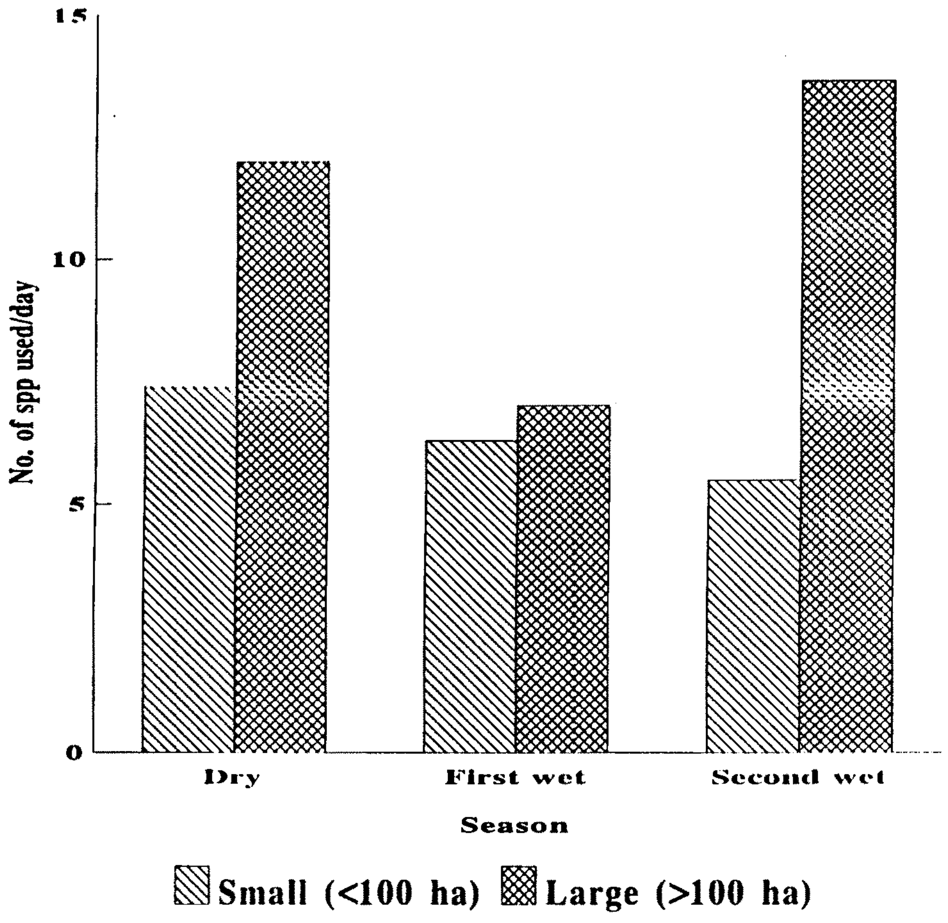


Figure 4.10 The mean number of food plants species used per day by Nilgiri langur in small and large fragments in three seasons.

Table 4.8. Percentage of time spent on young leaves, mature leaves, flowers and fruits out of total feeding time and the mean number of plant food species used in a day by the Nilgiri langur groups in four forest fragments in three seasons.

Season	Fragment	% young leaves	% mature leaves	% flower	% fruits	No.of plant spp used/day
Dry (Jan-Apr)	Tata	58.16	1.00	5.92	34.90	6.00
	Korangumudi	73.54	0.40	13.13	12.91	8.80
	Andiparai	54.42	0.52	8.38	36.68	12.00
	Akkamalai	41.69	1.37	7.26	49.80	12.00
Ist wet (May-Aug)	Korangumudi	27.92	22.98	0.96	48.13	6.30
	Akkamalai	36.29	15.73	5.74	42.23	7.00
IInd wet (Sep-Dec)	Tata	27.30	17.89	22.40	29.44	5.00
	Korangumudi	41.71	11.80	9.20	39.89	6.00
	Andiparai	47.56	7.73	7.11	37.61	14.00
	Akkamalai	73.69	12.92	9.67	3.72	13.20

the first wet season also it did not differ between the large and small fragments (M-W U=4, P=0.12). In the second wet season it differed significantly among fragments (K-W χ^2=8.18, P=0.043) and was significantly higher (60.63%) in the larger fragments than in the smaller fragments (34.51%, M-W U=3, P=0.04).

Mature leaves

Generally less time was spent feeding on mature leaves (Table 4.8). A total of 11 species were used for feeding on mature leaves, the major species being *Gomphandra coriacea, Macaranga peltata, Syzygium laetum* and *Erythrina subumbrans.* During the first wet season it was a major component of the diet in both the fragments, not differing significantly among themselves (M-W U=3, *P*=0.51). In the second wet season it varied from 7.73% to 17.89%, the highest was in a small fragment and the lowest in a large fragment. It did not differ significantly between the large (>100 ha) and small (<100 ha) fragments (M-W U=23, *P*=0.56, Figure 4.11b). In the dry season, only less than 1.50% of the feeding time was spent on mature leaves in all fragments (Table 4.8). Over all seasons, mature leaves consumption was higher (10.8%) in the small and degraded fragments than the large and undisturbed fragments (7.65%), but the difference was not statistically significant (M=W U=194, *P*=0.60).

Flowers

Flowers of 19 species were eaten by the Nilgiri langur, *Mesua ferrea, Symplocos cochinchinensis, Cullinea exarillata, Erythrina subumbrans* and *Spathodia campanulata* being the major species. Flowers formed less than 10% of the diet in eight of the ten observation sessions (Table 4.8). In the dry season, it was greater (9.53%) in the small fragments (<100 ha) than large (7.82%) but not significantly so (M-W U=26, *P*=0.12, Figure 4.11c), while in the first wet season it was significantly higher (5.74%) in the large fragment than small (0.96%, M-W U=1, *P*=0.04). During the second wet season, the proportion of flowers in the diet was higher (14.85%) in the small fragments than in the large fragments (8.39%), the difference however not being significant (M-W U=15, *P*=0.13).

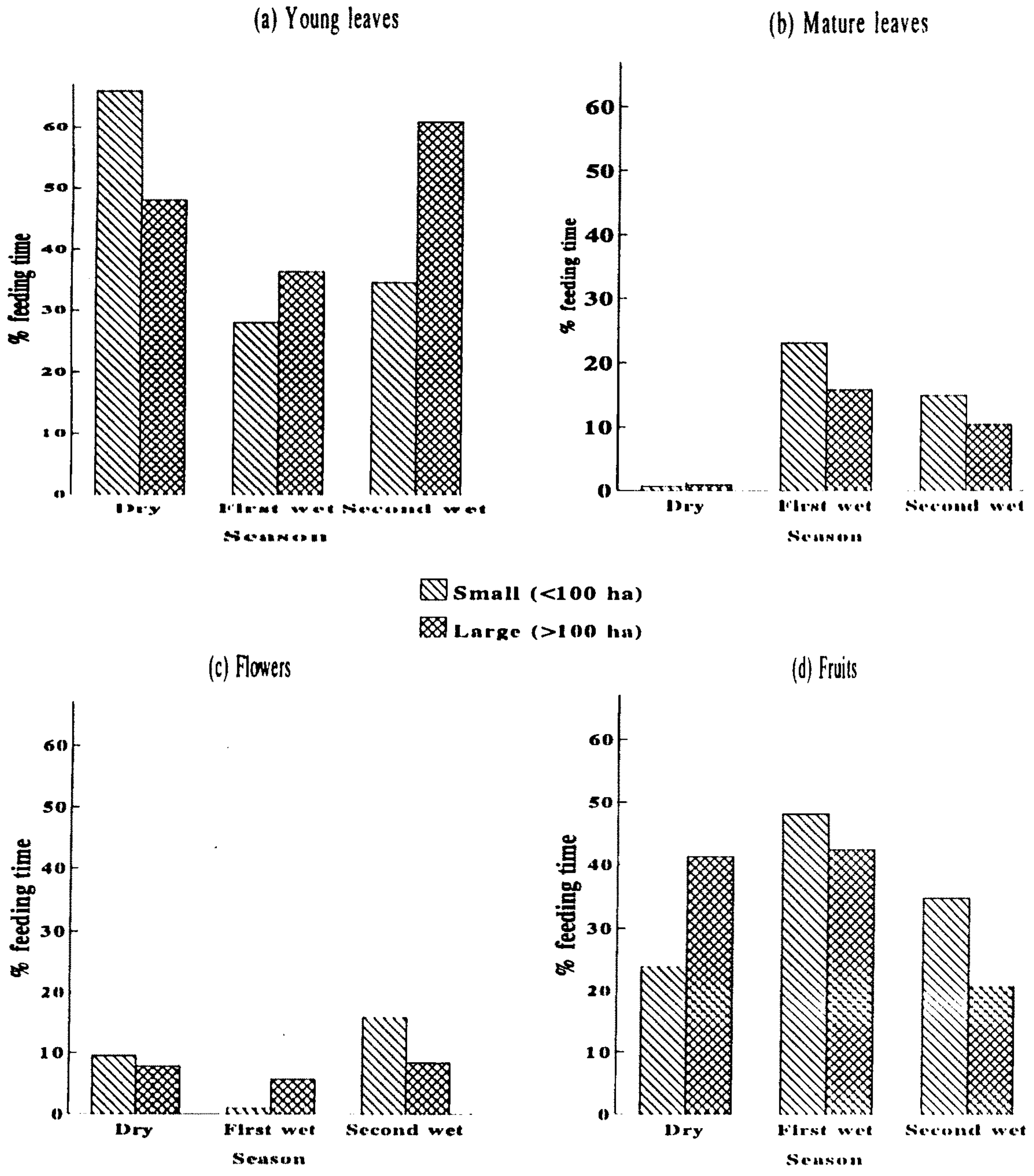


Figure 4.11 Percentage of time spent feeding on young leaves (a), mature leaves (b), flowers (c) and fruits (d) out of total feeding time by the Nilgiri langur in small and large fragments in three seasons.

Fruits

A total of 10 species were used for feeding on fruits and seeds, which formed more than 30% of the diet in eight observation sessions (Table 4.8). Most of the fruits eaten were unripe (*Macaranga peltata, Canarium strictum, Artocarpus heterophyllus* and *Myristica dactyloides*). A few were ripe when eaten *e.g. Symplocos cochinchinensis* and *Glochidion bourdillonii*. The Nilgiri langur fed on even the dry seeds of *Cullinea exarillata* during second wet season. Feeding time on fruits differed among the fragments in the dry season from 12.91% to 49.80%, and was higher (40.29%) in the larger fragments (>100 ha) than the small fragments (23.9%) but not significantly so (M-W U=24, *P*=0.086, Figure 4.11d). In the first wet season it was a major food item in both the fragments. In the second wet season, it was very low in Akkamalai shola (3.72%) and more than about 30% in the other fragments. There was no significant difference between large and small fragments (M-W U=15, *P*=0.13).

Abundance of food plants

A total of 500 trees of 20 species were monitored for changes in the abundance of the young leaves, mature leaves, flowers and fruits. The abundances are expressed as percentages of trees with young leaves, mature leaves, flowers, and fruits (Table 4.9). As expected the abundance of trees with mature leaves did not vary much with the seasons or among the fragments. The abundance of trees with young leaves was highest during the late dry season (after the pre-monsoon showers), and lowest during the first wet season. The abundance of trees with flowers was

Table 4.9. Percent of trees with young leaves, mature leaves, flowers and fruits out of total monitored food trees (500 trees of 20 species in each season) of Nilgiri langur.

Season	Fragment	% with young leaves	% with mature leaves	% with flowers	% with fruits/seeds
Dry	Tata	35.50	64.50	17.78	20.00
(Jan-Apr)	Korangumudi	43.60	56.40	11.60	39.10
	Andiparai	23.12	76.91	10.00	38.89
	Akkamalai	35.83	64.20	12.20	46.34
Ist wet (May-Aug)	Korangumudi	11.70	88.30	19.10	32.70
	Akkamalai	10.40	89.60	15.38	50.00
IInd wet (Sep-Dec)	Tata	17.50	82.51	22.22	32.35
	Korangumudi	19.20	80.80	32.25	49.54
	Andiparai	26.21	73.82	12.50	28.12
	Akkamalai	13.00	87.00	15.15	27.27

highest during the second wet season. Trees with fruits were more abundant during the late summer and the first wet season. It should however be noted that this variation in the abundance of trees with different phenological stages, is only with reference to food plants of the Nilgiri langur. The time spent (the seasonal mean time) on young leaves was only weakly correlated with the abundance of young leaves (r_s=0.45, n=10, *P*>0.05) and fruits (r_s=-0.37, n-10, *P*>0.05). But feeding on mature leaves was significantly and negatively correlated with the abundance of young leaves (r_s=-0.85, n=10, P<0.05). Overall, the phenological data did not show major differences among the fragments (Table 4.9).

Thus, there were no striking and consistent differences among the fragments in the time spent on feeding by the Nilgiri langur on different plants parts. The total time spent feeding also did not vary much among the fragments. Relatively little time was spent on mature leaves and flowers in most of the observation sessions. Greater time was spent on fruits and less time on young leaves in the larger fragments in dry season, whereas the converse was true in the other two seasons.

4.4.3. Giant squirrel

4.4.3.1. *Time budget: Time spent on various activities*

Activity bouts

The activity of the giant squirrel began at dawn by moving out of the resting tree to search for food trees. Even though giant squirrels are nucivorous they also fed on a variety of other plant parts such as leaves, flowers, fruits, bark and resin. The duration of feeding bouts varied depending on the available food. When seeds were plenty, the bouts continued for more than two hours in the same tree, otherwise they moved about in search of food. There were often four major feeding bouts in a day between 0700 and 0930 hrs, 1100 and 1200 hrs, 1400 and 1530 hrs, and 1730 and 1830 hrs. The giant squirrel often took rest between two feeding bouts, when most of the social activities such as chasing, aggression and scent marking, and reproductive activities such as nest building occurred.

Feeding

Feeding was a major activity, with seasonal means for a fragment ranging from 19.85% to 42.05% (Table 4.10). Unlike the lion-tailed macaque and Nilgiri langur, the giant squirrel fed throughout the day with three to four feeding peaks.

Table 4.10. The percentage of day time spent on various activities and day range length in the giant squirrel in the four forest fragments in three seasons.

Season	Fragment	% feeding	% ranging	% resting	% other activities	Day range length (m)
Dry (Jan-Apr)	Tata	19.85	5.65	73.09	1.04	227.50
	Korangumudi	38.69	10.02	50.66	0.63	164.00
	Puthuthottam	36.87	8.42	47.39	7.27	316.30
	Akkamalai	40.88	5.04	52.69	1.66	160.00
Ist wet (May-Aug)	Puthuthottam	41.66	10.04	47.63	0.90	216.70
	Akkamalai	42.65	4.14	50.21	3.00	62.60
IInd wet (Sep-Dec)	Tata	37.11	6.77	53.31	0.79	151.00
	Korangumudi	29.68	9.25	59.75	1.29	196.30
	Puthuthottam	37.11	7.83	52.93	2.07	163.00
	Akkamalai	41.38	7.02	50.81	0.78	190.00

The time spent on feeding varied considerably among the fragments, from 19.85% to 40.88%, the variation being significant in the dry season (K-W χ^2=8.78, P=0.032) and nearly so in the second wet season (K-W χ^2=7.55, P=0.056). As a function of area, time spent feeding was greater in the larger fragments in all seasons (Figure 4.12), the difference

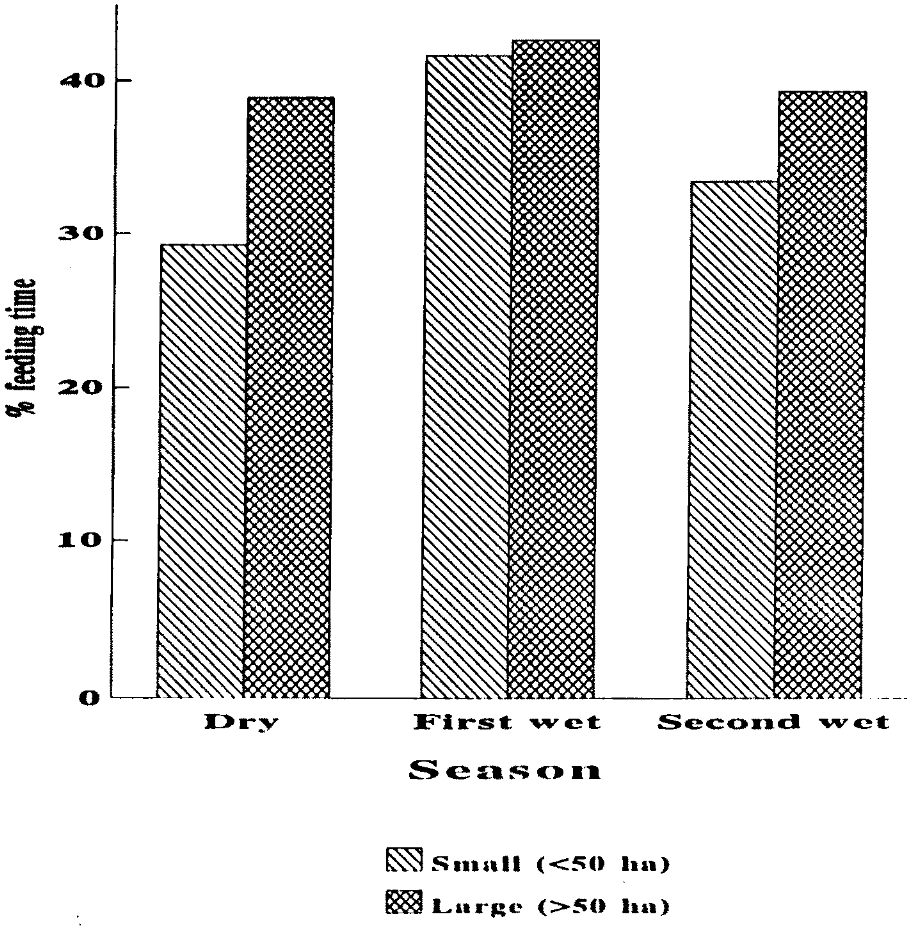


Figure 4.12 Percentage of time spent on feeding by the giant squirrel in small and large fragments in three seasons.

approaching significance in the dry season (M-W U=18, P=0.08) and second wet season (M-W U=22, P=0.10).

