ECOLOGY OF THE BROWN PALM CIVET *Paradoxurus jerdoni* IN THE TROPICAL RAINFORESTS OF THE WESTERN GHATS, INDIA

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in
ZOOLOGY

by
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July 2001

CERTIFICATE

This is to certify that the thesis, entitled "**Ecology of the brown palm civet *Paradoxurus jerdoni* in the tropical rainforests of the Western Ghats, India**" is a record of original research work done by **Ms. Divya Cauvery Mudappa B.** in the Division of Conservation Biology, Sálim Ali Centre for Ornithology and Natural History, as a full time Research Scholar during the period of study 1998 – 2001 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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I do hereby declare that the thesis entitled "**Ecology of the brown palm civet *Paradoxurus jerdoni* in the tropical rainforests of the Western Ghats, 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 1998 – 2001 under the supervision and guidance of Dr. Ajith Kumar 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

The small carnivores of the mammalian Families of Viverridae, Herpestidae, and Mustelidae play very important roles in tropical rainforest ecosystems, as predators, prey, and seed dispersers. These roles have been poorly studied, even as small carnivore communities are undergoing changes due to severe loss and fragmentation of rainforests. This thesis explores the ecology of a small carnivore, the brown palm civet (*Paradoxurus jerdoni* Blanford 1885), endemic to the rainforests of the Western Ghats hill ranges of India, and also examines changes in the structure of the terrestrial and arboreal small carnivore community as a whole, due to rainforest fragmentation.

The ecology of the brown palm civet, an endemic and nocturnal viverrid, was examined with reference to its role as a seed disperser, and the factors governing its diet composition, and ranging and activity behaviour, in the relatively undisturbed, large tract of rainforest in the Kalakad-Mundanthurai Tiger Reserve (KMTR), between May 1996 and December 1999. The small carnivore community here was compared with that in the rainforest fragments of the Anamalai Hills that were surveyed between January and May 2000. Habitat correlates of the occurrence of small carnivores were also examined.

The brown palm civet was highly frugivorous. Of 1013 scats examined, 91.12% contained seed, fruit or flower remains of native species. Only 14.2% of the scats had invertebrate or vertebrate remains. Fruits of 53 native and 4 introduced species, and flowers of 2 species were eaten. No species contributed >10% to the overall diet, although 10 species accounted for 25–75% of the diet in certain months. There was considerable intra- and inter-annual variation in the diet. Most fruits eaten were of trees and lianas. Compared with non-consumed species, a greater proportion of consumed fruits were drupes or berries, and had moderately thick and watery pulp. Fourteen species of fruits were identified as important for the year-round sustenance of the brown palm civet.

Seeds from scats were viable in 14 of the 17 species assessed, but a greater proportion of defecated seeds germinated in only 2 out of 6 species tested. In 3 species, germination rate was significantly different (2 lower and 1 higher) between defecated and control seeds. The brown palm civet plays a major functional role, as a seed disperser in the rainforests of Western Ghats. They do not damage seeds of the fruits they consume, and assist in dispersing them away from the parent plants, where the seeds have a higher chance of predation. The brown palm civet is also a reliable disperser as it consumes a variety of species, even in times of low overall availability of fruits in the habitat.

Flowering and fruiting phenology of 450 trees of 22 food species was monitored between January 1998 and December 1999 in Sengaltheri, KMTR. Densities of food tree species were estimated from 184 point-centred quarter plots, and their distribution from 327 circular plots of 5 m radius. Pronounced inter- and intra-annual variations were observed in the number of species and individuals with flowers and ripe fruits, as well as in flower and fruit abundance. Excluding *Ficus* spp., the others were biannual, annual, biennial, or supra-annual in their fruiting periodicity. However, in any given month, a minimum of 3 of these 22 species was in fruit. The phenological pattern of abundance of ripe fruits was strongly influenced by the "mass fruiting" behaviour of the supra-annual species. The food species of the brown palm civet were abundant (53% of the total tree density) in the study area, and most of them tended to be clumped in distribution. A greater number of species were consumed in almost equal proportions, during times of low ripe fruit availability. But, at times of greater food availability, the civets' choice of some fruits was evident, as one species tended to dominate in the diet.

Factors influencing home range size, activity, and habitat choice of the brown palm civet were examined with data from a radio-telemetry study between March 1998 and December 1999 in Sengaltheri. Five males and two females fitted with activity transmitters, were tracked for 12 to 238 days. Their home ranges varied between 6 and 57 ha, substantially smaller than the home ranges of similar species elsewhere. Body size was positively related to home range size, and individuals in areas with higher tree density, tree species, and basal area, had smaller home ranges than expected.

The civets showed a distinct nocturnal activity regime, being active 79% of the time between dusk and dawn (1800 h – 0600 h), with the exception of two injured animals. The animals spent significantly less time moving and greater time foraging (including feeding) during months of greater fruit availability. The brown palm civets predominantly used Malabar giant squirrel (*Ratufa indica*) nests for day-bedding. The day-beds were on trees that were larger in girth and height, and also had greater canopy contiguity and number of trees > 30cm girth around it, as compared to random trees in the habitat. These variables correctly classified about 75% of the random and day-bed trees analysed.

A combination of methods, such as track plots, camera-traps, spot-lighting (night walks and drives), and direct sightings were used assess the relative abundance of small carnivores in KMTR and Anamalai Hills. Two endemic species—brown palm civet and Nilgiri marten (*Martes gwatkinsi*)—were the most frequently sighted nocturnal and diurnal carnivores, respectively, in KMTR. There was a significant decrease in the occurrence of small carnivores in the track plots and camera-traps in the rainforest fragments. The success rate was greater in

KMTR in the case of brown palm civet, but not for the small Indian civet and the mongooses. The number of photo-captures and direct sightings of the mongooses (brown and stripe-necked mongoose) were higher in the fragments and the matrix around them than in the undisturbed rainforests. The brown palm civet success rate was positively correlated to altitude. The success rates were not significantly correlated to any of the habitat or site parameters. The brown palm civets occurred even in rainforest fragments that were highly disturbed. Their persistence may be due to the occurrence of food tree species in the fragments, and the presence and protection of relatively large (200 ha) rainforest fragments in an otherwise highly disturbed landscape. The more widespread and omnivorous species exhibited no significant change in relative abundances between KMTR and Anamalais, although they were more common in the latter (fragmented landscape).

Tropical forests and their species diversity are being threatened by extensive deforestation and forest fragmentation. The endemics—brown palm civet and Nilgiri marten—are among the small carnivores that are likely to be severely affected among the small carnivores of the Western Ghats, if the present rate of disturbance continues. The brown palm civet is an effective disperser of many rainforest plant species, and is a key player in the dynamics of seed dispersal, germination, and regeneration in rainforests of the Western Ghats. They can also play an important role in maintaining degraded rainforest fragments and to restore them. Although its area requirements in a relatively undisturbed rainforest is one of the smallest known for a viverrid, it will require larger areas in rainforest fragments, which are disturbed and usually have low food tree densities and other resources. The rainforest fragments are also likely to have greater variations in fruit availability due to openness of the habitat, and local climatic changes, necessitating availability of diverse species in the habitat. It is also likely to face competition from other sympatric, but widespread and common species of small carnivores. Therefore, even in a fragmented landscape, conservation efforts should include protection and maintenance of relatively undisturbed and large tracts of forests with high diversity of native trees and lianas. At the same time, efforts should be made to protect even small forest fragments that hold wild populations of many endemics, including the brown palm civet. Restoration efforts can also be made to improve the quality of highly degraded fragments.

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CHAPTER 1

GENERAL INTRODUCTION

1.1 SMALL CARNIVORES

1.1.1 Background

The Order Carnivora is among the most speciose of the mammalian orders with about 272 species (Wozencraft 1989, Corbet and Hill 1992). This Order comprises of large, medium, and small sized animals that are adapted to varied habitats and habits. Among the Carnivora, 54% of the species, which belong to the Families Herpestidae, Viverridae, and Mustelidae (Wozencraft 1989), are commonly referred to as small carnivores. Only a few of the felids (Felidae) are small, and sometimes included along with these species, when small carnivore community is considered in its entirety. This group of mammals exhibits a high degree of diversity and endemism in several regions of the world. The Herpestidae, including mongooses and meerkats, and Viverridae, comprising civets and their relatives, are restricted to the Old World, with the exception of the genets (*Genetta*) and a species of *Herpestes*, that extends into the Mediterranean region. In contrast, the Mustelidae (otters, weasels, and badgers) are found worldwide, except in Australia and Antarctica. Mustelidae is also the most diverse family containing 64 species in 22 genera, followed by the Herpestidae with 37 species in 16 genera, and Viverridae with 35 species in 19 genera (Wozencraft 1989).

The mustelids occur from snow-covered tundra to tropical rainforests, and are aquatic, terrestrial or arboreal in habit, being mostly diurnal and solitary. The viverrids and herpestids occur in various tropical habitats ranging from savannah to the rainforests. Viverrids are usually nocturnal, arboreal, and solitary, whereas herpestids are mostly diurnal, terrestrial, and, in some species such as meerkats (*Suricata* spp.), live in social groups. In many areas, several species of small carnivores occur sympatrically, forming species-rich communities (Schreiber *et al.* 1989), with the highest diversity in tropical rainforests. The herpestids reach their highest diversity in the dry tropical forest and savannah habitats of Africa, the viverrids in tropical moist forests of South and South-east Asia, and the mustelids in sub-tropical and temperate regions. The small carnivores range from being predominantly frugivorous to strictly carnivorous in diet, with a majority of them being omnivorous (Eisenberg 1989).

Small carnivores are critical for the functioning of natural ecosystems because of the key roles they play as predators, prey, and seed dispersers. They can affect food webs and community structure of lower trophic levels (Palomares *et al.* 1995, Crooks and Soulé 1999). Like most other species today, small carnivores are also threatened by habitat loss, degradation, and fragmentation the world over (Schreiber *et al.* 1989, Zielinski and Kucera 1995, Heydon and Bulloh 1996). Small carnivores sometimes face additional threats, as they are hunted for meat, fur, pelt, or extraction of secretions from their scent glands (Schreiber *et al.* 1989, Madhusudan and Karanth 2000). Despite their ecological significance and the threats they face, small carnivores have been poorly studied, particularly in the tropics. This thesis explores in detail the ecology of a small carnivore, the brown palm civet (*Paradoxurus jerdoni*), endemic to the rainforests of the Western Ghats hill ranges of India, and also examines changes in the structure of the terrestrial and arboreal small carnivore community as a whole due to rainforest fragmentation.

1.1.2 Evolution, taxonomy, and morphology

The first members of the Order Carnivora can be found in the fossilised records of the Upper Eocene (56.5 million years BP), and persisted until the Oligocene (35.5 million years BP, Eisenberg 1989). These earliest known Carnivora include small, arboreal forms belonging to the Sub-family Viverravidae, believed to be ancestors of the modern viverrids (Gregory and Hellman 1939), and a second group of viverrid-like animals, the miacids (Sub-family Miacidae). These groups are sometimes placed in the Family "Miacidae" (Martin 1989). Mesozoic carnivores were predominantly insectivorous and occurred in all tropical forests. The early carnivores were mainly nocturnal, as their radiation occurred during the epoch of the large, diurnal reptiles. Arboreal habit is also a primitive trait among the Carnivora. The extant civets are the most primitive of the carnivores in form and habits. In the course of time, the development of an omnivorous diet that included fruits appears to have evolved (Martin 1989). The herpestids and the viverrids do not occur in the American continents, suggesting that their centre of radiation was at lower latitudes, and that they were unable to traverse the colder northern latitudes and enter the New World through the Bering land bridge. This is in contrast to the mustelids that probably radiated from the northern latitudes and now occur worldwide (Martin 1989). Based on their diversity, it is likely that the herpestids radiated out of Africa, and the viverrids from South-east Asia.

The three families of interest in this thesis are classified under the Sub-order Fissipedia (the terrestrial carnivores). The herpestids and the viverrids are placed along with the cats and the hyenas in the Super-family Aeluroidea (Feloidea), in which the tympanic bulla is incompletely divided by a low septum (Eisenberg 1989). The herpestids of the Indomalayan region all belong to a single genus, Herpestes, a distinguishing feature of which is that the males have one chromosome less than the females (Corbet and Hill 1992). The mustelids are grouped along with the canids and ursids in Arctoidea (Canoidea) as they have a single-chambered tympanic bulla. There are a few species whose taxonomic placement is difficult, and also those that exhibit affinities towards more than one family. Pocock (1933a,b,c, 1934a,b, 1936, 1939) has dealt with a detailed taxonomic classification and distribution of South Asian species of mongooses and civets. Wozencraft (1989), Corbet and Hill (1992), and Ewer (1998) have reviewed their taxonomic status in later years. This thesis uses the taxonomic classification of Wozencraft (1989) and Corbet and Hill (1992).

There are marked differences among these small carnivore families in their morphology. Civets have a small face and an elongated skull. The body and tail are long, and the legs short. They have larger ears than the mongooses. The digits are held close and have short claws. Most civets are nocturnal, arboreal with plantigrade feet, and predominantly frugivorous or omnivorous (Eisenberg 1989). The carnivorous species stalk their prey and, like cats, use their long whiskers as sense organs. The true civets (*e.g.*: *Viverra* spp. and the small Indian civet *Viverricula indica* of the Sub-family Viverrinae) exude a secretion from their perineal scent glands, which is used in the perfume industry.

The mongooses have a small head with a pointed snout. The body is long and sausage-shaped and the tail bushy and tapering. They have short legs and are similar to civets in their body structure. However, they can be distinguished from civets by their small semi-circular ears, longer body, and bushy tail. Their ears do not project above the head and are modified into a series of folds that can shut down over one another so as to completely cover the ear openings in order to protect them from dust while the mongoose digs burrows to hunt (Prater 1980). Their feet are flayed unlike in civets, and the toes have much longer claws, aiding them in their hunting forays. They lack scent glands but possess anal glands enclosed in a naked glandular sac. A spray of foul-smelling secretion is used as defence (much as in skunks), particularly by the crab-eating (*Herpestes urva*) and stripe-necked (*H. vitticollis*) mongooses. They are predominantly diurnal and, being terrestrial in habit, have digitigrade feet. No systematic ecological study has been carried out on any of the mongooses in India.

The Family Mustelidae is classified into Sub-families Lutrinae (otters), Mustelinae (weasels, martens, and honey badgers), and Melinae (other badgers). The otters are aquatic, with streamlined bodies and webbed feet, while the other species are terrestrial. The mustelids have long bodies, and short legs and tail. Some species in the temperate region change their pelage in accordance with the seasons. They are highly carnivorous in their diet. In the Western Ghats, there are representatives of two sub-families (Mustelinae and Lutrinae), of which the Nilgiri marten (*Martes gwatkinsi*) was one of the study species.

Dentition is another key characteristic used in the classification of mammals. In the Order Carnivora, many forms have evolved their dentition based on their habits and their evolutionary stock. The tooth structure of the genus *Herpestes* is least modified from the primitive miacid-type carnivores (Petter 1969) that were more insectivorous in habit. The civets have a rather unspecialised dentition. The brown palm civet has a larger and distinctive upper fourth premolar (P^4) than the common (*Paradoxurus hermaphroditus*) and the golden (*P. zeylonensis*) palm civets (Corbet and Hill 1992). It also has the medial lobe broadly confluent with the rest of the tooth, not separated by a posterior constriction, and larger teeth than the masked palm civet (*Paguma larvata*). The mustelids, being the most carnivorous among the small carnivores, have the typical dentition of carnivores with prominent shearing teeth or carnassials.

1.1.3 Role in the ecosystem

Small carnivores form diverse assemblages in tropical forests (Rabinowitz 1991), and are critical to the functioning of natural ecosystems because of the key roles that they play in the ecosystem as predators, prey, and seed dispersers. Carnivores, being at the apex of food chains, are indicative of ecosystem health and integrity (Eisenberg 1989). As predators, small carnivores—particularly the herpestids and mustelids—may regulate populations of many species of invertebrates, rodents, and other small vertebrates (Palomares *et al.* 1995, Ray 1997), thus affecting community structure of lower trophic levels (Palomares *et al.* 1995, Crooks and Soulé 1999). Small carnivores may also be an important prey base—all three groups are predated by large carnivores like the leopard *Panthera pardus* and pythons *Python molurus* (Joshi *et al.* 1995, D. Mudappa *unpublished data*, A.Kumar *personal communication*—of a dead python with a small Indian civet in the stomach in southern India). One of their most critical functions may be as seed dispersers, as several small carnivores, particularly the palm civets that are highly frugivorous, disperse the seeds of many tropical plant species (Bartels 1964, Rabinowitz 1991). However, this is an aspect of their ecology that has not received adequate attention (Herrera 1989).

1.1.4 Cultural significance

The cultural and economic significance of small carnivores cannot be overlooked. Since ancient times, many small carnivores have been symbols of courage, strength, ferocity, and wealth in folklore and mythology (IUCN publication). In India, Kubera, the god of wealth has been depicted as carrying a mongoose-shaped purse or a mongoose. The Egyptian mongoose (*Herpestes ichneumon*) was regarded as a guardian of wealth, and held sacred by ancient Egyptians. Mongooses are well known as controllers of rodent and insect pests. However, unmonitored and uncontrolled introductions of mongooses in many islands to check agricultural pests have led to the decimation of other local and endemic fauna, especially snakes. Mongooses and civets are often kept as pets, particularly in tropical Asia. There are reports of the endangered Malabar civet (*Viverra* *civettina*) also being kept in captivity by people in Kerala, India, in order to collect the *civet* (Ashraf *et al.* 1993). The *civet* or scent is used in perfume industries and in Indian medicine for their purported aphrodisiac properties and also treatment of several ailments (Prater 1980). The coffee seeds collected from the droppings of the frugivorous palm civets are known as *kopi luwak* and sold for a special price in South-east Asian countries (Bartels 1964, Wemmer and Watling 1986). The mustelids have been used in cruel recreational sports such as "badger fights" in England. Hunters in many parts of America, Europe, Africa, and Asia have used the tracking abilities of small carnivores such as genets, weasels, and polecats (IUCN publication).

1.1.5 Threats in the wild

The estimated loss of tropical moist forest in Asia is an alarming 3.4 million ha per year (1981–90, Whitmore 1998). A consequence of this, that is a major concern, is habitat fragmentation and degradation of these patches. This is a continuing process, and more so in the tropical regions. Among the 25 identified global biodiversity hotspots, are the unique and rich Western Ghats and Sri Lanka (Myers *et al.* 2000). This area, being a hotspot, ranks third in terms of the number of endemic vertebrates/area ratio (species/100 km^2), but also has the highest human population densities among the hotspots (Cincotta *et al.* 2000). The Western Ghats face severe threats from human disturbance due to deforestation, developmental activities, conversion to plantations, and habitat fragmentation (Nair 1991). Menon and Bawa (1997) estimated that between 1920 and 1990, forest cover in the Western Ghats declined by 40%, resulting in a four-fold increase in the number of fragments, and an 83% reduction in size of forest patches. In the present state of worldwide habitat loss and alterations, management of the small, but biologically valuable species and populations and populations should be based on scientific knowledge of their ecological needs. Animal species likely to be affected by habitat loss and fragmentation are wide-ranging carnivores and frugivores (Terborgh and Winter 1980, Leighton and Leighton 1983, Johns 1983, 1988; Laurance *et al.* 1997).

In addition, most small carnivores are hunted throughout the world. They are an important protein source for many local communities in the tropics (IUCN publication). Often, accidental trapping contributes to the death of many small carnivores. Meat, fur, scent extract, internal organs, fat, and skin are used in many oriental medicines (Hanfee and Ahmed 2000). The viverrids, particularly the African civet (*Civettictis civetta*) and the small Indian civet are farmed and commercially exploited for the *civet* or scent, extracted at regular intervals from the perineal gland using spray posts or a special wooden spoon (Xavier 1993). Despite animals being kept in captivity, the *civet* is sometimes collected from wild caught animals. A more common and widespread exploitation of mustelids and viverrids is for fur. Ermines (*Mustela erminea*), sable (*Martes zibellina*), mink (*M. vison* and *M. lutreola*) are some of the common species in the pelt and fur trade. Trapping of fur-bearers has led to the decline of many species in America and Europe, and even to the extinction of the sea mink (*Mustela macrodon*) from the coast of New England (Schreiber *et al.* 1989). However, development of captive-breeding centres and fur-bearer farms, and strict regulations of international trade, have helped reduce the pressure on wild populations.

In the Western Ghats, hunting or poaching for commercial use in local markets is negligible, although hunting does occur (Madhusudan and Karanth 2000). Most people are not even aware of the existence of many of the small carnivore species found in the Western Ghats. Sometimes, herpestids, viverrids, and mustelids are captured from the wild and sold to private collections and zoos. Roadkills are found commonly on busy highways, both within and outside wildlife reserves (Kumara *et al.* 2000a). The extent of persecution of small carnivores in the Western Ghats is not clearly known. A number of small carnivore species are considered vulnerable and threatened in tropical Asia (Schreiber *et al.* 1989). In India, viverrids, herpestids, and mustelids are listed under Schedules I to IV of the Wildlife (Protection) Act of 1972 (Anonymous 1994), which ensures some security for these species. However, the fate of more restricted and endemic species such as the brown palm civet, Malabar civet, and the Nilgiri marten remains threatened.

1.1.6 Research on small carnivores

Globally, fewer than 15% of the known species of terrestrial carnivores have been subjected to intensive field study, many of these being large carnivores and species found in the temperate region (Schaller 1996). This is also the case in South and South-east Asia, where most large carnivores have been studied in detail (Schaller 1967, Sunquist 1981, Johnsingh 1983, Rabinowitz 1989, Schaller *et al.* 1989, Chundawat 1992, Chellam 1993, Jhala 1993, Karanth and Sunquist 1995). In contrast, there have been few detailed studies of small carnivores, particularly the viverrids (Rabinowitz 1990, 1991, Joshi *et al.* 1995, Grassman 1998, Kumar and Umapathy 2000). However, many species of herpestids and mustelids have been studied in Africa and Spain, and in the temperate region (Rasa 1977, Palomares 1993a, Clevenger 1993 a,b; Cavallini and Nel 1995, Zielinski and Kucera 1995, Ray 1997, Jędrzejewska and Jędrzejewski 1998 to cite a few).

As Schaller (2000) has rightly pointed out, "Although considered archaic by some, natural history remains the cornerstone of knowledge about species (including the human species) and their role in ecosystems, and it provides the basis for elucidating the biological patterns and principles upon which conservation must depend". Besides knowing basic dietary requirements of small carnivores, it is important to understand the ecological interactions determining their behaviour. Being both carnivorous and frugivorous in diet, small carnivores may switch their feeding habits depending on habitat-wide availability of food resources as in other vertebrates (Leighton and Leighton 1983) or nutritive quality of food items (Herrera 1989). Resource availability could also determine their ranging and movement patterns, and habitat choice (Joshi *et al.* 1995, Lovari *et al.* 1996). Many species of small carnivores, particularly the palm civets, are known to be predominantly frugivorous (Bartels 1964, Herrera 1989, Rabinowitz 1991). They may be important agents of seed dispersal and regeneration of many plant species. The role of small carnivores as seed dispersers is one of the most poorly studied aspects of their ecology, despite knowledge of their frugivorous habits (Leighton and Leighton 1983, Smythe 1986). It remains to be determined whether they are effective seed dispersers (Herrera 1989), an aspect which has potential implications for the maintenance of rainforests in degraded area and abandoned plantations in the Western Ghats.

Similarly, home range area requirement is a critical parameter, as it is often related to extinction proneness, susceptibility to habitat fragmentation, and is required to evaluate the efficacy of protected areas and forest patches for conservation of wide-ranging carnivores and frugivores (Thiollay 1989, Poonswad and Tsuji 1994, Turner and Corlett 1996). Sex and season also influence home range size. Males tend to have larger home ranges in most carnivores, due to size dimorphism and social organisation (Gittleman and Harvey 1982). Ecological effects on home range size and habitat use occur due to seasonality in food or other resource availability, with home range size expected to be inversely related to food availability (as shown in the common palm civet, Joshi *et al.* 1995). Allometric considerations of body size also influence home range size and energetic requirements of carnivores (Gittleman and Harvey 1982, Silva *et al.* 1997). Frugivorous habit tends to reduce basal metabolic rates in small carnivores (McNab 1995), but its implications for home range size are poorly known.

Another aspect of small carnivore ecology that needs detailed research is their conservation status, and distribution-abundance patterns, in light of ongoing fragmentation and human disturbances. Carnivores, because of their relatively large home range needs, may be particularly vulnerable to such habitat transformations. Decline in habitat area relative to home range needs *per se*, or concurrent changes in specific habitat parameters due to edge effects and human disturbances, affect the distribution and abundance of mammals (Lovejoy *et al.* 1986, Turner 1996), including small carnivores (Heydon and Bulloh 1996). In human-dominated modern landscapes, where much habitat will survive only as fragments, the remnant patches attain high significance for conservation and cannot be ignored (Madhusudan 1995, Turner and Corlett 1996).

1.2 SMALL CARNIVORES OF THE WESTERN GHATS

1.2.1 Diversity

The 30 species of small carnivores found in India, belonging to the three earlier mentioned families (Johnsingh 1986), occur in two major pockets of small carnivore diversity. The Himalaya and north-east India is one, where mustelids dominate the small carnivore community at higher altitudes with temperate climatic regimes. The second important centre of small carnivore diversity is the Western Ghats.

The Western Ghats is a chain of hills running for a stretch of 1600 km along the west coast of India from 8° N to 21° N. It encompasses various forest types such as the tropical rainforests, moist and dry deciduous forests, montane grasslands, and dry thorn forests (Champion and Seth 1968). These habitats occur over an altitudinal range from sea level to 2700 m asl. Each of these habitats contains a distinct assemblage of small carnivores. Apart from being elusive, cryptic, and nocturnal, many of these small carnivores occur in habitats where they are difficult to sight, and therefore little is known of their ecology.

The Western Ghats has 13 species of small carnivores: 4 civets, 4 mongooses, and 5 mustelids. The four species of viverrids are the common palm civet (*Paradoxurus hermaphroditus*), brown palm civet (*P. jerdoni*), small Indian civet (*Viverricula indica*), and Malabar civet (*Viverra civettina*). The four species of herpestids are the ruddy mongoose (*Herpestes smithii*), common grey mongoose (*H. edwardsii*), stripe-necked mongoose (*H. vitticollis*), and brown mongoose (*H. fuscus*). The mustelids are the Nilgiri marten (*Martes gwatkinsi*), ratel (*Mellivora capensis*), smooth-coated otter (*Lutrogale perspicillata*), small-clawed otter (*Amblonyx cinereus*) and common otter (*Lutra lutra*). The small felids that occur in the region are the leopard cat (*Prionailurus bengalensis*), jungle cat (*Felis chaus*), rusty spotted cat (*P. rubiginosus*), and fishing cat (*P. viverrinus*). However, the focus of this ecological study was the brown palm civet, and the four other species of interest described below that are non-aquatic and occur in tropical rainforests. Brief descriptions of the study species are given in the following sections.

1.2.2 Study species

1.2.2.1 *The civets*

The **brown palm civet** or the **Jerdon's palm civet**, the focus of this study, replaces the common palm civet in tropical rainforests of the Western Ghats south of 13° 45' N. It has a uniformly brown pelage, darker around the head, neck, shoulder, legs, and tail (Plate 1). The dark tail sometimes has a white tip. It has no distinct markings on the body or the face as in the common palm civet.

Sometimes the pelage may be slightly grizzled. A distinctive feature is the reversed direction of hair growth on the nape, similar to that in the golden palm civet of Sri Lanka. It is about as large as the common palm civet, but with a long and sleek tail.

The brown palm civet is an endemic, restricted to the rainforest tracts of the Western Ghats south of 13° 45' N. They have been reported from an altitudinal range of 500–1300 m, being more common in higher altitudes (Mudappa 1998). Recent photographs or sight records are from Anamalais, Nilgiris, and Coorg (Schreiber *et al.* 1989 and references therein), Silent Valley (Christopher and Jayson 1996), and Kalakad-Mundanthurai Tiger Reserve (Mudappa 1998). The brown palm civet is probably sympatric with the common palm civet only in the transition zones between the rainforests and drier habitats. It is a relatively rare species, earlier known only from museum collections or sight records and captive animals in four zoos (Schreiber *et al.* 1989). This is the first ecological study of the species.

The **small Indian civet** is a true civet, with tawny grey or greyish brown pelage. It has dark or black lines along the back and black spots on the flanks (Plate 2). The tail has distinct black and white rings. The small Indian civet is widely distributed. Its range extends from Sind and Punjab in the west, along the Himalayan foothills in the north, south to Kanyakumari, and east into Indo-China and all south-east Asian countries upto Malaya. It has been introduced into Madagascar and a few other islands in the north-west Indian Ocean (Corbet and Hill 1992).

This species occurs in almost all kinds of habitats, including the arid zones of western India. It prefers scrub and dry forests or grasslands and is relatively rare in undisturbed rainforests (Prater 1980, Mudappa 1998). Garbage dumps near settlements are known to attract these civets. They are omnivorous but feed largely on invertebrates, particularly insects (Chuang and Lee 1997). They den in burrows and crevices under rocky outcrops and hedges. Despite being good climbers, they forage largely on the ground. Secretions from their perineal glands are used to mark territories. The only ecological studies are that of Rabinowitz (1991) in Thailand, and Kumar and Umapathy (2000) in India. These studies showed that they are nocturnal in habit and have home ranges of 2 – 3 km^2.

1.2.2.2 *The mongooses*

The **brown mongoose** is found in the Western Ghats, south of north Karnataka (14° N), and in Sri Lanka. It has a characteristic bushy, conical tail, and black feet (Plate 2). In the Western Ghats, it occurs in tropical rainforests up to an altitude of 1850 m, and is relatively rare (Mudappa 1998). They are also found in coffee plantations. The Sri Lankan race is more common and is considered a major pest of poultry (Prater 1980).

The largest of the Asiatic mongooses is the **stripe-necked mongoose** (Plate 2). It is restricted to the Western Ghats in India and Sri Lanka. In the Western Ghats, it is found south of North Kanara District in Karnataka. The species has a distinct black stripe with a white border on the sides of the neck. The fur is a reddish brown, being more reddish in the southern populations. The stripe-necked mongoose occurs in well-wooded habitats, particularly in dry and moist deciduous forests. They are known to prefer streams and rivers, and are believed to feed extensively on crabs. There are reports of them hunting small mammals such as mouse deer in Sri Lanka (Prater 1980).