Ranging

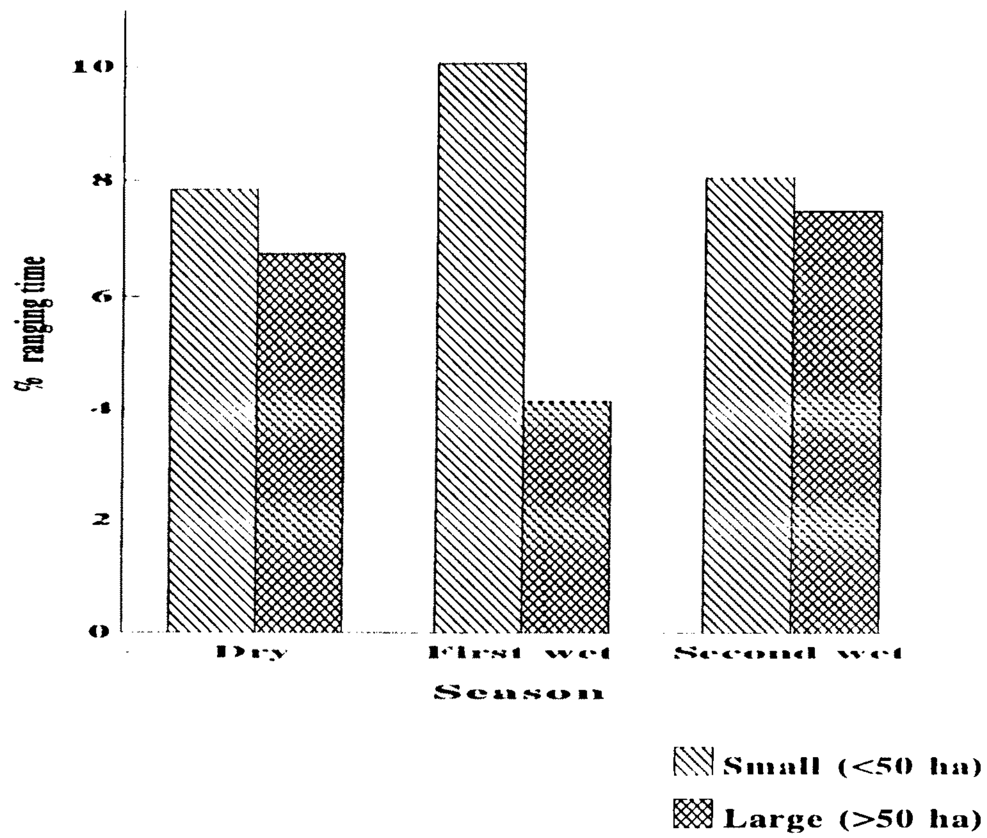
Giant squirrel spent only 4.14% to 10.04% of day time in ranging, mostly between food trees or while defending territory (Table 4.10). Even though ranging did not show any difference among the seasons, it varied within season among the fragments. In the dry season and second wet season there was no difference among the fragments (K-W χ^2=5.62, P=0.13 for dry season; K-W χ^2=5.8, P=0.15 for second wet season). In first wet season ranging time was higher (10.04%) in Puthuthottam than Akkamalai (4.14%), the difference being not significant (M-W U=1, P=0.08). Ranging was higher in small and degraded fragments than large and undisturbed fragments in all seasons (Figure 4.13a) but not significantly so even over all seasons (M-W U=180, P=0.63).

Day range length varied from 62.6 m to 316.3 m (Table 4.10). During the dry and second wet season it did not vary among fragments (K-W χ^2=7.04, P=0.6 for dry; χ^2=7.6, P=0.6 for second wet season). In the first wet season it was significantly greater (216.7 m) in the small fragment than in the large (62 m, M-W U=1, P=0.05, Figure 4.13b).

Resting

Like the Nilgiri langur, the giant squirrel also spent considerable time on resting, more than 45% of day time in all observation sessions (Table 4.10). The giant squirrel often took rest on a branch after a long feeding bout, mostly alone or sometimes with a breeding partner or with a

(a) Ranging



(b) Day range length

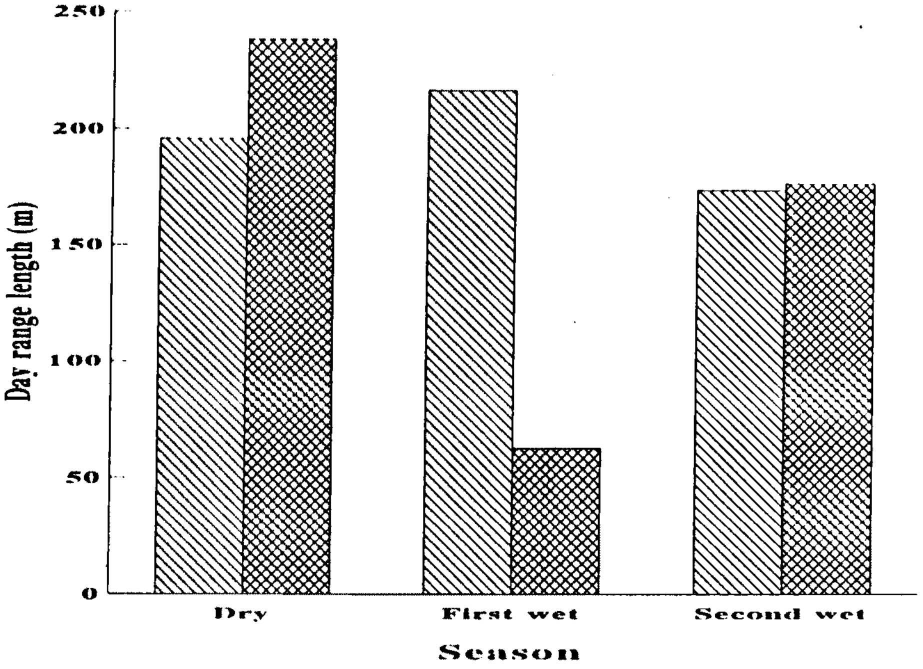


Figure 4.13 Percentage of time spent on ranging (a) and day range length (b) in the giant squirrel in small and large fragments in three seasons.

young one. Resting significantly varied in the dry season (K-W $\chi^2=9.07$, $P=0.028$), and was greater in the smaller fragments than large, but not significantly so (M-W U=21, $P=0.14$, Figure 4.14a). In the second wet season also resting was greater in the small fragment, though not significantly so (M-W U=4.4, $P=0.20$). In the first wet season resting time was similar in the small and large fragments. Overall, time spent on resting was higher (59.00%) in small fragment than large (50.52%, M-W U=107, $P=0.013$).

Other activities

Less than 5% of the time was spent in nine of the ten observation sessions on other activities that included social interactions and alarm behaviour. Even though the difference among the seasons were not significantly different (K-W, $\chi^2=4.21$, $P=0.23$ for dry; K-W, $\chi^2=2.13$, $P=0.54$ for second wet; M-W U=1, $P=0.08$ for first wet season) the time spent on other activities was higher in the large fragments in all seasons (Figure 4.14b).

4.4.3.2 *Feeding ecology*

Number of plant species used

A total of 34 species were used for feeding on seeds, fruits, flowers and leaves (Appendix III). The number of species used in a day was influenced by the availability of seeds; for example when *Grewia tiliifolia* was in fruit the giant squirrel fed only on their seeds not moving out of the tree. The seasonal means did not vary much among the fragments, ranging

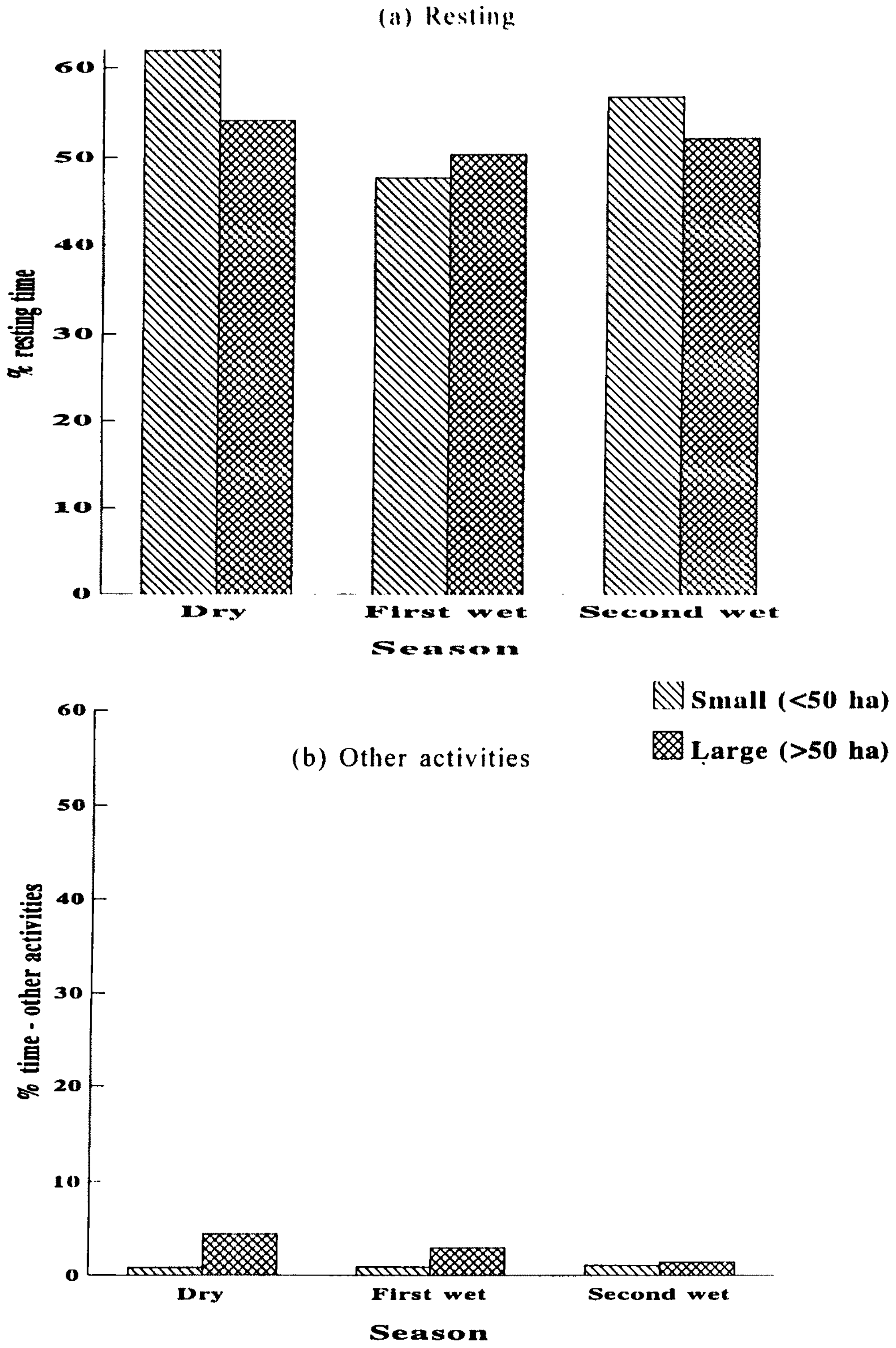


Figure 4.14 Percentage of time spent on resting (a) and other activities (b) by the giant squirrel in small and large fragments in three seasons.

only from 3.25 to 7.25, mostly 3 or 4 species (Table 4.11). The highest difference was in the dry season when squirrels in the larger fragments used more species (6.37/day) than those in the small fragments (4.1/day), the difference being significant (M-W U=16.5, *P*=0.03). In the other two seasons also more species were used in the larger fragments, but the differences were not significant (M-W U=3.5, *P*=0.10 for first wet season; U=3, *P*=0.38 for second wet season, Figure 4.15).

Use of plant parts

Leaves

Leaves, including petioles, were the second major constituent of the diet, forming above 15% of the feeding time in seven observation sessions (Table 4.11). A total of 20 species were used for feeding on leaves. The leaves were eaten mostly when fruits and seeds were not available. The major species used for feeding on leaves were *Canarium strictum, Bischofia javanica, Ficus* spp, *Mesua ferrea* and *Artocarpus heterophyllus*. In the small fragments giant squirrel fed on exotic and non-native species such as *Erythrina subumbrans* and *Eucalyptus* spp. The seasonal mean time spent feeding on leaves in a fragment varied from 1.87 to 46.85% of total feeding time (Table 4.11). Overall, squirrels in the small and degraded fragments spent more time feeding on leaves than in large fragments (Figure 4.16a). In the dry season it was greater in the small fragments (23.00%) than in the large fragments (13.01%) the difference however being not significant (M-W U=27, *P*=0.24). In the second wet season it was significantly higher in the small fragments (31.45%) than large (10.62%, M-W U=16, *P*=0.03).

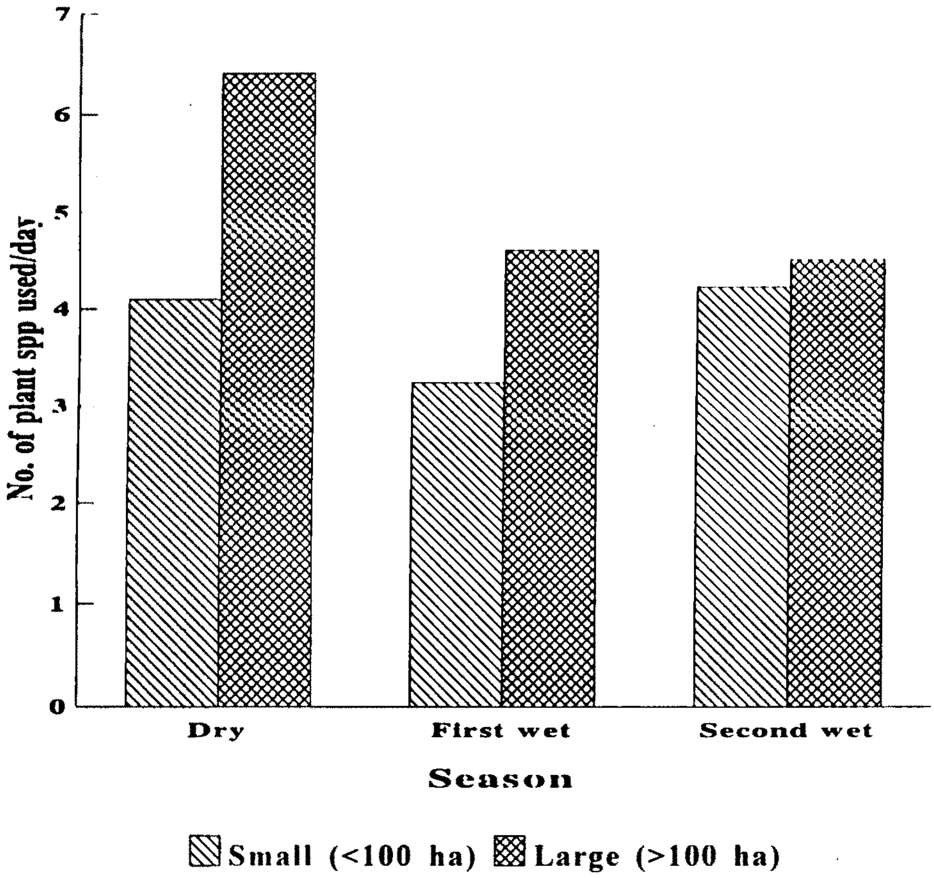


Figure 4.15 The mean number of food plant species used by the giant squirrel in small and large fragments in three seasons.

There was no difference between large and small fragments during the first wet season (M-W U=24, P=0.20).

Table 4.11. The mean number of plant food species used in a day and percentage of time spent on leaves, flowers, fruits and seeds out of total feeding time by the giant squirrel in four forest fragments in three seasons.

Season	Fragment	plant spp used/day	% leaves	% flowers	% fruits	% seeds	% others
Dry (Jan-Apr)	Tata	4.20	11.18	1.26	11.86	71.44	0.00
	Korangumudi	4.00	33.02	3.46	23.18	40.32	0.00
	Puthuthottam	7.25	20.20	0.00	21.30	50.99	7.51
	Akkamalai	5.50	6.10	0.00	5.15	88.28	0.40
Ist wet (May-Aug)	Puthuthottam	3.25	27.50	0.00	0.00	72.27	0.00
	Akkamalai	4.60	30.86	1.50	5.26	62.38	0.00
IInd wet (Sep-Dec)	Tata	4.20	19.13	64.92	5.49	10.58	0.00
	Korangumudi	4.25	46.85	37.73	1.58	13.90	0.00
	Puthuthottam	4.00	17.63	23.34	54.65	2.70	1.78
	Akkamalai	5.00	1.87	27.78	14.50	55.85	0.00

Flowers

Only six species were used for feeding on flowers. Except in the second wet season, flowers did not contribute significantly to the diet of squirrels (Table 4.11). In the second wet season the flowers eaten were mostly from *Cullinea exarillata, Bombax malabaricum* and *Mesua ferrea.* In this season, squirrels in the smaller fragments spent significantly more (52.70%) time on flowers than in larger fragments (25.31%, M-W U=17.5, P=0.04, Figure 4.16b).