1.2.2.3 *The mustelid*

The **Nilgiri marten** is the southern counterpart of the yellow-throated marten (*Martes flavigula*) of the Siwalik hills and the Himalaya. It is endemic to the Western Ghats, and known to occur from south of 12° N (Coorg). It has a mostly black body with a stout tail, typical weasel-like legs, and a flat, pointed head (Plate 1). The throat is brightly coloured, ranging from pale yellow to bright orange. Its gait is weasel-like while hopping on the ground, and it seems very comfortable on trees. It has been observed to traverse long distances on the canopy in undisturbed, dense, rainforests (*personal observations*). Moist forests, tropical rainforests, and montane sholas are its preferred habitats (within an altitudinal range of 300–1200 m). It is mostly diurnal in its activity.

Nilgiri martens have been observed to hunt small vertebrates like mouse deer *Moschiola meminna* and the monitor lizard *Varanus bengalensis* (N. M. Ishwar *personal communication*, and *personal observation*). There is a report of them feeding on the nectar of *Ceiba pentandra* (silk cotton tree, Hutton 1944). In some areas of their distribution (as in Coorg), they are considered pests as they raid honey from boxes in farms (A. Kumar, *personal communication*). The ecology of this species remains largely unknown. The species has been reported from various parts of the southern Western Ghats (Madhusudan 1995, Yoganand and Kumar 1995, Christopher and Jayson 1996, Gokula and Ramachandran 1996, Mudappa 1998).

1.3 OBJECTIVES AND ORGANISATION OF THE THESIS

This is the first study of the ecology of the brown palm civet and of the impact of fragmentation on small carnivores in the Western Ghats. This study aimed to

- understand the dietary requirements of the brown palm civet, and its role as a seed disperser in tropical rainforests.
- examine the influence of body size, habitat, and food availability on the ranging and activity patterns of the brown palm civet in a relatively undisturbed rainforest.

- determine the community structure of small carnivores in undisturbed rainforests.
- assess the changes in small carnivore community as a result of rainforest fragmentation and associated habitat alterations.

The thesis is organised into six chapters. Chapter 1 (this chapter) deals with the diversity, distribution, and characteristics of the study group. It also provides the background for the study and descriptions of the study species. In Chapter 2, a detailed description of the study sites and a brief description of the methods used for data collection and analyses are given. This is followed by four chapters describing the main results of the study. Each results chapter contains a comprehensive review of earlier studies, details of the methods and analyses used, results, and their interpretation. Chapter 3 gives an account of the diet of the brown palm civet, the basis of its food choice, and an assessment of the species as a seed disperser. As the species was found to be highly frugivorous, in Chapter 4, the intra- and inter-annual patterns of fruit availability are presented. This chapter also deals with the spatial distribution of some of the important food plant species of the civet. In Chapter 5, I examine the ranging, movement, and activity patterns of the brown palm civet in relation to habitat quality and food availability. In the final results chapter, Chapter 6, I examine the changes in the small carnivore community in rainforest fragments in comparison with a relatively undisturbed and extensive rainforest. The main conclusions and conservation implications of the study are briefly highlighted in a concluding section.

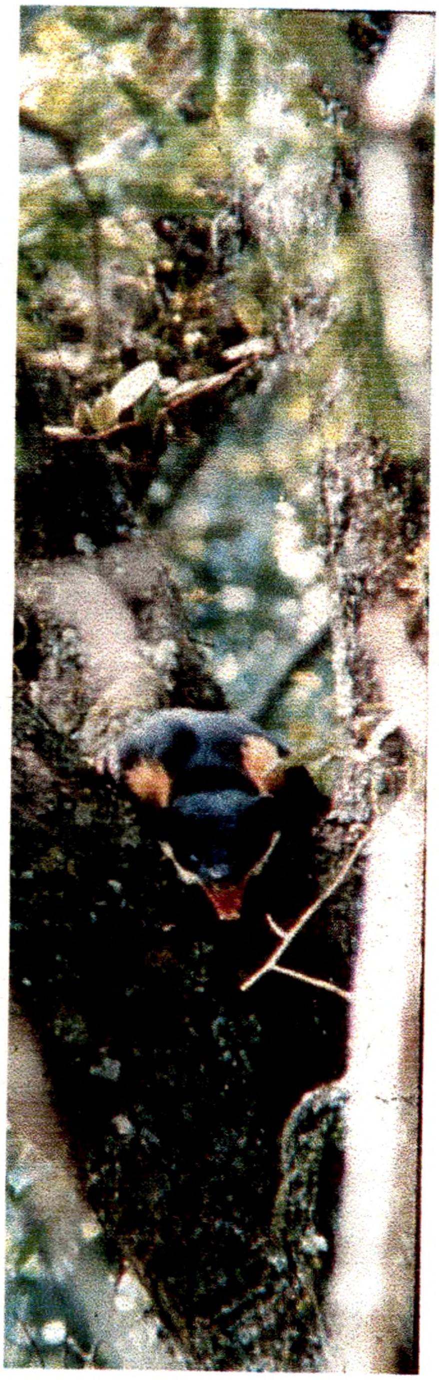

Plate 1: Endemic small carnivores of the Western Ghats.

Nilgiri marten (left) and brown palm civets (above).

PLATE 2


SMALL INDIAN CIVET


BROWN MONGOOSE


STRIPE-NECKED MONGOOSE

Chapter II

2 WEED ECOLOGY - A REVIEW.

2.1 Weeds: definition and classification

Weed is a general term for any troublesome or otherwise undesirable plant, which is usually inadvertently introduced and grows without intentional cultivation (Herbert 1962). According to Encyclopaedia Americana (1962) weed is a plant growing out of place, where it is not wanted because it is taking the place reserved for something else. More or less closely similar definition is accepted by National Academy of Sciences, Washington (1971), Gupta and Lamba (1978), Rao (1983) and Indian Society of Agronomy (1987). Crafts and Robbins (1973) proposed a more realistic definition of the weeds as “plants, out of place, unwanted, not useful, often prolific and persistent, competitive, harmful and even poisonous and interfere with agricultural operations, increase labour, add to costs, reduce yields and detract from the comforts of life”.

A variety of classifications based on various criteria are proposed for weeds. A brief discussion of such classifications is given here. According to their life cycle, weeds can be annuals, biennials or perennials. Based on their association with human habitations they are classified as obligate weeds and facultative weeds (Zohary 1962). Those found only in association with man and never in wild are obligate weeds. While those that grow both in wild (in primary habitat) and in association with man in cultivated fields are facultative weeds. According to their origin, weeds can be called as 1) alien (foreign in origin) 2) apophytes (indigenous to a country). Many of them introduced by man are known as anthrophytes. Weeds are also classified according to stem character, those having aerial stem (herbs, shrubs, bushes or woody species) and those having sub aerial stem with storage organs (nuts or rhizomes). Both dicot and monocot plants are seen as weeds. Weeds can be also classified according to their soil preference; some plants prefer alkaline soil and some acidic soil (Table 2.1).

Table 2.1 Classification of weeds

Classification based on		**Example**
Life cycle	Annuals	*Argemone mexicana*, *Tephrosia purpurea Chenopodium album*, *Phalaris minor*, *Eleusine indica* and *Avena fatua.*
	Biennials	*Daucus carrota* and *Zingiber casumunar*
	Perennials	*Lantana camara*, *Cynodon dactylon* and *Imperata cylindrica.*
Association with man	Obligate	*Convolvulus arvensis*, *Phalaris paradoxa*, *Amaranthus hybridus*, *Chenopodium murale* and *Anagallis arvensis.*
	Facultative	*Argemone mexicana*, *Euphorbia dracunculoides* and *Indigofera cordifolia.*
Origin	Alien	*Argemone mexicana*, *Parthenium hysterophorus*, *Eichhornia crassipes*, *Chromolaena odorata* and *Lantana camara.*
	Apophytes	*Acalypha indica*, *Sida* spp. and *Cassia tora.*
Stem characters	Herbs	*Chenopodium album* and *Eclipta alba.*
	Shrubs	*Abutilon indicum* and *Lantana camara.*
	With storage organs	*Cyperus rotundus*, *Inula indica* and *Colocasia antiquorum.*
Habitat	Terrestrial	*Lantana camara, Sida acuta and Cassia tora.*
	Aquatic	*Pistia stratiotes*, *Eichhornia crassipes*, *Potamogeton pectinatus* and *Vallisneria spiralis.*
Soil preference	Alkaline	*Cressa cretica* and *Sporobolus diander.*
	Acidic	*Rumex acetosella* and *Pteridium aquilinum.*

(Sen 1981, De and Mukhopadhyay 1984, De 1995).

2.2 Introduced weeds

Species which have originated through evolution and natural selection in the particular region, are called native or indigenous, while those species which have not originated in the region but have immigrated from elsewhere, are known as alien, exotic, non-indigenous, adventitious, neophyte, introduced or migrant (Mack 1985, Saxena 1991). Exotic weeds are very vexatious and aggressive than the indigenous ones. Many of them establish self-sustaining population outside their native range (Lodge 1993). According to Saxena (1991), 40% of the species in the Indian weed flora are introduced. A successful invasion by exotic species is because of the similarity of the original habitats of exotics and the new habitats in climatic and edaphic conditions (Holdgate 1986) and absence of their competitors and predators in the new location (Pimm and Gilpin 1989).

There are over 2000 species of non-native plants in the United States of America, many of which cause significant economical and ecological damage (Anonymous 1993). Since European settlement, 1500 - 2000 species of plants have been introduced in Australia. Over 200 plant species are considered noxious weeds in one or more states of Australia and many of them are environmental weeds (Humphries *et al.* 1991, Parsons and Cuthbertson 1992). In US and Australia many invasive plant species are found to have the ability to spread over large areas and threaten the natural ecosystems. Still plant introduction continues at an alarming rate (Anonymous 1993). In India and other countries plant invaders successfully colonise open habitats, created by a high degree of disturbance (Crawley 1987, Ramkrishnan and Vitousek 1989, Hobbs 1989, DeFerrari and Naiman 1994). Invaders cause change in disturbance regimes, which profoundly alters the composition and succession of the community and affects the ecosystem development (Mack and D' Antonio 1998).

Many exotic weeds in India (Table 2.2), were introduced intentionally for agricultural, forestry, ornamental and other purposes. A few were introduced accidentally through transportation by people and because of negligence. *Parthenium hysterophorus, Phalaris minor* and *Avena fatua* were introduced with imported seeds. *Chromolaena odorata, Mikania micrantha, Erigeron* spp., *Ageratum conyzoides, Lantana camara, Parthenium hysterophorus,* all of tropical American origin are well adapted to manmade habitats. Many of these species have also invaded areas far from human habitations (Azeez *et al.* 1999) and have expanded at an alarming rate during the last few decades.

Table 2.2 Common exotic weeds in India

Species	**Native to**
Acanthospermum hispidum	South America
Ageratina adenophora	Central America
Ageratum conyzoides	Tropical America
Argemone mexicana	West Indies
Bidens pilosa	South America
Chromolaena odorata	Subtropical and tropical America
Croton bonplandianum	South America
Eichhornia crassipes	America
Eupatorium riparium	Tropical America
Eupatorium repandum	South America
Galinsoga parviflora	Tropical America
Lantana camara	Subtropical and tropical America
Lippia germinata	South America
Mimosa invisa	South America
Mikania micrantha	South America
Mimosa pudica	South America
Opuntia dillenii	South America
Parthenium hysterophorus	West Indies & North Central America
Prosopis juliflora	Central America
Synedrella nodiflora	West Indies
Tridax procumbens	Central America
Xanthium strumarium	South America

(Sen 1981, Saxena 1991, Matthew 1991, Muniappan and Viraktamath 1993).

Parthenium hysterophorus, a native of West Indies and North Central America was introduced with food grain imports. Within a few decades, it became a serious weed in the country. According to Rao (1956), it was first time occurred in the western part of Peninsular India in 1956, while according to Bennet *et al.* (1978) the species was reported since 1810 in different herbarias. Towards the end of 1970s it had spread all over the country and became a dominant weed (Rao and Suryanarayanan 1979). The weed has spread all over India, covering approximately five million hectaresof land. It has taken over many cultivated areas. *Parthenium hysterophorus* is more successful in open habitat where native vegetation is severely damaged. It is a less aggressive invader in natural forest because of its small size, limited competitive ability, and is mostly incapable of colonising areas with thick vegetation.

Because of railways and steam-ships, many weeds got entry in India. *Acanthospermum hispidum*, *Alternanthera echinata* and *Croton bonplandianum,* native to America and introduced via surface transport, grow abundantly in south India. *Acanthospermum hispidum* was first noticed near a railway station (Tadulingam and Venkatnarayana 1932). *Croton bonplandianum* is found mostly along the east-coast railway. *Flaveria australasica* first appeared near ports of East Coast in south India. Some inadvertently imported common weeds are; ornamentals (*Saponaria, Linaria, Polygonum, Eichhornia, Salvinia* and *Lantana*), forage and grazing plants (grasses) and kitchen garden herbs (*Brassica* and *Portulaca*).

Lantana camara is a native of tropical and subtropical America. It was introduced as an ornamental plant to Asia and Africa in early 1800s (Muniappan *et al.* 1996). Today this aggressive, fast growing, drought tolerant plant is ranked among the ten most troublesome weeds in the world (Holm *et al.* 1977). *Lantana camara* has established as a weed throughout the tropics and sub tropics from the USA and the Mediterranean in the North to South Africa and the northern tip of the New Zealand in the south (Swarbrick *et al.* 1995). *Lantana camara* was first introduced in Calcutta in 1909 as an ornamental plant. It forms monospecific stands along the road sides, fence lines and waste lands, disturbed forests, pastures and plantations (Thaman 1974, Waterhouse and Norris 1987). On invading disturbed forests and plantations the species dominates the under storey.

Chromolaena odorata, a native of subtropical and tropical America from Florida to Argentina is commonly found in areas below 1000 meters altitude except undisturbed rain forest (Chevalier 1949, Waalkes 1953, McFadyen 1989, Gautier 1993). It is considered as a noxious weed in 23 countries of the world. including India (Olaoye 1986, Torres and Paller 1989, Waterhouse 1994, Slaats *et al.* 1996). It has infested millions of hectares of natural grazing lands in Asia and Africa. In Asia it is a major weed of the pasture and plantations and disturbed forests (Ivens 1974, Soerjani *et al.* 1975, Ambika and Jayachandra 1980, Leggitt 1983, Wu *et al.* 1984, Olaoye 1986, McFadyen 1995, McFadyen 1996, Slaats *et al.* 1996). It was introduced in India in 1840s, probably via the Botanical Garden in Calcutta (McFadyen 1989, Gautier 1992). From Calcutta, the species spread east into Assam and Myanmar (Burma), and then to east and southeast through Indonesia and Indochina (McFadyen 1989). It has become a serious menace specifically in the southwest and northeast warm humid regions of India within a period of 50-60 years (Saxena 1991). In Kerala, it was accidentally introduced via clothings of soldiers of II World War returning from Bengal (Maheshwari 1962, Muniappan and Viraktamath 1993). Its invasion is responsible for shifting entire villages in some areas of India (Holm *et al.* 1977). It was first noticed in the Philippines in the late 1960s (Pancho and Plucknett 1971). It came to the West Africa in the 1930s (Prasad *et al.* 1996), to Guam in 1963 (Marutani and Muniappan 1991), to Marianas in 1973 (Fosberg and Falanruw 1973) and to East New Britain in 1982 (Henty and Pritchard 1982). In all the affected countries it has spread rapidly and has been a serious weed of plantations, disturbed forests and pastures (Ivens 1974, Soerjani *et al.* 1975, Ambika and Jayachandra 1980, Leggitt 1983, Wu *et al.* 1984, Olaoye 1986, Slaat 1996, McFadyen and Skarratt 1996, Gautier 1996).

Argemone mexicana, commonly known as Mexican-poppy was introduced in India, from Mexico and is a weed of fallow land. It competes well with other species. *A. mexicana* and *A. ochroleuca* are two closely related exotic species distributed throughout the Indian subcontinent (Ramakrishnan 1972).

Prosopis juliflora was introduced in India in 1870 from Mexico. This species introduced in Rajasthan, due to its sand stabilisation qualities, currently is invading fertile agricultural land and is very difficult to control (Singh *et al.* 1999). *Mimosa invisa,* native of South America, invades vacant land as well as agricultural field. It does not invade closed forests. This species forms thickets that are impenetrable. *Bidens pilosa* (known as Spanish needle or beggar's tick), of neotropic origin, has spread in coffee plantation and roadsides. *Mikania micrantha,* commonly known as 'mile a minute plant', is also of neotropical origin. This species has become a serious problem species in many natural forest patches in central and south Kerala (Muniappan and Viraktamath 1993, Azeez *et al.* 1999, Sankaran and Sreenivasan 1999)

Ageratina adenophora, known as crofton weed, is a native of Mexico. In India it is mainly observed in the forests of Himachal Pradesh, foothills of Himalayas, north-east India and the Western Ghats. It prefers humid temperate climate. It invades vacant lands, roadsides and disturbed forests, grows rapidly, and produces many shoots. *Ageratina adenophora* is now very common in higher elevation areas with cooler temperature and high rainfall (Saxena 1991).

Eichhornia crassipes, the aquatic weed, grows in a wide range of habitats and exhibits phenotypic plasticity. It is native of America and has spread extensively into subtropical parts of USA, Portugal in Europe, tropical Australia, Africa and Asia, wherever climatic conditions are comparable to the native sites (De 1987). It was introduced in eastern India as an aquatic ornamental flowering plant. It is a most troublesome aquatic weed spreading all over country because of its fast vegetative multiplication. It is a serious pest of Bengal and is known as a Terror of Bengal. *E. crassipes* has choked the canal system of Bhakra, Rajasthan and many other canals and water ways. It multiplies by stolon and seeds. It can produce up to 5000 seeds per plant. The seeds sink to the bottom and remain viable for at least 15 years (Chandra Singh and Rao 1976). It has upright leaves serving as sails helping in its distribution. Petiole is long, round and bladder shaped which helps in keeping the plant self-buoyant. It contaminates drinking water. Many water bodies are so thickly infested with this weed that they resemble a green terrestrial field.

Sub optimal conditions may adversely affect native species but help in invasion of an exotic species. *Eichhornia crassipes* has selective advantage over native *Pistia stratiotes* in the Asian tropics, which is related to their pH tolerance. *Pistia* has a narrow tolerance range with optimal growth at pH-4, while *Eichhornia* has wider ecological amplitude with optimal growth in close to neutral water. Growth of *Pistia* was more in nutrient rich water, while *Eichhornia* grows better and rapidly multiplies in both nutrient rich as well as poor waters (Chadwick and Obeid 1966).

Alien species like *Xanthium strumarium*, *Parthenium hysterophorus, Argemone mexicana*, *Ageratum conyzoides* and *Erigeron linifolius* usually dominates highly disturbed and artificial landscapes. Species such as *Citrullus vulgaris* and *Canabis sativa,* which were deliberately introduced, have started to grow wild.

2.3 Adaptations

Weeds have unique capability for adaptation. They can survive in varied environmental conditions and have high potential to adapt to changed situations. Most of the weeds produce large number of seeds, which can remain dormant in unfavourable conditions. They have ability to grow rapidly, multiply fast under stress conditions, and can compete successfully with native vegetation. According to Saxena (1991), fast growth and multiplication through an effective utilization of environmental resources in disturbed habitats are the key strategy characteristics which contribute to success of plant invaders. Weeds compete with other species mainly for space, nutrients, light and water. Most of the invaders are r- strategist. This is one of the reasons of their successful invasion and establishment (Ramakrishnan 1991). Seed polymorphism, existence of ecotypes and ecological races are some of the other features, which help weeds to cope with varying microenvironment (Table 2.3).

Table 2.3 Weeds and their adaptations

Adaptations	**Weedy species**
Adaptations to various environmental changes	
Drought	
Small leaves, spines, deep root system	*Prosopis juliflora*
Coiled root system	*Convolvulus microphyllus*
Stoloniferous under ground stem and tuber	*Cyperus* spp. *Cynodon dactylon* *Eleusine compressa*
Tolerance to hot and dry conditions	*Trianthema portulacastrum* *Portulaca quadrifida* *Cyanotis cucullata*
Plasticity and adaptability to environmental extremes	*Chromolaena odorata* *Lantana camara* *Parthenium hysterophorus*
Photoperiodically and thermoperiodically neutral	*Parthenium hysterophorus*
Capacity of resprouting after burning	*Lantana camara* *Chromolaena odorata*
Allelopathy	
Allelopathic to other plants	*Parthenium hysterophorus* *Argemone mexicana* *Prosopis juliflora* *Mikania micrantha* *Chromolaena odorata*
Morphological adaptations	
Imitating general appearance of crop plant	*Phalaris minor* *Avena fatua*
Special devices of armatures, such as spines, prickles, bristles, stinging hair and glandular hair.	*Mimosa* spp. *Bidens pilosa*

	Tribulus terrestris
Ecotypic and Phenotypic plasticity	*Lantana camara* *Ageratina adenophora*
Multiplication	
Both vegetative and reproductive multiplication	*Cenchrus setigerus* *Mikania micrantha*
Numerous seed production	*Argemone mexicana* *Chromolaena odorata* *Parthenium hysterophorus* *Phalaris minor* *Ageratina adenophora* *Mikania micrantha*
Rooting at nodes	*Citrullus colocynthis* *Ipomoea pescaprae*
Presence of adventitious roots from aerial node	*Eriocaulon* spp. *Cyperus* spp. *Sphaeranthus* spp. *Cynodon dactylon*
Seed dispersal	
Anemochory (by wind)	
Seeds having pappus	*Chromolaena odorata* *Pulicaria* spp *Echinops* spp.
Seeds having fine hairs	*Calotropis* spp. *Asclepias* spp. *Pergularia* spp.
Seeds can move on soil surface	*Aristida* spp. *Tragus* spp. *Cenchrus* spp.
Extremely minute seeds can be easily blown by wind.	*Orobanche* spp. *Striga* spp.
Exozoochory (seeds get attached to animals skin and get dispersed)	
Seeds having hooks, spines and stiff hair.	*Bidens pilosa* *Tribulus terrestris* *Achyranthes aspera* *Aristida funiculata* *Triumfetta rotundifolia* *Tragus racemosus* *Xanthium strumarium* *Alternanthera echinata*
Endozoochory	
Attractive to birds	*Loranthus* spp. *Viscum* spp. *Abrus precatorius* *Lantana camara* *Croton bonplandianum*
By field rats and rabbits	*Cenchrus setigerus* *Dactyloctenium aegyptium*
Having explosive, twisting mechanism for seed dispersal.	*Ruellia prostrata* *Ruellia patula*

	Clitoria ternatea *Tephrosia* spp. *Argemone mexicana*
Seed dormancy and viability	
Having seed dormancy and viability	*Cenchrus* spp. *Dactyloctenium* spp. *Indigofera* spp. *Lathyrus* spp. *Heliotropium* spp. *Citrullus* spp. *Chenopodium album*
Resistance to fire	*Crotalaria medicaginea*
Parasitism	
Stem parasites	*Loranthus* spp. *Cuscuta* spp.
Root parasites	*Striga* spp. *Orobanche* spp.
Adaptations to escape from control measures	
Deep penetrating root system and storage organs to escape chemical treatment and ploughing	*Imperata cylindrica* *Sorghum halepense*

(Sen 1981, Rao 1983, De 1995)

2.3.1 Adaptations to various environmental changes

As weeds have large ecological amplitude, they are capable of multiplying and flourishing even in changing environment. Weeds are tolerant to adverse edaphic, climatic and biotic factors as compared to other plants and crops. They bear certain special attributes, which help in their perpetuation, multiplication, dissemination, stabilisation and overall adaptation (Table 2.3, De 1995).

2.3.1.1 Drought

In order to tide over drought conditions many species have modified morphology. Reduction in leaf size, mucilaginous and hairy stems, rapidly spreading and deep penetrating root system and physiology which maintains higher osmotic potential, translocation, storage and photosynthetic pathways are common adaptations (De 1995). Weeds are mainly C4 plants or under drought change to C4 pathway to achieve higher efficiency in photosynthesis (Sen 1981). Because of restricted availability of water, many weeds in arid regions complete their seed germination and establishment in a brief span. Many of them bear special structural modification to curtail water loss during drought, such as thick cuticle, sunken stomata and waxy coating (Mohan Ram and Gupta 1997). In arid regions like deserts in Rajasthan, *Prosopis* and other weed species compete with other plant species for soil moisture. *Prosopis juliflora,* an aggressive, fast spreading and highly adaptable species for all types of soils including saline alkali soils, is seen almost everywhere except cold deserts and stagnant water areas (Troup 1983, Vimal and Tyagi 1984, Singh 1994, Singh *et al.* 1999). It is also a halophyte as it can tolerate high soil salinity (Felker 1981). *P. juliflora* has high nutrient uptake capacity and tolerates temperatures up to 46°C. Under dry situation, its roots can reach to 7-18m depth. In certain situations, the roots are found even up to 50m depth and lateral root up to 48m depth (Prajapati 1971). *Prosopis* also shows other adaptations to arid conditions such as small leaves and spines. In weeds like *Convolvulus microphyllus* root system is coiled to increase surface area and length for increased absorption efficiency. Arid zone plants such as *Boerhavia diffusa* and *Crotalaria burnia* have tapering main root and limited number of laterals. Grasses such as *Cynodon dactylon, Cyperus* spp. and *Eleusine compressa* are known to survive under very dry conditions. Leaves of these grasses may get dried up but the thick roots, swollen stoloniferous under ground stem and tuber remain alive to regrow in favourable conditions.

Weeds have a wide range of moisture requirement for seed germination. Weed species efficiently utilise available moisture. Many weeds are tolerant to crowding. They have higher relative frequency and density compared to other plants in the community (De 1995). Some weed species either endure, escape or evade unfavourable environmental changes by adopting various dormancy forms (De 1995). Many weeds have thick cuticle, cork and bark as defence against fungi, insects and adverse climate. Weeds such as *Parthenium hysterophorus, Lantana camara* and *Chromolaena odorata* are not much affected by soil, climate and other environmental conditions and have remarkable plasticity and adaptability to environmental extremes except extreme cold. *Chromolaena odorata* shows strong climatic adaptations and competes well with native vegetation. It dries during summer but clumps remain alive to sprout after the first rain. However, *Chromolaena odorata* can not survive in shady vegetation in dense undisturbed forests.

When certain weeds migrate from moist to dry area, they exhibit some changes e.g. *Echinops echinatus* and *Convolvulus arvensis* are winter season weeds of Rabbi crop in north India but they have established well in arid zone by germinating in rainy season. In many weeds of Indian deserts, growth of shoot stops temporarily for certain duration after producing first few leaves but root system penetrates deep down into soil and absorbs moisture from deeper layers. After establishing a deep root system, they can compete with other plants and even if shoot is damaged, young plant can sprout vigorously from well-established roots (Sen 1981). In dry lands, weeds exhaust the soil moisture,

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putting the crop in stress. Weeds with radicoid forms easily escape drought, fire, soil erosion and man made modifications such as repeated cultivation, ploughing and irrigation (De 1995). Some weeds such as *Trianthema portulacastrum, Portulaca quadrifida* and *Cyanotis cucullata* can survive in hot dry conditions for many days.

2.3.1.2 Light

Some weeds like *Parthenium hysterophorus* are photoperiodically and thermoperiodically neutral (Sen 1981). Many of them can sustain themselves even at ten percent of incident light (sciophytes).

2.3.1.3 Fire

Lantana camara burns rapidly even when green and creates additional favourable sites for own expansion. *Lantana, Chromolaena* and *Mikania* regenerate more profusely after fire, and suppress other native species. *Chromolaena odorata* can resprout after burning and converts the forest in to thickets by its vigorous growth and sprawling habit (Rouw 1991).

2.3.2 Allelopathy

Allelopathy is one of the important strategies that increase the competitive ability of a species (Fischer *et al.* 1994, Langenheim 1994). Molisch (1937) suggested the term allelopathy for expressing the detrimental effects that one plant species has on another through the formation of chemical retardants. The concept of allelopathy was further developed by Bonner (1950), Bonner *et al.* (1959), Grummer and Beyer (1960), Evenari (1961), Tukey (1969), Sen *et al.* (1969), Muller and Chou (1972), Rice (1974), Roy (1974), Putnam and Duke (1978), Achhireddy and Singh (1984) and Sahid and Sugau (1993).

A broad-spectrum of growth inhibitors is found in different parts of the weeds. They liberate these metabolites through the process of weathering, leaching, exudation or volatilisation. *Parthenium* contains allelochemicals such as caffeic, vanillic, fernlic, chlorogenic and anisic acids and sesquiterpene, lactone and parthenia. Seed leaching in *Parthenium* inhibits germination of other seeds. Its association deleteriously affects seedling growth and root proliferation of wheat, because of allelopathic syndrome (Sen 1981). Toxic compounds such as chlorogenic, P-commaryquinic and gentisic acids produced by Eucalyptus suppress under growth under the plantations (Del Moral and Muller 1970) but, this suppressive effect is less apparent under high rainfall because of its dilution effect (Ramakrishnan and Vitousek 1989). *A. mexicana* has allelopathic chemicals,which inhibit growth of other plant species (Sen 1980). Leaf litter of *Prosopis juliflora* inhibits germination of black gram and sorghum due to its allelopathic phenolic compounds. Leaf extract and root extract of *P. juliflora* reduced the germination percentage of *Parthenium hysterophorus* (Chellamuthu 1994). *Mikania micrantha* is allelopathic to other plants. It climbs as a vine on other plants and smothers them. *Chromolaena odorata* and *Lantana camara* are known to be highly allelopathic to other plants (Mersie and Singh 1987, Prasad and Srivastava 1991, Sahid and Sugau 1993, Gentle and Duggin 1997a).

2.3.3 Morphological adaptations

Some weeds have developed the special measures of defence by imitating general appearance, colour, shape or typical feature of other crop plants e.g. seedlings of *Phalaris minor* and *Avena fatua* are similar to wheat and barley seedling, making it very difficult to eradicate them from the field. Some weeds bear special devices of armature such as thorns, spines, prickles, bristles, stinging hair and glandular hair. For example *Mimosa invisa,* a giant sensitive plant, is a fast growing scrambler having four to five rows of sharp prickles and armed stems, which protects them from destruction by animals and human beings.

Aquatic weeds shows morphological adaptations such as aeranchymatic cells, absence of stomata or functionless stomata on the lower surface of leaves, breathing roots, absence of root hair and root cap instead of root packets and even absence of roots.

2.3.4 Ecotypic and phenotypic plasticity

Plant invaders have wide ecological amplitude through extreme phenotypic plasticity or due to ecological races adapted to specific habitat (Ramakrishnan 1991). In southern India, *Lantana camara* covers an altitudinal range up to 2000m altitude in the Palni hills, because of its phenotypic plasticity (Matthew 1972). *Ageratina adenophora* an exotic weed in Meghalaya in north-east India, which occurs between 550-1960m altitude shows both plasticity and ecotypic variations (Dev 1981). Some weeds have ecotypes with differential resistance to insect attack and varied nutrient absorbing capacities (Cooley and Martin 1978).

2.3.5 Multiplication

Most weeds have great reproductive capacity and massive potential to recoup. Perpetuation of weeds can be through either seeds or vegetative propagules. In unfavourable environmental conditions adult mother weed plants produce propagules which are resistant to extreme adverse conditions, before their death and maintain their survival (De 1995). Weeds have fast regenerating, restoring, rejuvenating and resurging capacities of both roots and shoots. They are quickly responsive to favourable environment after passing through stressful conditions. Some weed species can produce few million seeds per square meter of field, and enrich the weed-seed population in soil. Some times number of seeds produced by weed per unit area are hundred times more than crop plants (De 1995). Seed production in *Chromolaena odorata* is prolific; the achenes bear a small stiff pappus and are wind dispersed. In Sri Lanka, it has been found that on an average, each plant produces 93,000 seeds (Weerakoon 1972). Seed output of *Argemone mexicana* is 476 per plant (Sen 1981). *Mimosa invisa* produces large number of seeds and they remain viable for a long period. Weeds such as *Pulicaria, Echinops* and *Parthenium* mostly propagate through seeds and a single plant is capable of producing more than 10,000 seeds. Those weeds which reproduce by vegetative method as well as by seeds, multiply enormously (De *et al.* 1986). For example, a successful weed in Indian desert, *Cenchrus setigerus,* regenerates by both seed and vegetative reproduction. *Parthenium hysterophorus* has invaded all over India in a very short period because of its fast vegetative multiplication and numerous seed production (Sen 1981). *Phalaris minor* can produce a number of mature seeds even after uprooting and heaping at the flowering stage (De 1995). Unlike exotic weeds belonging to Asteraceae, *Lantana camara* does not produce large number of seeds. It propagates by seeds, distributed by birds (Mishra and Mishra 1996, Balasubramanian *et al.* 1998) and animals and through hardy root suckers. *L. camara* is not as aggressive as *C. odorata*. In the Western Ghats, the *Lantana* is suppressed and replaced by *Chromolaena odorata* in due course in many locations (Matthew 1972) because aggressive invaders are known to monopolise the ecosystem (Saxena 1991). *Mikania micrantha* roots at nodes when it comes in contact with soil. It reproduces by seeds as well as clonal propagation. Some weeds germinate periodically and some of them germinate throughout the year. In weeds like *Citrullus colocynthis* and *Ipomoea pes-caprae* rooting at thick nodes helps multiplication of plants. Weeds like *Eriocaulon* sp., *Cyperus* spp., *Sphaeranthus* sp. *and Cyanodon dactylon* remains firm in the soil because of presence of adventitious roots from aerial nodes. Even after pulling or grazing a considerable part of the plant remains intact in the soil to regenerate quickly. *Echinochloa colonum* and *E. indica* can re-establish even if a single root is left in the soil.

2.3.6 Seed Dispersal

Seeds of weeds are dispersed by birds, animals, wind, water and by man and his activities. In agricultural fields weed seeds are disseminated by man through handling contaminated food grains, organic mulch, manures, tillage implements, soil and water. Most seeds remain unaffected in the digestive systems of animals and birds, and get dispersed easily through faecal matter, e.g. *Cassytha, Loranthus, Opuntia* and *Lantana*. Hardy seeds of *Trianthema portulacastrum* remain unaffected in the alimentary canal of cattle and disperse through dung. Many weed-seeds are dispersed by birds. For example, seeds of *Loranthus* and *Viscum* stick to beaks of birds while eating fruits and carried by them, get stuck to branches of other trees when they clean their beaks on them. Seeds of *Croton bonplandianum* resemble beetles and may be picked by insectivorous birds and thrown away after finding them useless. Field rats, rabbits and ants help in seed dispersal of *Cenchrus setigerus* and *Dactyloctenium aegyptium* in deserts of Rajasthan. The seeds of weeds such as *Pulicaria, Echinops* and *Parthenium* possess pairs of wings or pappus and can be carried by wind to long distances (Sen 1981). Weeds like *Calotropis, Asclepias* and *Pergularia* of family Asclepiadaceae have fine hairs by which they float in the air and get carried for long distances. Parasitic weeds such as *Orobanche* and *Striga* produce extremely small seeds, which can be easily blown by wind. Downy seeds of grasses such as *Saccharum* and *Cenchrus* are also carried several kilometres by wind. Like other Asteraceae members *Mikania micrantha* and *Ageratina adenophora* produce numerous seeds, which are dispersed by wind. Some weed seeds have hooks, spines and stiff hair, which get attached to the fur of animals, shoes and clothing of people and disperse to a long distances, e.g. *Bidens pilosa, Tribulus terrestris, Achyranthes aspera* and *Aristida funiculata*. *Triumfetta rotundifolia*, *Tragus racemosus, Xanthium strumarium* and many other plants have hooks on the fruit coats or on bracts and are dispersed by sheeps and goats (Fischer *et al.* 1996). In

Alternanthera echinata, the perianth of the fruit is very flat and spine tipped, which sticks to shoes and tyres of vehicles and get carried for long distances.

Many species of Acanthaceae like *Ruellia prostrata* and *Ruellia patula* have explosive mechanisms for seed dispersal. Fruits of these weeds have elastic valves, which spring back forcefully with a slight explosion on getting wet by rain and shoot out seeds to a long distance away from mother plant (Tadulingam and Venkatnarayana 1932). In *Clitoria ternatea* and *Tephrosia* spp. pods dehisce by sudden twisting and throw seeds to considerable distance to prevent shading by mother plant. In *Argemone mexicana* the capsule breaks at the top only by the short valves and numerous seeds inside the fruit scatter over a large area, when the branches shake in the wind.

2.3.7 Seed dormancy and seed viability

Seed dormancy, delayed germination, longevity, and viability of buried seeds for years, help in reproduction and completing the life cycle of weeds year after year. Dormancy is a state of suspended development of seed. Hard seed coat prevents entry of water, light and gas and helps in delaying the germination until suitable environmental conditions occur. Dormant weed seeds are more likely to escape chemical sprays. Many weeds belonging to families such as Fabaceae, Malvaceae, Tiliaceae, Cucurbitaceae, Convolvulaceae and Poaceae show seed dormancy due to hard seed coat, which is impermeable to water. In *Amaranthus retroflexus, Alisima plantago* and *Ipomoea aquatica*, although seed coats are permeable to water, embryo expansion is resisted. Some weed seeds contain inhibiting chemicals such as coumarin, ferulic acid, parascorbic acid, dehydracetic acid and ammonia to delay germination. Many weed seeds can remain viable for ten to forty years. Weeds of Poaceae (e.g. *Cenchrus, Dactyloctenium*), Fabaceae (*Indigofera, Lathyrus*), Boraginaceae, (*Heliotropium, Arnebia*) and Cucurbitaceae (*Citrullus, Mukia*) show seed viability varying from 1 to 15 years (Sen 1981). Seeds of *Chenopodium album* are reported to germinate after remaining buried for 20 to 40 years. Generally, low temperature promotes germination of weeds while high temperature inhibits it. However, weed-seeds of Indian desert germinate only after passing through high temperature of 60 to 70^{o} C during day and low temperature at night, following rainy season. Seeds of *Crotalaria medicaginea* resist even fire. Even after burning in weed infested field, after rains, profuse germination is seen.

2.3.8 Nutrient uptake efficiency

Weeds produce a higher biomass than crop plants per unit area and time. Many of them are capable of absorbing higher amount of N, P and K and other plant nutrients than crop plants. Weeds assimilate six times N, eight times P_2O_5 and three times K_2O, than sugarcane crop at 35 days after planting (Sankaran 1988). Verma *et al.* (1983) estimated N losses up to 64.4 kg/ha in the unweeded control plot within a period of 85 days after planting. Vengris *et al.* (1953) noted that because of high nutrient uptake capacity of weeds, maize yield reduced up to 51-56%. In Indian arid zone, weeds compete with crop for nitrogen, where soil is very poor in nitrates (Sen 1981). Shetty (1973) observed that 65% of N, 62% of P and 65% of K were shared by weeds in direct sown rice crop. A significant negative relationship was observed between N uptake by the crop and weed (Raja 1985, Cinnamuthu 1990). Bai *et al.* (1992) reported that weeding had significantly increased N and P uptake in green grams. Superiority in nitrogen extraction from soil, along with an efficient retranslocation of nitrogen from senescing leaves, is one of the adaptations which enables *Lantana camara* to perform as an invasive species in different sites (Rawat *et al.* 1994).

2.3.9 Adaptations, which help weeds to escape from control measures

Many weeds escape from chemical treatment, as they have deep penetrating root system. Chemicals, which do not leach with water, can not reach down to the absorbing region of the roots. Even after applying adequate control measures some weed seeds escape, as all plants of a single species in a particular habitat do not germinate or grow or bear seed synchronously (De 1995). Changes in weed community in response to tilling are reported by Sans (1993) and Sans and Masalles (1992, 1995). Weeds such as *Imperata cylindrica* and *Sorghum halepense* hide their storage organs well below the plough layer so that they can regenerate even after ploughing the land. Ground stratum weeds escape the reaping and uprooting type of harvesting and produce large number of seeds during the post harvest period (De 1995).

2.3.10 Chemical defence against predators

Many weeds contain poisonous substances such as latex, alkaloids, irritating, bitter, or substances with bad odour that help to protect them from natural enemies (De 1995). *Lantana* is poisonous to domestic as well as wild animals (Swarbrick *et al.* 1995) and affects their liver on consumption. It contains poisonous chemical, lantadene, toxic to cattle and goat (Lal and Kalra 1960, Sastry and Mahadevan 1963). It promotes allergic skin reactions in sensitive individuals (Muniappan and Viraktamath 1993). *Lantana* also shows allelopathic potential to a number of crops (Sahid and Sugau 1993). This feature offers the species a selective advantage over palatable native species.

Ipomoea carnea, Lochnera pusilla, Crinum defixum and *Abrus precatorius* are poisonous to mammals. *Xanthium strumarium*, *Martynia annua* and *Asphodelus tenuifolius* affect the quantitative and qualitative products of livestock. After consuming weeds such as *Cleome viscosa* and *Paederia foetida*, milch animals produce bad flavoured milk. *Astragalus lentiginosus, Astragalus pubentissimus* and *Oxytropis sericea* cause abortion and congenital malformation in sheep and cattle. *Lupinus* sp. causes 'crooked calf disease'. After consuming fresh leaves of *Phalaris tuberosa*, cattle die within 6 hours. *Polygala klotzchii* causes gastro-enteritis and pulmonary haemorrhage in cattle. Fruits and seeds of *Xanthium strumarium, Triumfetta rotundifolia, Pupalia atropurpurea* and *Achyranthes aspera* entangle with the wool. Hooks of *Martynia annua* cause injury to hides. Weeds such as *Parthenium hysterophorus*, *Chenopodium album, Argemone mexicana* and *Heliotropium indicus* cause irritation, allergy and eczema to animals and labourers on contact. Skin rashes caused by *Parthenium* are slow to heal. Weeds such as *Mimosa pudica, Tribulus terrestris, Centipeda minima* and *Datura stramonium* cause wounds, headache, sneezing, giddiness and vomiting. *Datura stramonium* is a deadly poisonous weed. Consumption of plant or its seeds may cause death, disorder or permanent disability. *D. metel* contains alkaloids such as atropine and hyoscyamine, which are poisonous to human beings and animals. Pollen grains of certain weeds cause hay fever. *Rhus diversiloba, R. toxicodendron* and *R. vernix* are poisonous to touch and occasionally cause death after eating fruits, seeds and tubers. In the western USA, *Halogeton glomeratus* kills thousands of sheep every year. Horses suffer with throat ache after consuming barley mixed with *Euphorbia drancunculoides*. Seeds of *Withania somnifera* are poisonous, containing an alkaloid called somniferin (Table 2.4).

Table 2.4 Poisonous weeds and their effects.

Harmful effects	**Weedy species**
Poisonous to animals	*Lantana camara* *Ipomoea carnea* *Lochnera pusilla* *Crinum defixum* *Abrus precatorius*
Deadly poisonous	*Phalaris tuberosa* *Datura stramonium* *Halogeton glomeratus*
Poisonous to touch, poisonous tubers, seeds and fruits	*Rhus diversiloba* *R. toxicodendron*
Contains lantadene, poisonous to cattle	*Lantana camara*
Seeds contain poisonous alkaloid, somniferin	*Withania somnifera*
Contains poisonous alkaloid such as atropine and hyoscyamine	*Datura metel*
Causes wounds, headache, sneezing, giddiness and vomiting	*Mimosa pudica* *Tribulus terrestris* *Centipeda minima* *Datura stramonium*
Hazardous to human health	*Rhus radicans* *Rhus vernix* *Lolium temulentum* *Agrostemma githago*
Causes death, disorder or permanent disability	*Datura stramonium*
Affects quality and quantity of products of livestock	*Xanthium strumarium* *Martynia annua* *Asphodelus tenuifolius*
Affects flavour of milk of milch animals	*Cleome viscosa* *Paederia foetida*
Causes abortion and congenital malformation in sheep and cattle	*Astragalus lentiginosus* *Astragalus pubentissimus* *Oxytropis sericea*
Causes crooked calf disease	*Lupinus spp.*
Causes gastroenteritis and pulmonary haemorrhage in cattle	*Polygala klotzchii*
Fruits and seeds entangle with wool of animals and cause injury	*Xanthium strumarium* *Triumfetta rotundifolia* *Pupalia atropurpurea* *Achyranthes aspera* *Martynia annua*

Causes skin allergy, irritation, eczema to animals and labourers	*Parthenium hysterophorus* *Chenopodium album* *Argemone mexicana* *Heliotropium indicus*
Causes throat ache to horses	*Euphorbia drancunculoides*

(Tadulingam and Venkatnarayan 1932, Sen 1981, Rao 1983, De 1995).

2.4 Impact of weeds

2.4.1 Parasitism

According to Loomis and Wilson (1953), there are about 2500 species of parasitic flowering plants. Loranthaceae and Scrophulariaceae are the families with largest number of parasitic weeds. The commonly seen destructive genera are *Loranthus, Cuscuta, Orobanche* and *Striga. Loranthus* and *Cuscuta*, known as stem parasites,are seen on the aerial portions of the plants. *Orobanche* and *Striga* are root parasites. *Orobanche* causes damage to crops such as tobacco, tomato and brinjal. The economic losses in solanaceous crops due to *Orobanche indica* and *O. cernua* are to the extent of 5-10% in West Bengal, 15-20% in Maharashtra and Gujarat, 20-30% in Madhya Pradesh and 30-33% in Tamil Nadu (Sen 1986). Seeds of *Orobanche* are minute and very similar to tobacco seeds. *Loranthus* causes serious problem in Indian forest plantations especially of teak, casuarina and wattle. Wattle plantation in Nilgiris, southern India, is seriously affected by this parasitic weed. It attacks about 110 species of trees including *Tectona grandis* and *Acacia* spp. *Loranthus longiflorus* attacks *Mangifera* spp., *Albizia* spp., *Acacia* spp. and pomegranate. *Loranthus elasticus* prefers mango, cashewnut, orange and nutmeg as host plants. *Viscum monoicum* and *Viscum orientale* affect *Albizia* spp., *Pongamia* spp. and

Santalum album affects pomegranate. *Cuscuta* attacks lucerne, clovers, ipomoea and lagasca.

Striga angustifolia, a root parasite has come from south India to north India. It causes enormous damage to maize, sorghum and sugarcane in several states (Hosmani 1975). In western Indian desert, it has established on *Pennisetum typhoides* (bajra), the main crop under rainfed agriculture. In Kerala loss by this weed was estimated to be about 80%. *Balanophora* causes serious damage to coffee. Parasitic weeds badly affect the plant growth and may even kill the host plants.

2.4.2 Competition with crop plants

Agricultural field is a favourable ecosystem for weeds to germinate and flourish. They compete with crop plants for nutrients, light, air, water, space and other factors in the micro-environment. They reduce the effectiveness of irrigation. Competition between weed and crop is acute when available resources become limited for plant growth. Weeds affect the standing crop as well as crops in sequence. They also have an effect during fallow period. Weeds in crop fields interfere in inter-cultivation, harvesting, threshing and cleaning. Weed competition can reduce the quality of produce. In root crops, it alters size, quality and distribution of tubers. Some weeds like *Trianthema portulacastrum* produce mature seeds much earlier before we recognise their flowering stage as they produce very minute or inconspicuous flowers (De 1995). Some weeds like

Echinochloa colonum produce mature seeds before the crop seedlings get ready for uprooting for transplanting. Weeds like *Crotalaria medicaginea* and *Merremia aegyptia* appear dominantly in alternate years making better chances of their survival. Many weeds like *Avena ludoviciana*, *Cleome viscosa* mature at the same time of crop and they mostly shed their seeds before the harvest of crop so that the weed seeds get harvested with the crop plants.

2.4.3 Harbouring insect pests

Weeds provide feeding, breeding and hiding sites for insect pests, pathogens and parasites. Many Solanaceous weeds harbour insect pests feeding on leaves. Some weeds like *Echinochloa, Panicum* and *Zizania* are alternate hosts for rice stem borer. These pests infect crop plants and weeds get opportunity to dominate the infected weak plants.

2.5 Association of weeds

Some weeds like *Cynodon dactylon,* and *Echinochloa colonum* do not show any specificity with respect to season and site occurrence. While, some weeds prefer to grow in crop field only and some of them have a distinct association with specific crops (Table 2.5), may be due to their life cycle, growth habitat and other characteristics necessary for successful competition with the crops. Many weeds associated with grain crops are not found in sugar cane field and vice versa (De 1995).

Table 2.5 Associated weeds of different agricultural crops.

Crop	Associated weeds
Barley	*Phalaris minor, Avena fatua, Chenopodium album*
Black gram	*Solanum nigrum, Physalis minima*
Chick-pea	*Croton bonplandianum, Cleome viscosa*

Cotton	*Cyperus rotundus, Ageratum conyzoides, Abutilon indicum*
Groundnut	*Phyllanthus niruri, Ageratum conyzoides*
Jute	*Corchorus acutangulus, Cyperus rotundus*
Maize	*Eclipta alba, Echinochloa colonum*
Peas	*Lathyrus aphaca, Gnaphalium indicum*
Pigeon-pea	*Cyperus rotundus, Echinochloa colonum*
Potato	*Chenopodium album, Spergula arvensis, Anagallis arvensis*
Rape and mustard	*Cleome viscosa, Spergula arvensis, Chenopodium album*
Rice	*Echinochloa colonum, Echinochloa crus-galli*
Sorghum	*Striga lutea, Tridax procumbens*
Sugar-cane	*Sorghum halepense, Imperata cylindrica*
Tobacco	*Cyperus rotundus, Orobanche indica*
Wheat	*Chenopodium album, Phalaris minor*

(De 1995)

In brief, it could be noted from the discussion above that the weedy species of plants show wide adaptations to tide over environmental vagaries. However, many of these adaptations are not specific to weeds. A number of other plants show such adaptations to survive in the natural conditions. Weeds generally are euryoecious (wide range of tolerance), while native plants are comparatively stenoecious (narrow range of tolerance). Weeds have wide-ecological amplitude, are more opportunistic, and hence are more successful.

To explain the process of biological invasion, two alternative hypotheses are considered by Hengeveld (1988). One is based on the theory of the balance of nature and other on non-equilibrium theory and individualistic species responses. The theory of balance of nature is based on the classical work of the Elton (1958). It is based on the logic that competition, predation, diseases and other such biotic interactions help in maintaining multispecies equilibrium by curtailing the predominance or extinction of individual species in the community. Biotic interactions in more saturated native community resist the exotic invasions. Diverse, complex and mature forest ecosystems are likely to be less invadable than the less diverse, comparatively homogenous and open communities (Saxena 1991 and Lodge 1993).

On the other hand, non-equilibrium theory is based on the hypothesis that species shift their region or expand or contract their geographical range in response to spatio-temporal variations. These two theories by Hengeveld explain invasions at different time scales and situations (Saxena 1991). 'Geographical- range expansion of a species in response to change in climate', can not explain the invasion of Indian sub-continent by the alien species, as most of them are introduced by man accidentally or intentionally (Saxena 1991). According to Crawley (1987), existence of vacant niches in the community, created by different perturbations, makes community invasible. Slobodkin (1980) also gives similar indications. Disturbances created by anthropogenic activities are responsible for increasing distribution of species outside their native range (Ramakrishnan and Vitousek 1989, Lodge 1993).

As discussed earlier in this chapter, invaders bear certain characteristics such as r- selected traits, dual reproduction (vegetative and sexual), high dispersal rate, high genetic variability, phenotypic plasticity, allelopathy, high nutrient uptake efficiency, and human commensalism, which help them to successfully invade different areas (Saxena 1991, Lodge 1993). However, many of these characteristics are yet to be quantitatively tested and proved. Nevertheless, early successional, climatically matched with native habitats of invaders, less diverse, and disturbed habitats are found more vulnerable to the invasion by exotics (Saxena 1991, Ramakrishnan 1991, Lodge 1993).

CHAPTER 2

STUDY AREA AND METHODS

2.1 STUDY AREA

2.1.1 Western Ghats

The Western Ghats is a 1600 km long hill range running from the southern tip of the Indian peninsula at 8° N to the River Tapti at 21° N, spreading over an area of 160,000 km^2. The chain of hills is narrow (73° to 77° E), mostly less than 100 km wide over much of the range, and is interrupted by the 30 km wide Palghat Gap (11° N) that acts as a major biogeographic barrier (Mani 1974, Pascal 1988, Figure 2.1). The region south of this gap is referred to henceforth as the southern Western Ghats. Most of the higher hills (1000–2000 m above mean sea level) in the Western Ghats are found towards the south, between 8° and 13° N. Details of the geology and other physical aspects of the region can be found in Pascal (1988).

The Western Ghats along with Sri Lanka has been identified as one of the 25 biodiversity hotspots (Myers *et al.* 2000), and also as one of the 200 most important ecoregions in the world (Olson and Dinerstein 1998). However, this is also one of the hotspots in the world with the highest human population densities (Cincotta *et al.* 2000). Various developmental activities have resulted in habitat loss, degradation, and fragmentation, particularly of the biologically rich rainforests. Menon and Bawa (1997) estimated a four-fold increase in the number of fragments, along with 83% reduction in size of forest patches in the Western Ghats, between 1920 and 1990.

Moist forests, including tropical rainforest, are more extensive in the southern Western Ghats. Biological diversity and endemism in various plant and animal groups are also higher in this region. This pattern can be ascribed to higher precipitation, shorter dry season, and the occurrence of rainforests on the medium and high elevation reaches of the wet western slopes (Pascal 1988). Pascal (1988) has classified the tropical wet evergreen forests or rainforests of the Western Ghats into low (< 700 m), medium (700–1400 m), and high (> 1400 m) elevation types. The vegetation becomes drier as one progresses from west to east (rain shadow) across the hills. Lower altitudes on the eastern aspect, receiving less than 1000 mm annual rainfall contain tropical dry deciduous and thorn forest, with tropical moist deciduous forests in wetter areas. With increasing altitude, rainforest appears along the higher slopes and ridges. At higher altitudes (>1700 m), the forests gives way to the unique shola-grassland vegetation type, particularly in the southern Western Ghats. The average annual rainfall in the rainforests ranges from around 1800 to 7500 mm (Pascal 1988).

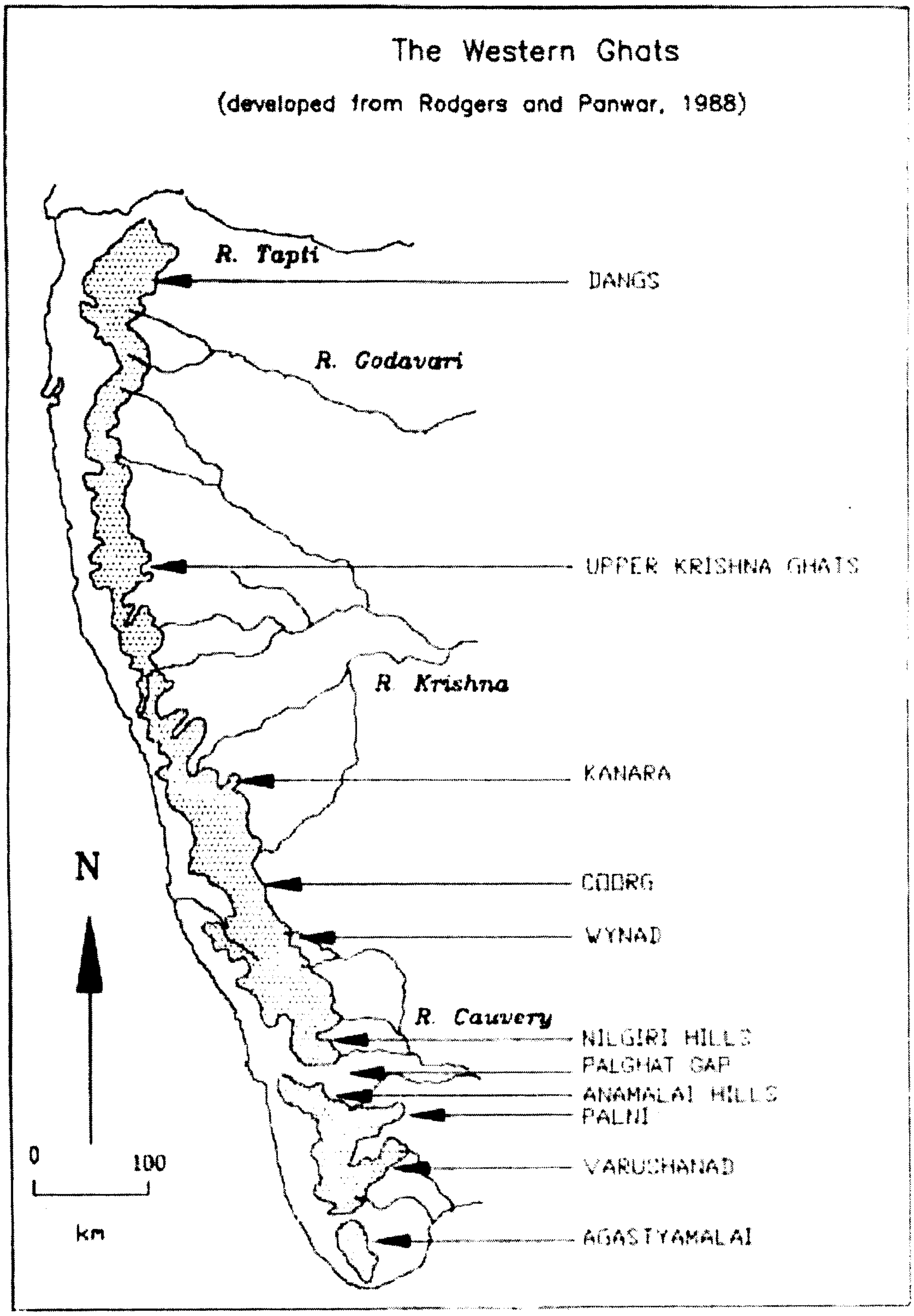


Figure 2.1: Map of the Western Ghats showing major hill ranges.

The Western Ghats has a high percentage of endemics, comparable to oceanic islands (Mani 1974). It covers only 5% of India's land area, and but contains about 4000 flowering plant species, of which about 1500 (c. 35%) are endemic (Nair and Daniel 1986). Of the 490 tree species in low and mid-elevation forests, 63% (308) in 58 genera are endemic, and 42 of these are monotypic (Kumar *et al.* 1999). Some of the plant genera and groups that are particularly speciose, and exhibit high endemism are: *Impatiens* (86% of nearly 90 species), *Dipterocarpus* (92% of 13 species), *Calamus* (92% of 25 species), Ebenaceae (60% of 20 species), and native leguminous trees (all 12 are endemic). While much of the plant and vertebrate diversity within this region is documented, invertebrate diversity remains largely unexplored, particularly in the tropical rainforests.

Among the animals, there is a high degree of endemism, particularly among the lower vertebrates. Nearly 10% (245 species) of the fishes found in India occur in the Western Ghats, of which 42% (103) are endemic. Of the 215 species of amphibians known in India, 120 are recorded in the Western Ghats, and 90 (75%) of them are restricted to the rainforests (Johnsingh 2001). High diversity and endemism are observed in two groups of amphibians, namely, caecilians (limbless amphibians, 88% endemism) and rhacophorids (tree frogs, 83%, Kumar *et al.* 1999). About 480 species of reptiles occur in India, and 197 are known from the Western Ghats. Of the over 500 species of birds that occur in the Western Ghats, 15 are endemic, of which 12 are found chiefly in the rainforests. Mammalian diversity in the Western Ghats is relatively low, with about 125 of the 400 species of Indian mammals occurring in this region, with 22 endemics (Kumar *et al.* 1999). Two genera, *Latidens* (bat) and *Platacanthomys* (rodent), are unique to the Western Ghats.

The Agasthyamalai-Ashambu hills, with relatively undisturbed rainforests, and the Anamalai hills, with fragmented rainforests, are in the southern Western Ghats, and were the two study areas. These are high-diversity and high-conservation priority regions in the Western Ghats. Both these areas have been subjected to intensive research on various plant and animal taxa since the early 1970s. A detailed review of the studies in KMTR is given by Johnsingh (2001). In the Anamalais, vegetation studies have been carried out by Ayyappan and Parthasarathy (1999). Ecological studies of endangered species like the lion-tailed macaque (*Macaca silenus*) and Great Hornbill (*Buceros bicornis*) have been carried out by Kumar (1987) and Kannan (1994), respectively. In recent years, the impact of fragmentation on small mammals, arboreal mammals, herpetofauna, birds, and butterflies have been carried out (Prabhakar 1998, Umapathy 1998, Babu 2000, Rajamani 2000, Vasudevan 2000, Ishwar 2001, T. R. S. Raman *in preparation*).

2.1.2 Kalakad-Mundanthurai Tiger Reserve

2.1.2.1 *Geography and climate*

The Kalakad-Mundanthurai Tiger Reserve (KMTR, 8° 25' - 8° 53' N and 77° 10' - 77° 35' E) is situated at the southern extremity of the Western Ghats (Figure 2.2), and extends over an area of about 895 km^2. The altitude of the Reserve ranges from 50 m to 1700 m asl, with rainforests occurring chiefly above 600 m. KMTR, along with the adjoining Neyyar, Peppara, and Shendurni sanctuaries in Kerala state, forms a nearly 1500 km^2 tract of forest on the Agasthyamalai-Ashambu hill range, and is one of the most significant areas for conservation of biological diversity in the Western Ghats (Johnsingh 2001). This region includes over 400 km^2 of relatively undisturbed and contiguous rainforests (Ramesh *et al.* 1997, Plate 3).