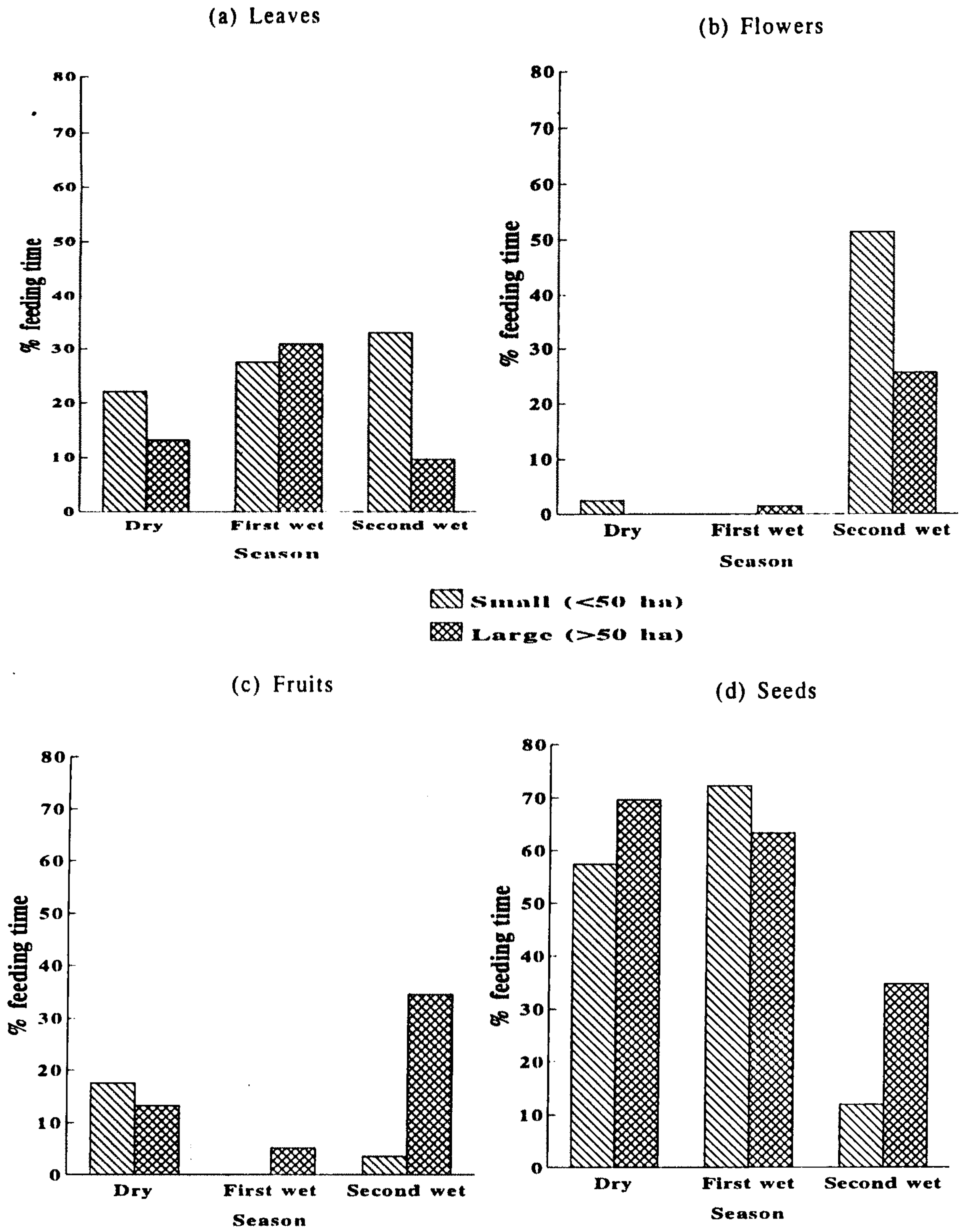


Figure 4.16 Percentage of time spent on leaves (a), flowers (b), fruits (c) and seeds (d) in the small and large fragments by the giant squirrel in three seasons (Dry: Jan-Apr; Ist wet: May-Aug; IInd wet: Sep-Dec).

Fruits

A total of 14 species were used for feeding on fruits. Most of the fruits were small in size, the major species being *Ficus* spp, *Schleichera oleosa, Macaranga peltata* and *Glochidion bourdillonii,* which were eaten full. Fruits formed more than 10% of the diet in five of 10 observation sessions. In the dry season, it varied considerably among the fragments from 5.15% to 23.18%, (K-W χ^2=2.8, P=0.41) but there was no significant difference between large (13.22%) and small fragments (17.52%, M-W U=40, P=0.90, Figure 4.16c). In the first wet season, fruits were not eaten in the small fragment and formed a small part of the diet in the large fragment (5.22%). In the second wet season, it differed significantly among fragments (K-W χ^2=9.85, P=0.01) and was greater (36.80%) in the larger fragments than in the smaller (4.12%, M-W U=12, P=0.008).

Seeds

Seeds were the major part of the diet, forming more than 40% of the time spent feeding in seven of the ten observation sessions. Seeds of 21 species were eaten, the major species were *Grewia tiliifolia, Schleichera oleosa, Mesua ferrea, Artocarpus heterophyllus* and *Myristica dactyloides*. During the dry season the consumption of seeds which constituted most of the diet, varied significantly among the fragments (K-W χ^2=8.81, P=0.03). It was greater in the large fragments (69.63%) than in the smaller ones (57.38%) but not significantly so (M-W U=30, P=0.37, Figure 4.16d). In the first wet season also there were no significant difference between the two fragments (M-W U=8, P=0.62). In the second wet season seeds were eaten more in the large fragments (25.22%) than in the smaller ones (11.83%), the difference again not being statistically significant (M-W U=31, *P*=0.35).

There was thus no consistent pattern in the time spent on different plant parts by the giant squirrel in the different fragments. The second wet season seemed to be the lean season for fruits and seeds, when they formed only 39.78% of the feeding time (over all fragments), compared to 79.10% for dry season and 70.71% for the first wet season. During this season fruits and seeds formed 63.81% of the feeding time of squirrels in the larger fragments, compared to only 15.82% in the smaller fragments. Leaves and flowers formed a greater part of the diet in this season in the smaller fragments. In the first wet season there was no major difference between fragments in feeding on different plant parts. The time spent on various plant parts was not correlated with the abundance of trees with the respective plant parts (see Table 4.9, for abundance of plant parts).

4.5. DISCUSSION

Surprisingly there were no consistent differences in any of the three species in the time that they spent on feeding, ranging, resting, and other activities and in day range length, between the four fragments in which they were studied. The major difference in the lion-tailed macaque was a reduction in time spent feeding and resting, and an increase in ranging in the first wet season between large less degraded fragments. The day range length was however greater in the larger and less disturbed fragments. In the Nilgiri langur, the major difference was an increase in ranging time and distance travelled, and a reduction in resting time in the smaller and more disturbed fragments. In the giant squirrel the major differences was an increase in day range length and ranging time in smaller fragments, especially in the first wet season.

The most evident change in the feeding ecology of all species was a reduction in the number of plant species that they used each day and a reduction in the use of lianas and an increase in the use of shrubs or understorey plants. In the lion-tailed macaque, there was a decline in the proportion of insects in the diet in the small fragments in the dry and second wet seasons. There was also a decline in the time spent on fruits and seeds and an increase in the time spent on flowers in the dry season. In the giant squirrel, the major difference was a reduction in time spent on leaves in the small fragments.

Only very few studies have examined the changes in the time budget and ecology of animals, especially arboreal mammals, due to habitat fragmentation (Menon 1993; Menon and Poirier 1996). Several studies have examined these changes in arboreal mammals due to habitat disturbances, especially logging. These studies show that habitat disturbance have different impacts on the time budget and feeding, depending on the nature of changes and ecology of the species. In a logged forest in Malaysia, Southwick and Cadigan (1972) found that changes in primate community favoured cercopithecines over colobines and lesser apes. However, several studies have shown that folivores that feed more on regenerating or colonising species in primary forest often survive better in the logged or secondary forest *e.g. Gorilla gorilla* (Goodall 1977), black and white colobines *Colubus guereza* (Oates 1977) and Phayre's leaf monkey *Presbytis phayrei* (Gupta and Kumar 1994). The more terrestrial and wide ranging frugivore primates such as pig-tailed macaques are less affected than the more arboreal and less ranging frugivores such as gibbons and giant squirrels (Johns 1983; Johns and Skorupa 1987). However, Heydon and Bulloh (1997) found that two species of mouse deer in logged forest in Borneo, were more adversely affected than arboreal frugivores. Studies on animals in forest fragments show that those which are able to use secondary vegetation around the fragments especially for feeding are better able to survive (Laurance 1990, 1991a, 1991b, 1994, 1996; Bierregaard *et al.* 1992; Mills 1995).

In general, the changes in the availability of food resources is a major determinant of the changes in time budget and feeding ecology. Greater abundance of colonisers and young foliage following disturbance often favour folivorous mammals. The reduction in fruit abundance that follow physical damage to trees and a lower plant species richness adversely affect frugivores, especially those that are highly arboreal or sedentary (Johns and Skorupa 1987). The presence of keystone species such as *Ficus* may be a critical factor affecting the survival of frugivores (Heydon and Bulloh 1997). The importance of *Ficus* as keystone species during scarcity (Terborgh 1983, 1986; Borges 1993), may be limited only to wide ranging species but not to sedentary species (Gautier-Hion and Michloud 1989), such as giant squirrels (Borges 1993). This is due to the low density and spatial clumping of many of the *Ficus* species (Borges 1993).

There was no substantial differences on the time budget of the three species, between the forest fragments, despite considerable difference in fragment area and levels of disturbances. This was due to several reasons. The potential reduction in food abundances in fragments (due to less area, lower tree density, basal area and species richness) was to a great extent compensated by changes in vegetation. The vegetation that immediately surrounded the fragments, consisted of coffee plantations and orchards of Mangos, Jack fruits, guava, *Maesopsis eminii*, and so on, most of which were of considerable food value to the arboreal mammals. All three species spent considerable time feeding on these species. Moreover, colonisers in disturbed forest such as *Macaranga peltata* and *Ficus hispida* and even weeds such as *Lantana camera* were also used extensively by all three species. Some of the important species, which are aseasonal in fruiting (*e.g. Ficus* spp), providing flowers and fruits over long periods of time (*e.g. Cullinea exarillata*) have been left intact in fragments since these were not of commercial importance. Hence, compared to contiguous undisturbed forest, small fragments had a greater proportion of standing food trees. Another factor that probably compensated for reduction of food abundance was increased productivity of young foliage and fruits in the remaining trees. This is due to increased crown volume as well as greater penetration of solar radiation as a result of greater canopy opening. Crowns of trees in disturbed forests were often spherical or cylindrical rather than hemi-spherical as in undisturbed forests. This was especially true for *Ficus* spp and *Cullinea exarillata* the two keystone plant taxa. Yet another factor was that the animals often fed on fruits at an earlier stage of maturity in small fragments compared to large fragments. A typical example was feeding on *Artocarpus heterophyllus* by the lion-tailed macaque. In undisturbed and contiguous fragments, fruits of this species were often eaten only when they were very big, whereas in small fragments these were eaten when the fruits were relatively very small.

Thus, the vegetation around the matrix and the colonisers and weeds provide important food species. Key stone species such as *Ficus* spp and *Cullinea exarillata* that have been left behind in fragments, greater productivity of remaining trees due to increased penetration of solar radiation also increased food abundance. Moreover, the animal might also feed on fruits at an earlier phenological stage. It is due to a combination of these factors that there were no major changes in the time budget in the species, between large and contiguous forest and small disturbed forests.

Despite the absence of major differences in time budget, especially time spent feeding, it is very likely that the diet composition might have been adversely affected in the lion-tailed macaque and the Nilgiri langur. The lion-tailed macaque spent significantly less time feeding on invertebrates out of total feeding time in the smaller and disturbed fragments. Since fruits and seeds contain very little protein, invertebrates are an important source of protein to frugivorous mammals (Redford *et al.* 1984; Kumar 1987). There are two reasons for a reduction in the time spent feeding on invertebrates. First, a decline in quality of plant foods (*e.g.* by eating fruits at an earlier phenological stage) may have forced them to feed more on plant foods to meet energy requirements. Secondly, there may have been a reduction in invertebrates availability in the small disturbed fragments. This reduction can result from the reduction in plant species diversity, and canopy foliage as indicated by canopy cover. Green foliage is the most important source of invertebrates for the lion-tailed macaque (Kumar 1987). Moreover greater penetration of solar radiation can also alter insect abundance in the canopy (Kapos 1989). Malcom (1991) found that insect abundance was greater in the canopy of contiguous forest, while fragments had greater abundance of understorey insects. In undisturbed forest Kumar (1987) found that the juveniles spent significantly more time feeding on insects. Thus, the decline in invertebrates in the diet of lion-tailed macaque could adversely affect immature growth rate and survival.

The fruits and seeds eaten by frugivores do not vary much in their composition, mostly containing simple carbohydrates, lipids and very little protein (Milton 1981). In contrast, leaves of different species and phenological stages in tropical rain forest vary considerably in their fibre content and the occurrence and abundance of several secondary compounds. Arboreal folivores have different tolerance levels to different secondary compounds. One of their feeding strategies is to avoid the consumption of any secondary compound beyond its tolerance level, by feeding on a wider variety of plant species (Hladik 1978; Waterman 1984). The number of plant species in the diet or dietary diversity is thus more important to arboreal folivores, than to frugivores. Fruits and secondary compounds are already known to be important in diet selection in Nilgiri langur (Oates *et al.* 1980). Thus, the drastic reduction in number of plant species fed on by Nilgiri langur in the smaller and more degraded forests can be expected to lead to a reduction in diet quality, due to various reasons. These could include greater energy expenditure in detoxification of secondary compounds consumed in excess of tolerance levels, toxicity, and the unavailability of particular amino acids.

The giant squirrel is apparently the least affected with no changes in the diet composition or time budget, except for increased ranging. This may be partly because of its smaller body size hence lower resource needs (Johns and Skorupa 1987), and greater ecological amplitude of the species that makes it much more adaptable to disturbance. Studies elsewhere have reported greater ranging and home range among Eurasian red squirrel (Wauters *et al.* 1994) and greater foraging time in chipmunk (Mahan 1996) as a result of fragmentation. Borges (1993) suggested that keystone species such as *Ficus* that are rare and clumped in occurrence, may not be of much importance to giant squirrel which is sedentary. This is unlikely to be true in the case of forest fragments, in which giant squirrel had a greater day range length and also often moved into the vegetation around the fragments to feed.

4.6. SUMMARY

1. The objective in this Chapter was to examine the changes in the activity pattern and feeding ecology of the lion-tailed macaque, Nilgiri langur and giant squirrel with reference to area and vegetation status of fragments.

2. Data on activity pattern and feeding ecology were collected for the three species in four fragments for one year (January 1995 to December 1995). Data were collected for five days in each fragment in each season. I used group scan method with 10 minutes interval for the lion-tailed macaque and Nilgiri langur, and focal sampling for the giant squirrel with two minutes interval.

3. Overall there was no consistent difference among the three species in the time that they spent on various activities between the four fragments. In the lion-tailed macaque, the major difference was a reduction in time spent in feeding and resting and increased ranging in the small and more degraded fragment during the first wet season. In the Nilgiri langur, the major difference was an increase in ranging time and distance travelled and a reduction in resting in the smaller and more disturbed fragments. In the giant squirrel, the major difference was increased day range length and ranging time in smaller fragments in the first wet season.

4. The major impact on feeding ecology of the three species was a reduction in number of plant species used per day, and a reduction in the use of lianas in the smaller and disturbed fragments. In the lion-tailed macaque, there was a reduction in the proportion of insects in the diet in the small fragments in the dry and second wet seasons, and also a reduction in the proportion of fruits and seeds in the dry season. In the Nilgiri langur there was no major consistent changes in the feeding ecology. There was an increase in time spent on mature leaves and

fruits, and decrease in time spent on young leaves in the small fragments in the first and second wet seasons. But, there was also decrease in time spent on fruits and increase in time spent on young leaves in the smaller fragments in the dry season. In the giant squirrel, the major difference was a reduction in time spent on leaves in the large fragments in the dry and second wet seasons.

5. Even though there were considerable differences in fragment area and levels of degradation there was no significant difference in the time budget of the three species. This may be because of, 1) reduction of food abundance was compensated by changes in vegetation; 2) the vegetation that immediately surrounded the fragments were of considerable food value to the arboreal mammals; and 3) the keystone species such as *Ficus* spp and *Cullinea exarillata* that have been left behind in fragments. Greater productivity of remaining trees due to increase penetration of solar radiation also increases food abundance. It is due to a combination of these factors that those were no major changes in the time budget between large less disturbed and, small more disturbed fragments.
6. Among the three arboreal mammals the giant squirrel is the least affected partly because of its small body size hence lower resource needs and also because of the greater ecological amplitude of the species that makes it much more adaptable to habitat disturbance.

5. DEMOGRAPHIC STUDIES

5.1. INTRODUCTION

Ecological and behavioral consequences form the first phase of the interaction between a species and fragmentation of its habitat. These include changes in the activity pattern and feeding ecology (which were discussed in Chapter 4), changes in predation pressure, inter-specific competition, and host-parasite relationships. The demographic consequences form the final response of the species to habitat fragmentation, leading either to its decline and extinction or to its survival. While some of the demographic consequences are intricately related to the ecological consequences, others are inherent properties of small populations (Soulé 1986; Quinn and Hastings 1987).

Only a few studies have reported demographic consequences, either qualitatively or quantitatively, of ecological changes due to habitat fragmentation. Several studies have reported demographic consequences of habitat degradation or severe resource depression, that may be similar to the consequences of habitat fragmentation. Severe food shortage due to drought caused greater mortality among the immatures followed by a reduction in birth rate in toque macaques, *Macaca sinica* in Sri Lanka (Dittus 1979). Similarly, stoppage of provisioning caused a drastic reduction in birth rate and to a lesser extent in juvenile survival in the Japanese macaques, *Macaca fuscata* (Sugiyama and Oshawa 1982). A shortage of food caused a reduction in population of vervet monkeys (*Cercopithecus aethiops*) in Amboseli, Kenya, through increased mortality

(Struhsaker 1976). A reduction in birth rate and increase in juvenile mortality following resource crunch has been predicted by models on the evolution of group living (*e.g.* Wittenberger 1980; van Schaik 1983). Following selective logging, several primates suffer from poor nutrition that affect their maturation, mortality and reproduction potential (Johns and Skorupa 1987; Barton *et al.* 1992; Decker 1994; Menon and Poirier 1996). Greater mortality from loss of canopy contiguity which increased vulnerability to predation, and falls from trees, especially of infants and juveniles has also been reported (Johns 1985; Johns and Skorupa 1987; Menon and Poirier 1996). Vulnerability to predation may also be associated with a change in the predator community following habitat disturbance (Andrén 1992; Laurance 1994). Pathogens and parasites can pose severe threats to population in fragments due to reduced nutrition level, greater environmental stress, and introduced parasites and pathogens (McCallum and Dobson 1995; Combes 1996; Holmes 1996).