The annual rainfall ranges from 750 mm in the rain shadow regions of the (lower) eastern slopes to over 3000 mm in the western parts. The mean monthly temperature (average of mean daily maximum and mean daily minimum calculated across all days in the month) in the rainforest ranges between 19° C in January and 24° C in April–May at mid-elevations (in Sengaltheri, 1040 m). The lowest temperature recorded on any day in Sengaltheri was 15° C (January 1998) whereas the maximum was 31° C (June 1998). The average annual rainfall is over 2200 mm. There are three distinct seasons: (a) dry season (February to May), (b) south-west monsoon (June to September), and (c) north-east monsoon (October to January). However, March is the only month with less than 100 mm rainfall. Strong winds occur during the south-west monsoon, and periods of heavy rainfall often alternate with days of bright clear weather. Elevations above 1000 m experience frequent mists and cloud cover, which may be prolonged over days or even weeks during the north-east monsoon. KMTR receives most of the rainfall during the north-east monsoon. The average relative humidity ranges from around 60% in March to about 97% in November–December. The higher reaches with rainforests are major watersheds, from where many important perennial rivers such as the Manimuthar and Tambaraparani originate, supporting millions of people and agriculturists living in the plains of Tamil Nadu state.

Sengaltheri (8°31' N and 77°26' E), a rainforest site on the ridge, and partly on the eastern aspect of the Reserve, was selected as the intensive study area in KMTR. This site was surrounded by rainforests (800 m - 1250 m) within an area of about 10–15 km^2 around the base camp. Sengaltheri is contiguous with rainforests on all sides except towards the east, where it is adjacent to wooded grasslands. Two other sites: Kannikatti (8°37' N and 77°16' E, 650 m - 1000 m), and Kakachi (8°50' N and 77°30' E, 1200 m - 1300 m) were also surveyed periodically for scats, to document the diet of the brown palm civet over a wider geographical area, and also assess the relative abundances of the small carnivores.

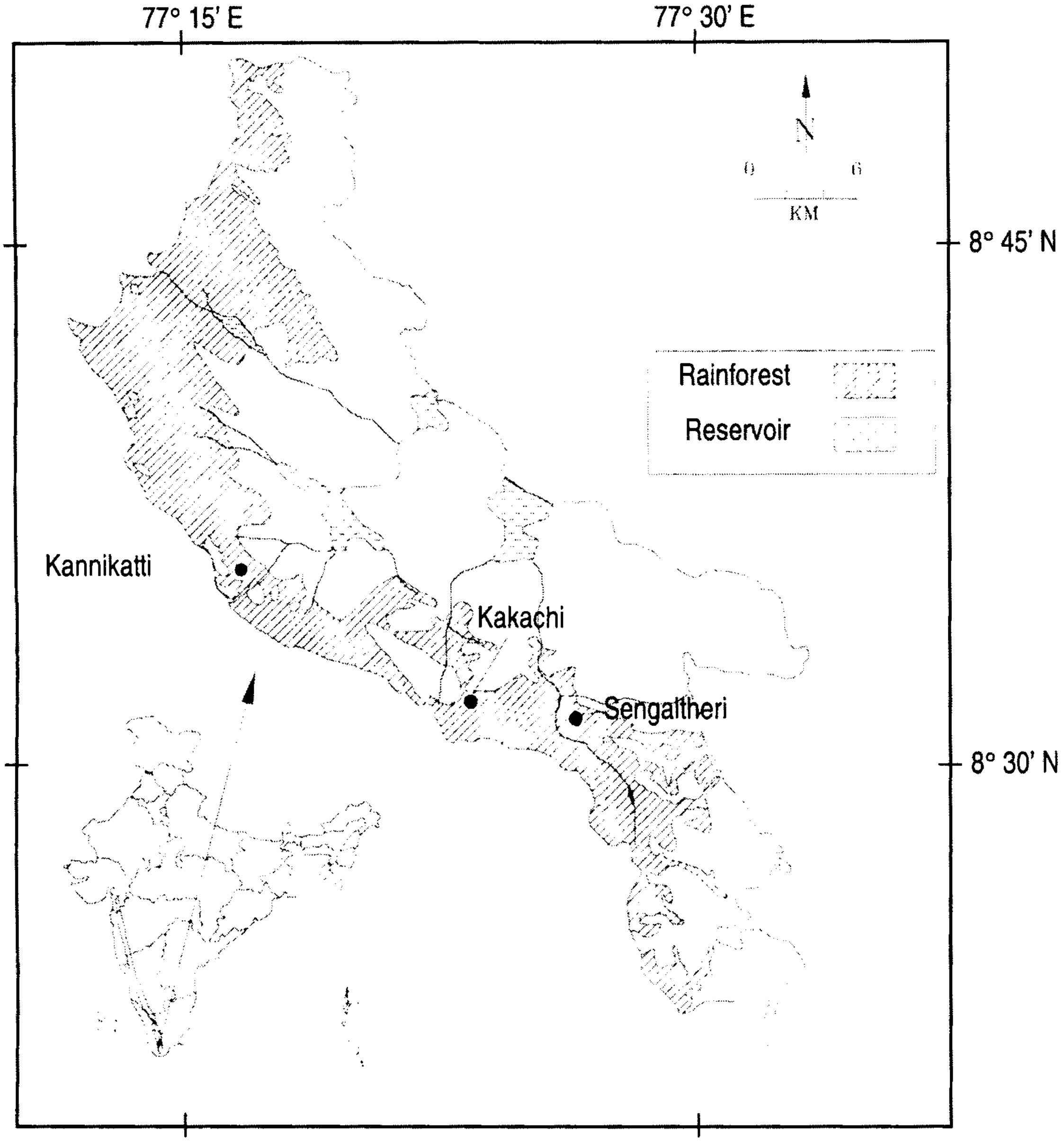


Figure 2.2: Map of Kalakad-Mundanthurai Tiger Reserve showing the three study sites and distribution of rainforest.

2.1.2.2 *Vegetation*

Within the Western Ghats, KMTR has one of the largest remaining contiguous tracts of tropical rainforests spreading over 400 km^2, including the Ashambu range in the adjoining Kerala state (Ramesh *et al.* 1997). The mid-elevation (700 m – 1400 m) rainforest classified as southern hill top tropical evergreen forest (Champion and Seth 1968), is now categorised as the mid-elevation tropical wet evergreen forest of the *Cullenia exarillata - Mesua ferrea - Palaquium ellipticum* type, and has about 43% endemism in flowering plants (Pascal 1988). At least 2000 of about 4000 flowering plant species found in the Western Ghats are believed to occur in KMTR (Nair and Daniel 1986, Ganesh *et al.* 1996). The type of vegetation varies along an altitudinal gradient. Thorny-scrub forests predominate the lower rain shadow altitudes in the east, with natural and plantation teak (*Tectona grandis*) forests, and dry and mixed deciduous forests in the mid altitudes, giving way to semi-evergreen and wet evergreen (rainforest) at higher reaches (Parthasarathy 1999). Beyond this, high altitude grasslands harbouring the endemic Nilgiri tahr *Hemitragus hylocrius* are found. Detailed descriptions of rainforest vegetation in the area are available elsewhere (Ganesh *et al.* 1996, Parthasarathy 2001).

2.1.2.3 *Fauna*

Although 273 bird species have been recorded in and around KMTR, only about 70 species occur regularly in rainforests (Johnsingh 2001, T. R. S. Raman *personal communication*). The remaining species occur mainly in drier forests, water bodies, and other habitats. The rainforest avifauna of KMTR includes 10 species of winter migrants and 12 of the 15 species endemic to the Western Ghats. The mammalian fauna of KMTR includes 76 species, of which 8 species are endemic to the Western Ghats (Johnsingh 2001). Four species of large carnivores occur in the rainforests of KMTR: tiger *Panthera tigris*, leopard *P. pardus*, dhole *Cuon alpinus*, and sloth bear *Melursus ursinus.* Seven species of small carnivores occur in the rainforests within the reserve (Mudappa 1998). Among the five species of felids in KMTR, one of the smaller cats, the leopard cat *Prionailurus bengalensis*, occurs in the rainforests. Other mammals occurring in the rainforests include Asian elephant *Elephas maximus*, gaur *Bos gaurus*, sambar *Cervus unicolor*, mouse deer *Moschiola meminna*, lion-tailed macaque *Macaca silenus*, bonnet macaque *M. radiata*, Nilgiri langur *Trachypithecus johnii*, Nilgiri tahr *Hemitragus hylocrius*, Malabar giant squirrel *Ratufa indica*, large brown flying squirrel *Petaurista philippensis*, seven other species of rodents, and three species of shrews (D. Mudappa *unpublished data*). The smaller mammals among those listed above are potential prey of the small carnivores. At least 17 bat species also occur within the reserve (Johnsingh 2001).

2.1.3 Anamalai hills

The Anamalai hills occur just south of the Palghat gap and include the Nelliampathy hills towards the west, the Palni hills in the south-east, and the Eravikulam, High Wavy and other ranges towards the south. A number of protected areas span this region, including the Indira Gandhi Wildlife Sanctuary (WLS, 987 km^2), Eravikulam WLS (97 km^2), Chinnar WLS (90 km^2), Parambikulam WLS (274 km^2), reserve forests, and the proposed Kodaikanal WLS in the Palni hills. Vast stretches of teak plantation also occur in the area.

This region, similar to KMTR in fauna and flora, contains vast stretches of the mid-elevation tropical evergreen forests (also known as the tropical rainforests). However, a major difference is that much of the rainforest occurs as fragments (Plate 3). Although a significant portion of this is within the Indira Gandhi Wildlife Sanctuary (10° 12' N to 10° 35' N and 76° 49' E to 77° 24' E, Figure 2.3), many of the rainforest fragments are on private lands in the Valparai plateau. The

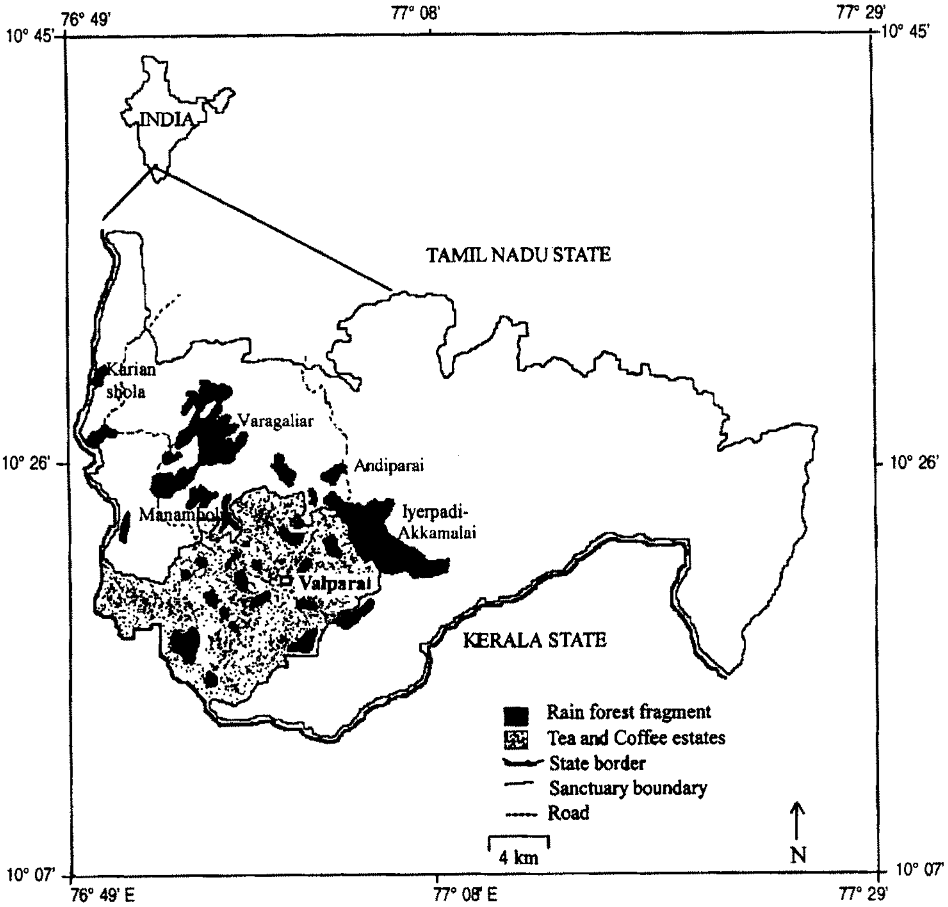


Figure 2.3: Map of Indira Gandhi Wildlife Sanctuary showing rainforest fragments.

natural vegetation of this region, receiving over 2500 mm of rainfall annually, particularly during the south-west monsoon (June – September), has been classified as mid-elevation tropical evergreen forest of the *Cullenia-Mesua-Palaquium* type (Pascal 1988), the same type as in KMTR. The Valparai plateau contains a large area of tea, coffee, and cardamom estates occupying over 130 km^2, and lying centrally amidst the above-mentioned conservation areas. This area has a small town (Valparai) and a human population of over 200,000 people, mostly estate labourers, scattered across the town and estates.

At least 30 rainforest fragments have been identified, of which the larger and relatively undisturbed ones are part of the protected area, and the rest (about 14) are on private lands (Umapathy and Kumar 2000). Most of these fragments were formed in the period between 1860 and 1980, when large areas of pristine rainforests were cleared, mostly during the reign of the British in India, to establish plantations of tea, coffee, *Eucalyptus*, and cardamom (Congreve 1941), while drier regions were converted into teak plantations. In the post-independence period, many reservoirs were constructed, and a network of roads established in this region, which further fragmented the landscape. However, even the relatively small fragments on private lands continue to harbour many endemic and endangered species of plants and animals. This is aided by the landscape of plantations and fragments being surrounded on all sides by protected areas that contain significant wildlife populations. Many species move through this fragmented landscape between conservation areas, including large mammals such as elephants, tigers, leopards, and wild dogs, and birds such as hornbills. The conservation of rainforest fragments is also important as corridors for these wide-ranging taxa (Kumar 2000).

2.2 METHODS

Detailed descriptions of the methods followed for data collection are given in the respective results chapters. Here, the general methods and analyses followed during the study are briefly described. The study was carried out between May 1996 and December 1999 in KMTR, and between January and May 2000 in the Anamalais.

Diet of the brown palm civet was analysed by examining scats collected along the trails in KMTR. An assessment of seed viability and dispersal was done by comparing seeds from scats and those collected directly from the plants. Flowering and fruiting phenology of a set of 22 important and common food tree and liana species was monitored for two years (1998–99). Individual trees and lianas were identified, marked, and their phenophases noted once every month at regular intervals. The densities of food trees were estimated from data from PCQ plots, and the dispersion of the food trees assessed from 5 m radius circular plots laid randomly in the study area. These data are used for assessing monthly fruit resource availability, similarity in food availability between years, and the relationship between food consumption and availability.

Data on home range and activity pattern come from seven brown palm civets that were radio-collared and monitored regularly during 1998–99. Locations were determined by triangulation from known points on mapped trails in the study area. Several vegetation and habitat attributes were quantified within the home range of each radio-collared individual. Civet day-bed sites were discovered by homing-in, and their characteristics were compared with random sites, in order to identify variables that are important in the selection of day-bed sites.

Camera-trapping, track plots, and direct sightings were used to estimate the relative abundance of small carnivores in four sites in KMTR, and ten rainforest fragments in the Anamalais. Data on vegetation and habitat parameters were collected to identify the correlates of success rates in the fragments.

2.3 DATA ANALYSES

Throughout the thesis, with a few exceptions, non-parametric tests were used to test for statistical significance (Siegel and Castellan 1988, Zar 1999). All tests were 2-tailed and a probability level of ≤ 0.05 was considered statistically significant, and $P \leq 0.10$ was considered nearly significant. The statistical analyses were carried out using SPSS version 8.0. Spearman's rank correlation, Mann-Whitney U test, Wilcoxon matched-pairs signed ranks test, G test, and chi-square tests were frequently used. The variance-to-mean ratio was used to assess the dispersion of food tree species. Principle components analysis (PCA) was used to summarise vegetation variables (Pielou 1984). Hierarchical cluster analysis was used to group rainforest fragments based on their vegetation structure and occurrence of small carnivores. LOCATE II and CALHOME computer programs were used for home range data analysis. The monthly home range was compared to the abundance of food, and the annual home ranges were related to age/sex and body weight of the individual animals, in order to identify the factors that govern ranging pattern. Frequency of occurrence and percent occurrence were used to assess the importance of various species in the diet. Diversity and similarity indices were used to determine the variation between years and among months in the dietary diversity, composition, and dominance of the species. Diversity, evenness, dominance, similarity, and dispersion indices were calculated based on Magurran (1988) and Krebs (1989).

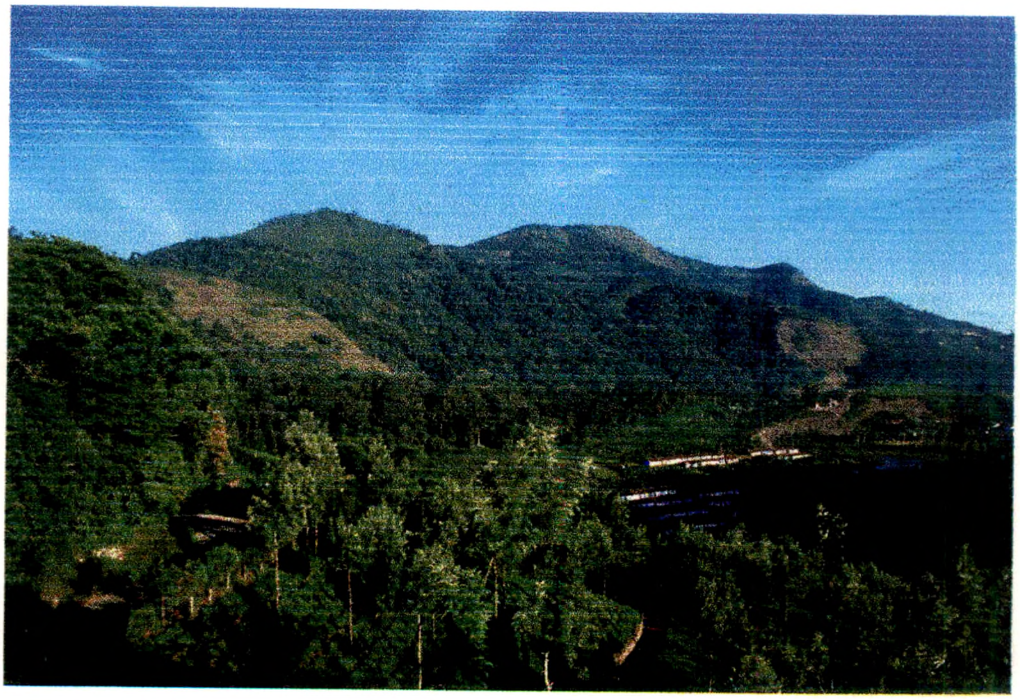


PLATE 3: THE RAINFORESTS OF KALAKAD-MUNDANTHURAI TIGER RESERVE (TOP) ARE RELATIVELY UNDISTURBED AND CONTIGUOUS—A VIEW OF SENGALTHERI. THE LANDSCAPE OF THE ANAMALAI HILLS (BOTTOM), IN CONTRAST, IS SEVERELY FRAGMENTED—THE ANDIPARAI RAINFOREST FRAGMENT ABUTTING HUMAN SETTLEMENTS AND TEA ESTATES.

Chapter III

3 STUDY AREA

3.1 Nilgiri Biosphere Reserve (NBR)

The Nilgiri Biosphere Reserve is located in south-west India, between 10° 45' - 12' 15° N and 76° 10' - 77° 10' E. Geological evidences suggest that the underlying rocks are archaean, about two billion years old. Topography ranges from low-lying valleys in the west to mountains over 2000m (2695m being the highest) and a flat elevated table land at 800 - 1000m above sea level. The wide altitudinal and geographic variation has resulted in diverse climatic vegetation zones (Daniels 1993). The NBR receives both south-west and north-east monsoon. South-west monsoon extends from June to September and north-east monsoon from October to December. The NBR embraces Mudumalai and Wynad Wildlife Sanctuaries, Nagarhole, Bandipur, Silent Valley and Mukurthi National Parks, forest hill slopes of Nilambur and Nilgiris, the Upper Nilgiri plateau, and Siruvani hills (Figure 3.1).

3.2 Locations selected for study

Study sites in various vegetation types were selected in 1) Mudumalai Wildlife Sanctuary, 2) Silent Valley National Park, 3) Upper Bhavani and 4) Siruvani forest. The vegetation types present in the different study locations were moist deciduous forest, dry deciduous forest, mixed deciduous forest, scrub jungle, evergreen forest, shola, coffee and tea plantation, teak plantation, eucalyptus plantation and wattle plantation. Eleven locations (Table 3.1) in total, distributed in the above vegetation types, were selected for laying transects and plots.

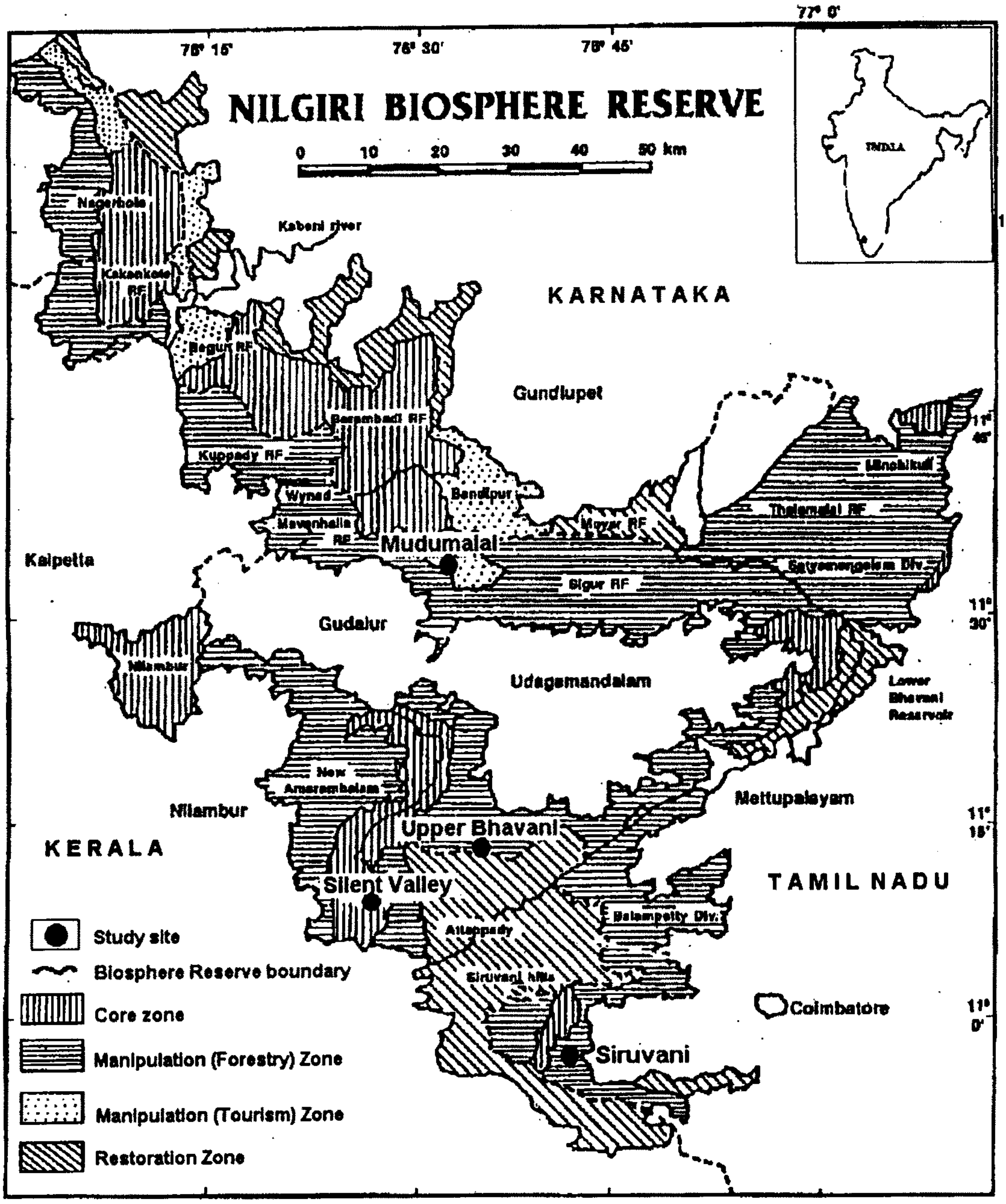


Figure 3.1 Nilgiri Biosphere Reserve indicating study locations

Table 3.1 Locations selected for the study

Forest types	**Study sites**
Mudumalai Wildlife Sanctuary	
Moist deciduous forest	Benne, Nagampally and Chinakooly
Dry deciduous forest	Masingudi, Kalmalai and Kakkanalla
Scrub jungle	Anaikatti,Valethottam and Mavanahalla
Coffee and tea plantation	Biderkad
Ecalyptus plantation	Masingudi
Teak plantation	Thorpalley
Silent Valley National Park	
Evergreen forest	Sirendhri
Upper Bhavani	
Sholas	Bison Swamp
Wattle plantation	Bison Swamp
Siruvani forests	
Mixed deciduous forest	Siruvani

3.2.1 Mudumalai Wildlife Sanctuary

Mudumalai Wildlife Sanctuary, situated between 11° 32' and 11° 43' N and 76° 22' and 76° 45' E, lies along the eastern slopes of Western Ghats. The sanctuary, a part of NBR, falls in the Nilgiri district of Tamil Nadu state and extends over an area of 321 km^2. The sanctuary is bounded on the north by the Bandipur National Park of Karnataka and on the west and south-west by the Kerala state (Figure 3.2).

The sanctuary consists of undulating hills with elevations ranging from 850 to 1258 m. Moyar river flows through the sanctuary and is the major water source. Rocks are of typical archaean biotite and horneblendic gneiss with intensive bands of charnokite and much younger biotite, granite, pegmatite and basic doleric dykes. Black sandy loam and red heavy loam soils occur in this area. April and May are the hottest months and December and January the coldest.

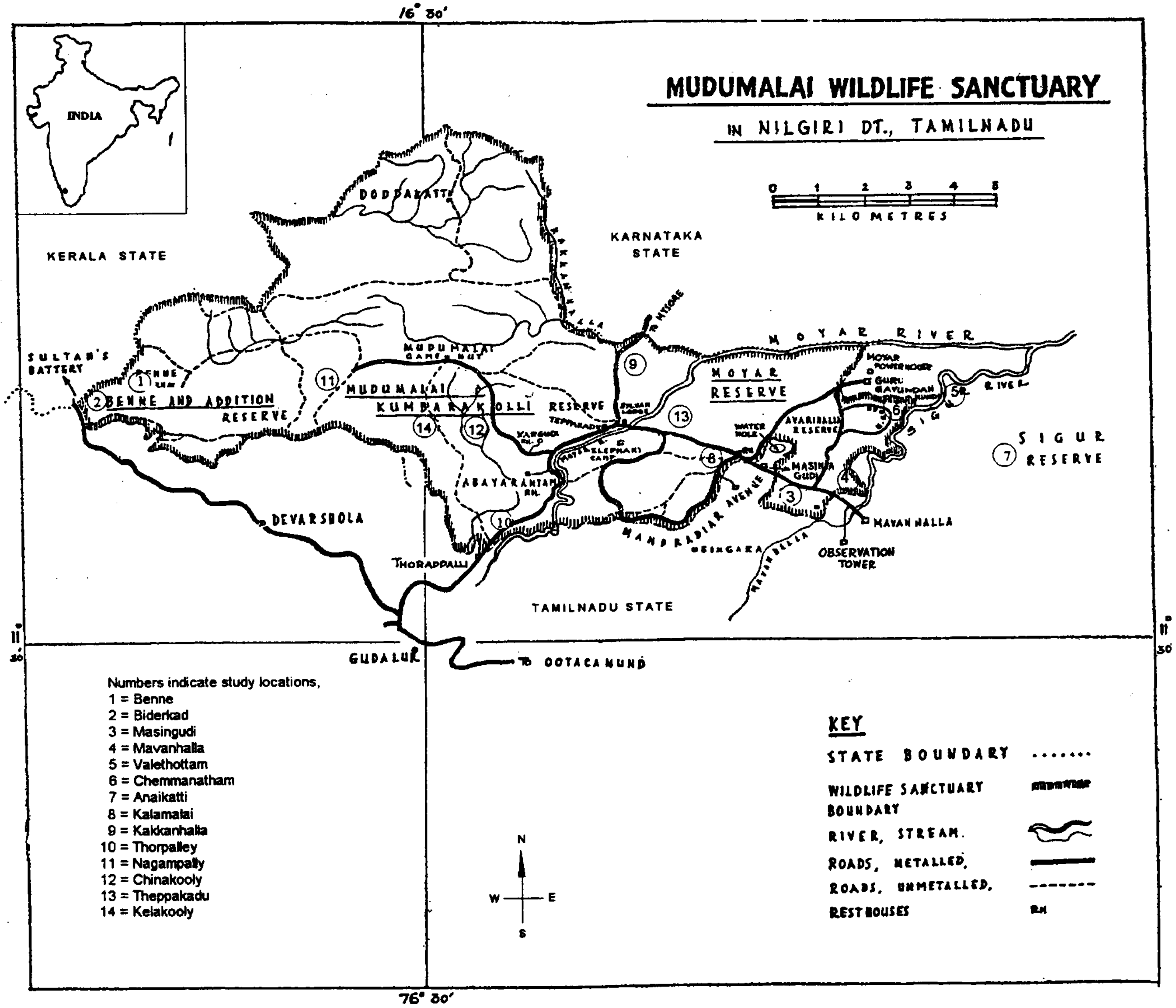


Figure 3.2 Mudumalai Wildlife Sanctuary indicating study locations

Sanctuary receives rain from both the monsoons. Western side of the sanctuary receives more rainfall than eastern part during the south-west monsoon between June to September and eastern side receives the rainfall mostly during the north-east monsoon between October and December. The mean annual rainfall varies from 600 to 2000 mm. Because of the variation in the rainfall, vegetation also varies in different parts of the sanctuary. Tropical moist deciduous, tropical dry deciduous and southern tropical thorn forests (Champion and Seth 1968, Azeez *et al.* 1997) are the three major vegetation types present in the sanctuary.

In the south-west part of the sanctuary, where annual rainfall is about 1800 mm per annum, tropical semi-evergreen forest is present. Dominant trees include *Meliosma simplicifolia, Olea dioica, Glochiodion velutinum, Viburnum punctatum* and *Memecylon* spp. Tropical moist deciduous forest occurs in the western and southern areas of the sanctuary. This region receives above 1500 mm rainfall per annum. Dominant tree species are *Lagerstroemia lanceolata, Terminalia crenulata, Pterocarpus marsupium, Bischofia javanica, Grewia tiliaefolia, Kydia calycina, Terminalia bellirica and Radermacheria xylocarpa.* Understorey is dominated by shrubs such as *Helicteres isora, Desmodium pulchellum* and *Curcuma* spp. and grasses such as *Themeda cymbaria*, *Apluda mutica, Imperata cylindrica* and *Cymbopogon flexuosus* .