A demographic consequence inherent to fragmented small populations is demographic stochasticity. As local population becomes small, the variation inherent in the discrete nature of births and deaths can lead to extinction (Soulé 1986; Quinn and Hastings 1987). This could lead to unfavourable or highly biased sex-ratio and age structure, causing loss of reproductive years, reduced birth rates, and high variation between years and populations in population size, births and deaths. Moreover, as population become fragmented, the mean number of alleles in sub-populations declines and mean homozygocity increases, the latter especially contributes to greater mortality and lower fertility (Soulé and Simberloff 1986).

One factor that can substantially modify the above demographic consequences is dispersal between fragments. Dispersal can increase the persistence and stability of fragmented populations as a metapopulation, through increased survival, recolonisation, and genetic exchange (Levin 1969; Hanski and Gilpin 1991; Arnold *et al.* 1993; Kozakiewicz 1993). The ability of animals to disperse or move between fragments depends on the presence of corridors that are consistent with the ecology of the species, especially diet, denning, arboreality and social systems (see Chapter 6). Several studies have reported species differences in their ability to disperse across man modified habitats; small mammals (Kozakiewicz 1985, 1993) arboreal marsupials (Laurance 1990, 1994; Downes *et al.* 1997), birds (Bierregaard *et al.* 1992; Wilson *et al.* 1994) and insects (Powell and Powell 1987; Klein 1989; Bierregaard *et al.* 1992; Hill 1995; Punttila 1996).

The dynamics of fragmented populations and metapopulation have been intensively modelled, especially in the context of population viability analysis. Most of these models incorporate demographic and environmental stochasticity, catastrophes, inbreeding, hunting, and dispersal between fragments and progressive decay in carrying capacity of the habitat (Lacy 1993). However, in the absence of field data on the relevant parameters, models remain to be validated. Dobson and Lyles (1989) estimated that primate populations under disturbance collapse over long periods of time, often 20-30 inter-birth intervals. Populations often become endangered when the survival of adult females falls below about 70% per inter-birth interval (*op.cit.*).

The important demographic consequences due to habitat fragmentation include reduced immature survival, birth rate, and altered and highly variable demographic parameters such as population size, growth rate and sex ratios. Species might differ in the extent to which these effects are modified by dispersal.

The objective of this Chapter is to examine the demographic consequences of population fragmentation in the lion-tailed macaque and Nilgiri langur. The parameters examined are group size, age/sex composition, birth rate and population growth rate, in relation to the various habitat parameters. An analysis of the giant squirrel could not be done because of difficulties in estimating demographic parameters.

5.2. STUDY AREAS

Data on demography of lion-tailed macaque was collected for 11 groups from eight forest fragments (Varagaliar, Akkamalai, Urulikkal, Andiparai, Puthuthottam, Pannimedu, Korangumudi and Tata estate). For the Nilgiri langur data was collected for eight groups from four fragments (Akkamalai, Andiparai, Korangumudi and Tata). A description of some of these fragments is given in the Chapter 4 (see Section 4.2), and that of rest of the fragments is given below.

5.2.1. Varagaliar

Isolated during 1930s, Varagaliar is one of the largest wet evergreen forest fragments in the Indira Gandhi Wildlife Sanctuary, and is located south of Topslip (Figure 2.1). It covers about 2,000 ha of relatively undisturbed forest, in an altitudinal range of 650 m to 850 m. This shola is mostly surrounded by teak plantations, except for a narrow corridor with another fragment (Kuruvampalli). Part of this fragment was selectively felled during 1930s. A tribal settlement (Kummatti) and a captive elephant camp are located on the edge of the fragment. This is one of the least disturbed areas of the Indira Gandhi Wildlife Sanctuary, with about 10 groups of lion-tailed macaque and several groups of Nilgiri langurs, and numerous giant squirrels.

5.2.2. Monampoly

It is a large fragment (>1000 ha), located in the Valparai range, west of Valparai Town and within the limit of the Sanctuary. This was isolated in the 1920s, and is surrounded by coffee and tea plantations. It has a narrow connectivity with another evergreen fragment (Shekkalmudi shola) on its western side. The altitude ranges from 650 m to 1220 m. There is a labour settlement at the edge of the fragment. This is a relatively undisturbed fragment, with at least one group of lion-tailed macaque and several groups of Nilgiri langur, and many giant squirrels.

5.2.3. Pannimedu

It is a small (<50 ha) and privately owned fragment, located south-west of Valparai Town. This was formed in the 1920s, and is completely isolated from other forests and surrounded on three sides by the Sholaiyar Reservoir and on one side by tea plantation. It is relatively less disturbed compared to other small fragments. All arboreal mammals exist here and even the large mammals such as elephant and gaur often visit this fragment.

5.3. METHODS

The demographic parameters estimated for the lion-tailed macaque and Nilgiri langur were group size, age/sex composition, birth rate and growth rate of groups. The group size and age/sex composition were estimated during surveys conducted in eight fragments between March and May 1996. I attempted to get demographic data from as many groups and fragments as possible. It was often difficult to locate groups, especially in large fragments and when sighted groups were shy. Moreover, long periods of time were required to get accurate data on group composition because of poor visibility and wide group dispersal. Due to these reasons accurate data could be obtained only from 11 groups in eight fragments, including the four main study groups. The age/sex classification was based on a comparison with individuals of known age (approximately) in the main study groups (see section 4.2.1). The birth rate was estimated for each group as the number of infants (<1 year old) as a proportion of the adult females. For the main study groups the age/sex composition in May 1996 was used for analysis.

Unlike the lion-tailed macaque, the Nilgiri langur was relatively easy to locate given its higher density. However, obtaining accurate data on age/sex composition was much more difficult because most of the groups were very shy and fled or hid themselves among foliage. Moreover, in the absence of striking sexual dimorphism, sex identifications of even adults was difficult. Demographic data on the Nilgiri langur is therefore limited, and come from the main study groups. For the giant squirrel, the infants were often not visible since they were mostly in the nests. Individuals outside the nest were not easily classified according to age and sex, due to a lack of sexual dimorphism. Therefore, no data is available on age/sex and birth rate of giant squirrel, which is hence not considered for analysis in this chapter. The following age/sex data were recorded for lion-tailed macaque and Nilgiri langur

1. Infants: up to 1 year old.
2. Juveniles: further classified into four categories, J1 to J4 from 1 to 4 years of age, respectively.
3. Sub-adults: for lion-tailed macaque only; 5 years to first birth at 6.5 years for females; 5 years to about 8 years for males.
4. Adult females: females that have given birth at least once
5. Adult male: above 8 year of age.

The exponential growth rate of groups was calculated for the four main study groups of lion-tailed macaque and Nilgiri langur for one year (from March 1995 to Feb 1996), as $r=\ln(N_1/N_0)$, where N_0 is the group size in 1995, and N_1 is the group size in 1996. Data on area and habitat parameters were taken from Table 3.2.

5.4. RESULTS

5.4.1. Lion-tailed macaque

5.4.1.1. *Group size*

Group size and composition were recorded for 11 groups from 8 forest fragments. Both the largest (36 animals) and the smallest (8 animals) groups were from medium sized fragments (Table 5.1), in Puthuthottam and Pannimedu, respectively. There was no correlation between group size and fragment area (Table 5.2).

Table 5.1. Demographic parameters in 11 groups of lion-tailed macaques in eight forest fragments in Indira Gandhi Wildlife Sanctuary and nearby private forests.

Groups	Area (ha)	Group size	No. of adult male	% Af*	% Imm#	Imm/Af	Af/Am$	Birth rate
Varagaliar I	2500	14	1	42.86	50.00	1.17	6.00	0.50
Varagaliar II	2500	10	1	50.00	50.00	0.80	5.00	0.20
Varagaliar III	2500	13	1	38.40	53.00	1.40	5.00	0.60
Akkamalai	2000	11	1	36.36	54.54	1.50	4.00	0.75
Monampoly	1000	12	1	41.67	50.00	1.20	5.00	0.60
Andiparai	185	26	2	50.00	42.31	0.85	6.50	0.46
Puthuthottam-I	65	36	2	52.78	41.67	0.79	9.50	0.26
Puthuthottam II	65	11	2	36.36	45.45	1.25	2.00	0.50
Pannimedu	50	8	1	50.00	37.50	0.75	4.00	0.25
Korangumudi	35	21	2	52.38	38.09	0.73	5.50	0.27
Tata	24	15	2	46.67	40.00	0.86	3.50	0.14

* - Adult female; # - Immature; @ - Immature/Adults; $ - Adult female/Adult male.

The larger fragments (>100 ha) had an average group size of 14.3 animals (SE=2.40, n=6) while the smaller fragments (<100 ha) had an average of 18.2 animals (SE=4.95, n=5), the difference being close to significance level (M-W test U=12.5, P=0.06). The group size had weak negative correlations with tree density (r_s=-0.34 P=0.15), basal area (r_s=-0.28, P=0.12), and had weaker correlation with other habitat parameters (Table 5.2). There was a tendency for groups to become larger as fragment becomes smaller and disturbed. The group size also seemed to vary considerably as fragments become smaller, with some groups being very small and others being very large (Figure 5.1). In the large fragments (>100 ha) group size had a considerably lower coefficient of variation

Table 5.2. Spearman rank correlation coefficients between different demographic parameter of 11 groups of lion-tailed macaque and habitat parameters of the respective fragments (Probability values in parenthesis).

Parameters	Area	Tree density	Canopy height	Canopy cover	Basal area
Group size	-0.26 (*0.22*)	-0.34 (*0.15*)	0.04 (*0.46*)	0.19 (*0.08*)	-0.28 (*0.19*)
% adult females in the group	-0.36 (*0.12*)	-0.33 (*0.16*)	-0.23 (*0.24*)	-0.24 (*0.24*)	-0.47 (*0.07*)
% immatures in the group	0.86 (*0.01*)	0.77 (*0.01*)	0.59 (*0.03*)	0.46 (*0.08*)	0.60 (*0.03*)
Immature/adult female	0.44 (*0.09*)	0.35 (*0.15*)	0.32 (*0.17*)	0.46 (*0.08*)	0.57 (*0.04*)
Adult female/adult male	0.33 (*0.16*)	0.24 (*0.24*)	0.21 (*0.26*)	0.23 (*0.25*)	-0.07 (*0.42*)
Birth rate	0.49 (*0.07*)	0.51 (*0.05*)	0.28 (*0.47*)	0.32 (*0.17*)	0.63 (*0.02*)

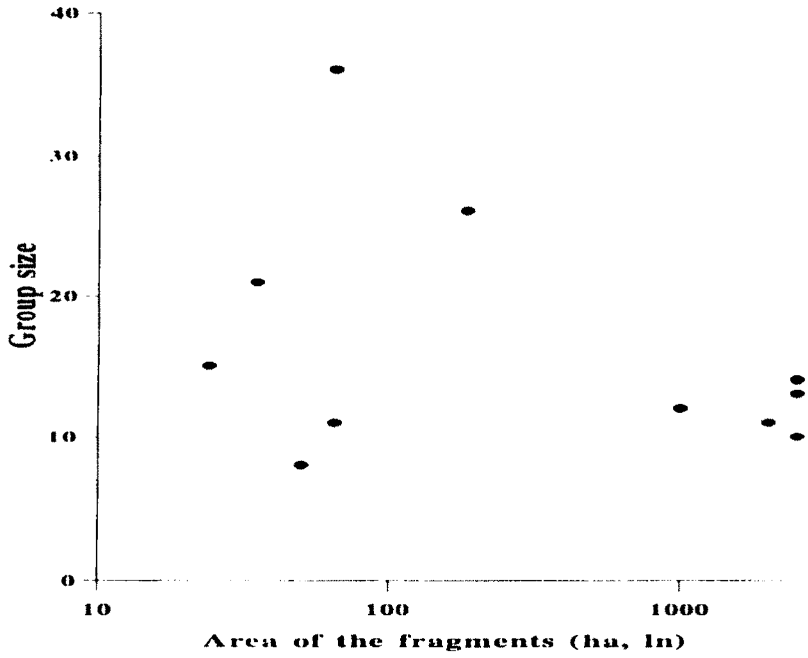


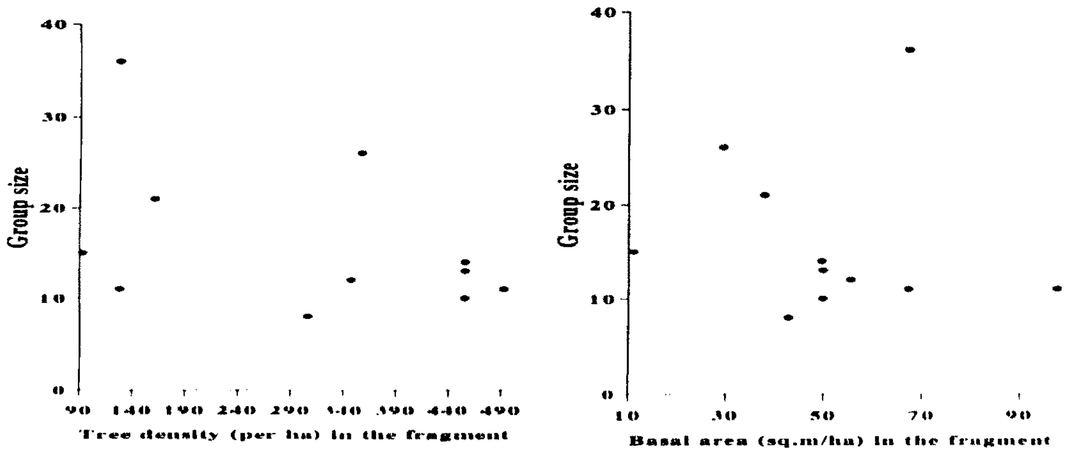
Figure 5.1. The variation in group size of the lion-tailed macaque (11 groups) with the area of the forest fragments in which they occurred.

(CV=41.10%, n=6) compared to the smaller fragments (60.91%, n=5). As expected, group size became more variable when disturbance increased as indicated by other habitat parameters (*e.g.* Tree density, Figure 5.2).

5.4.1.2 *Age/Sex composition*

The monkeys in 11 groups from 8 fragments were classified into adult males (>6 years), adult females (>5 years) and immatures (<5 years). Five groups had two adult males and the remaining six groups had one adult male each. Four two-male groups were in small fragments and one in the Andiparai, which is a large fragment. In contrast, five one-male groups were from larger fragments, and only one from a small fragment. Thus 5 out of 6 one-male groups were from large fragment, while 4 out of 5 two-male groups were from small fragments, the difference being close to significance level (Fisher exact test P=0.06). The number of adult males in a group increased with a decrease in fragment size and tree density (r_s=-0.70, n=11, P=0.008 and r_s=-0.76, P=0.012 respectively), and was also significantly correlated with group size (r_s=0.67, n=11, P=0.003). A multiple regression showed that only area was correlated (negatively) with the number of adult males per group (Multiple R = 0.79). There is thus a tendency for groups to be larger in the smaller fragments, and for them to have more adult males.

The number of adult females in a group ranged from 4 (in three groups Akkamalai, Puthuthottam-II and Pannimedu) to 19 (in Puthuthottam-I). The percentage of adult females in a group, ranged from 36.36% to 52.8%. The large fragments (>100 ha) had slightly fewer adult



(a) Tree density

(b) Basal area

(c) Canopy cover

(d) Canopy height

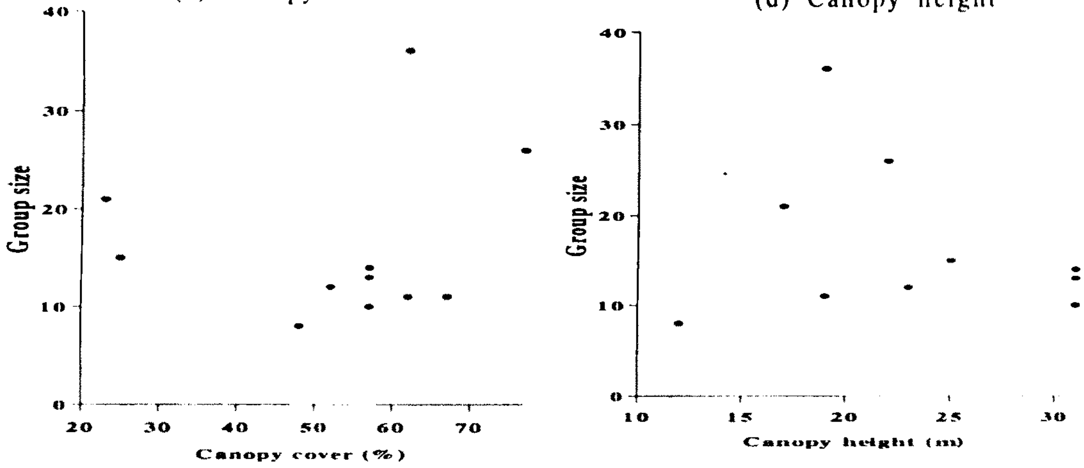


Figure 5.2. The variation in group size of the lion-tailed macaque with the mean tree density, basal area, canopy cover and canopy height of the forest fragments in which they occurred.

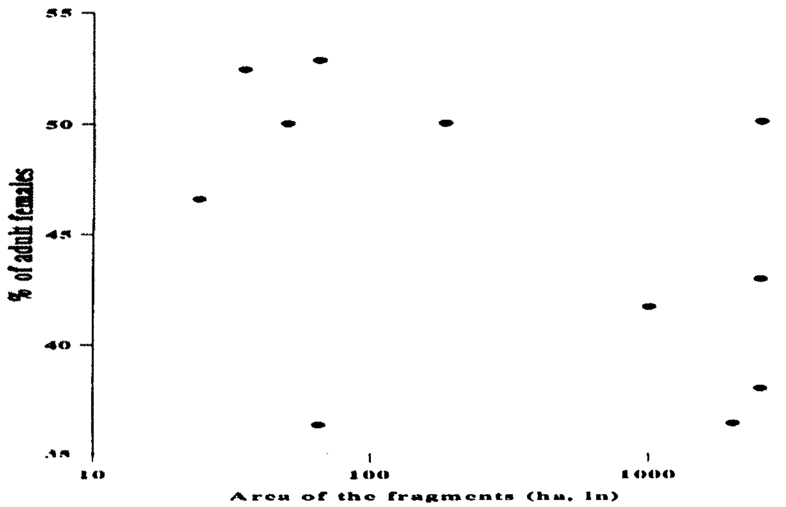
females (43.21%, n=6), than the smaller fragments (47.60%, n=5), but area and percentage of females in the group were not significantly correlated (r_s=-0.36, *P*=0.14, Figure 5.3). The other habitat parameters such as tree density, basal area, canopy height and canopy cover also were not related to percent of adult females in the group (Table 5.2).

The number of immatures in a group ranged from 4 to 15, the lowest being in Pannimedu and the highest in Puthuthottam-I. The percentage of immatures was highest in Akkamalai (54.54%) and lowest in Korangumudi (38.09%). The percent of immatures was positively correlated with the area of the fragment (r_s= 0.86, n=11, *P*=0.001, Figure 5.4). The larger fragments (>100 ha) had an average of 49.97% immatures, while the smaller had 40.54%, the difference being highly significant (M-W test, U=1, *P*<0.01). The percent of immatures was also significantly and positively correlated with tree density, basal area and canopy height (Table 5.2, Figure 5.5). A multiple regression showed that area was alone strongly correlated with percentage of immatures in the group (Multiple R= 0.91).

The ratio of immatures/adult female was highest in a large fragment Akkamalai (1.50) and the lowest (0.73) in a small fragment (Korangumudi). The ratio decreased with area and tree density, but not significantly (r_s=0.43, *P*=0.08, r_s=0.35, *P*=0.15 respectively, n=11) and was significantly and positively correlated with basal area (r_s=0.57, *P*=0.03, n=11).

When the data from different fragments were pooled into large (>100 ha) and small (<100 ha) fragments, there was no significant difference between them in the relative proportion of the three age/sex

(a) Area



(b) Tree density

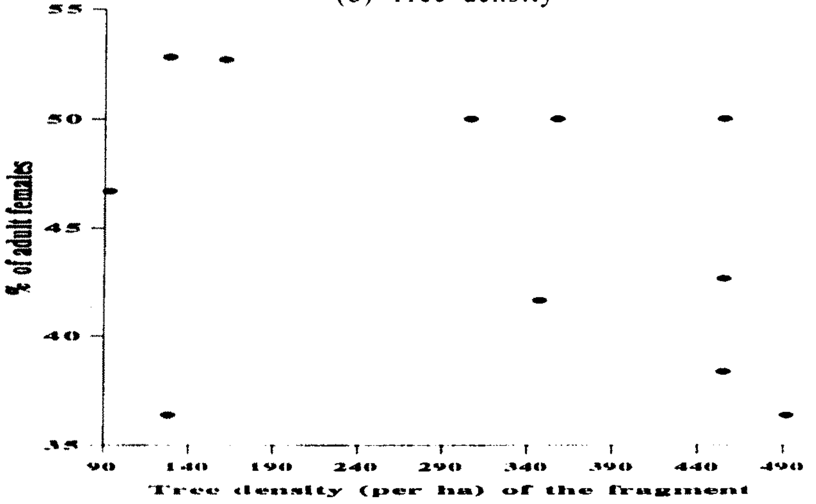


Figure 5.3. The variation in the percentage of adult females in 11 groups of lion-tailed macaque with area and tree density of the forest fragments in which they occurred.

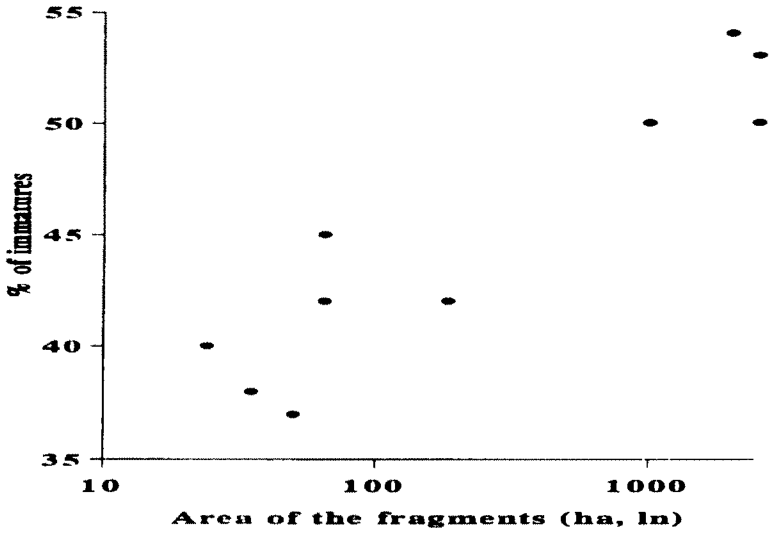
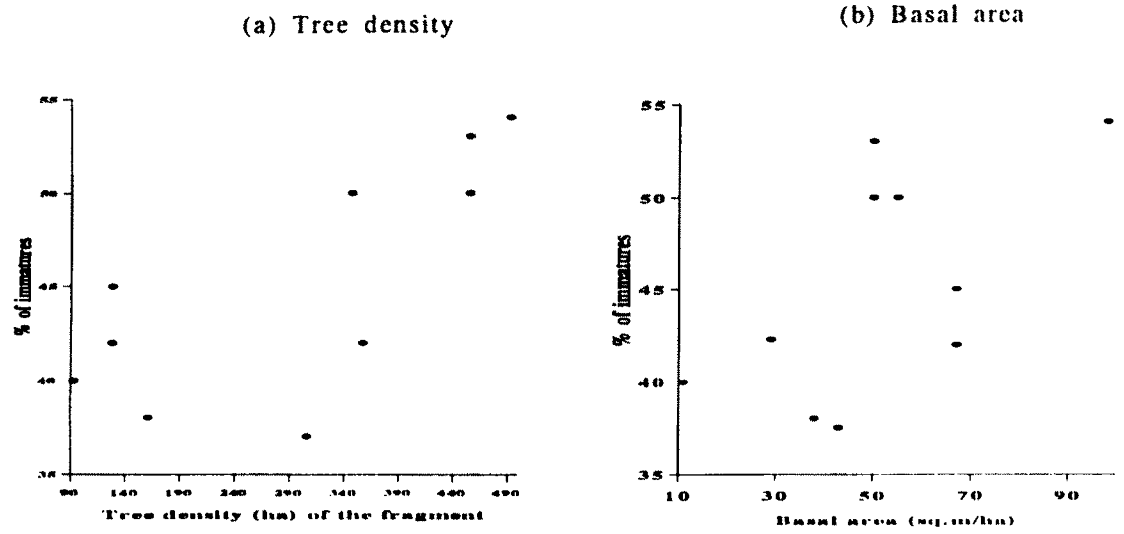
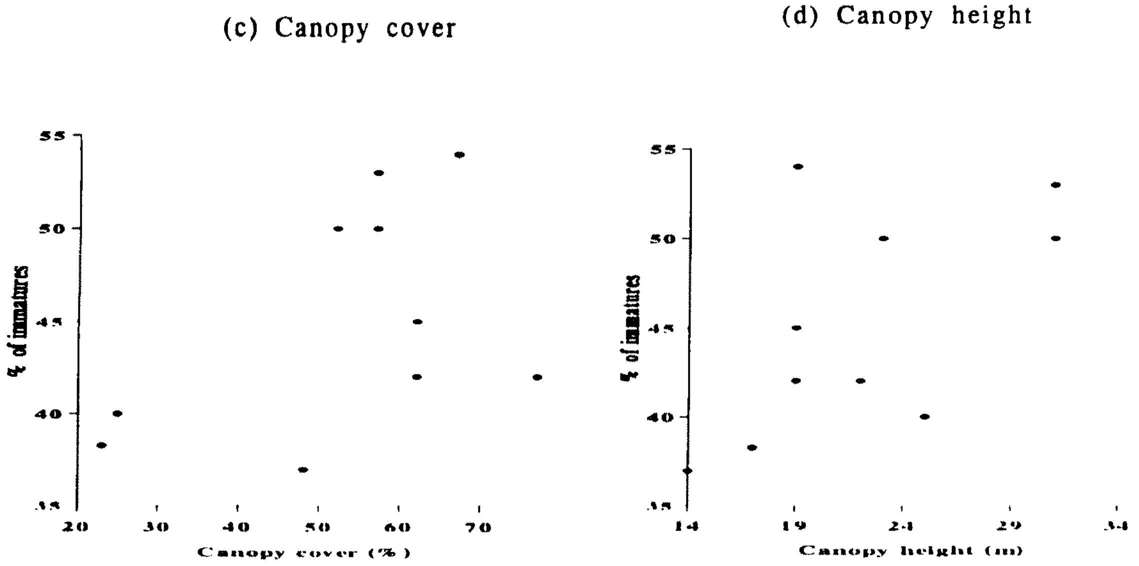


Figure 5.4. The variation in the percentage of immatures in 11 groups of lion-tailed macaque with area of the forest fragments in which they occurred



(a) Tree density

(b) Basal area



(c) Canopy cover

(d) Canopy height

Figure 5.5 The variation in the percentage of immatures in 11 groups of lion-tailed macaque with tree density, basal area, canopy cover and canopy height (a to d respectively) of the forest fragments in which they occurred.

classes (adult male, adult female and immatures (χ^2=1.2, df=2, P>0.05). However, as shown by the correlation between percentage of each age/sex class with area, the smaller fragments had few immatures and more adults (Figure 5.6). Unlike in the case of group size, there was no major difference between small and large fragments in the coefficient of variation in percentage of females (14.18% and 13.28%, respectively) and immatures (14.18% and 8.43%, respectively).

The number of adult females per adult male in a group varied from 2 to 9.5. the highest and the lowest were recorded from the two groups in Puthuthottam Estate. There was no correlation in the ratio of adult females to adult male with reference to area and other habitat parameters of the fragments surveyed. However, the ratio was highly variable in the smaller fragments (mean=4.7, CV=62%) compared to the larger fragments (mean=5.3, CV=15%).

5.4.1.3 *Birth rate*

Birth rate was estimated in May 1996 for 11 groups from eight fragments, as the number of infants (<1 year old) per adult female (Table 5.1). The highest birth rate (0.75) was recorded for a group in a very large fragment (Akkamalai shola) and the lowest (0.14) in a small fragment (Tata Estate). The birth rate decreased with decreasing area of forest fragment (Table 5.2, Figure 5.7), but it was better correlated with tree density and basal area (Table 5.2, Figure 5.8). Canopy cover and canopy height were not correlated with birth rate. The low correlation was due to the effect of an out-lier, a group in a large fragment which had a low birth rate unlike

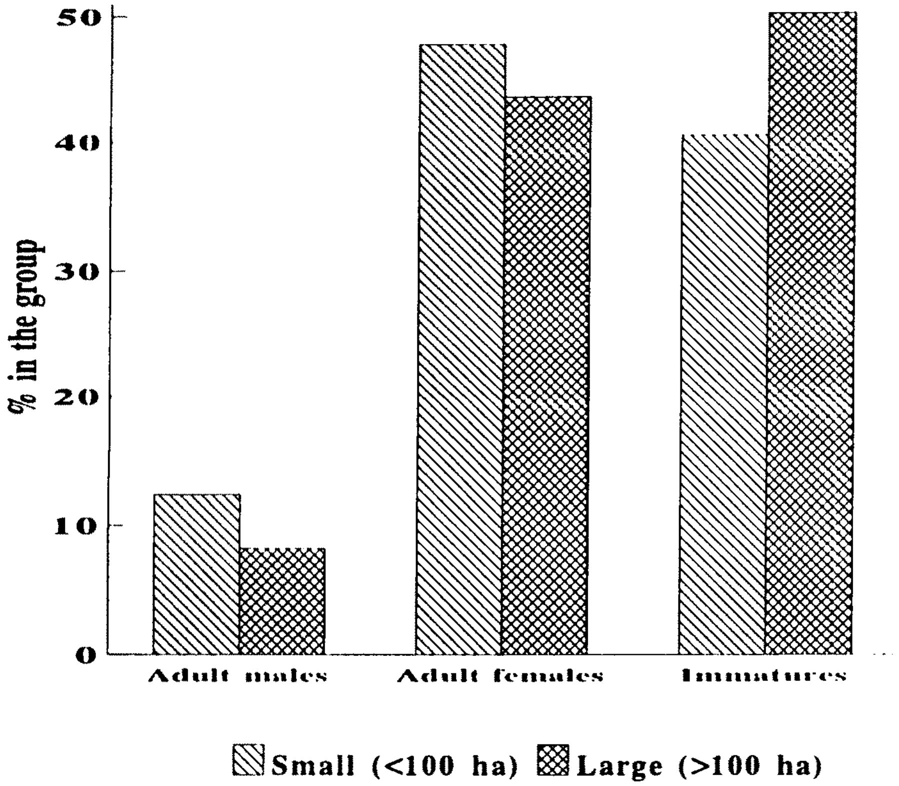


Figure 5.6. The percentage of adult males, adult females and immatures in 11 groups of lion-tailed macaque in small (<100 ha) and large (>100 ha) forest fragments.

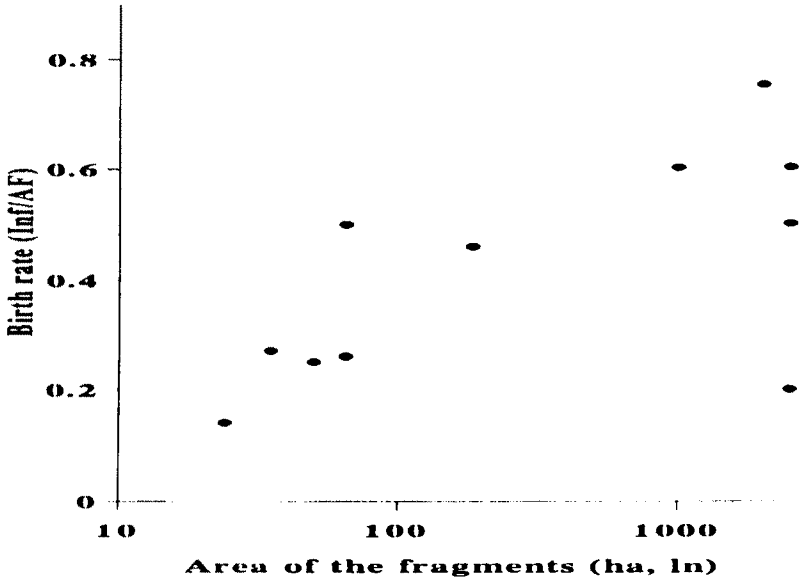
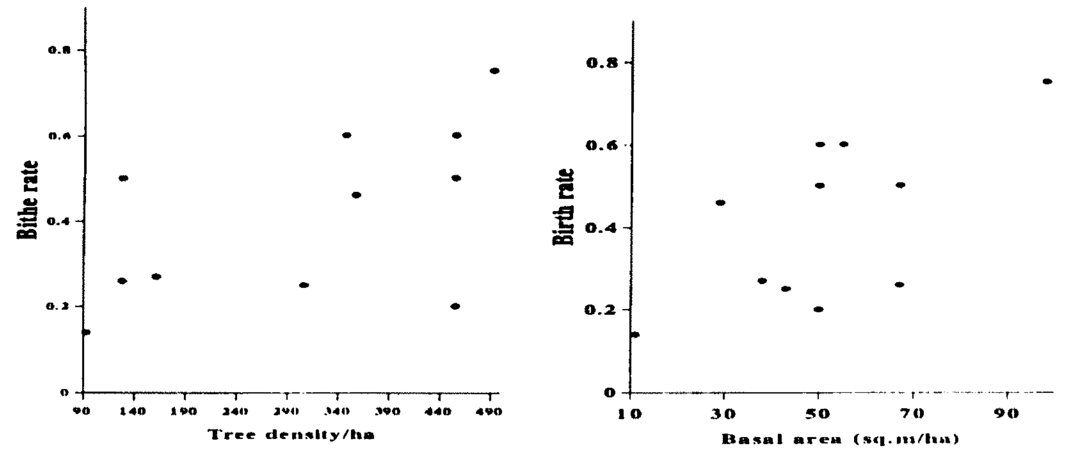
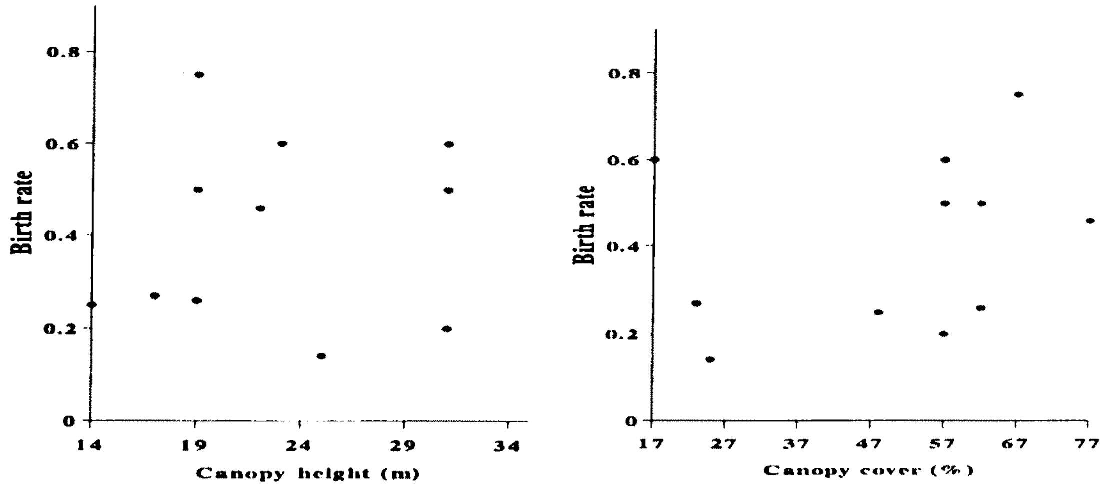


Figure 5.7. The variation in birth rate in 11 groups of lion-tailed macaque with the area of the forest fragments in which they occurred



(a) Tree density

(b) Basal area



(c) Canopy height

(d) Canopy cover

Figure 5.8. The variation in birth rate in 11 groups of lion-tailed macaque with mean tree density, basal area, canopy height and canopy cover of the forest fragments in which they occurred.

other groups. When this group was excluded from the analysis, the birth rate was highly correlated with area (r_s=0.83), tree density (r_s=0.76), canopy cover (r_s=0.49), canopy height (r_s=0.35) and basal area (r_s=0.63). A multiple regression including all groups revealed that only tree density was correlated with birth rate (Multiple R=0.68 $P<0.05$). There was a large difference in the birth rate between large (mean=0.52, n=6) and small (mean=0.28, n=5) fragments, but not statistically significant (χ^2=2.02, $P>0.05$), due to small sample size. The birth rate in small fragments had a slightly larger coefficient of variation (46.35%) than in the large fragments (35.79%).