In the eastern side of the sanctuary, having rainfall in the range of 900 - 1500 mm per annum, tropical dry deciduous forest is present. *Anogeissus latifolia, Tectona grandis, Dalbergia latifolia, Bombax ceiba, Madhuca indica, Gmelina* *arborea, Phyllanthus emblica, Butea monosperma, Cassia fistula* and *Mitragyna parvifolia* are some of the dominant tree species found here. Shrubs include *Helicteres isora, Pavetta indica* and *Lantana camara*. Ground layer consists of grasses such as *Heteropogon contortus, Themeda cymbaria, Themeda triandra* and *Cymbopogon flexuosus*.

Southern tropical thorn forest occurs in the eastern part of the sanctuary, where annual rainfall is in the range of 600 to 900 mm. This forest is dominated by *Acacia* spp. While, some elements of dry deciduous forests are also seen here. Dominance of thorny species, which have xerophytic adaptations, are characteristics of this vegetation. Dominant trees are *Acacia sundra, A. leucophloea, A. ferruginea, Givotia rottleriformis, Premna tomentosa, Albizia amara, Zizyphus mauritiana, Z. xylopyrus, Z. oenoplia, Erythroxylon monogynum, Chloroxylon swietenia, Strychnos potatorum, Elaeodendron glaucum and Naringi crenulata*. Shrubs include *Opuntia dillenii, Euphorbia* spp., *Acacia intsia, Capparis sepiaria, Carissa carandas, Scutia myrtina, Gymnosporia montana, Flacourtia indica* and *Argyreia cuneata*. Grasses such as *Heteropogon contortus, Digitaria* spp. and herbs like *Leucas aspera, Evolvulus alsinoides* and *Indigofera* spp. dominate the ground cover.

Mudumalai has a diverse fauna consisting of Asian Elephant (*Elephas maximus*), Gaur (*Bos gauras*), Sambar (*Cervus unicolor*), Chital (*Axis axis*), Four horned Antelope (*Tetracerus guadricornis*), Black buck (*Antilope cervicapra*), Mouse deer (*Tragulus meminna*), Barking deer (*Muntiacus muntjak*), Tiger (*Panthera tigris*), Leopard (*Panthera pardus*), Indian Wild dog

Plate 1 Moist deciduous forest in Mudumalai Wildlife Sanctuary

Plate 2 Evergreen forest in Silent Valley

(*Cuon alpinus*), Sloth bear (*Melursus ursinus*), Wild boar (*Sus scrofa*), Bonnet macaque (*Macaca radiata*) and Giant squirrel (*Ratufa indica,* Suresh *et al.* 1996).

3.2.2 Silent Valley National Park

The Silent Valley National Park is situated at the south-western corner of Nilgiris on a plateau of 1000 m elevation, in the Palghat district of Kerala (Figure 3.3). It is a part of the core area of NBR, covering an area of 89. 52 km^2, and is located at 11° 00' and 11° 15' N and 76° 15' and 76° 35' E (Chand Basha 1999, Swaminathan 1999). It is bound by high and continuous ridges (over 2000m above MSL) along its entire north, north-east and east borders and little lower ridges (over 1200m above MSL) along the entire western and southern border. The highest peaks on the northern and north-eastern boundary are Anginda (2383m) and Sispara (2206m) and on the west, Poochapara (1376m) and Valiamullumala (1237m, Manilal 1988). Major watercourse in this park is the perennial river Kunthipuzha, a tributary of Bharathapuzha.

The prevailing rock formations in Silent Valley are foliated gneisses to grantoid gneisses and granites referable to Archaen complex (Manilal 1988). Both south-west and north-east monsoons occur in Silent Valley. Silent Valley receives over 5000 mm of rainfall annually (Singh *et al.* 1984). Maximum precipitation is during the south-west monsoon. The area receives highest rainfall in July. In dry months of January, February and March, also Silent Valley receives scanty showers. Average minimum temperature ranges from 8 to 14 °C and the average maximum temperature from 23 to 29 °C.

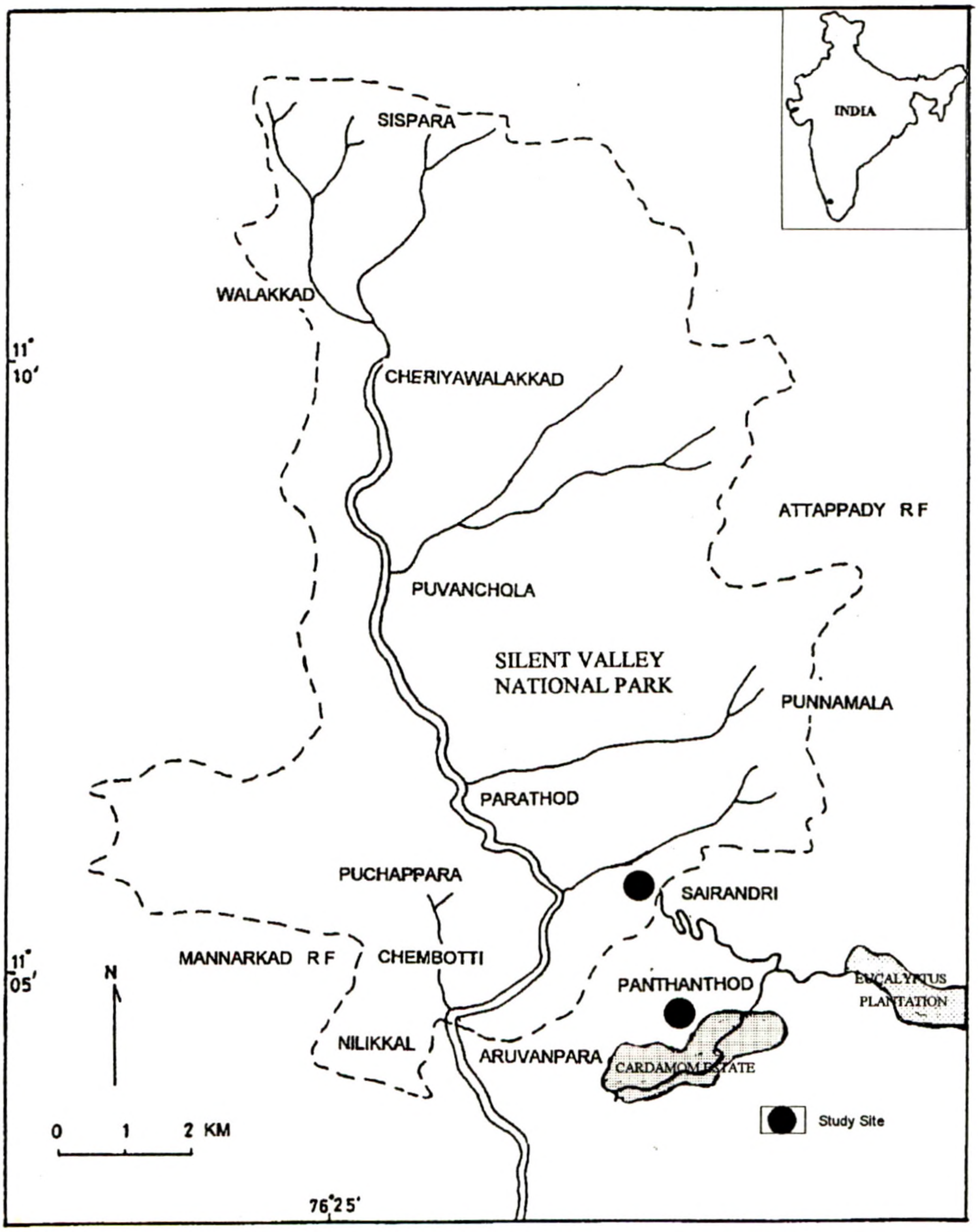


Figure 3.3 Silent Valley National Park indicating study locations

Silent Valley vegetation consists of primarily wet evergreen forest, with a multi-storeyed and dense canopy. It harbours 2000 plant species including over 1000 species of flowering plants (Pushpangadan and Sathish Kumar 1999). Trees are very tall (up to 50m). Epiphytic orchids and ferns are frequent. Common trees are *Actinodaphne malabarica, Litsea* spp., *Cinnamomum* spp., *Palaquium ellipticum, Cullenia exarillata, Syzygium laetum, S. mundagum, Garcinia morella, Elaeocarpus* spp., *Artocarpus heterophyllus, Mesua ferrea, Mallotus philippinensis, Eugenia* spp., *Agrostistachys borneensis, Gomphandra tetrandra* and *Myristica fragrans.* Shrub layer includes *Thottea siliquosa, Psychotria nigra, Pavetta indica, Laportea crenulata, Saprosma foetens, Elatostemma lineolatum, Memecylon heyneanum, Antistrophe serratifolia and Strobilanthes* spp. and climbers such as *Thunbergia mysorensis, Smilax perfoliata* and *Smilax zeylanica. Sarcandra chloranthoides* and *Rhynchotechum permolle* are common herb species.

Fauna of Silent Valley includes many endangered animals (Prasad *et al.* 1979, Balakrishnan 1999, Ramachandran and Gigi 1999) such as Lion tailed macaque (*Macaca silenus*) and Nilgiri Thar (*Hemitragus hylocrius*). Other common animals found are Asian Elephant, Gaur, Sambar, Chital, Mouse deer, Barking deer, Tiger, Leopard, Indian Wild dog, Leopard cat (*Felis bengalensis*), Ruddy mongoose (*Herpestes edwardsii*), Small Indian civet (*Viverricula indica*), Nilgiri langur (*Trachypithecus johnii*), Bonnet macaque and Sloth bear.

3.2.3 Upper Nilgiris (Upper Bhavani)

The Upper Nilgiris is located between 11° 10' and 11° 30' N and 76° 25' and 77° 00' E at the junction of the Eastern Ghats and the Western Ghats (Figure 3.4). It covers an area of 800 km^2. The Upper Nilgiris ranges from 1800 to 2500m above MSL in altitude and falls steeply to the surrounding plains.

The vegetation of the Upper Nilgiris consists of stunted evergreen forest, called sholas, and grasslands (Champion and Seth 1968). Original shola and grasslands are found only in small pockets as natural vegetation has been replaced at many places by plantations like wattle, pine, tea and eucalyptus. The rainfall ranges from 5000 mm on the western slopes to 1000 mm in the east.

Upper Bhavani receives rainfall mainly from south-west monsoon from June to August. Maximum rainfall is during July. It does not receive much rainfall from north-east monsoon. In dry season temperature ranges up to 20°C and night temperature may fall below freezing point. Because of high wind velocity, the trees in sholas are stunted with rounded canopies. The shola vegetation is dominated by members of families Lauraceae, Rubiaceae, Symplocaceae, Myrtaceae and Euphorbiaceae (Sukumar *et al.* 1995).

The major trees are *Daphniphyllum neilgherrense, Mahonia leschenaultii, Michelia nilagirica, Rhododendron nilagiricum, Syzigium montanum*, *Symplocos* spp., *Viburnum hebanthum and Cryptocarya lawsoni.* Understorey consists of shrubs such as *Psychotria congesta, Strobilanthes* spp, *Lasianthus* spp., *Gaultheria fragrantissima, Polystricum* spp. and climbers like *Piper*

Plate 3 Scrub jungle in Mudumalai Wildlife Sanctuary

Plate 4 Shola vegetation in Upper Bhavani

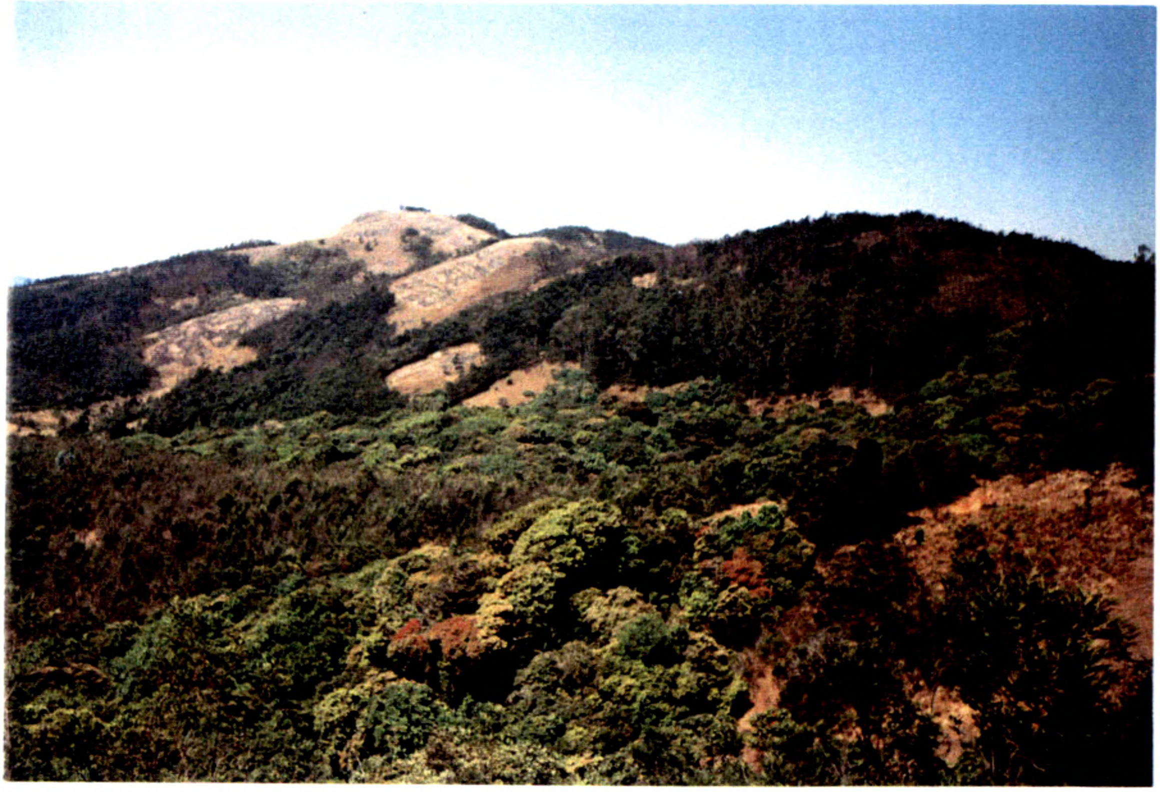


Plate 5 Shola patches mixed with Wattle plantation

Plate 6 Dry deciduous forest in Mudumalai

Plate 7 Tea plantation

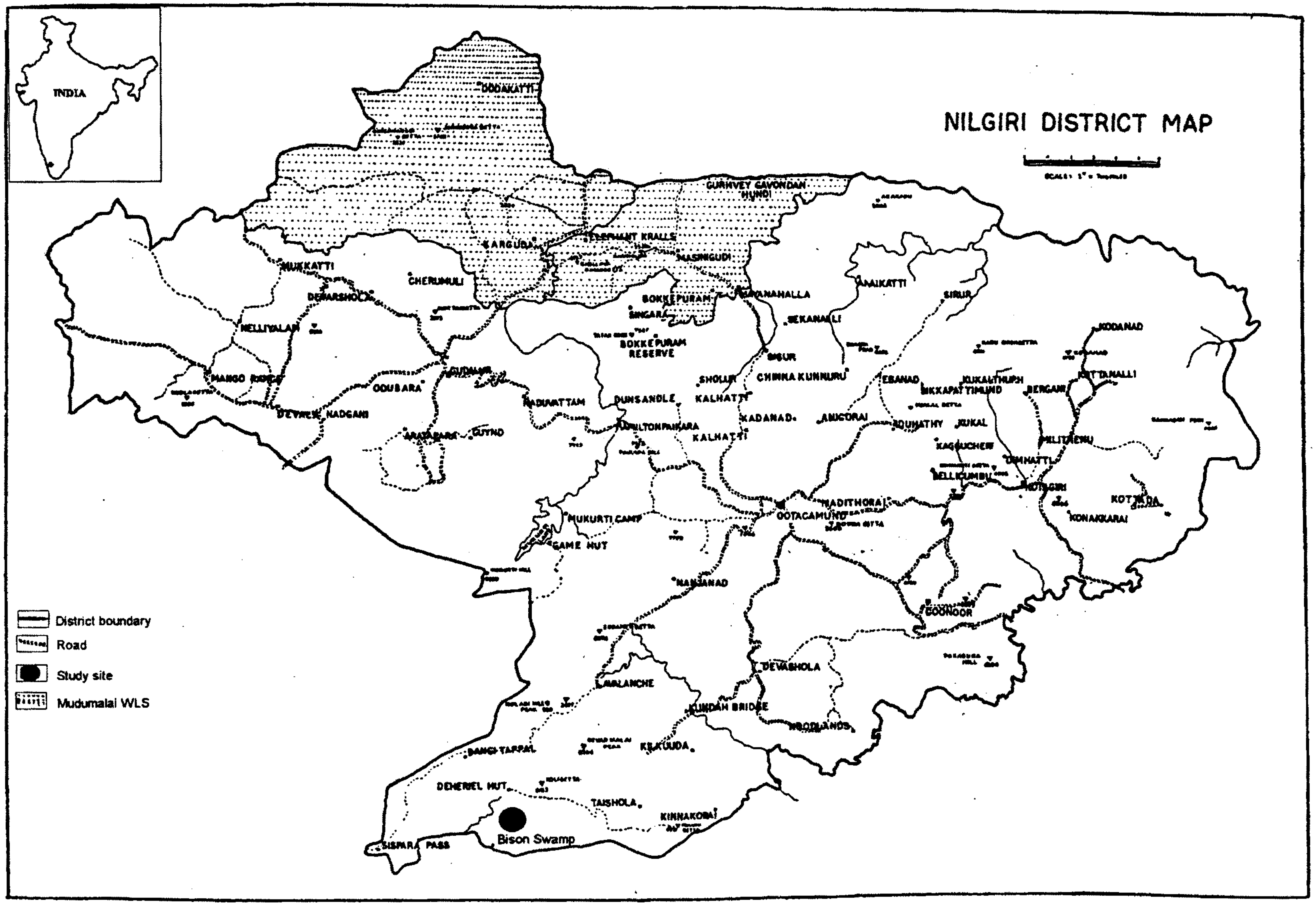


Figure 3.4 Nilgiri District indicating the study area – Upper Bhavani (Bison Swamp)

argyrophyllum, *Smilax* spp. Herb layer is not much dense and includes species such as *Fragaria* spp., *Themeda* spp. and *Cymbopogon* spp.

Fauna of Upper Bhavani includes Nilgiri thar, a highly endangered species. Other mammals found here are Sambar, Asian elephant, Barking deer, Jackal (*Canis aureus*), Jungle cat (*Felis chaus*), Leopard cat, Ruddy mongoose, Small Indian civets, Nilgiri marten (*Martes gwatkinsi*), Indian Wild dog (*Cuon alpinus*), Leopard, Tiger, Nilgiri langur and Bonnet macaque. Malabar Rock Pit Viper (*Trimeresurus malabaricus*) and Horse-shoe Pit Viper (*Trimeresurus strigatus*) are common reptiles.

3.2.4 Siruvani

The mixed deciduous forest of Siruvani, which is situated in the foot hills of the Western Ghats of Tamil Nadu lying north to Palghat gap,was selected for further ecological studies on select weedy species (Figure 3.5). The Siruvani area is situated 34 km west of Coimbatore city. Siruvani forest falls under Boluvampatti range of Coimbatore forest division, Tamil Nadu, which lies between 10° 15' and 11° 0' N and 76° 42' and 76° 51' E. Siruvani water purification plant, the main source of drinking water to Coimbatore city, is located in this area. Siruvani is easily approachable by road. River Noyyel flows closely parallel to this road on its northern side. Agricultural cultivations such as sugarcane, paddy, cotton, banana and millets are common on both sides of the road.

The underlying rock in Siruvani forest is gneiss of Archean group. The gneiss is finely foliated and is composed of quartz, felspar, horneblende and biotite (black

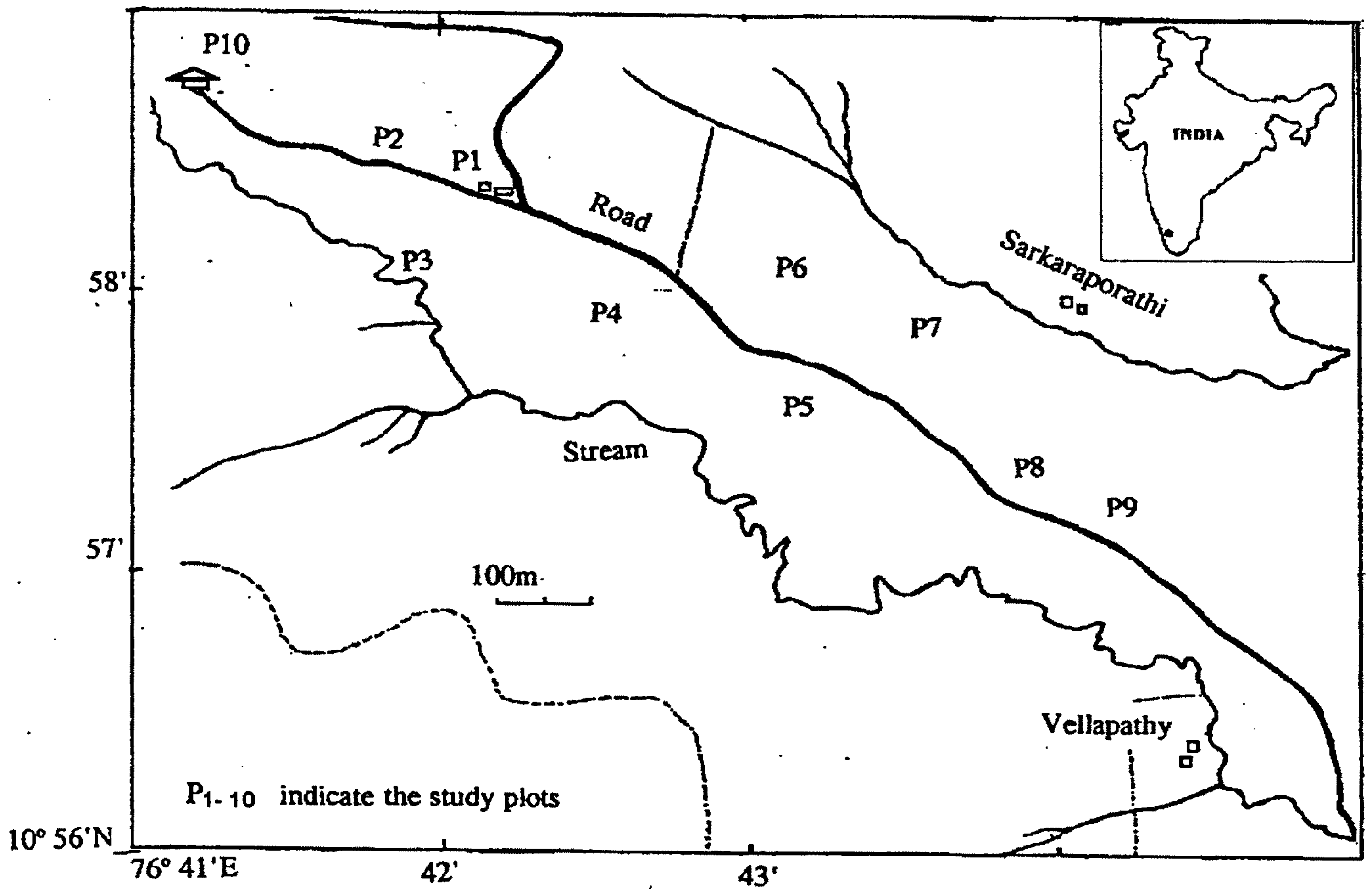


Figure 3.5 Study site at Siruvani indicating the location of study plots

mica) with an occasional admixture of garnet (Subramanyam 1959, George 1984). Laterite in pure form is not observed in the hills. Soil is reddish with yellow clay along the foothills (Subramanyam 1959). The rocks undergo a change akin to laterite metamorphosis, which results in the formation of pale yellow to red coloured soil. The soil along the banks of the river Noyyel is black, clayey alluvial and very fertile (Subramanyam 1959, Subramaniyan 1966).

March, April and May are the hottest months. Except during these months climate is cool and pleasant throughout the year. Temperature ranges from 24 to 38° C at day time and night temperature ranges from 18 to 29° C. Mean annual humidity is 75%. The area receives good rainfall during the monsoon. The area receives both south-west and north-east monsoon and the rainfall during south-west monsoon is heavy usually starting by the end of May or beginning of June and lasts up to August. North-east monsoon commences in October and continues up to December. Mean annual rainfall is 2000 mm.

Forest in Siruvani area comes under the southern tropical moist deciduous type (Champion and Seth 1968). These deciduous forests gradually merge into the southern tropical evergreen forests at higher elevations (Subramaniyan 1966). While, vegetation in the study plots was represented by elements of dry deciduous as well as moist deciduous forests, so forest in study location is considered as mixed deciduous forest.

Flora of Siruvani forest mainly consists of evergreen elements such as *Litsea floribunda*, *Macaranga peltata, Alstonia scholaris, Lagerstroemia lanceolata,* *Syzigium cumini*, deciduous trees such as *Terminalia bellerica, Terminalia paniculata, Anogeissus latifolia, Tectona grandis, Dalbergia latifolia, Cordia wallichii, Bridelia retusa, Stereospermum tetragonum* and *Albizia amara*. Shrubs include *Glycosmis pentaphylla, Grewia hirsuta, Helicteres isora, Desmodium pulchellum, Zizyphus nummularia, Chromolaena odorata* and *Lantana camara*. Climbers commonly seen, are *Ipomoea staphylina, Clematis gouriana, Dioscorea bulbifera, Dioscorea pentaphylla, Cryptolepis buchanani, Naravelia zeylanica*, *Zizyphus oenoplia, Toddalia asiatica, Pterolobium indicum* and *Spatholobus roxburghii.* Ground layer includes rare plants such as *Rauwolfia serpentina* and common species such as *Hemidesmus indicus, Curculigo orchioides, Sida acuta, Mimosa pudica, Stachytarpheta jamaicensis, Urena lobata, Commelina* spp. and *Phaulopsis imbricata.* Major grasses are *Cyrtococcum deccanense, Panicum* spp. and *Oplismenus compositus.*

Asian Elephant, Sambar, Barking deer, Leopard, Indian Wild dog, Nilgiri langur, Bonnet macaque, Sloth bear and Giant squirrel are common in the Siruvani forest.

CHAPTER 3

THE BROWN PALM CIVET AS A FRUGIVORE AND SEED DISPERSER IN TROPICAL RAINFORESTS

3.1 INTRODUCTION

Carnivores, being at the apex of food-chains, are indicative of ecosystem health and integrity (Zielinski and Kucera 1995), and can potentially affect food-web and community structure of lower trophic levels (Eisenberg 1989, Palomares *et al.* 1995). The order Carnivora is a diverse group of mammals comprising of animals with varied food habits. While there are a few strictly carnivorous and folivorous species such as the tiger and giant panda (*Ailuropoda melanoleuca*), respectively, many members of the families Canidae, Ursidae, Viverridae, and Herpestidae, are omnivorous and opportunistic in their dietary habits (Eisenberg 1989). Many of them are small-bodied animals, frequently referred to as 'small carnivores'. Small carnivores are also important functional components of tropical forest ecosystems. Some small carnivores in the family Viverridae, particularly in the sub-family Paradoxurinae, are known to be highly frugivorous (Bartels 1964, Corlett 1998). Adapted to frugivory, many of these species are suspected to influence the dynamics of their forest habitats by being important agents of seed dispersal and regeneration of many plant species, thereby shaping plant community structure (Herrera 1989, Rabinowitz 1991, Corlett 1998).

Plant-animal interactions such as pollination, frugivory, and seed dispersal have received much research attention in recent years. Theories governing these interactions and adaptations have been examined in ecological studies of various taxa, mainly birds, bats, and primates (*e.g.*: Estrada and Fleming 1986, Corlett 1998, Lambert and Garber 1998, Norconk *et al.* 1998). One group known to play a significant role in frugivory and seed dispersal, but which has been inadequately studied, are the small carnivores, particularly civets and mongooses (Herrera 1987, 1989; Gruèzo and Soligam 1990, Rabinowitz 1991). Being both carnivorous and frugivorous in habit, small carnivores may switch their feeding habits, depending on the habitat-wide availability of food resources (Leighton and Leighton 1983), or based on the nutritive quality of food items (Herrera 1987, 1989).

The role of small carnivores as seed dispersers is one of the most poorly studied aspects of their ecology despite knowledge of their frugivorous habits (Leighton and Leighton 1983, Smythe 1986). It remains to be determined whether they are effective seed dispersers (Herrera 1989), an aspect that has potential implications for the maintenance of plant communities and the restoration of degraded areas. Nevertheless, few studies have tried to examine the proportion of fruits in the diet of small carnivores, and their role as frugivores and seed dispersers (Gruèzo and Soligam 1990, Herrera 1989, Corlett 1998, Engel 2000).

In this chapter, I discuss the dietary habits of the brown palm civet *Paradoxurus jerdoni*, a small carnivore endemic to the tropical rainforests of the Western Ghats. The brown palm civet was the most common small carnivore in the Kalakad-Mundanthurai Tiger Reserve (KMTR, Chapter 6). Its role as a seed disperser of rainforest plant species was also assessed. The study was carried out for a period of 3½ years between May 1996 and December 1999.

3.2 OBJECTIVES

In this chapter, the following questions are addressed:

a. What is the diversity of species/taxa/kinds of items consumed by the brown palm civet?
b. What is the relative importance of different species in their diet? How do these vary intra- and inter-annually?
c. Do physical characteristics of fruits influence choice by civets?
d. Are brown palm civets important and effective seed dispersers in the rainforest? Are they the sole dispersers of any plant species?

The results of this study are used to assess the functional and conservation importance of brown palm civets in the tropical rainforest of the Western Ghats.

3.3 METHODS

3.3.1 Diet composition: scat analysis

Food habits of the brown palm civet were studied using scat analysis, a technique widely used to study small carnivore diet (Herrera 1989, Rabinowitz 1991, Palomares 1993a, Palomares *et al.* 1995, Chuang and Lee 1997). All scats encountered along existing forest trails and in the rainforest interior were examined thoroughly in the field or collected for macroscopic examination at the base camp. Scats observed or collected from forest edges were not used for analysis.