5.4.1.4 *Growth rate*

The exponential growth (r) rate of groups was calculated for one year (from May '95 to April 1996) in the five continuously monitored groups of Akkamalai shola, Andiparai shola, and Puthuthottam, Korangumudi and Tata estate. Andiparai shola had the highest growth rate of 0.314 (from 19 to 26 individuals) and the lowest growth rate of 0 (15 to 15) was in the Tata Estate, the smallest fragment. Growth rate of groups decreased with decreasing area (r_s=0.88, $0.10>P<0.05$, Figure 5.9) and was also significantly correlated with tree density (r_s=0.91, P=0.01, n=5).

5.4.2. Nilgiri langur

5.4.2.1. *Group size*

Since the Nilgiri langurs were very shy in nature, it was not possible to identify the age/sex of the individuals or even to obtain reliable counts of group size. Hence, the demographic analysis is restricted to eight groups

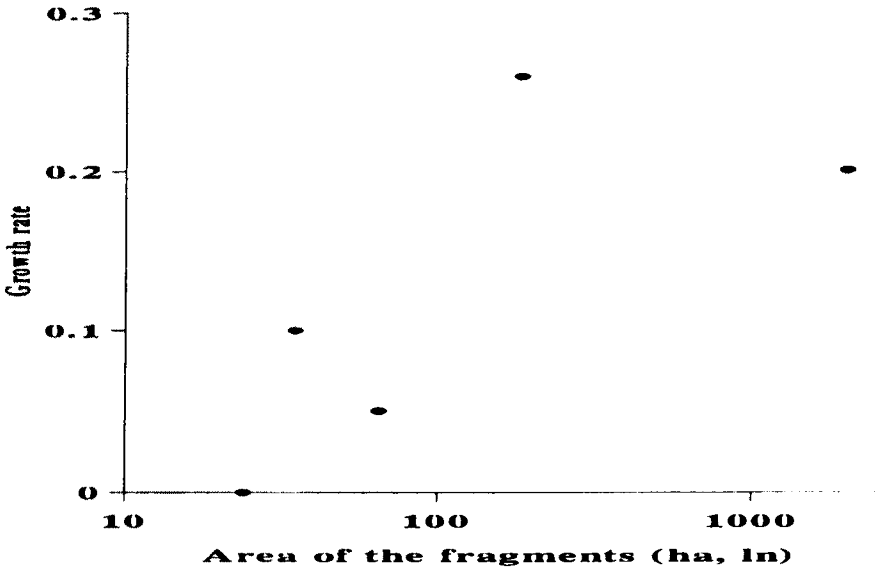


Figure 5.9. The variation in exponential growth rate of five lion-tailed macaque groups for 1995-96 with the area of the forest fragments in which they occurred.

in the four fragments (Akkamalai shola, Andiparai shola, Tata Estate and Korangumudi Estate) in which the intensive ecological studies were carried out (see Section 4.2.1). Another eight groups from the same fragments are also included for group size analysis, but not in age/sex analysis.

The largest (18 animals) and smallest (7 animals) groups were in a small fragment (Korangumudi Estate, Table 5.3). The larger fragments (>100 ha) however had a slightly higher group size (mean=13.2, SE=0.70, n=9) than smaller fragments (mean=11, SE=1.34, n=7), the difference not being significant (M-W U=16.5, $P>0.05$). When the groups were classified into two categories, below 13 (small group) and above 13 (big group) animals, the large and small fragments had an almost equal proportion of groups (6/8 groups, 5/8 groups respectively), the difference not being significant ($\chi^2=1.2$, df=1, $P>0.05$).

5.4.2.2. *Age/sex composition*

Age/sex composition was recorded only for eight groups from the four fragments in which the species was studied intensively. The number of adult males in a group did not vary much, six groups had one adult male, and only two had two adult males (Table 5.3). The number of the adult females in a group ranged from 3 to 10, both from a small fragment (Korangumudi Estate). The percentage of adult females in a group varied from 42.86% to 58.33%, the difference between large and small fragments not being significant (M-W U=7.5, $P>0.05$). It was also not correlated with any of the habitat parameters (Table 5.4). The ratio of adult females to adult males varied from 3 to 10, both in small fragments, with a mean of

Table 5.3. Demographic parameters of eight groups of Nilgiri langur in four forest fragments.

Group	Group size	No.of adult male	% adult female	% immatures	Imm/ Af	Af/ Am#	Birth rate
Akkamalai-I	17	1	52.94	41.18	0.78	9	0.33
Akkamalai-II	10	1	50.00	40.00	0.80	5	0.40
Andiparai-I	15	1	46.67	46.67	1.00	7	0.29
Andiparai-II	13	1	46.15	46.15	1.00	6	0.33
Korangumudi-I	18	1	55.56	38.89	0.70	10	0.30
Korangumudi-II	7	2	42.86	42.80	1.00	3	0.00
Tata-I	12	1	58.33	36.57	0.57	7	0.14
Tata-II	13	2	46.15	38.46	0.83	3	0.33

* - Immature/Adult female; # - Adult female/Adult male

6.75 for the larger fragments and 5.75 for small fragments. The ratio did not significantly correlate with any of the habitat parameters (Table 5.4). However, it was more variable in the small fragments (CV=59%) than in large fragments (CV=25%), even though there was no difference in the ratio (M-W U=3, *P*=0.07).

The percentage of immatures in a group ranged from 36.57% to 46.67%, highest was in a large fragment (Andiparai shola) and lowest in the smallest fragment (Tata Estate). The larger (>100 ha) fragments had a higher average (43.50%) than the smaller (<100 ha) fragments (39.17%), but not significantly so (M-W U=2, *P*=0.08). The percentage of immatures was most correlated with area, tree density and canopy cover, with correlation approaching significance levels (Table 5.4).

Table 5.4. Spearman rank correlation between demography of Nilgiri langur and habitat parameters.

Parameters	Area	Tree density	Basal area	Canopy cover	Canopy height
Group size	0.15 (*0.36*)	0.15 (*0.36*)	0.07 (*0.43*)	0.15 (*0.36*)	-0.07 (*0.43*)
% adult females in the group	0.10 (*0.40*)	0.10 (*0.40*)	0.07 (*0.43*)	0.19 (*0.32*)	0.22 (*0.28*)
% immatures in the group	0.59 (*0.07*)	0.59 (*0.07*)	0.29 (*0.24*)	0.59 (*0.07*)	-0.29 (*0.25*)
Immature/adult female	0.20 (*0.30*)	0.20 (*0.30*)	0.10 (*0.34*)	0.20 (*0.30*)	-0.10 (*0.40*)
Adult female/adult male	0.22 (*0.29*)	0.22 (*0.29*)	0.22 (*0.29*)	0.07 (*0.43*)	-0.20 (*0.30*)
Birth rate	0.55 (*0.08*)	0.55 (*0.08*)	0.35 (*0.19*)	0.45 (*0.13*)	0.10 (*0.40*)

The ratio of immatures (<5 years old) to adult female ranged from 0.5 to 1. The ratio was highest in three groups, two from large fragments (Akkamalai shola and Andiparai shola), and one from a small fragment (Korangumudi shola) and the lowest was in the smallest fragment. The ratio did not show any difference between large and small fragments (χ^2=0.4, df=1, P>0.05). The ratio also did not correlate with any habitat parameters (Table 5.4).

There was no major difference in the percentages of the three age/sex classes between small (<100 ha) and large (>100 ha) fragments (χ^2=0.36, df=2, P>0.05, Figure 5.10). However, the ratio of infants,

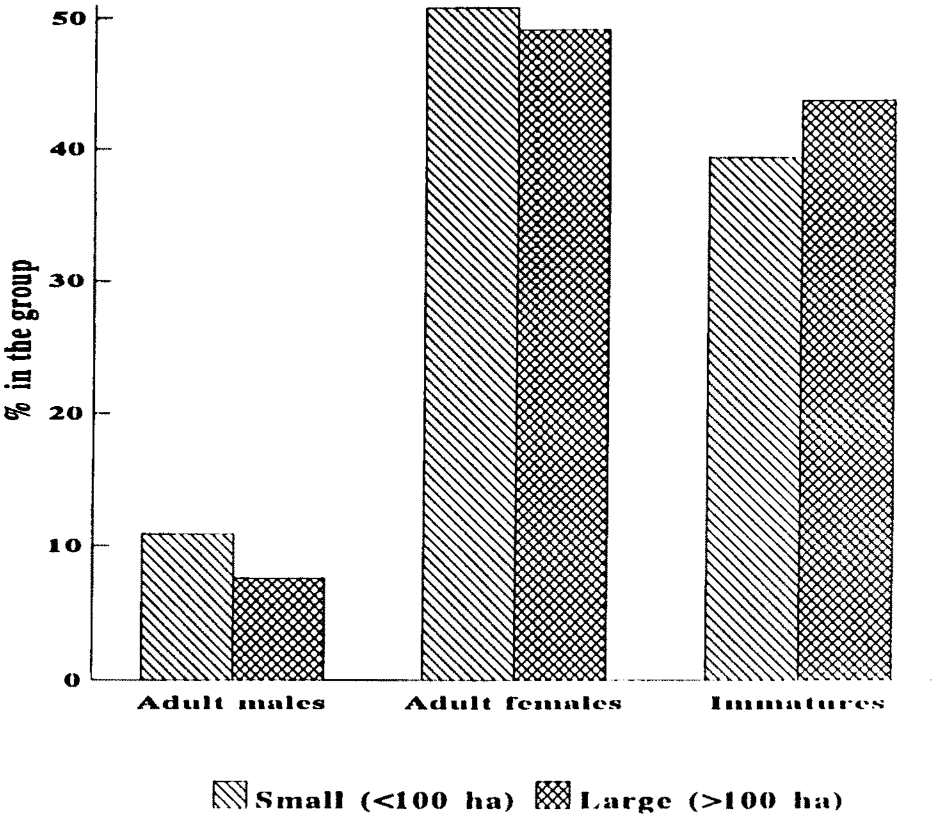


Figure 5.10. Percentage of adult males, adult females and immatures in eight groups of Nilgiri langur in small (<100 ha) and large (>100 ha) fragments.

juveniles, and immatures as a whole were greater in the larger fragments, though not significantly so (Figure 5.11).

5.4.2.3. *Birth rate*

Birth rate was estimated for 8 groups from 4 fragments as the ratio of infants (<1 yr) to adult females, at the time of the survey in May 1996. Birth rate was highest (0.4) in the very large fragment (Akkamalai shola) and lowest (0) in a small fragment (Korangumudi Estate). Even though statistically not significant, the birth rate appeared to decrease with the decreasing fragment area (r_s=0.58, n=8, *P*=0.07) and tree density (r_s=0.55, n=8, *P*=0.07). There was a large difference between birth rate in large fragments (mean=0.34) and small fragments (0.19), even though this was not statistically significant (χ^2=0.4, df=1, *P*>0.05). The birth rate was also highly variable in small fragments (CV=79%) than the large fragments (CV=13.6%).

5.4.2.4. *Growth rate*

The exponential growth rate of groups was calculated for one year (May 1995 to April 1996) for four continuously monitored groups in Akkamalai and Andiparai sholas, and Korangumudi and Tata Estates. The groups in Akkamalai shola had the highest growth rate of 0.194 (14 to 17) and the lowest 0.15 was in the large fragment Andiparai shola. The other two groups (Korangumudi and Tata Estates) had each a growth rate of 0.17 (16 to 19, 11 to 13 animals respectively).

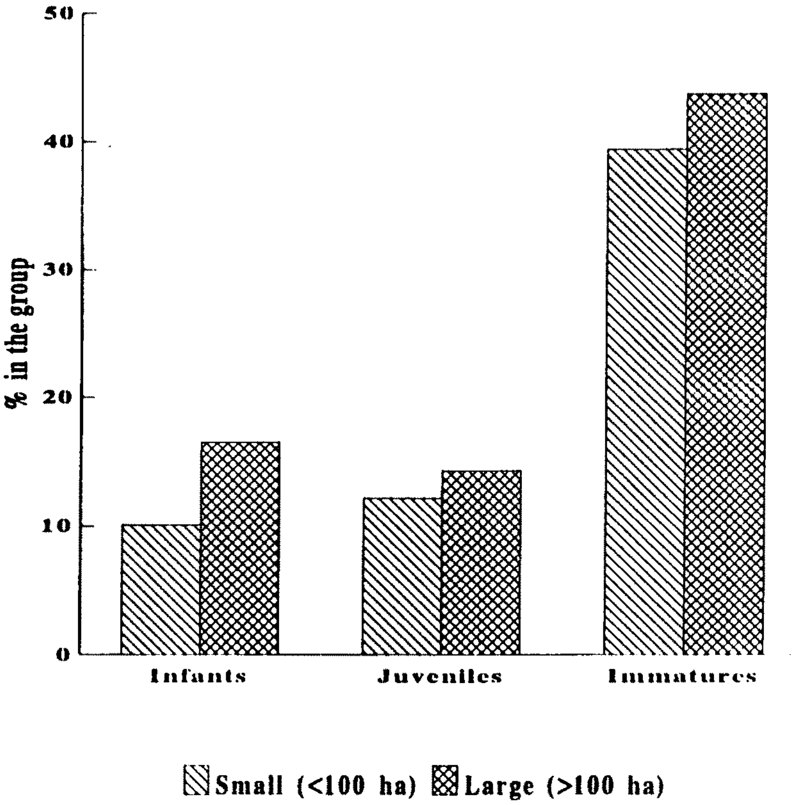


Figure 5.11. The percentage of infants (<1 yr), juveniles (1-4 yrs) and immatures (infants+juveniles +subadults)in eight groups of Nilgiri langur in small (<100 ha) and large (>100 ha) forest fragment

5.5. DISCUSSION

The major demographic changes due to fragmentation in the lion-tailed macaque were a reduction in birth rate and proportion of immatures in the group, and an increase in group size, number of adult males and variability in adult sex-ratios, with decreasing area and increasing disturbance levels. In the Nilgiri langur also, there was a similar decrease in birth rate and proportion of immatures; however, there was no change in group size and adult sex-ratios. Growth rate of groups also decreased with area and disturbance levels in the lion-tailed macaque.

Very few studies have examined changes in demographic parameters in arboreal mammals in relation to habitat fragmentation. Several studies have examined changes in demographic parameters in primates due to increasing density, group size or resource shortage. Wittenberger (1980) predicted that when group-living evolved due to greater predation protection, there would be a reduction in birth rate with increasing group size due to competition. van Schaik (1983) also made a similar prediction for female-bonded group-living primates, and found empirical evidence in several species. Kumar (1995b) found that birth in the lion-tailed macaque decreased with increasing group size, due to increasing competition. In *Macaca sinica* in Sri Lanka, Dittus (1979) found an extensive reduction in birth rate and juvenile survival, and very little change in adult survival, during a period of acute food shortage. Similarly, in Japanese macaque (*Macaca fuscata*), the stoppage of provisioning caused a drastic reduction in birth rate, and to a lesser extent in juvenile survival (Sugiyama and

Ohsawa 1982). Drastic reduction in the proportion of immatures has also been reported in primates following selective logging (Marsh *et al.* 1987; Johns 1987) due to mortality following disturbance. Dobson and Lyles (1989) suggested that primates respond to perturbations over several inter-birth intervals with a rapid decline in birth rates, while number of adults declined more slowly.

Reduction in survival, especially of immature, also resulted from increased predation. Increased densities of diurnal and nocturnal raptorial predators have been reported from logged forests in Malaysia (Johns 1985). Similarly, in logged forests in Africa, a more open canopy made primates more vulnerable to predation by eagles (*op.cit.*). Such increased predation on birds has also been reported from forest fragments in Sweden (Andrén 1992). Thus, a reduction in birth rates and immature survival both due to resource shortage and the latter also due to increased predation, is a major demographic consequences of habitat disturbance in primates. This is very similar to the pattern found in the lion-tailed macaque. In Chapter 4, it was shown that the diet of lion-tailed macaque in the small and more degraded forest is adversely affected. The major impacts are a reduction in dietetic diversity and in the proportion of invertebrates in the diet, both of which are very likely to adversely affect the birth rate. Invertebrates are the major source of protein for the lion-tailed macaque (Kumar 1987), and its reduction in the diet might adversely affect immature growth and survival.

Other major reasons for an increase in mortality were falls from trees and predation. Greater canopy discontinuity in the smaller more disturbed

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fragments often forced the monkeys to jump over larger distances, which increased risk of falling from trees. At least one death due to this has been recorded (Menon 1993). Greater canopy discontinuity also force the monkeys to spend more time on the ground, thereby increasing the risk of predation from terrestrial predators. Even though there is no data on ground predators, the number of feral or domestic dogs was often high in small fragments. A few cases of predation of lion-tailed macaque juveniles by such dogs have been reported by local people. Predation by raptors might also be higher in small fragments due to increase in their density as well as vulnerability of monkeys because of a more open canopy.

The Nilgiri langur in the smaller and more disturbed forest also showed a decrease in birth rate and proportion of immatures in the group, which were less than in the case of lion-tailed macaque. The major ecological impacts on the Nilgiri langur, was a reduction in dietetic diversity which is critical for the species (see Chapter 4). This could lead to a reduction in birth rate. As in the lion-tailed macaque, mortality could increase in the small and disturbed forest due to fall from trees and greater predation, even though there is no data to support this. In both the Nilgiri langur and lion-tailed macaque, hunting by humans is probably greater in the smaller fragments because of proximity to human settlements.

The lion-tailed macaques in the smaller fragments had a larger group size, lower adult sex ratios (adult females/adult males) as well as greater variability in adult sex ratio. In contrast, the Nilgiri langur did not show any variation in these parameters. This difference between the two species is related to the difference in their ability to use and disperse across the vegetation around the fragments, and their different social systems (see Chapter 6 for a discussion of dispersal). Even though the lion-tailed macaque spent more than 20% of their time on the ground in highly disturbed fragments, they were never seen to move into areas that were totally devoid of trees such as tea estates that often surrounded the fragments. Even though adult and sub-adult males in contiguous forests emigrate from and immigrate into groups (Kumar 1987) this was not observed in any of the groups that were intensively studied. Thus, male migration most probably does not occur between forest fragments.

Increased demographic stochasticity is a typical property of small populations (Soulé 1986). This was reflected in the greater coefficient of variation in group size, adult sex ratios and birth rate of lion-tailed macaque in the small fragments. As populations become small, the sampling variation inherent in the discrete nature of births and deaths, can lead to distorted adult sex ratios, and a high variability. In contiguous forests these are compensated for by adult male migration. The lack of male migration between fragments therefore causes a greater number of adult males per group in some fragments, reducing the adult sex ratio and increasing the variability in adult sex ratio. Since macaques live in female-bonded groups, females seldom migrate between groups (Wrangham 1980; van Schaik 1983). Thus, female dispersal is also unlikely to compensate for distorted sex ratios. Group fission and subsequent dispersal as by a matriline (Chepko-Sade and Sade 1979) is also unlikely because of the inability of the lion-tailed macaques to use the treeless vegetation that often surrounds fragments. This is the major reason for an increase in group size in the smaller fragments. Thus, the larger group size, greater number of adult males per group, and greater variability in adult sex ratio in the smaller fragments is due to the absence of dispersal between fragments. In contrast, the Nilgiri langur underwent no such change, because of their ability to disperse. Both males and females were often seen to move across treeless vegetation either natural or man-made. They were also seen on isolated trees on the roadside, far away from any forest. In Puthuthottam estate, which had no Nilgiri langur, males were seen on a few occasions even though the fragment was totally surrounded by tea estates.

In many folivores female also disperse from groups (Moore and Ali 1984). Dispersal by female and male in the Nilgiri langur compensates for distortion in group size and sex ratios. This difference in dispersal pattern between the lion-tailed macaque and Nilgiri langur has the other implications in the persistence of the species in their fragment habitat. This is discussed in Chapter 6.

5.6. SUMMARY

1. The objective in this Chapter was to examine the demographic consequences of population fragmentation in the lion-tailed macaque and Nilgiri langur. The parameters examined were group size, age/sex composition, birth rate and population growth rate, in relation to the various habitat parameters.

2. Demographic parameters of the lion-tailed macaque were estimated for 11 groups in eight fragments, and that of the Nilgiri langur from eight groups in four fragments during January to May 1996. The exponential growth rate of groups was calculated for the four main study groups of lion-tailed macaque and Nilgiri langur for one year (from March 1995 to February 1996).

3. Demographic changes in the lion-tailed macaque included a reduction in birth rate and proportion of immatures in the group, and an increase in group size, number of adult males and variability in adult sex-ratios, with decreasing area and increasing disturbance levels. In the Nilgiri langur also, there was a similar decrease in birth rate and proportion of immatures; however, there was no change in group size and adult sex ratio. Growth rate of groups also decreased with area and disturbance level in the lion-tailed macaque.

4. The decrease in birth rate and survival in the lion-tailed macaque might be due to reduction in diet quality. The latter might also be due to fall from trees and greater predation in the small fragments. Lack of dispersal between fragments may be the reason for the fluctuation in adult sex ratios and larger group size. In the Nilgiri langur, there was a reduction in birth rate and immature survival, probably due to the some reasons as in the case of the lion-tailed macaque. There was no difference in sex ratios and group size of the Nilgiri langur because of their dispersal between fragments.

6. CONCLUDING DISCUSSION AND RECOMMENDATIONS

6.1. INTRODUCTION

Chapter 3 examined the landscape and habitat parameters that govern the occurrence and abundance of five species of arboreal mammals in forest fragments. Chapter 4 examined the changes in time budget and feeding ecology of the diurnal arboreal mammals, while the demographic consequences on the two primate species were examined in Chapter 5. The area of fragment may be an important determinant of the occurrence of arboreal mammals only in the very small fragments. This was probably because the chances of the smaller fragments initially harbouring the species were low and proportional to the density or home range of the species. The current occurrence and abundance were more related to the isolation mediated habitat variation which was partly correlated with area. The vegetation immediately surrounding the fragment was also an important factor.

The major ecological impact on the three species was a reduction in the number of food plant species that they used. There were no major changes in the time budget of the three diurnal species. In the lion-tailed macaque, the major impact was a reduction in the proportion of invertebrate food items in the diet in the smaller and more disturbed fragments. This might affect the growth and survival of immatures. In the Nilgiri langur, the major impact was a reduction in the number of plant species that they fed on each day. Dietary diversity is more important for arboreal folivores than frugivores, since the former often need to select species so as to avoid the build up of secondary compounds beyond their tolerance levels. The giant squirrel showed no major changes except for a reduction in dietary diversity.

The major demographic consequences of habitat fragmentation on the lion-tailed macaque included a reduction in birth rate, immature survival and growth rate of groups, an increased group size, and highly variable adult sex ratio. The reduction in birth rate and survival might be partly due to the decrease in diet quality, while the latter might also result from greater predation by feral dogs and falls from trees due to decreased canopy contiguity. Using demographic parameters estimated from contiguous forests, Kumar (in prep) has estimated that populations of less than 45 animals have a survival probability of only less than 80% in the next 50 years, if mortality increased even slightly. In the Nilgiri langur, the major demographic consequences was a reduction in birth rate and perhaps immature survival. Unlike the lion-tailed macaque, group size and adult sex ratio did not vary. This difference between the two species is attributable to the difference in the dispersal capabilities of the two species.

In this Chapter I discuss three other factors that are important to the survival of the species that I studied in their fragmented habitats, but for which only anecdotal data exist. These factors are dispersal, genetic consequences, and the importance of parasites and pathogens. This is followed by a concluding section and recommendations for management.

6.2. DISPERSAL

Among the various factors that govern the persistence of a fragmented population, dispersal between fragments is considered among the most important. Dispersal enhances the survival of a fragmented population as a metapopulation, through recolonisation, genetic exchange, and dampening of demographic and environmental stochasticity in small populations. Dispersal has been the subject of considerable theoretical debate and modelling, since Levin (1969) proposed the term 'metapopulation' for demographically interacting fragmented populations (Hanski and Gilpin 1991; Opdam 1991; Arnold *et al.* 1993). The ability to use and disperse across modified vegetation around the fragments has been reported to be a major factor affecting the occurrence of a species in forest fragments. The ability to disperse depends on the presence of 'corridors' or connectivity between fragments, their length and width, and to what extent such corridors are consistent with the ecology of the species, especially its arboreality, diet and denning requirements (Laurance 1990, 1994; Saunders and Hobbs 1991; Hill 1995; Downes *et al.* 1997). While some small mammals disperse over long distances across a matrix of altered and man-made habitats (*e.g.* rodents, Kozakiewicz 1993), some tropical forest species are unable to cross even very small clearings *e.g.* dung beetles and carrion feeders (Klein 1989), understorey birds (Bierregaard and Lovejoy 1989; Newmark 1991) and euglosoine bees (Powell and Powell 1987).

Another factor that affects dispersal is the social and mating system of the species. For example, monogynous wood ants are able to disperse between fragments, while polygynous species occur only in large fragments (Punttila 1996). In most mammals, females show a high degree of philopatry (Pusey and Packer 1986), and dispersal over long distance is mostly by males. This is especially true of female-bonded group-living mammals such as macaques (Wrangham 1980; van Schaik 1983). In group-living folivorous primates that are not female-bonded, females also often disperse (Moore and Ali 1984; Packer 1985). Females of solitary mammals, and group-living mammals that are not female-bonded, females emigrate from natal groups, and disperse across longer distances. In female-bonded groups, on the other hand, female dispersal often follows group fission and is over short distances, often to areas adjacent to the previous home ranges (Chepko-Sade and Sade 1979). Since dispersal by male and female is necessary to recolonise unoccupied fragments, the chances of this occurring is much greater in mammals in which females also emigrate. The chances of dampening demographic stochasticity through dispersal is also greater when females and males emigrate or disperse.

The five species of arboreal mammals that I studied differed in their arboreality, diet, denning needs and social systems, and thus in their ability to disperse between fragments. The role that dispersal can play in enhancing their persistence in forest fragments (through recolonization, genetic exchange and dampening demographic stochasticity) varied among the five species. Even though the lion-tailed macaque spends less than one percent of their day time on ground in contiguous forest (Kumar 1987 and this study), in forest fragments, especially when canopy contiguity was low, they spent more than 20% of their time on the ground either foraging or moving. However, they were never seen to move across areas such as tea estates which were totally devoid of tree cover. They are thus incapable of dispersing across even short distances in the absence of tree cover. In nearly four years of observation, Kumar (1987) did not also observe his study group in Varagaliar shola moving into teak plantations that bordered the forest. The lion-tailed macaques thus may not also disperse over long distances across plantations of teak or eucalyptus. Moreover, all macaques live in female-bonded societies in which females rarely emigrate or disperse from natal groups, except following group fission. Thus, not only the groups are very unlikely to disperse across open areas and man-made plantations, even individual females are also unlikely to do so. Subadult and adult males are known to migrate between groups. Kumar (1987) estimated that males emigrate from groups at a rate of 0.08 males/year, and immigrate into groups at a rate of 0.35 males/group/year. During the intensive study in forest fragments, no emigration or immigration of males were recorded. In the absence of female dispersal, and the very low or totally absent male dispersal because of the absence of connectivity between fragments, there is only a very little chance of recolonisation of fragments or of dampening demographic stochasticity. Thus, the lion-tailed macaques in the fragmented habitats occur as totally isolated populations rather than as a metapopulation.

In contrast, it is very likely that the Nilgiri langur in the same landscape occur as a metapopulation. Even though it is an arboreal folivore, the Nilgiri langur often spends considerable time in the understorey in undisturbed forest, and on the ground in disturbed forest (this study). They often move across grasslands, while moving between forest fragments in the higher elevations (pers. obs.). They are also frequently sighted in teak plantations, at considerable distance from natural forests, often feeding on petioles and tender leaves of teak. During this study, both males and females were often seen on small clumps of trees on the roadside, surrounded by tea plantations. They are thus capable of dispersing across open areas such as tea estates, often as one or a few individuals rather than as a group, provided there were occasional clumps of trees. In Puthuthottam Estate a single individual was seen for short durations, even though the fragment had no resident groups (Umapathy and Prabhakar 1997). Folivorous primates are often not female-bonded (van Schaik 1983) which facilitates dispersal among females. Many of the folivorous primates live in single male bisexual groups in which subadult males show high rates of migration and dispersal. In the Nilgiri langur also most of the groups had only one adult male. A folivorous diet also facilitates dispersal. Thus, in the Nilgiri langur, high rates of male and female emigration from natal groups would facilitate both recolonisation of unoccupied fragments and dampening of demographic stochasticity. Therefore, unlike the lion-tailed macaque, the fragmented population of Nilgiri langur is more likely to exist as a metapopulation.

The three species of squirrels show a very high degree of arboreality, spending very little time on the ground. While the need for tree contiguity is perhaps high in the case of giant squirrel (Dutta and Goyal 1996), the two species of flying squirrels are less sensitive (Muul and Lim 1978). However, none of the three species would be able to disperse across open treeless areas such as tea estates. All the species are often sighted in teak plantations, through which they might be capable of dispersing. Both males and females might emigrate, the former often over longer distances than latter as in most solitary mammals. Thus, the squirrels may be able to disperse between fragments that have some tree contiguity, the giant squirrel being more sensitive to it than flying squirrels. Their populations in fragments that are totally surrounded by tea estates are likely to be completely isolated.

Dispersal between fragments is thus likely to be severely limited in the lion-tailed macaque, because of its inability to disperse across areas with low tree cover and also due to their social system. Giant squirrels and flying squirrels can disperse across teak and eucalyptus, and across areas with low tree contiguity. All three would be completely isolated in fragments surrounded by a tree-less matrix. In contrast, Nilgiri langur is the species that is the most capable of dispersing between fragments because of its diet, ability to move across tree-less vegetation, and social system.

6.3. GENETICS

Apart from recolonisation of vacant fragments and dampening of demographic stochasticity, dispersal also facilitates genetic exchanges between fragmented populations. Genetically isolated populations are known to loose genetic variability, suffer from inbreeding depression and homozygocity, and become genetically differentiated among themselves. The demographic consequences include reduced fertility and survival, and increased susceptibility to diseases, and possibly outbreeding depression in the long run (Soulé and Simberloff 1986; Quinn and Hastings 1987). Since most mammals are polygamous (Wilson 1975) and females show greater philopatry, the genetic flow between populations are often maintained by male dispersal (Packer 1985; Melnick *et al.* 1984; Melnick 1987). This is particularly true of female-bonded group-living mammals in which females are very unlikely to leave their natal groups. In solitary mammals and in group-living mammals that are not female-bonded, the dispersal by males is often over considerably longer distance than that by females. Female-bonded group-living primates show low levels of inbreeding because of male migration and short male tenure in groups (Melnick *et al.* 1984; Melnick 1987; Shotake and Nozawa 1991; Leberg 1991). Factors that prevent such dispersal, can increase inbreeding and differentiation among fragmented population, *e.g.* wild turkeys in USA (Leberg 1991). Since dispersal between fragments is most adversely affected in the case of lion-tailed macaque, this is the species that is expected to suffer most from the genetic consequences of habitat fragmentation. The demographic consequences could include reduced fertility and survival, especially among immatures. This may be one of the reasons for the reduction in birth rate and immature survival observed in small and totally isolated fragments (see Section 5.4.1). However, direct linkage between genetics and demography are very difficult to prove even under laboratory conditions. It is suspected that the lion-tailed macaques in six out of 10 fragments with the species might suffer from genetic consequence of habitat fragmentation, since these have less than two groups and are totally isolated. Similarly, the three species of squirrels with only limited capabilities of dispersal between fragments might face genetic consequences, even though their densities increased as fragments become more disturbed and isolated. In contrast, with relatively high levels of dispersal, the Nilgiri langur is likely to suffer the least genetically in the current landscape.

6.4. PARASITES

Pathogens and parasites which are important components in the structure of ecological communities can pose severe threats to species in restricted environments such as forest fragments due to many reasons (MaCallum and Dobson 1995; Holmes 1996). Greater environmental stress resulting, for example, from reduced nutrition levels (Wauters *et al.* 1996) can increase susceptibility whereby parasites become pathogens, new diseases emerge and epidemics increase, and even generalist parasites show increased pathogenicity (Holmes 1996). An increase in the frequency of contact among animals due to high densities especially in a restricted environment can increase transmission of parasites (Scott 1988). Interspecific competition can be altered or mediated by the changed parasitic or pathogen loads (Combes 1996). Moreover, increased edge and resulting invasion by other species can introduce new parasites and pathogens to which the resident species can be highly susceptible (Loye and Carrol 1995; Holmes 1996). Following fragmentation, there is often a reduction in number of parasitic species but increase in the load and percent of infected animals *e.g.* in bank voles (Kozakiewicz 1993). Thus, as ecosystem fragments and shrinks, diseases are likely to become a major threat to several species (Holmes 1996).

Wildlife health, disease and parasites in particular, has received very little research attention in India. Epidemics, foot and mouth disease, reindeer pest, and to a lesser extent anthrax have in the past wiped out large populations of ungulates. The incidence of parasites, pathogens and epidemics among the smaller mammals have been very little researched, even less with reference to habitat degradation. There are, nonetheless, reasons to hypothesise that parasites and pathogens could significantly affect the survival of arboreal mammals that I studied. First, at least the lion-tailed macaque and Nilgiri langur might be under nutritional stress in the forest fragments (see Chapter 4). Second, it has been reported that several generalist mammal species invade forest fragments in the same area. These include the bonnet macaque, and several species of rodents such as *Mus musculus, M. booduga, Golunda ellioti* and *Rattus blandfordi* (Prabhakar *in prep*; Anon. 1997). These could introduce new parasites and pathogens into the fragment to which the arboreal mammals might be susceptible. The deaths due to Kysanur Forest disease, caused by a tick-borne arbovirus in bonnet macaques and common langurs in northern Karnataka, is a typical example of what could happen to arboreal mammals. It is suspected that the primates contacted the pathogen through ticks from rodents, because they had to come down to the ground more often due to habitat degradation. There are several examples of such transmissions of parasites and pathogens. However, no large scale mortality has been reported from fragments among the arboreal mammals that I studied. Also, no dead bodies were recovered of any of the arboreal mammals, during the study.