Scats of the brown palm civet were identified based on their shape, size, and location. Brown palm civet scats are straight, cylindrical ($\leq$ 2 cm in diameter), rounded at both ends and usually defecated as a single bolus on prominent places like fallen logs and rocks. This defecation behaviour is typical of palm civets (Bartels 1964). Unlike felid scats, civet scats lacked a pungent smell. These attributes of scats were directly confirmed by comparison with scats produced by brown palm civets captured as part of a radio-telemetry study (Chapter 5). Thin-Layer Chromatography (TLC) technique, which is highly influenced by the diet (Quinn and Jackman 1994), could not be used to identify brown palm civet scats in the study area. Preliminary assessment using this method did not produce reliable results due to the dominance of plant material in the scats (A. Kumar *personal communication*, D. Mudappa *personal observation*).

A total of 1035 scats were collected during the study from three rainforest sites in KMTR between May 1996 and December 1999. Of these, 1013 were classified as those of brown palm civets, based on the criteria mentioned above, and their remains were examined in detail. The remains in scats were identified by comparison with a reference collection of fruits, seeds, and hair samples. All fruits, with the exception of *Ficus*, were identified to specific level. All the *Ficus* species were treated as one group, as the species could not be distinguished based on the seeds in scats. Among invertebrates, insects were also treated as a group, while crabs, snails, millipedes, and centipedes were dealt with as separate species groups, as they were easily identified in the field. Among the mammals, only the Malabar spiny dormouse (*Platacanthomys lasiurus*) was identified to the specific level, while the rest of the mammalian hair remains were treated as a single species group. Henceforth, each of the species as well as groups of species mentioned above will be referred to as *species*.

The contribution of each species to the diet (fruits, invertebrates, vertebrates, etc.) was calculated following Genovesi *et al.* (1996) as:

(i) the frequency of presence (F_a) in scat,

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

where,

n_a = number of scats with item *a*,

N = total number of scats; and

(ii) the absolute frequency of occurrence (F_i) of each item or species,

$$F_i = \frac{N_i}{N} \times 100$$

where,

N_i = number of occurrences of species *i*,

N = total number of occurrences of all species (ΣN_i).

The importance of a dietary species was assessed based on its frequency of occurrence (F_i) in the diet (Genovesi *et al.* 1996). Any species contributing to more than 25% of the diet in a given month was considered to be an important species. F_a was calculated for the overall diet as it makes the data comparable with results of most other studies, although F_i has been recommended as being a better estimate (Genovesi *et al.* 1996).

Apart from this, an importance species index (IS) was calculated for the species consumed each month in order to identify a set of food species of importance for the year-round sustainability of the brown palm civet. This was calculated using the formula,

$$IS = NY_i + RF_i + NM_i$$

where,

NY_i = the number of years species i occurred in the particular month over the study period (*e.g.*: if species i was found in 3 of the 4 Julys in the 3½ year study period, then $NY_i = 3$),

RF_i = relative rank of its occurrence in scat (with the most frequently occurring species getting the largest rank within each month),

NM_i = the number of subsequent months from the month of interest that the species occurred.

Using the number of occurrences and proportion of each species, the species richness, Shannon-Wiener diversity index (H'), evenness (E), and dominance (d) of fruit species were calculated (Magurran 1988) for each of the years for scats from Sengaltheri.

$$H' = -\Sigma p_i \ln p_i$$

where

H' = Shannon-Wiener Diversity Index,

p_i = proportion of i^{th} species in the scats

$$E = \frac{H'}{H_{max}} \times 100$$

where

E = evenness measure (range 0–1)

H' = Shannon-Wiener diversity index

H_{max} = maximum value of $H' = \ln S$, where S = total number of species

$$d = \frac{N_{max}}{N} \times 100$$

where

d = Berger-Parker index of dominance

N_{max} = number of occurrences of the most abundant species in a given month

N = total number of items in scats for that month

Sorenson similarity index (C_S, Krebs 1989) was used to assess the inter-annual and monthly overlap of food species for Sengaltheri in the years 1998 and 1999.

$$C_S = \frac{2j}{(a + b)} \times 100$$

where

a = number of species in month or year 1

b = number of species in month or year 2

j = number of species common to both the months or years

Inter-annual comparisons (similarity index) were made between only 1998 and 1999, as scats were collected in all the months only in these two years.

3.3.2 Fruit characteristics

In order to test for choice of particular physical traits of fruits by brown palm civets, characteristics of 35 most commonly consumed species were compared with the 30 most abundant non-civet food plants in the study area. Following Herrera (1989), fruits were classified into various groups based on their physical characteristics as observed in the field or taken from published literature (Gamble 1935). All the species eaten and those listed in the two published literature accounts (Ganesh *et al.* 1996, Parthasarathy 1999) were categorised as fruits of lianas, shrubs, or trees (plant form). The fruit type categories used were: drupe, defined as an indehiscent fleshy fruit with a single seed; berry, indehiscent fleshy fruit with more than one seed, usually soft, embedded in the pulp; arillate, usually capsules; and others, including both fleshy compound fruits, and dry, dehiscent fruits like follicles and pods. Other characteristics used were fruit size (<1 cm diameter = small, 1–2 cm = medium, >2 cm = large), colour of ripe fruit (yellow, purple, brown + pink to red, blue + green), presence or absence of resin or latex, odour, number of seeds, seed sizes (≤ 0.5 cm = small, 0.6–1 cm = medium, >1 cm = large), pulp (0 = absent, <1 mm = thin, 1–4 mm = moderate, > 4mm = thick), and water content (<25% = dry, 25–50% = moderate, >50% = watery). The choice of particular fruit characteristics was assessed by χ^2 contingency table tests (Siegel and Castellan 1988). Expected frequencies were generated from data.

3.3.3 Seed germination experiments

Regeneration experiments were carried out in order to determine the effectiveness of brown palm civets as seed dispersers. Percentage germination and rate of germination of seeds from scats were compared with control seeds collected directly from fruiting trees. Identical trays were filled with a layer of moistened surgical cotton and kept in a shaded greenhouse under identical environmental conditions near the field base camp. Undamaged defecated and control seeds were planted in these trays and their viability (probability of germination) and rates of germination (number of days to germinate) were monitored regularly. The number of seeds used was between 25 and 65 each for both control and defecated, for all species but *Palaquium ellipticum*, for which only 3 seeds were available from the scats. The proportion of seeds that were damaged in the scats was also noted. Statistical differences between defecated and control were tested using χ^2 tests (Siegel and Castellan 1988).

3.4 RESULTS

3.4.1 Adequacy of sample size

Of 1013 brown palm civet scats collected, the number of scats collected from each site differed—Kakachi - 186, Kannikatti - 271, and Sengaltheri - 556. Scats were collected during 5 months in 1996, during 10 months in 1997, and during all months in 1998 and 1999 in Sengaltheri (fewer months in other sites).

The number of scats collected in each month varied between 2 and 112 (Figure 3.1), whereas the number of items represented in scats per month varied from 2 to 140. There was a significant positive correlation between the monthly number of items and number of scats in all the

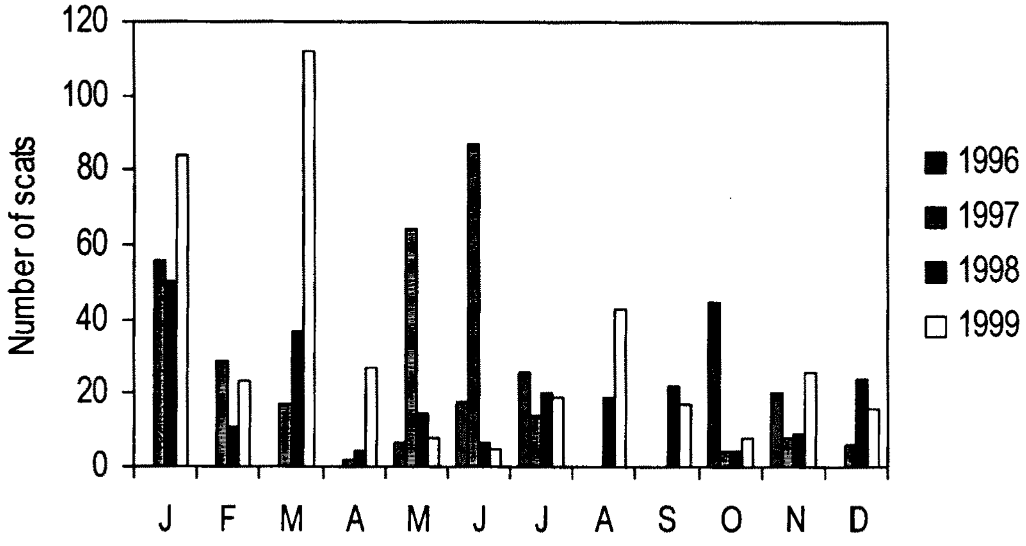


Figure 3.1: Number of brown palm civet scats collected monthly during the study period between May 1996 and December 1999 in Kalakad-Mundanthurai Tiger Reserve (KMTR).

years (Spearman rank correlation $r_s = 0.90$, $n = 39$, $P < 0.04$). Across years, the monthly number of species found in the scats was also significantly positively correlated to the number of scats (Figure 3.2, $r_s = 0.678$, $n = 39$, $P < 0.001$) and items ($r_s = 0.721$, $n = 39$, $P < 0.001$).

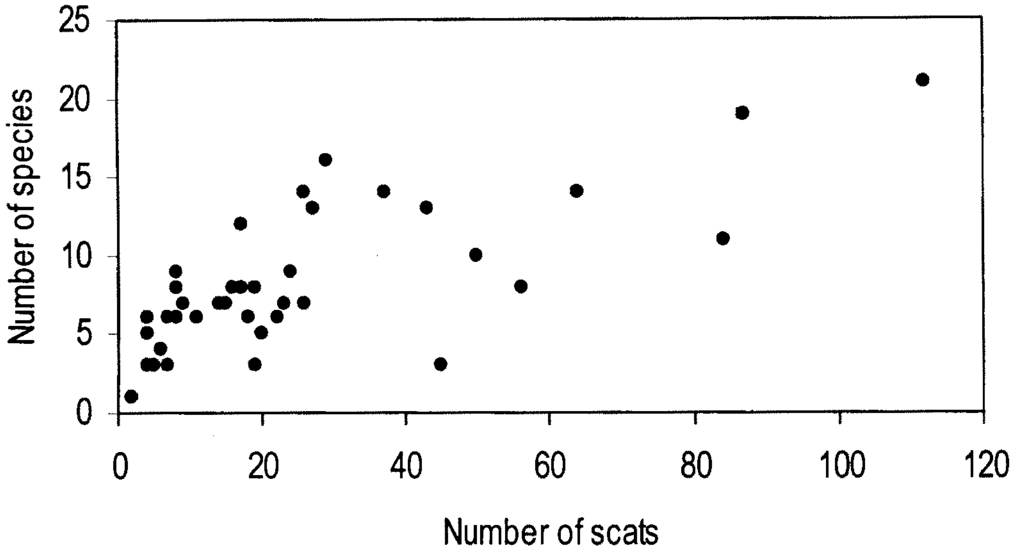
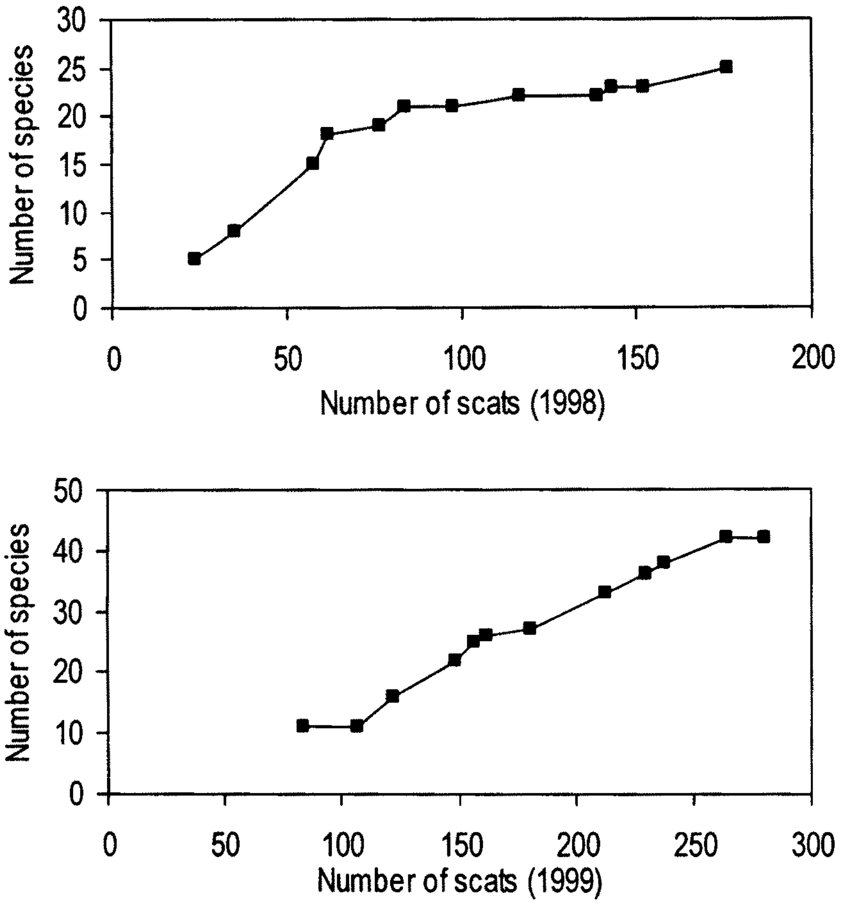


Figure 3.2: Correlation between the number of food species and the number of scats of brown palm civets collected monthly between May 1996 and December 1999 in KMTR.

The cumulative number of species in the scats in the years 1998 and 1999 (when scats were collected in all months) was plotted as a function of sample size, i.e. the number of scats collected (Figure 3.3). In 1998, the number of species appeared to reach an asymptote at about 80 scats, collected over 6 months. In contrast, there was a steady increase in the number of species recorded in the scats in 1999 and an asymptote appeared to be reached only after 250 scats, or 10 months of collection (Figure 3.3).

3.4.2 Diet composition

Fruits constituted the predominant diet of the brown palm civets in the region—91.12% of scats had fruit remains of native plant species. Fruits of 53 native species of plants from 27 families (including 8 unidentified species) were consumed by brown palm civets. Fruits of four species of exotic, introduced, or domesticated plants (banana *Ensete paradisiaca*, cardamom *Eletteria cardamomum*, coffee *Coffea arabica*, and guava *Psidium guajava*) were also consumed. When exotic fruits were also included, 97.04% of scats contained fruit remains. Fifteen scats (1.48%) had remains of flowers of two rainforest tree species—*Cullenia exarillata* (Bombacaceae) and *Syzygium* sp. (Myrtaceae). Grass pellets were occasionally found in scats.



Figures 3.3: Cumulative increase in the number of species in the diet of the brown palm civet (from scats collected) in Sengaltheri, KMTR.

Invertebrate remains (insects, millipede, centipede, snail, or crab) were found in 116 scats (11.45%). The occurrence of vertebrates, including rodents, other mammals, birds or reptiles, in the scats was rare (3.75%, 38 scats). Twelve scats had grass (usually along with vertebrate remains), and one had bees wax. A single species (or species group) was recovered from 79.86% (809) of the scats, 16.19% (164) contained remains of two species, 3.36% (34) had three, and only 6 (0.59%) scats had four species. None of the scats had more than four discernible species.

The above plant food species formed nearly a third of the plant species and half of the plant families in the area. The six most dominant fruits in the diet were *Elaeocarpus munronii* (average absolute frequency of occurrence, F_i, across 1996-99 = 9.73%), *Holigarna nigra* (9.52%), *Acronychia pedunculata* (5.80%), *Nothopegia beddomei* (5.76%), *E. serratus* (4.66%), and *Palaquium ellipticum* (4.62%, Appendix 1).

No fruit contributed more than 10% to the overall diet (average F_i across years, Figure 3.4), while nearly 62% (39 including animal matter) contributed to less than 1%. Only two species, *Elaeocarpus munronii* and *Holigarna nigra*, contributed between 9% and 10% to the overall diet (Figure 3.4).

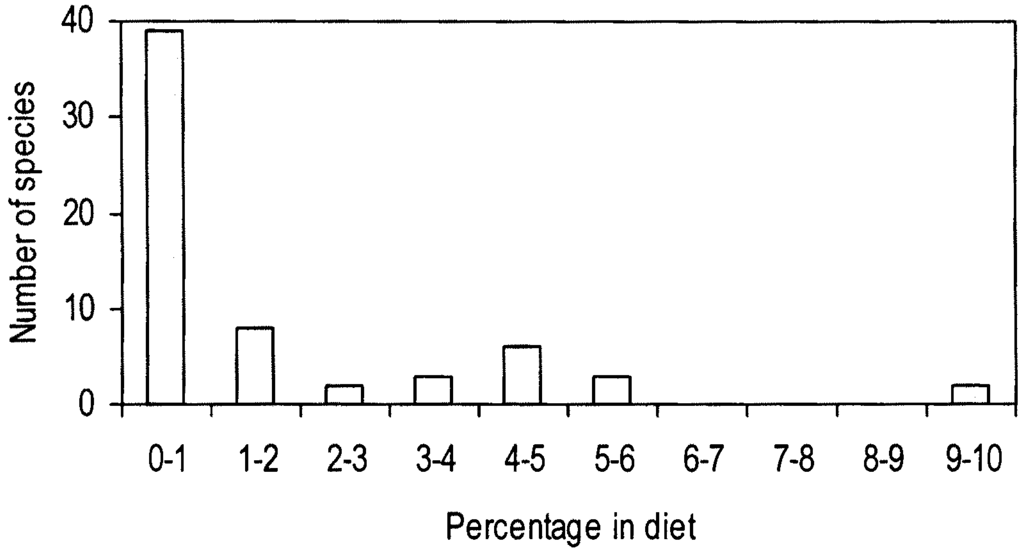


Figure 3.4: Frequency distribution of the percentage occurrence of various species in the diet of the brown palm civets in KMTR.

3.4.3 Inter- and intra-annual variation in diet

3.4.3.1 *Inter-annual variation*

There was considerable inter-annual variation in the species and their frequency of occurrence in the civets' diet. The data are summarised in Appendix 1. There was variation between years in the number of species consumed in each month (Figure 3.5). In Sengaltheri, although 17 identified plant species (excluding the exotics and grass) were consumed in 1998 and 33 species in 1999, only 15 were common to both years (appendix 1). The Shannon-Wiener diversity index was 2.801 and 2.930 in 1998 and 1999, respectively. The evenness index was higher for 1998 ($E = 0.86$) than for 1999 ($E = 0.77$).

Of the 10 most commonly eaten species (see section 3.4.3.2) in 1998 and 1999, five (*Holigarna nigra, Acronychia pedunculata, Elaeocarpus serratus*, coffee, and insects) were common to both years. The relative frequency of occurrence, as well as importance (based on percentage occurrence), of the top 10 species differed between years. The species with the highest frequency of occurrence was *Palaquium ellipticum* (14.4%) in 1998 and *Elaeocarpus munronii* (12.1%) in 1999.

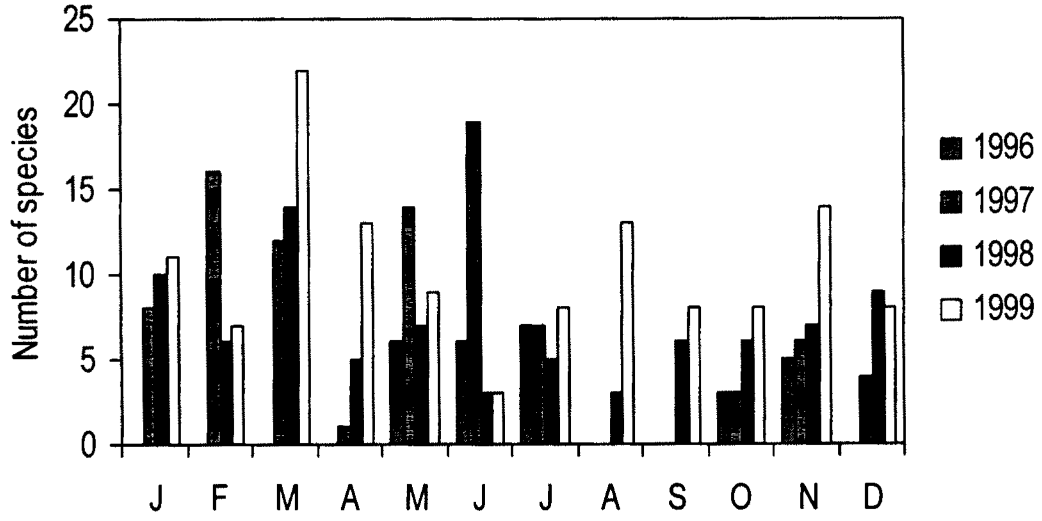


Figure 3.5: Number of species in brown palm civet scats collected between May 1996 and December 1999 in KMTR.

3.4.3.2 *Monthly variation*

The number of species recorded in a month ranged from one to 22 (Figure 3.5), the highest being in March, both in 1998 and 1999. The number of species recorded monthly in scats was significantly positively correlated to the monthly number of scats collected (r_s = 0.59 and 0.75 for 1998 and 1999, respectively, n = 12, P < 0.05). The overlap between successive months (Sorenson's index of similarity) in the species consumed was low in 1998 and in 1999 (C_S < 0.5 in 14 out of 23 pairs of months, Figure 3.6). In 1998, the overlap was highest between August and October (C_S = 0.667),

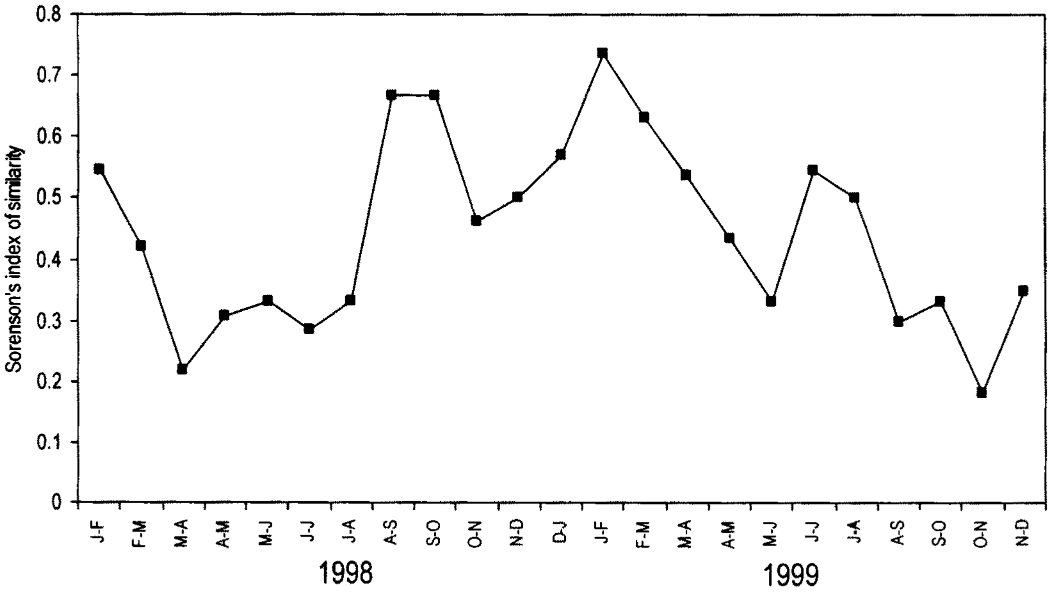
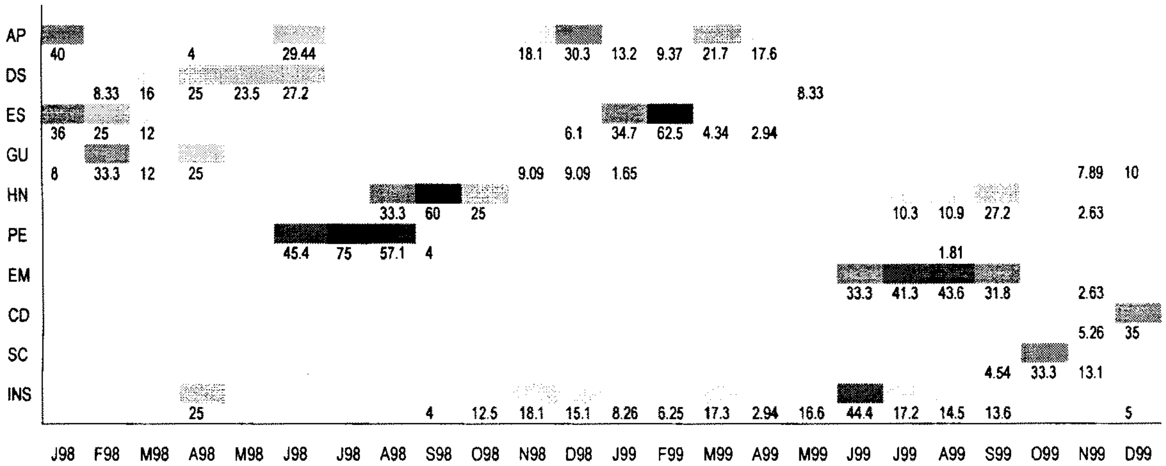


Figure 3.6: Overlap (Sorenson's similarity index) between successive months in the number of species in the diet of brown palm civets in Sengaltheri, KMTR.

and lowest during March – April (C_S = 0.220). In 1999, the lowest overlap was during October – November (C_S = 0.182), and the highest between January and February (C_S = 0.706).

Each of the 10 species (9 fruit species and insects) accounted for 25–75% of the diet in some months in the years 1998 and 1999 (Figure 3.7). Among the introduced species, coffee contributed significantly to the diet. The gymnosperm *Gnetum ula* was also one of the most commonly eaten fruits. Fruits of palms such as *Bentinckia codapanna*, *Caryota urens*, *Pinanga dicksoni*, and *Calamus* sp. were also eaten.

Figure 3.7: Food species/items contributing to over 25% of the diet of the brown palm civet in Sengaltheri, KMTR, 1998–1999 (percentages mentioned below the shades. Darker shades imply higher percentages). AP – *Acronychia pedunculata*, DS – *Diospyros sylvatica*, ES – *Elaeocarpus serratus*, GU – *Gnetum ula*, HN – *Holigarna nigra*, PE – *Palaquium ellipticum*, EM – *E. munronii*, CD – *Canthium dicoccum*, SC – *Strychnos colubrina*, INS – Insects and other arthropods.



The importance value index (*IS*) identified *Ficus* spp., *Chrysophyllum lanceolatum*, *Pandanus* sp., *Gnetum ula*, *Artocarpus heterophyllus*, *Diospyros sylvatica*, and insects, along with *Holigarna nigra*, *Elaeocarpus serratus*, *Acronychia pedunculata*, *Nothopegia beddomei*, and *Palaquium ellipticum* (the six species mentioned earlier in section 3.4.2), as a set of species that is most consistently used by the brown palm civet over the years (Table 3.1). *Elaeocarpus munronii*, *Filicium decipiens*, and *Lepisanthus decipiens* were also identified as important species. Although the percentage contribution of *Ficus* spp. and insects to monthly diet was low on an average, their importance emerges when the numbers of months and years that they were eaten in were considered.

There was also considerable variation in the occurrence of animal matter in the diet across months in the two years (Figure 3.8). The frequency of occurrence of invertebrates and vertebrates was the highest in April (25%) and October (37.5%) in 1998, and in June (44.4%) and August (27%) in 1999. The first peak in 1998 was milder than the second, while in 1999 the second peak was milder. The milder peaks in both the years corresponded with the drier periods of the year, and the

Table 3.1: Monthly sets of five significant food items identified using the important species index (AP – *Acronychia pedunculata*, ES – *Elaeocarpus serratus*, CL – *Chrysophyllum lanceolatum*, DS – *Diospyros sylvatica*, FD – *Filicium decipiens*, AH – *Artocarpus heterophyllus*, GU – *Gnetum ula*, EM – *E. munronii*, HN – *Holigarna nigra*, PE – *Palaquium ellipticum*, NB – *Nothopegia beddomei*, LEPI – *Lepisanthus decipiens*).

Month	**Species →**				
	1	**2**	**3**	**4**	**5**
January	AP	ES	Insects	Figs	Vertebrate
February	Figs	ES	Insects	AP	Vertebrate
March	Insects	CL	Figs	AP	DS
April	Figs	Insects	FD	GU	AP
May	Figs	Insects	AP	CL	AH
June	EM	PE	Insects	Figs	AH
July	EM	HN	Figs	Insects	CL
August	EM	HN	PE	Insects	LEPI
September	Insects	HN	EM	NB	Figs
October	Insects	GU	NB	HN	*Pandanus*
November	Insects	GU	HN	AP	EM/NB
December	Figs	Insects	GU	AP	ES

stronger peaks (October and June) corresponded with a different monsoon period in the two years. The higher occurrence of animal matter during the dry season could be influenced by the low availability of fruit resources in the dry season (Chapter 4), although the stronger peaks did not correspond to lows in fruit availability.

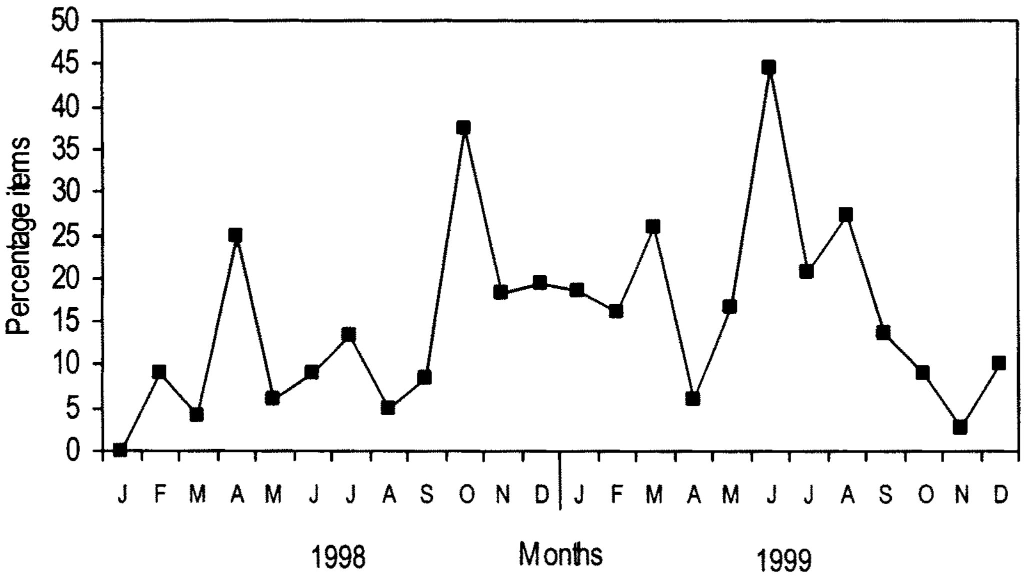


Figure 3.8: Frequency of occurrence of animal matter in the scats of brown palm civets in 1998 and 1999 in Sengaltheri, KMTR.