6.5. CONCLUSIONS

1. Area of the fragment is an important factor in deciding the occurrence of arboreal mammals only when fragments are very small, probably less than 10 ha. In the larger fragments, habitat variation or quality is more important; the indicator of this was canopy height for the lion-tailed macaque and tree density for the Nilgiri langur. However, habitat variation showed a high correlation with area.

2. The abundance of lion-tailed macaque and Nilgiri langur fluctuated considerably as fragments became smaller. In contrast, the abundance of giant squirrel and flying squirrel increased with decreasing area and disturbance, within the range of values that are currently present in the fragments. This increase is partly because these species are generalists, but might also be because of the absence of lion-tailed macaques with which they overlap in the use of food resources.

3. The major ecological changes in the three diurnal arboreal mammals was a reduction in the number of species that they fed on, and greater dependence on shrubs compared to lianas in the larger and less

disturbed fragments. In the lion-tailed macaque there was a reduction in the relative proportion of invertebrates in the diet, which might affect immature growth and survival. The giant squirrel showed no major changes. None of the three species showed major consistent changes in overall time budget, largely because they use the man-made vegetation around the fragment to their benefit.

4. The major demographic effect on the lion-tailed macaque was a reduction in birth rate, immature survival, growth rate of groups and a wide fluctuation in the adult sex ratios and other parameters. The decrease in birth rate and survival might be due to reduction in diet quality, the latter might also be due to fall from trees and predation. Lack of dispersal between fragments may be the reason for the fluctuation in adult sex ratios and increase in group size. In the Nilgiri langur there was a reduction in birth rate and immature survival but not in sex ratios and group size because of dispersal between fragments.

5. Dispersal between fragments might be most limited in the lion-tailed macaque, because of its inability to use treeless matrix, and plantations of teak and eucalyptus, and the female-bonded social system that prevents female dispersal. Dispersal might also be limited in squirrels because of their inability to use treeless matrix, even though their social system allows female dispersal. The Nilgiri langur has high capability for dispersal because of their ability to move across treeless vegetation and a social system with male and female dispersal. Thus, the fragmented population of lion-tailed macaque is unlikely to occur as a metapopulation

that allows recolonisation, dampening of demographic stochasticity and genetic exchange. The squirrels might exist partially as a metapopulation, while most of the Nilgiri langur populations might form part of a metapopulation.

6. Greater susceptibility to parasites and pathogens due to greater environmental stress, and introduction of new parasites and pathogens by invading species due to greater edge effect, might also make fragmented populations more prone to extinction.

6.6. RECOMMENDATIONS

Since the occurrence of the arboreal mammals in fragments is related to `habitat quality' rather than area it should be possible to retain the populations that currently exist in fragments (unless fragments are very small). The following guidelines are suggested for the management of fragmented populations of arboreal mammals.

6.6.1. Habitat management

1. The vegetation immediately around the fragments has played a major role in enhancing the survival of lion-tailed macaques in the relatively small and privately owned fragments. Most of these have been logged repeatedly and have had their under growth and lianas removed. The lion-tailed macaques have been able to survive because the vegetation that immediately surrounds such fragments contain several important food species. Both coffee plants and their shade tree *Maesopsis eminii* and naturally occurring or planted jack fruit trees, mango tree and guava in the

human settlements in the privately owned fragments have considerably enhanced the availability of fruits to lion-tailed macaque and, giant and flying squirrels. Small fragments such as Puthuthottam and Korangumudi Estates, have supported populations that are higher than in the larger fragment Andiparai shola (which does not have such a matrix) due to this reason. It is therefore necessary that the man made vegetation immediately around the fragments that consist of coffee, *Maesopsis eminii* and *Artocarpus heterophyllus* is retained as such, and not converted into other vegetation, for example tea plantation.

2. Even though the small privately owned fragments have been repeatedly logged, several species of *Ficus*, and *Cullinea exarillata* have been left behind. *Ficus* and *Cullinea* provide the lion-tailed macaque with food (fruits, seeds and flowers) over long periods of time. Due to increased penetration of sunlight in the disturbed forest, the productivity of these species might also have gone up. Thus, *Ficus* spp and *Cullinea exarillata* are important for the continued survival of lion-tailed macaque. Other species that are important but which have mostly been removed include *Artocarpus heterophyllus*, *Palaquium elipticum* and *Diospyros* spp. Unlike in the large and undisturbed fragments, lion-tailed macaque depends on 4 or 5 major food species in the small fragments. It is thus necessary to retain these species.

3. Tree density and canopy height are good indicators of the occurrence of Nilgiri langur and lion-tailed macaque. Privately owned fragments have lower tree densities and canopy height, due to logging (legal

and illegal) and shade management (in cardamom estates). Further reduction, would severely threaten the survival of lion-tailed macaque and Nilgiri langur. An attempt should be made to increase tree density through assisted regeneration. The species that could be planted are given in Appendix I and II. Assisted regeneration is necessary since the dispersal of seeds of many of these species into fragments is unlikely. The aim should be to keep a mean tree density of about 400 trees/ha, the density at which the abundance of lion-tailed macaque shows low variability.

4. In fragments which have been under-planted with cardamom, the lion-tailed macaque and Nilgiri langur would continue to depend on very few species for their food. This makes them highly susceptible to environmental stochasticity, further removal of trees, and changes in the matrix around the fragment (*e.g.* removal of orchards, replacement of coffee with tea plantation). If these changes happen, then translocation may become necessary at least for the lion-tailed macaque. To the best of our knowledge suitable habitats for translocate may not exist in the Anamalai Hills, even though this requires a detailed study.

5. Even though lion-tailed macaque has been the major deterrent to logging and eventual loss of several privately owned fragments, it is important to realise that fragments have other equally or more important conservation values. These values include;

a) Several species of amphibians and reptiles including many poorly known caecilians (limbless amphibians) and shield-tails: Since these species have very patchy distribution, it is very likely that many of these may not occur elsewhere.

b) Several endemic small mammals such as spiny dormouse, brown mongoose, brown palm civet, stripe-necked mongoose and Nilgiri marten occur in these fragments.

c) Day time refuge for large mammals such as sambar, gaur and barking deer, and their predators leopard, tiger and wild dog, that survive in the landscape that is dominated by tea estates.

d) Temporary refuge for elephants as they migrate between northern and southern parts of the Sanctuary.

It is important to recognise these other conservation values, so that these are retained even if the lion-tailed macaque were to become locally extinct or are translocated.

6.6.2. Population management

Demographic exchange between isolated populations in habitat fragments is necessary in order to recolonise vacant fragments, correct skewed sex ratios (*e.g.* resulting from death of single adult male), and to avoid inbreeding depression.

1. Due to very low dispersal capabilities, lion-tailed macaques in fragments currently occur as totally isolated populations in most of fragments. Demographic exchanges are possible only through translocation. Recolonisation of vacant fragments is possible only through translocation of social groups. Even though there are currently many fragments that do not have lion-tailed macaque (Table 3.2), all of them are highly degraded and can not support resident populations. Translocation of individuals is a distinct possibility, in order to correct for skewed sex

ratios and to avoid inbreeding depression. Some of the fragments have only one adult male (*e.g.* Pannimedu) the death of which would result in loss of many reproductive years for the group. One male need to be translocated into fragments which have currently only one adult male and no subadult males. It is best to translocate subadult males, since migration between groups is largely by this age/sex class, and is tolerated. In the absence of dispersal between fragments, some fragments have surplus of subadult males (*e.g.* Puthuthottam Estate).

2. It is also necessary to periodically monitor (probably at 6 months interval) adult sex ratios in the small fragments in order to identify the need for translocation.

3. It can be hypothesised that after nearly 10 - 12 generations of isolation, lion-tailed macaques in the small fragments would be highly inbred. This hypothesis need to be tested with data on allelic diversity, homozygocity and genetic distances between groups. If found true, a planned exchanges of males between groups need to be taken up.

4. The Nilgiri langur has shown remarkable dispersal between fragments. Active population management may not be necessary at present. The three species of squirrels are all found in high densities in fragments, and therefore occur in population sizes that might escape threats to small populations. However, with relatively low levels of dispersal, it can be hypothesised that these species especially the giant squirrel, would show high level of inbreeding. This needs to be tested, in order to assess whether population management is necessary.

5. Kumar (*in prep.*) found that lion-tailed macaque populations of less than 45 animals have high chances of extinction (>20% in 50 years), with a slight increase in mortality. The factors that could cause such an increase in mortality are falls from trees, predation by feral dogs and poaching. The construction of aerial bridges to reestablish lost canopy contiguity across roads (where fall from trees and predation by feral dog can be greater) could reduce mortality from falls from trees and dog predation. Considering the impact poaching can have on small populations, cases of poaching on lion-tailed macaque need to be taken very seriously.

6.6.3. Research needs

The following are the areas of research that could identify management needs, and improve our understanding of the conservation problems of the arboreal mammals.

1. Long-term monitoring of lion-tailed macaque, Nilgiri langur and giant squirrel populations in small fragments, especially privately owned, in order to identify the need for translocation of animals for recolonisation and correcting for skewed sex ratios.

2. The lion-tailed macaques in forest fragments have been isolated for the last 10 - 12 generations. It can be hypothesised that their populations are highly inbred, which would seriously affect their long term survival. The genetic consequences of population fragmentation need to be assessed, especially with reference to allelic diversity levels of homozygocity and genetic distances between population. This can be done using of blood

samples from a few individuals from several fragments. A similar study might also be useful in the case of giant squirrels.

3. The threats that parasites and pathogens pose to fragmented populations are now only being recognised. An assessment of the changes in the parasitic and pathogen profiles of population of lion-tailed macaque, Nilgiri langur and giant squirrel in a few fragments need to be made in order to identify potential threats.

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* Originals not referred.

APPENDIX-I

List of food plant species of the lion-tailed macaque in four fragments

Family	Plant species	Parts eaten
Anacardiaceae	*Semecarpus travancorica*	Hypocarp
	Mangifera indica	Mesocarp
	Nothopegia heyneana	Seed
Arecaceae	*Calamus rotang*	Seed
Bignoniaceae	*Oroxylum indicum*	Seeds
Bombacaceae	*Bombax malabaricum*	Nectar
Caesalpiniaceae	*Cassia* sp	Mesocarp
Dilleniaceae	*Vateria indica*	Seed
Ebenaceae	*Diospyros sylvatica*	Seed
Elaeagnaceae	*Elaeagnus kologa*	meosocarp
Elaeocarpaceae	*Elaeocarpus ferrugineus*	Mesocarp
	E. conferta	Mesocarp
	E. munronii	Seed
Euphorbiaceae	*Andidesma menasu*	Flower/Mesocarp
	Bischofia javanica	Mesocarp
	Glochidion bourdillonii	Mesocarp
	Mallotus tetracoccus	Flower
	Macaranga peltata	Flower/Mesocarp
Guttiferae	*Mosua forroa*	Mesocarp
Lauraceae	*Litsea insignis*	Mesocarp
	L. deccanensis	meoscarp
	L. oleoides	Mesocarp
Loranthaceae	*Loranthus tomentosus*	Mesocarp
Malvaceae	*Cullinea exarillata*	Mesocarp
Moraceae	*Artocarpus heterophyllus*	Seed/Mesocarp
	A. hirsutus	Seed/Mesocarp
	Ficus glomerata	Fruits
	F. hispida	Fruits
	F. macrocarpa	Fruits
	F. microcarpa	Fruits
	F. nervosa	Fruits
	F. travancorica	Fruits
	F. infectoria	Fruits
	F. integrifolia	Fruits

Myristicaceae	*Knema attenuata*	Mesocarp
	Myristica beddomii	Seed coat
Myrsinaceae	*Maesa indica*	Mesocarp
Myrtaceae	*Syzygium laetum*	Mesocarp
	S. lanceolatum	Mesocarp
	Syzygium sp	Fruits
	Psidium guajava	Fruits
Papilionaceae	*Erythrina subumbrans*	Nectar
Pandanaceae	*Pandanus thwaitesii*	Mesocarp
Piperaceae	*Piper pseudotenuis*	Seed
Rhamnaceae	*Maesopsis eminii*	Mesocarp
Rubiaceae	*Coffea arabica*	Mesocarp
Rutaceae	*Toddalia asiatica*	Fruits
	- var. *floribunda*	
	Vepris bilocularis	Mesocarp
	Glycosmis sp	
Sapotaceae	*Palaquium ellipticum*	Mesocarp
	Mimusops elengi	Mesocarp
Sapindaceae	*Schleichera oleosa*	Mesocarp
Sterculiaceae	*Sterculia guttata*	Seed
Symplocaceae	*Symploccos cochinchinensis*	Fruits
Tiliaceae	*Grewia tiliaefolia*	Seed
Verbenaecae	*Lantana camara*	Fruits
Vitaceae	*Cayratia pedata*	Mesocarp
Zingiberaceae	*Elettaria cardamomum*	Pith
Mushroom and Lichens		

APPENDIX-II

List of food plant species of the Nilgiri langur in four forest fragments

Family	Plant species	Parts eaten
Anacardiaceae	*Mangifera indica*	Leaves
	Semecarpus travancorica	Leaves/Fruitss
Arecaceae	*Calamus rotang*	Leaves
Bambusaceae	*Bambusa arundinacea*	Leaves/Shoot
Bignoniaceae	*Spathodia campanulata*	Leaves/Fruitss
Bombacaceae	*Bombax ceiba*	Flowers
Connaraceae	*Cannarium strictum*	Leaves/Fruitss
Dilleniaceae	*Vateria indica*	Leaves
Elaeocarpaceae	*Elaeocarpus ferrugineus*	Leaves/Fruitss
	E. tuberculatus	Leaves
Elaeognaceae	*Elaeagnus kologa*	Leaves/Fruitss
Euphorbiaceae	*Andidesma menasu*	Leaves
	Bischofia javanica	Leaves
	Drypetes oblongifolia	Leaves
	Glochidion bourdillonii	Leaves
	Macaranga peltata	Petioles/Leaves
	Mallotus tetracoccus	Leaves
Guttiferae	*Calophyllum* sp	Leaves/Fruitss
	Mesua ferrea	Leaves/Flowers
Icacinaceae	*Gomphandra coriacea*	Leaves/Fruitss
Lauraceae	*Cinnamomum verum*	Leaves
	Cryptocorya bourdillonii	Leaves
	Listea insignis	Leaves
	L. oleoides	Leaves
	L. deccanensis	Leaves
	Persea macrantha	Leaves
Loranthaceae	*Loranthus tomentosus*	Leaves
Malvaceae	*Cullinea exarillata*	Flowers/Seed
	Kydia calycina	Leaves
Meliaceae	*Aglaia bourdillonii*	Leaves
	Chukrasia tabularis	Leaves/Flowers
Moraceae	*Artocarpus heterophyllus*	Fruitss
	A. hirsutus	Fruitss
	Ficus glomerata	Leaves
	F. hispida	Leaves

	F. macrocarpa	Leaves
	F. Microcarpa	Leaves
	F. nervosa	Leaves
	F. infectoria	Leaves
	F. intergrifolia	Leaves
	F. travancorica	Leaves
Myristicaceae	*Myristica dactyloides*	Leaves
Myrsinaceae	*Maesa indica*	Leaves
Myrtaceae	*Syzygium laetum*	Leaves
	S. lanceolatum	Leaves/Flowers
	Syzygium sp	Leaves
Myrtaceae	*Eucalyptus* spp	Leaves
Papilionaceae	*Erythrina subumbrans*	Leaves/Flowers
Piperaceae	*Piper pseudotenuis*	Leaves
Rhamnaceae	*Maesopsis eminii*	Leaves
Sapindaceae	*Schleichera oleosa*	Leaves
Sapotaceae	*Mimusops elengi*	Leaves
	Palaquim ellipticum	Leaves
Symplocaceae	*Symplocos cochinchinensis*	Leaves/Fruitss
Tiliaceae	*Grewia tiliaefolia*	Leaves

APPENDIX-III

List of food plant species of the giant squirrel in four forest fragments

Family	Plant species	Parts eaten
Anacardiaceae	*Nothopegia colebrookiana*	Seeds
Bombacaceae	*Bombax ceiba*	Flowers
Connaraceae	*Cannarium strictum*	Leaves/Fruitss
Elaeocarpaceae	*Elaeocarpus tuberculatus*	Seeds/Leaves
Elaegnaceae	*Elaeagnus kologa*	Leaves/Fruitss
Euphorbiaceae	*Antidesma menasu*	Leaves
	Bischofia javanica	Leaves
	Glochidion bourdillonii	Leaves/Fruitss
	Macaranga peltata	Fruitss
	Mallotus tetracoccus	Fruitss
Guttiferae	*Mesua ferrea*	Leaves/Flowers
Lauraceae	*Cryptocarya bourdillonii*	Seeds/Leaves
	Persea macrantha	Leaves
Malvaceae	*Cullinea exarillata*	Flowers/Seeds
	Kydia calycina	Seeds/Leaves
Meliaceae	*Chukrasia tabularis*	Leaves/Flowers
Moraceae	*Artocarpus heterophyllus*	Seeds/Leaves
	A. hirsutus	Seeds/Leaves
	Ficus glomerata	Fruitss/Leaves
	F. hispida	Fruitss/Leaves
	F. macrocarpa	Fruitss/Leaves
	F. microcarpa	Fruitss/Leaves
	F. nervosa	Fruitss/Leaves
	F. infectoria	Fruitss/leaves
Myristicaceae	*Myristica beddomii*	Seeds
Myrsinaceae	*Maesa indica*	Seeds/Leaves
Myrtaceae	*Eucalyptus* spp	Seeds
	Syzygium laetum	Leaves
Papilionaceae	*Erythrina subumbrans*	Leaves/Flowers
Rhamnaceae	*Maesopsis eminii*	Leaves/Seeds
Sapindaceae	*Schleichera oleosa*	Seeds
Sapotaceae	*Palaquium ellipticum*	Leaves/seeds
Symplocaceae	*Symploccos cochinchinensis*	Leaves/Fruitss/Seeds
Tiliaceae	*Grewia tiliaefolia*	Seeds