3.4.4 Traits of food plant species

3.4.4.1 *Plant form*

Most fruits eaten were of trees and lianas; shrubs and herbs were rarely used ($\chi^2 = 30.28$, $df = 4$, $P < 0.001$; Table 3.2). Twenty seven overstorey and 7 understorey tree species, 9 species of lianas

Table 3.2: Comparison of brown palm civet food species (N=35) and non-food species (N=30) characteristics in the tropical rainforests of KMTR, Western Ghats (significant variables in bold).

	Class	Percentage of species				Chi-square	P
1.	**Plant form***	Trees	Understorey trees	Lianas	Shrubs		
	Civet food	57.45	14.89	19.15	8.51	23.48	<0.001
	Other	27.10	30.97	9.68	32.26		
2a.	Fruit type	Drupe	Berry	Arillate	Other		
	Civet food	45.71	34.29	11.43	8.57	6.08	<0.1
	Other	56.67	10.00	13.33	20.00		
2b.	**Fruit size**		Small	Medium	Large		
	Civet food		28.57	31.43	40.00	5.18	<0.05
	Other		6.67	43.33	50.00		
2c.	Pulp thickness	Thick	Moderate	Thin	Absent		
	Civet food	48.57	42.86	8.57	0.00	4.88	<0.1
	Other	26.67	50.00	20.00	3.33		
2d.	Water content		Watery	Moderate	Dry		
	Civet food		74.29	20.00	5.71	4.09	<0.1
	Other		53.33	26.67	20.00		
2e.	Colour	Purple	Yellow	Brown+ pink+red	Blue+ Green		
	Civet food	17.14	25.71	22.86	34.29	6.28	<0.1
	Other	23.33	3.33	26.67	46.67		
2f.	Odour			Presence	Absence		
	Civet food			14.29	85.71	3.3	<0.1
	Other			33.33	66.67		
2g.	Resin or latex			Presence	Absence		
	Civet food			17.14	82.86	0.003	NS
	Other			16.67	83.33		
3a.	Seed type			Stony	Soft		
	Civet food			54.29	45.71	1.03	NS
	Other			66.67	33.33		
3b.	Seed shape	Ellipsoid	Globose	Ovoid	Other		
	Civet food	28.57	17.14	45.71	8.57	3.68	NS
	Other	20.00	36.67	40.00	3.33		
3c.	Seed number			Solitary	Multi-seeded		
	Civet food			57.14	42.86	1.15	NS
	Other			70.00	30.00		
3d.	Seed size		Small	Medium	Large		
	Civet food		25.71	34.29	40.00	5.86	<0.1
	Other		13.33	16.67	70.00		

* Sample size was larger for plant forms: n (civet food) = 47 species; n (other) = 155 species, chi-square value for four categories only.

and climbers, and 4 species of shrub were used by the brown palm civet during the study period (Appendix 2).

3.4.4.2 *Fruit traits*

Brown palm civet consumed approximately equal proportions of large, medium-sized, and small fruits (Table 3.2). However, the proportion of smaller fruits was significantly higher in brown palm civet food species than among non-civet food species ($\chi^2 = 5.18$, $df = 2$, $P < 0.05$). Comparing fruits consumed by civets with non-consumed species, the characteristics that showed near significance were the type of fruits, pulp thickness, water content, colour, odour, and seed size (Table 3.2). The brown palm civets consumed a greater proportion of berries and drupes, and most of the fruits eaten had moderate to thick pulp. Fruits with >50% water content, smaller seeds, and yellow coloured fruits lacking odour seemed to be preferred. There was no significant difference between non-civet food species and those eaten by the civets in characteristics such as presence of odour, resin or latex, and in the number, kind, and shape of the seeds (Table 3.2).

3.4.5 Seed germination and seed dispersal

Seed viability assessments and germination experiments were done using 17 species. Seeds from scats were viable (able to germinate) in 14 species. For three species, neither tested nor control seeds germinated (*Acronychia pedunculata, Ensete superbum,* and *Elaeocarpus munronii*). Two species, *Elaeocarpus serratus* and *Gnetum ula* had a significantly greater proportion of defecated seeds germinating ($\chi^2 = 6.71$, $df = 1$, $P < 0.01$ and $\chi^2 = 2.98$, $P < 0.10$, Figure 3.9). *Filicium*

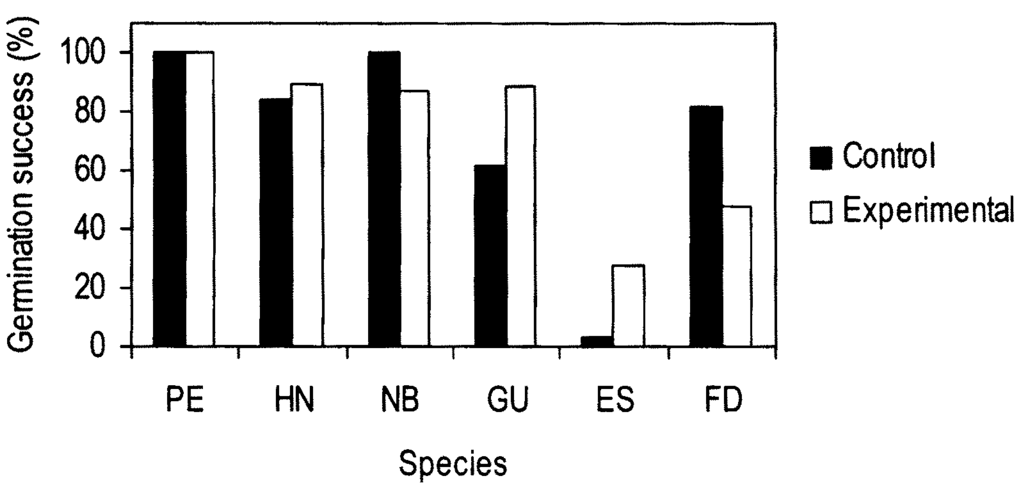


Figure 3.9: Germination success of seeds of six diet species—a comparison between seeds from plants and from scats of the brown palm civet in Sengaltheri, KMTR. PE – *Palaquium ellipticum*, HN – *Holigarna nigra*, NB – *Nothopegia beddomei*, GU – *Gnetum ula*, ES – *Elaeocarpus serratus*, FD – *Filicium decipiens*.

decipiens and *Nothopegia beddomei* had a significantly fewer defecated seeds germinating (χ^2 = 7.76, *df* = 1, *P* < 0.01 and χ^2 = 3.63, *P* < 0.10, Figure 3.9). However, *Filicium decipiens* seeds from scats germinated significantly faster than seeds collected from trees (Mann-Whitney test, *U* = 105, *P* < 0.003). In *Palaquium ellipticum* and *Holigarna nigra*, the germination rate (mean number of days to germinate) was significantly lower in control seeds than defecated seeds (*U* = 8, *P* < 0.07 and *U* = 524, *P* < 0.001, Figure 3.10).

The civets removed seeds of all the 53 species away from the parent trees, thereby reducing the probability of seed predation and clumping at high densities under the parent tree. For example, *E. serratus* and *A. pedunculata* seeds dispersed away from the parent trees had a higher probability of germination, as otherwise they suffered high predation and infestation under the parent trees (*personal observation*). Only in *Palaquium ellipticum* were seeds occasionally damaged.

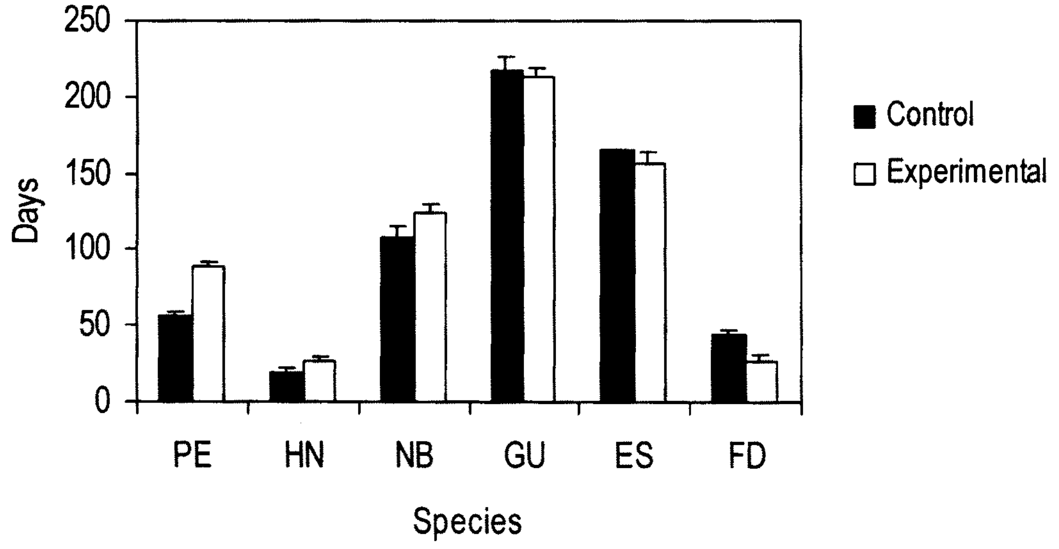


Figure 3.10: Rates of germination of seeds of six diet species—a comparison between seeds from plants and from scats of brown palm civet in Sengaltheri, KMTR (vertical bars = 1 S. E.; species codes as in Figure 3.9).

3.5 DISCUSSION

3.5.1 Adequacy of sample size

Although there was a very high correlation between number of species in the scat and the number of scats collected and the items represented in them, the rate of addition of new species to the diet reached an asymptote in 1998, while it continued to increase even after 250 scats were examined in 1999. This was probably highly influenced by the differences in the diversity of food species available in the two years (Chapter 4; see also Fleming 1986, Peres 1994, Struhsaker 1997, Stevenson *et al.* 2000). As there is usually a high spatio-temporal variation in food availability in any given habitat, a continuous variation in the food resource use can be expected (Terborgh 1990). Over the months and years, the diversity of dietary species may not have reached an asymptote due to the temporal turnover, however, within each month sampled, common and important species eaten were represented in the scats collected.

3.5.2 Diet composition

Of all the small carnivores studied thus far, the brown palm civet seems to be one of the most frugivorous, with 97.04% of its scats containing fruit remains, with a predomination of fruits and flowers of native plant species (91.12%). Among the small carnivores of the families Procyonidae, Mustelidae, Herpestidae, and Viverridae, the herpestids (mongooses) are the least frugivorous, while some mustelids (martens and weasels), procyonids (coatis and kinkajous), and viverrids (civets) are highly frugivorous (Wemmer and Watling 1986, Ewer 1998, Ray and Sunquist 2001). Among the viverrids, the members of the sub-family Paradoxurinae or the palm civets are more frugivorous than the others (Bartels 1964, Eisenberg 1989, Ewer 1998). A highly frugivorous diet comparable to that of the brown palm civet has been observed in a neotropical procyonid, the kinkajou *Potos flavus* (99% fruit, Roland 1999). In comparison with other carnivores (Rabinowitz 1991, Joshi *et al.* 1995, Yoneda *et al.* 1998a, Grassman 1998), the brown palm civet turns out to be the most frugivorous. Although many studies have shown that mustelids, herpestids, and viverrids are opportunistic in their diet choice, none of them have been shown to be so highly frugivorous (Table 3.3). For these species, fruits occur in greater proportion in their diet during seasons when fruit availability is high and alternative preferred foods are scarce.

In the brown palm civet, however, fruit predominates in the diet year-round. This pattern can be attributed to several factors. One factor is that it inhabits resource-rich tropical rainforests, where, although there are marked periods of fruit abundance and scarcity, there is year-round availability of fruits (Terborgh 1983, Fleming 1992, Struhsaker 1997). The second aspect is that the 'unspecialised' digestive system of the carnivores (with frugivory as an offshoot of evolution, Eisenberg 1989) and their ability to feed opportunistically, have probably enabled brown palm civets to become frugivorous. The third factor that could explain the frugivorous habit of the brown palm civet is a probable physiological adaptation to a frugivorous diet. Fruits are believed to be relatively nutrient poor (particularly protein, although see Martínez del Rio 1994). In order to meet their protein requirements, civets probably have adaptations that help in processing the food faster through short gut passage times thereby having a greater intake of low quality food (Alexander 1994). Also high

Table 3.3: Frequency of occurrence of flowers, fruits, and seeds in the diet of other small carnivores of families Procyonidae, Mustelidae, Herpestidae, and Viverridae.

Species (Common name)	**Frequency of occurrence of plant food (%)**	**Number of identified species**	**Source**
Nasuella olivacea (mountain coati)	37	1	Rodríguez-Bolaños *et al.* 2000
Potos flavus (kinkajou)	99	78	Roland 1999
Martes zibellina (sable)	22-38	2	Buskirk *et al.* 1996
Martes martes (pine marten)	5–35	9	Clevenger 1993a
Martes foina (stone marten)	59	16	Genovesi *et al.* 1996
Melogale moschata (ferret badger)	8	-	Chuang and Lee 1997
Herpestes ichneumon (Egyptian mongoose)	<5	-	Delibes *et al.* 1984
H. javanicus (small Indian mongoose)	29	4	Vilella 1998
H. naso (long-nosed mongoose)	8	-	Ray 1997
Atilax paludinosus (marsh mongoose)	8	-	Ray 1997
H. urva (crab-eating mongoose)	8	-	Chuang and Lee 1997
Macrogalidia musschenbroekii (Sulawesi palm civet)	62	3	Wemmer and Watling 1986
5 species of civets	76	18	Rabinowitz 1991
Paradoxurus hermaphroditus (common palm civet)	89	2	Yoneda *et al.* 1998a
Viverricula indica (small Indian civet)	58	7	Chuang and Lee 1997
Paradoxurus jerdoni (brown palm civet)	97	55	This study

intra- and inter-specific variation in fleshy fruit nutrient composition has been established (Herrera 1982, Debussche *et al.* 1987, Martínez del Rio and Restrepo 1992, Wendeln *et al.* 2000), and it is probable that these civets, like frugivorous bats and birds, meet their protein requirements by consuming a high diversity of fruits and flowers (Martínez del Rio 1994).

For the kinkajou, a nocturnal neotropical small carnivore similar in habits to the brown palm civet, the gut passage time was found to be between 35 and 215 minutes (Roland 1999), and for the Sulawesi palm civet *Macrogalidia musschenbroekii*, less than 12 hours (Wemmer and Watling 1986). The brown palm civets had gut passage time of less than 7 hours (approximate measure based on fruit consumption and defecation during capture and release of animals for radio-collaring, Chapter 5). Finally, the brown palm civets may meet their nutritional demands through low metabolic rates and correspondingly low energy needs (Gittleman and Harvey 1982, McNab 1989, 1995), by the use of less protein in physiological processes, and opportunistic consumption of invertebrates and vertebrates to supplement their diet (as seen in frugivorous bats, Fleming 1986, Courts 1998). Although their generally frugivorous nature is influenced by physiological and anatomical adaptations, their diet could also vary temporally according to the diversity and abundance of food available (Terborgh 1990, Fleming 1992, Ray and Sunquist 2001).

3.5.3 Temporal variation

Variation in species composition in the diet of the brown palm civets is pronounced, as indicated by very low species overlap between successive months. Many frugivorous species are known to either migrate to habitats with greater food resource availability during times of scarcity, or shift to feeding on animal matter and other rarer, aseasonal, or non-preferred fruits (Leighton and Leighton 1983, Terborgh 1986a, van Schaik *et al.* 1993, Struhsaker 1997). High temporal and spatial variation in fruiting in the tropics has been documented in earlier studies (Foster 1982, Leighton and Leighton 1983, van Schaik *et al.*1993, Kannan and James 1999). Intra- and inter-annual variations are likely to occur in the diet of unspecialised, though obligate, frugivores like the brown palm civet. There was very low overlap or similarity in species and also the frequency of occurrence of species eaten, both between months and years, probably a result of uneven temporal and spatial fruit production as observed in other areas (Terborgh 1986a, 1990). Even in bats in the neotropics, Fleming (1986) notes that they have a 'core' diet species pool, besides which they diversify their feeding habits based on food resource availability.

Despite such a high level of frugivory, brown palm civet scats frequently contained invertebrate and vertebrate remains. The increase in proportion of non-fruit items in the diet probably reflects a period of fruit scarcity in the area, making them more opportunistic in their diet. The importance of animal matter in the diet can be assessed only at finer levels of examination of the biomass and nutritive contribution of various food types, which was not done during this study. However, it must be noted that animal matter was consumed in 23 months during 1998 and 1999, and also that the peaks were in months when sample sizes were low. Although these civets feed on a diverse group of fruits and flowers, they seem to be consuming animal matter as a supplement, or at times as alternate food resources.

Although the brown palm civet diet comprised of a high diversity of plant species (flowers of 2 and fruits of 53 species), they did have a few species—*Holigarna nigra, Elaeocarpus serratus, Nothopegia beddomei, Gnetum ula,* and *Palaquium ellipticum*—that they preferred over the other abundantly flowering and fruiting species such as *E. munronii, Cullenia exarillata*, and *Antidesma menasu* (Chapter 4). However, in a given month not more than 14 species (usually less than 5 species) were found in the scats, implying the need for a diverse assemblage of food species in a given area. The predominant species differed between the years, suggesting not only food preference and the generalist nature (as they use a diverse number of species) of food choice of the brown palm civet, but also that they were probably tracking fruiting episodes, as shown in other species (Leighton and Leighton 1983, Terborgh 1983, Fleming 1992).

3.5.4 Fruit characteristics

Apart from the abundance of resources, diet choice may also depend on fruit traits—morphological or nutritive (Janson 1983, Gautier-Hion *et al.* 1985, Herrera 1989). Janson (1983) was able to classify two thirds of the plant species in a neotropical forest into bird and mammal dispersed species, based on their morphology. Large, orange, yellow, brown, or green fruits with husk have been identified as fruits with 'mammal syndrome' (Janson 1983, Gautier-Hion *et al.* 1985, Gautier-Hion 1990). Along with fruit colour, fruit size (diameter), pulp thickness, number of seeds, and persistence of fruits on the plant seem to determine the vertebrate dispersers that plants attract (Herrera 1989, 1998, Jordano 1995, Corlett 1996). Herrera (1989) found the fruits eaten by carnivores in the Mediterranean region of Spain to be heavy, pulpy, with many seeds, scented, and persisting for short periods on plants. The fruits consumed by carnivores in Spain also had less protein and total minerals, and higher fibre than the non-food species. The fruits eaten by brown palm civets were, on an average, smaller than those not eaten (although they did eat some of the large fruits like *E. serratus* and *P. ellipticum*, see Plate 4), which supports Jordano (1995) who points out that mammalian carnivores preferred small, pulpy fruits with small seeds, although the fruits eaten may be much larger than those eaten by avian frugivores.

The richness of tropical forest plant communities is well known (Richards 1996, Whitmore 1998). A majority of fruits in the tropical rainforest are fleshy, and a large variety of fruits is available throughout the year, often in superabundance (Terborgh 1986a). Being arboreal, a greater number of tree and liana fruits are eaten by the brown palm civets, and unlike the carnivores in the Mediterranean (Herrera 1989), they do not depend on fallen fruits. The preferred fruit types of the brown palm civet were small-seeded drupes and berries, usually blue or green in colour, with moderate to high water content in the pulp. The colour of fruits apparently does not influence their choice as the civets are nocturnal and tend to be colour-blind (Corlett 1998). The small carnivores reported from Spain preferred multi-seeded fruits (Herrera 1989).

As carnivores lack a specialised digestive system, they usually cannot consume fruits that are lipid-rich such as the fruits of the members of the families Lauraceae, Myristicaceae, and Annonaceae (Snow 1981, Corlett 1998), although these are some of the most common species in these forests (Ganesh *et al.* 1996, Parthasarathy 2001). Instead, they utilise the easily available and digestible sugar-rich fruits of the families Moraceae and Elaeocarpaceae. Martinez del Rio (1994) reports that mammals feed on sugar-rich fruits with high sucrose content. The physiological adaptations of viverrids, particularly palm civets, to their diet, has not been explored, although they seem to make up for the low quality diet by being opportunistic, and by having rapid gut passage time or a low metabolic rate (Gittleman and Harvey 1982, McNab 1995).

3.5.5 Seed dispersal

Many mammals, particularly primates and bats, have long been considered important seed dispersers (Fleming and Heithaus 1981, Izhaki *et al.* 1995, Corlett 1998, Dew and Wright 1998, Lambert and Garber 1998, Andresen 1999, Medellin and Gaona 1999, Voysey *et al.* 1999). However, in recent years, other species and groups of animals have also been recognised as important dispersers—these include invertebrates, birds, rodents, elephants, procyonids, viverrids, and other carnivores (Herrera 1989, Rabinowitz 1991, Balasubramanian and Bole 1993, Forget 1990, Levey and Byrne 1993, Yumoto and Maruhashi 1995, Corlett 1996, 1998, Wenny and Levey 1998, Whitney *et al.* 1998, James and Barry 1999, Roland 1999, Engel 2000). Among them, the role of civets as effective seed dispersers cannot be disregarded.

The members of the family Viverridae are probably the most important mammalian seed dispersers, with the only comparable taxa being primates and megachiropterans. However, the efficacy of these two latter groups as dispersers is debatable as (i) both of them ingest only the small seeds, (ii) often damage the seeds, and even predate on some, and (iii) drop the seeds under feeding trees, where they are likely to suffer higher density-dependent mortality and also predation. In contrast, the viverrids ingest many large seeds, do not predate or damage them, feed on a diverse array of fruit species, and are probably the only mammalian dispersers of fruits like *Acronychia pedunculata* and *Elaeocarpus serratus*. The frugivorous primates and large, frugivorous bats, with their large home-ranges may, however, disperse some seeds farther than civets. However, the probability of those sites being suitable for the germination and establishment of seedlings have to be examined.

Although the germination experiments conducted during this study were preliminary, the fact that seeds remained viable after passage through the gut should be noted. By feeding on a large number of species, civets are likely to play an important role in structuring rainforest plant communities. They also play an important role by carrying seeds away from under the parent trees, where they have been noted to have a high rate of predator infestation. However, effective dispersal of seeds is partly dependent on where they are defecated. If they are deposited on prominent or raised places, they may have to be 'assisted' in order to reach suitable micro-habitats for germination. Though there may not be any plant species that is solely dependent on the brown palm civet for dispersal in KMTR, in the absence or rarity of other large frugivores (Ganesh and Davidar 1999, 2001), the civet is probably the major seed disperser of many large-seeded fruits like the *E. serratus, G. ula, Diospyros* spp., and *Knema attenuata*. However, some of these species are also eaten and dispersed by sloth bears (*Melursus ursinus*). Large avian frugivores are relatively rare in the study area (Ganesh and Davidar 1999, T. R. S. Raman *personal communication*).

The role of brown palm civets as effective seed dispersers can be analysed by answering the following questions. Do they move seeds away from the parent trees, thereby reducing seed predation and infestation in areas of high densities? What proportion of the seeds is damaged? Are the defecated seeds viable? Are they deposited in the right macro- and micro-habitats? Do the civets increase the probability of germination by consuming them? Brown palm civets do move seeds away from the parent tree, with almost no damage, and have positive effects on seed viability and germination in most cases. As they are restricted to tropical rainforests, they do deposit the seeds in the right macro-habitat, although perhaps not always in the optimal micro-habitats (as they usually deposit them on fallen logs or large rocks).

The Neotropical and African forests are rich in primate seed dispersers (Terborgh 1983, 1986a; Struhsaker 1997), while south-east Asian forests are rich in avian and small carnivore seed dispersal assemblages (Leighton and Leighton 1983, Rabinowitz and Walker 1991, Heydon and Bulloh 1996). The community of vertebrate dispersers in the Western Ghats is depauperate when compared to these other areas (Ganesh and Davidar 1999, 2001). This accentuates the importance of the brown palm civet as a seed disperser in the tropical rainforest community of the Western Ghats. Being highly frugivorous, and generalist in nature, they make reliable seed dispersers for a large subset of rainforest species. An added benefit is that they feed on a wide range of species even in times of low food availability, dispersing even many rare species (*e.g.*: the palm *Bentinckia codapanna*). As they are confined to rainforests and do not migrate even in times of low resource availability, the probability of depositing seeds in the right macrohabitat is higher.

The brown palm civet is probably the most important mammalian seed disperser in the Western Ghats by virtue of being predominantly frugivorous and dispersing a greater number of species, compared to other sympatric arboreal mammals like the diurnal lion-tailed macaque (*Macaca silenus*), Malabar giant squirrel (*Ratufa indica*), and the nocturnal large brown flying squirrel (*Petaurista phillipensis*) that are mainly seed predators or consumers of little fruit (Ganesh and Davidar 1999). The brown palm civet could play a major role in the restoration of degraded rainforest patches along the Western Ghats. The knowledge of their diet will also help in identifying the important species or a minimal number of species that could sustain their populations round the year, in the light of continuing threats to their rainforest habitat in the form of loss and fragmentation. It is time that the small carnivores, particularly the palm civets are recognised as important seed dispersers and major players in the dynamics of forest communities (Herrera 1989, Engel 2000).

3.6 SUMMARY

1. In this chapter, I assessed the diet of the endemic brown palm civet *Paradoxurus jerdoni* and its role as a seed disperser. I also examined the traits that determine their choice of fruits.
2. Diet was studied by examining 1013 scats that were collected between May 1996 and December 1999 in the tropical rainforests of Kalakad-Mundanthurai Tiger Reserve. The brown palm civet was predominantly frugivorous, with 55 native species of fruits and flowers, and fruits of four species of introduced plants contributing to about 97% of their diet. Nine species of fruits and invertebrates were identified as important food for the year-round sustenance of the brown palm civet.
3. There was high intra- and inter-annual variation in the food consumed by the brown palm civets. While the civets consumed 16 species of fruits in 1998, they consumed 33 species in 1999, and only 15 were common to both the years. This could be partly explained by the variation in the availability of fruit between years. Civets adapted to fluctuations in fruit resources by feeding on a diverse range of species. The year-round frugivorous diet was supplemented by many invertebrate and vertebrate food.
4. Civets ate small, multi-seeded fruits, usually berries and drupes that were pulpy and had moderate to high water content. However, they also ate many large fruits like *Palaquium ellipticum*, *Elaeocarpus serratus*, *Holigarna nigra*, and *Knema attenuata*. The fruits eaten by them did not differ significantly from those not eaten either in fruit type, odour, latex, and size or shape of seeds.
5. The brown palm civet is an important seed disperser of many rainforest plant species. Most seeds were viable even after passage through the digestive tract of the civet. Of the 17 species that were assessed, 14 were viable. They did not predate or damage the seeds of any species except occasionally those of *P. ellipticum*. Germination success of *E.serratus* and *Gnetum ula* collected from the scats was higher than control seeds from plants, but was lower for two other species, *Filicium decipiens* and *Nothopegia beddomei*.
6. The brown palm civet is a key mammalian seed disperser in the tropical rainforests of the Western Ghats by virtue of it being predominantly frugivorous and dispersing a diverse array of species. It could play a major role in restoration of degraded rainforest patches along the Western Ghats.

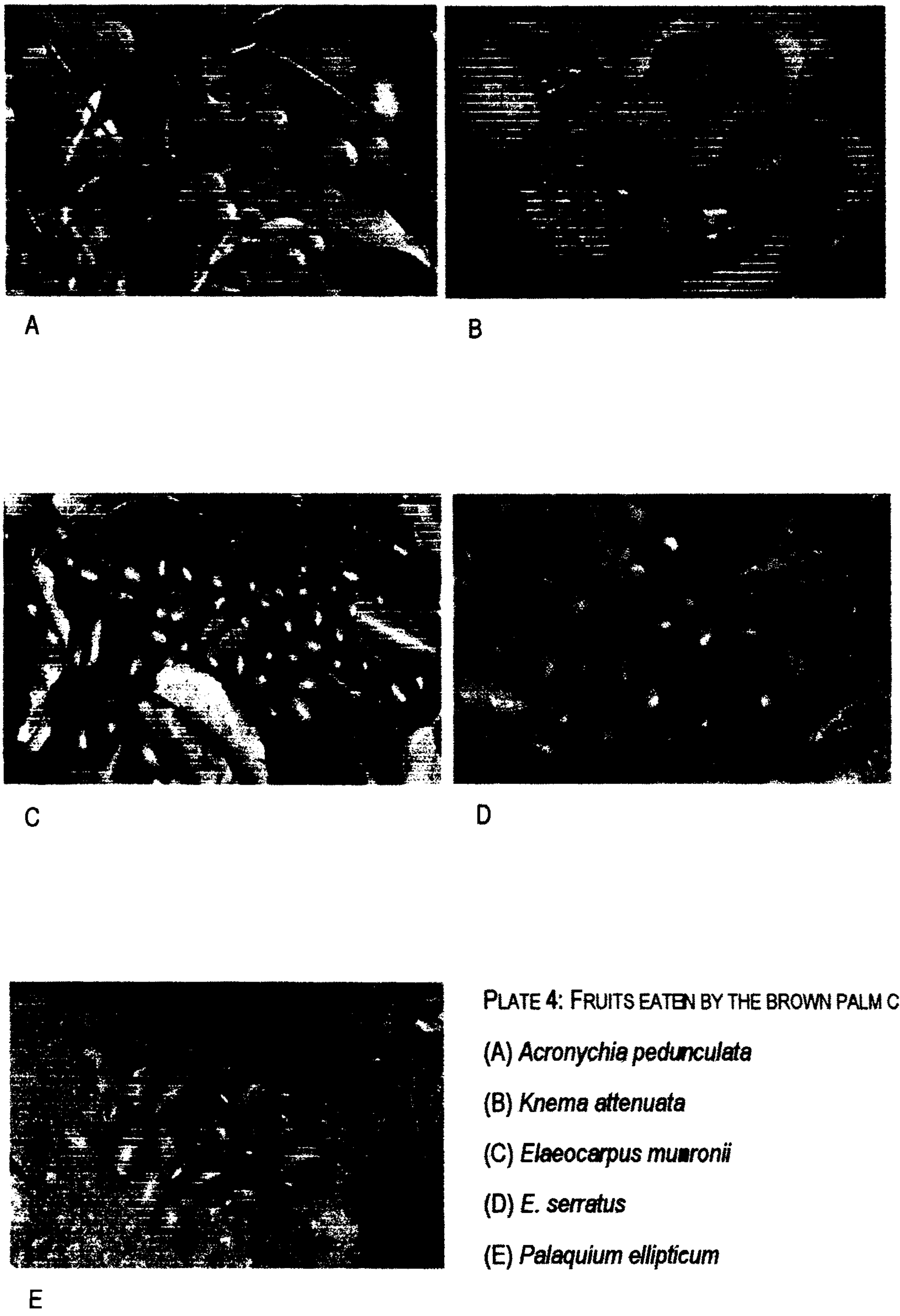


PLATE 4: FRUITS EATEN BY THE BROWN PALM CIVET

(A) *Acronychia pedunculata*

(B) *Knema attenuata*

(C) *Elaeocarpus munronii*

(D) *E. serratus*

(E) *Palaquium ellipticum*

CHAPTER 4

PHENOLOGY OF FOOD SPECIES AND FOOD CHOICE BY BROWN PALM CIVETS

4.1 INTRODUCTION

Seasonality in the tropics is not as pronounced as in the temperate regions. This apparent 'aseasonality' does not, however, imply a year of plentiful or uniform availability of resources; as studies have shown peaks and troughs in resource availability even in tropical forests (van Schaik *et al.* 1993, Richards 1996). Plant parts like leaves, flowers, fruits, and seeds are some of the most commonly and widely used resources in tropical rainforests. The availability of these resources, is often not well defined or predictable, and exhibits tremendous inter-annual and inter-site variations (Frankie *et al.* 1974, Leighton and Leighton 1983, van Schaik 1986, Newstrom *et al.* 1993, Stevenson *et al.* 1998). While many species are strictly seasonal in flowering and fruiting, some are aseasonal, and by being available even during periods of low resource availability, serve as keystone resources (*e.g.*: *Ficus* spp., McKey 1975, Gilbert 1980, Terborgh 1986b, but see Gautier-Hion and Michaloud 1989). Among the seasonal species are those that could be sub-annual, annual, or supra-annual, and also those that exhibit synchronous or staggered phenophases (Struhsaker 1997, Chapman *et al.* 1999).

Such variations in flowering and fruiting by plants can be influenced by abiotic and biotic factors. Irradiance peaks and minimum temperatures of previous dry seasons, trigger leaf flush and flowering in tropical forests (van Schaik *et al.* 1993, Chapman *et al.* 1999). Therefore, peaks in leaf flush and flowering are usually observed at the end of dry seasons, followed by peaks in fruit production in the subsequent wet seasons (van Schaik *et al.* 1993, Struhsaker 1997). Canopy openness and rainfall may also influence local phenological patterns. In addition to these abiotic factors, biotic factors may determine staggered or clustered phenological activity of many plant species (van Schaik *et al.* 1993, Poulin *et al.* 1999). Evidence from many studies suggests synchrony in phenological activity as an adaptation to reduce predation, through predator satiation, whereas staggered phenological activity may be a plant strategy to avoid competition for pollinators and seed dispersers (Wheelwright 1985). It has also been suggested that phenological patterns may be determined by the optimal time for ripening of fruit (Gautier-Hion 1990, Terborgh 1990).

The periodicity or unpredictability in resource abundance, in turn, plays a major role in determining food choice, movement patterns, ranging, reproductive periods, and other interactions within tropical animal communities (Leighton 1982, Terborgh 1983, Peres 1994, Kannan and James 1999). Animals exhibit some ecological flexibility and behavioural adaptations to cope with the fluctuations in resource availability. Phenological variation is known to stimulate resource tracking by many animal species, particularly nectarivores and frugivores (Leighton and Leighton 1983, Fleming 1992). Periods of low resource availability trigger some species to migrate to sites with better conditions, while others may temporarily switch their dietary habits (van Schaik *et al.* 1993). Although intricate plant-animal interactions are common in all habitats including tropical forests, there are a few evidences to show obligate mutualisms or one-to-one dependencies (Herrera 1998, Levey and Benkman 1999), particularly between vertebrates and plants. This is because interactions are governed by more than one factor.

Phenological patterns can be described as the periodic variation in the flowering and fruiting patterns of a species. It could be defined as variations in (a) the number of species in flower or fruit, (b) the proportion of plants bearing flower or fruits, and (c) the abundance of flowers or fruits over time (Blake *et al.* 1990). Monitoring plant phenology is imperative for the description of temporal variation in resource availability for frugivorous animals. The brown palm civet was found to be a highly frugivorous species (Chapter 3). Therefore, an understanding of fruit resource availability patterns would give a better insight into response of this species to phenological changes and the vagaries of food abundance. For instance, do animals select certain food types or species only in times of greater food availability, and show a catholic or reduced preference when food abundance is low? During this study, the brown palm civet was found to feed mainly on fruits (91.12% of the scats, Chapter 3) from 53 plant species. Flowering and fruiting phenology of a subset of 22 food species that contributed to about 60% of annual diet was monitored from January 1998 to December 1999 in order to relate brown palm civets' (1) movement and ranging patterns to resource availability (Chapter 5), and (2) food choice to diversity and abundance of available plant resources. Here, I describe the phenological pattern of important food trees and the pattern of their utilisation by brown palm civets in the tropical rainforests of Kalakad-Mundanthurai Tiger Reserve.

4.2 OBJECTIVES

In this chapter, I explore the following questions:

a. What is the general phenological pattern of flowering and fruiting exhibited by the major food species of the brown palm civet, and how do they vary between years?
b. How do rainfall and temperature influence phenology patterns?

c. Can the 11 most important food species be classified into different groups based on their flowering and fruiting periodicity? How do these plants with different fruiting strategies influence food availability in the habitat?

d. What are the densities of these brown palm civet food plant species, and how are they spatially distributed?

e. How do the diversity and abundance of available food resources affect food choice by the brown palm civet?

4.3 METHODS

4.3.1 Plant phenology

Three plots were established to monitor monthly variation in flowering and fruiting phenology (method modified after Chapman *et al.* 1994). Only the major civet food tree and liana species were marked and monitored. One plot was 2 ha (1000 m x 20 m) in area with 292 trees and lianas marked and monitored. The other two plots, each 1 ha in area, contained 158 (73 and 85) trees and lianas that were monitored. These three plots together contained 633 trees, of which, only 427 (including strangler figs) were monitored. Of the 25 individuals of lianas (food species), 23 were monitored (*Elaeagnus sp., Gnetum ula*, and a Vitaceae sp.). Among the 47 identified food plant species (trees and lianas), 22 species that were represented frequently in the diet (Chapter 3), and that were relatively common and well represented in the habitat, were monitored once every month (at mid-month, approximately at equal intervals).

All the plants that were monitored were >30 cm in girth at breast height (GBH), with the exception of a single individual each of *Artocarpus heterophyllus* (tree) and *Elaeagnus kologa,* (liana). A maximum of 20 individuals of each common species, and all the individuals (3–19) of the rare or less common species in the plots were monitored, from January 1998 to December 1999. The number of flowers, unripe fruits, and ripe fruits on each plant was scored as follows: 0 for none, 5 for less than 10 units (i.e. < 10 individual flowers or fruits), 55 for 11 to 100 units, 550 for over 100 units (each score corresponding to the mid-points of those class-intervals). However, for *Artocarpus heterophyllus*, the score of 0 for none, 5 for less than 4 fruits, 55 for 5-8 fruits, and 550 for >8 fruits was used in order to correct for the large size of the fruit.

Of the 14 species identified as the most important food species based on 2 indices (F_i, frequency of occurrence and *IS*, important species index, in Chapter 3), the flowering and fruiting patterns of 11 species well represented in the plots, were examined in greater detail.

Three different measures were used to assess the food availability in the habitat, represented by the 4 ha that were monitored:

1) Number of species flowering or fruiting in 4 ha (**N_{FL}** and **N_{FR}**): the total number of species among the monitored individuals flowering or fruiting in a given month;
2) Number of individual trees with flowers or fruits (**I_{FL}** and **I_{FR}**): the proportion of trees of each species flowering or fruiting was multiplied by that species' density and expressed as flowering or fruiting individuals per 4 ha, and this was summed across all species; and
3) Flower or fruit abundance score (**SC_{FL}** and **SC_{FR}**): The flower/fruit abundance score for a species in a given month was estimated as the product of the average flowering/fruiting score of the species and the species' density. The average score was calculated across all the monitored individuals of that species. Total flower or fruit abundance score for a given month was estimated by summing across all species.

The similarity in the temporal trends of flowering and fruiting episodes between the two years was assessed using the Spearman rank correlation coefficient (Siegel and Castellan 1988). Differences between corresponding months in the two years were tested using the Wilcoxon Matched-Pair Signed-Ranks Test (Siegel and Castellan 1988). The influence of rainfall, and minimum and maximum temperatures on the flowering and fruiting patterns, were tested using Spearman rank correlation.

4.3.2 Food tree density and distribution

Densities of food tree species (>30 cm GBH) were estimated from the Point-Centred Quarter (PCQ) method (Krebs 1989), from 184 plots (736 trees) distributed in various parts of Sengaltheri. For lianas, density was estimated from total counts in the three phenology plots.

Since the phenology plots were belt transects and restricted in their spread within the study area, these may not have captured the spatial distribution patterns of many of the rainforest plant species. Therefore, the dispersion of food plant species was estimated using circular plots laid throughout the study area. Three hundred and twenty seven 5 m radius plots were laid in the three study sites—Kakachi, Sengaltheri, and Kannikatti, in KMTR. All trees >30 cm GBH within these circular plots were measured and identified. The variance to mean ratio of density in the plots was used as the index of dispersion of all the food plant species (Krebs 1989). Based on this ratio, the plants were classified into three groups. The plants were uniformly dispersed when the species has a variance-to-mean ratio close to zero, and randomly when the ratio was close to one. Highly clumped species would have a variance-to-mean ratio greater than one and ranging up to the sum of the number of individuals in all the plots. Krebs (1989) reports that this ratio is only weakly affected by population density and is therefore a good measure of dispersion.

4.3.3 Food species availability and preference

The indices used to estimate food species availability were the number of species bearing edible flowers or ripe fruits in a given month, the number of individual trees in flower or fruit, and the sum of scores that represents the amount or abundance of fruits and flowers available. The absolute frequency of occurrence (F_i, see Chapter 3) of the 22 tree and liana species that were monitored (to estimate resource availability) in civet scats was taken as the index of use. For *Cullenia exarillata*, only flowers were occasionally consumed by brown palm civets. Unripe and ripe fruit measures were, however, included in the description of fruiting patterns of food species. For comparison of food availability with consumption, *Cullenia exarillata* was excluded from numbers of species and individuals, and abundance score of ripe fruits.

The species richness (S), Shannon-Wiener Diversity (H'), evenness (E), and Berger-Parker dominance (D) indices were estimated for every month, using scat data (for 22 species of plants in the diet), as well as for the phenological availability data (ripe fruit abundance score) in Sengaltheri in 1998 and 1999. The indices were estimated as (Magurran 1988):

$$H' = -\Sigma p_i \ln p_i$$

where,

p_i = proportion of the abundance score or species in scats belonging to the i^{th} species;

$$E = \frac{H'}{H'_{max}}$$

where,

H' = Shannon-Wiener diversity index

H'_{max} = maximum value of $H' = \ln S$, where S = species richness;

$$D = \frac{N_{max}}{N}$$

where,

N_{max} = abundance score or number of items in scat of the most abundant species in a given month

N = total abundance score or number of species in scats for that month.

The Spearman rank correlations among and between these diversity measures were used to understand the relationship between variables and between food availability and food consumption.

Ivlev's electivity Index (E_i) was used to measure monthly preferences of food species based on the utilisation of food resources in relation to their availability (Krebs 1989).

$$E_i = \frac{r_i - n_i}{r_i + n_i}$$

where,

r_i = percentage of species i in the diet (out of total number of items) in a given month

n_i = percentage of species i available in the habitat (out of total ripe fruit abundance score) in a given month

The preference values range between –1 and +1. Values between 0 and –1 indicate avoidance, while those between 0 and +1 indicate preference. The advantage of Ivlev's electivity index is that many food types can be included. However, the disadvantage is that the values tend to be influenced by the relative abundance of food types (Krebs 1989).

The Morisita-Horn (C_{MH}) measure was used as an index of similarity between consecutive months in the species composition of available food and in the diet. This index was calculated using the following equation (Magurran 1988):

$$C_{MH} = \frac{2\Sigma\,(X_{ia}\ X_{ib})}{(\lambda_a + \lambda_b)\ N_a\ N_b}$$

where,

X_{ia} = number of individuals/items of the i^{th} food species in a given month a

X_{ib} = number of individuals/items of the i^{th} food species in the subsequent month b

N_a = number of individuals/items in month a

N_b = number of individuals/items in month b

$$\lambda_a = \frac{\Sigma\, X_{ia}^2}{N_a^2}$$

$$\lambda_b = \frac{\Sigma\, X_{ib}^2}{N_b^2}$$

The index ranges between 0 and 1, where 0 represents no similarity and 1, complete similarity. Similarity between consecutive months in ripe fruit availability was calculated using the number of individuals with ripe fruits available in the phenology plots, whereas similarity in diet was calculated using the number of items of each species (F_i) that occurred in the scats. The Morisita-Horn index is the best overall measure of similarity for ecological use, as it is nearly independent of sample size, unless sample sizes are very small (Magurran 1988, Krebs 1989).

4.4 RESULTS

4.4.1 Species abundance and composition

The tree density in the rainforests of Sengaltheri was estimated to be about 714 trees (> 30 cm GBH) per hectare. Of the 97 species of trees recorded in a sample of 464 individuals (n = 116 PCQ plots), *Cullenia exarillata* and *Mangifera indica* were the most common overstorey trees, *Agrostistachys borneensis*, *Drypetes elata,* and *Myristica dactyloides* the mid-storey species, and *Cinnamomum malabathrum*, *Epiprinus mallotiformis*, and *Antidesma menasu* the under-storey tree species. Nearly 53% of the trees were comprised of the 24 food species of the brown palm civet. Among these food trees, *Cullenia exarillata*, *Holigarna nigra*, and *Palaquium ellipticum,* were the most frequently occurring overstorey species, while *Antidesma menasu* was the most common under-storey species. Fifty percent of the food plants represented in these PCQ plots had a density of over 10 trees per hectare.

Phenological patterns of these and the other food plants were interpreted on the basis of peaks and lows in the number of plant species, number of individual plants/4 ha, and abundance score of flowers and fruits/4 ha during the study period (January 1998 – December 1999). Some significant correlations were observed between the indices. The number of individuals with flowers in a month was significantly correlated to the abundance score of the flowers (r_S = 0.73, n = 24, P = 0.007). Similarly, the number of species with unripe fruits was significantly correlated to the number of individuals bearing unripe fruits (r_S = 0.83, n = 24, P = 0.001). The number of species bearing ripe fruits was significantly positively correlated to both the number of individuals bearing ripe fruits as well as the abundance score of ripe fruits (r_S = 0.78 and 0.68, respectively, n = 24, P = 0.003 and 0.015). Despite significant correlations between some of the indices, as further analyses showed each index to exhibit varying patterns, all the indices were used independently.

4.4.2 Flowering Phenology

4.4.2.1 *Species flowering*

The highest number of food species bearing flowers was observed between May and August in 1998 (8 – 11 species, 36.36 – 50% of species), and between April and June in 1999 (11 – 14

Table 4.1: Comparisons of variations in monthly climate, flowering and fruiting patterns of civet food species between 1998 and 1999 in Sengaltheri, KMTR. (Significant values in bold).

Parameter	**Mean (SE)**		**Wilcoxon *Z***	**Rank correlation**
	1998	**1999**	**(*P*)**	**r_s (*P*)**
Climate				
Total rainfall (cm)	19.03 (5.77)	18.59 (4.17)	-0.628 (0.53)	**0.80 (0.002)**
Min. temperature (°C)	19.93 (0.40)	19.95 (0.40)	**-2.134 (0.03)**	**0.89 (0.000)**
Max. temperature (°C)	24.39 (0.53)	23.91 (0.57)	**-2.118 (0.03)**	**0.87 (0.000)**
Flowers				
Species (#/4 ha)	6.25 (0.70)	7.42 (0.87)	-1.17 (0.24)	0.31 (0.33)
Individuals (#/4 ha)	61.12 (11.41)	51.93 (9.97)	-1.49 (0.14)	0.50 (< 0.10)
Abundance (fruits/4 ha)	18359.67 (2951.13)	16926.59 (4111.48)	-0.078 (0.94)	0.42 (0.17)
Unripe fruits				
Species (#/4 ha)	10.58 (0.88)	10 (0.49)	-0.772 (0.44)	0.32 (0.31)
Individuals (#/4 ha)	62 (9.48)	62.79 (5.02)	-0.157 (0.88)	0.31 (0.33)
Abundance (fruits/4 ha)	9820.19 (1560.71)	10759.13 (1419.22)	-0.234 (0.81)	-0.45 (0.14)
Ripe fruits				
Species (#/4 ha)	5.58 (0.63)	6.17 (0.54)	-1.853 (0.06)	**0.59 (< 0.05)**
Individuals (#/4 ha)	19.14 (3.25)	40.23 (8.45)	**-2.824 (0.005)**	-0.30 (0.35)
Abundance (fruits/ 4 ha)	1829.58 (399.08)	3930.95 (770.02)	-1.883 (0.06)	-0.50 (< 0.10)

species; 50 – 63.64% of species, Figure 4.1a). In the first year, the number of species with flowers was highest in May (11 species), followed by June (10 species), whereas in the second year, the peak was in April (14 species) followed by May and June (11 species in both months). In all the other months of 1998, the number of species flowering ranged between four and six, the lowest being in January, February, and September. In 1999, nine months had 4 – 8 species flowering, which was greater than in the corresponding months of 1998. The exceptions were the months of May with no difference between years in the number of species with flowers, and July, August, October, and November with more species in 1998.

There was no correlation between years in the temporal trend of number of species flowering (r_s = 0.31, n = 12, P = 0.33, Table 4.1). There was also no significant difference between years in the monthly number of species flowering (Wilcoxon matched-pairs signed-ranks test, Z = – 1.17, P = 0.24, Table 4.1). Among the monitored food species, *Dimocarpus longan* and *Chrysophyllum lanceolatum* flowered only in 1998, whereas *Canthium dicoccum* and *Tricalysia apiocarpa* flowered only in 1999. Other species flowered in both years, but the pattern of flowering varied between corresponding months for most species.

4.4.2.2 *Individuals flowering*

Although the peaks in number of species flowering in each month was different between the two years, the number of individuals with flowers was highest in May and June in both 1998 and 1999 (Figure 4.1b). The number of individuals flowering was greater in 1998 as compared to 1999 in May (168 vs. 129 individuals in 4 ha) and June (108 and 106 individuals in 4 ha). Of the total number of individuals (633 trees and 25 lianas) of these 22 food species in 4 ha, 25.53% and 19.60% of trees were flowering in May 1998 and 1999, respectively, whereas 16.41% and 16.11% were flowering in June 1998 and 1999, respectively. In 1998, a second peak was observed in November (67 individuals in 4 ha, 10.18%), which continued till February 1999, with a small dip in January.

A majority of flowering individuals in 1998 and 1999 comprised of *Antidesma menasu* in both May (46% and 59% of total individuals flowering) and June (35% and 55%). The other species contributing 8 – 10% of the individuals flowering in May 1998 were *Palaquium ellipticum, Syzygium zeylanicum, Elaeocarpus serratus*, and *Holigarna nigra*, whereas in May 1999, only *E. serratus* (12%) flowered substantially. The peak in flowering in November 1998 was contributed by *E. munronii* and *Cullenia exarillata.*

The correlation between years in the temporal trend of number of flowering individuals was positive but not significant (Table 4.1). The number of individuals with flowers was greater in all months in 1998 except in February, April, and August. This difference was greatly influenced by the flowering of *C. exarillata* in 11 months in the first year, but only in five months (with flowering occurring in fewer individuals) in the second year. There was, however, no statistically significant difference between years in the monthly number of individuals flowering.

4.4.2.3 *Abundance of flowers*

Similar to the earlier two measures (species and individuals), the highest abundance of flowers occurred in May and June, preceded by a relatively high score in April in both the years (Figure 4.1c). Another peak in abundance of flowers was observed in February in both 1998 and 1999. An increase in flowering was also observed from September to December of 1998, and in December in 1999. The species contributing to the major peaks were the same as mentioned earlier for the peaks in individuals flowering. The minor peaks were influenced mostly by the flowering of *C. exarillata* and *Filicium decipiens*. The correlation between years in the temporal trend of abundance of flowers was not significant ($r_S = 0.42$, $n = 12$, $P = 0.17$, Table 4.1).

Between January and August, the abundance of flowers was higher in 1999, but between September and December it was higher in 1998, once again influenced by the flowering of *C. exarillata*, which did not flower in the latter half of 1999. However, there was no statistically significant difference between years in the monthly abundance of flowers ($Z = -0.078$, $P = 0.94$, Table 4.1).

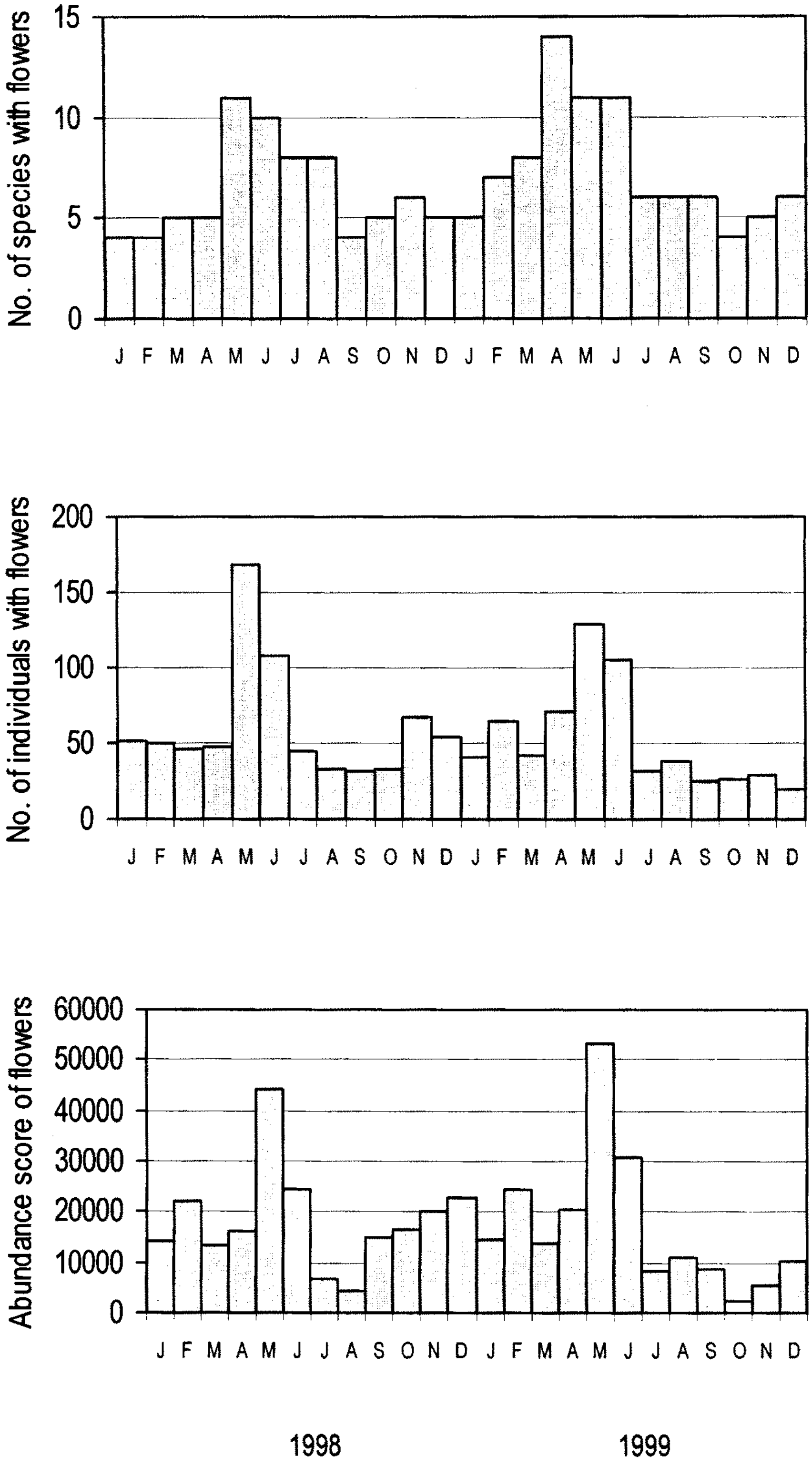


Figure 4.1: Flowering phenology of 22 brown palm civet food species in 4 ha in Sengaltheri, KMTR.

4.4.3 Fruiting Phenology: Unripe fruits

4.4.3.1 *Species with unripe fruits*

The peak in the number of species with unripe fruits was from June to October in 1998, and June to September in 1999 (Figure 4.2a). The highest number of species was in August both in 1998 and 1999 (16 and 13 species, 72.73% and 59.09% of total species, respectively). The monthly number of species with unripe fruits ranged between 7 and 16 (31.82% – 72.73%) in 1998, and 7 and 13 (31.82% – 59.09%) in 1999. There was a minor peak in January 1999 with 12 (54.55%) species bearing unripe fruits. The number of species bearing unripe fruits was greater between May and October in 1998 than in 1999, and less in months other than November and December, when the number was the same in both the years.

The correlation between years in the temporal trend of number of species with unripe fruit was not significant ($r_s = 0.32$, $n = 12$, $P = 0.31$, Table 4.1). There was also no significant difference between years in the monthly number of species with unripe fruit ($Z = -0.772$, $P = 0.44$, Table 4.1).

4.4.3.2 *Individuals with unripe fruits*

The number of individuals bearing unripe fruits peaked between June and September 1998, between November 1998 and January 1999, and then between April and August 1999 (Figure 4.2b). The highest number of individual trees and lianas bearing unripe fruits was observed in August (109, 16.56%) in 1998 and in May (88, 13.37%) in 1999.

The species contributing to the peak in July and August 1998 were mainly *Antidesma menasu* (21.85 and 18.10% of the individuals with unripe fruits in 4 ha), and *Palaquium ellipticum* (18.21 and 18.74%). The minor peak in December 1998 was due to the unripe fruits borne by individuals of *Acronychia pedunculata* (18.58%), *E. munronii* (28.74%), and *E. serratus* (17.60%). The peak in both May and July 1999 was influenced by *Antidesma menasu* (30.86% and 43.37%, respectively) and *E. munronii* (27.09% and 26.63%, respectively).

The correlation between years in the temporal trend of number of individuals with unripe fruits was not significant ($r_s = 0.31$, $n = 12$, $P = 0.33$, Table 4.1). The peak was more pronounced in 1998 than in 1999, when it was diffuse and spread across many months. The total number of individuals with unripe fruits was greater between January and June in 1999 when compared to the corresponding months in 1998, while in the latter half of the year there was a greater number of individual plants bearing unripe fruits in 1998. Due to this, there was no significant difference between years in the monthly number of individuals with unripe fruits ($Z = -0.157$, $P = 0.88$, Table 4.1).

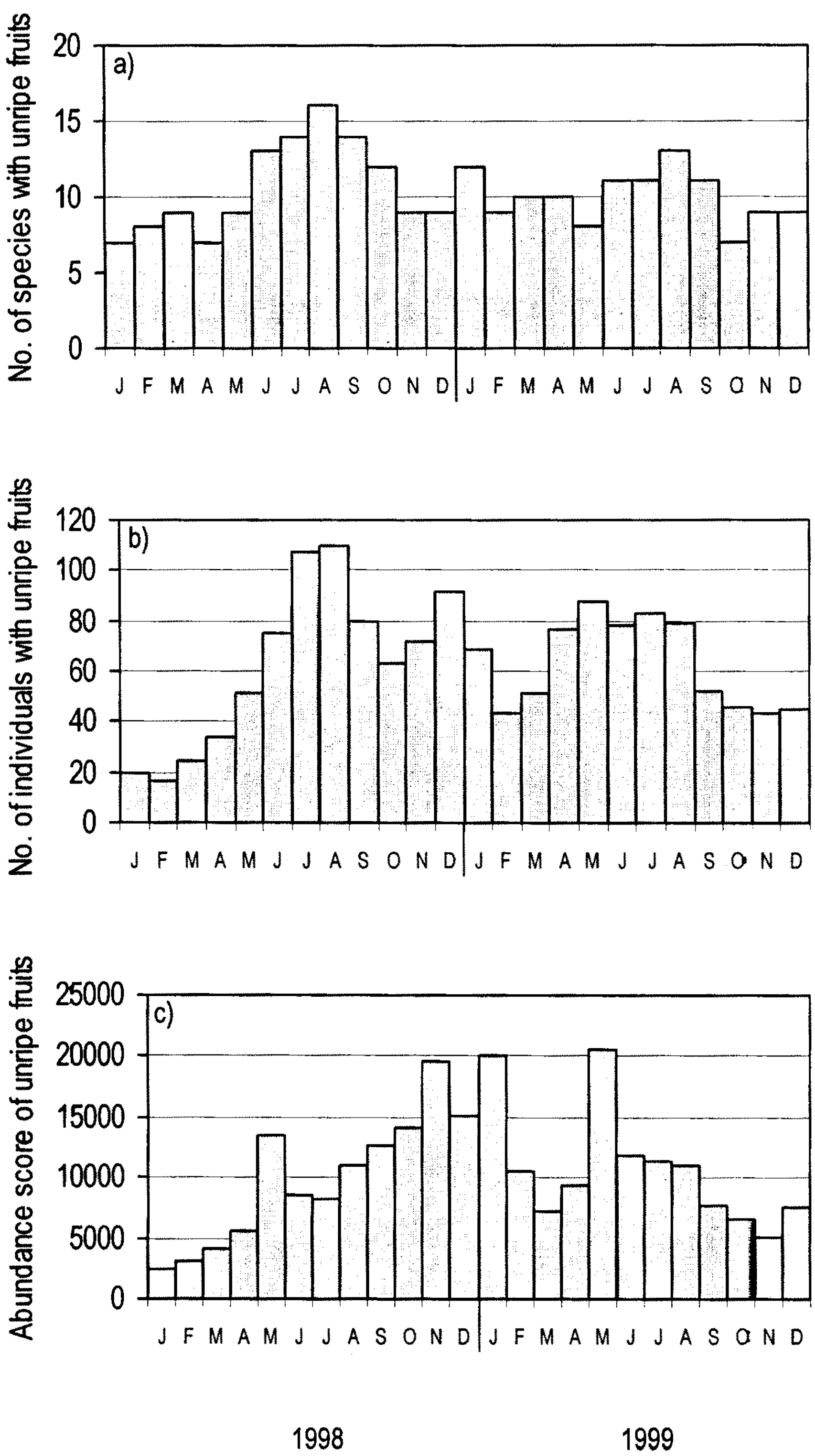


Figure 4.2: Fruiting phenology of unripe fruits of 22 brown palm civet food species in 4 ha in Sengaltheri, KMTR.

4.4.3.3 *Abundance of unripe fruits*

The major peaks in unripe fruit abundance were between August 1998 and February 1999, with the highest abundance scores in November 1998 and January 1999 (Figure 4.2c). In 1999, the peak abundance was between May and August, with the highest being in May. A minor peak in the abundance of unripe fruits was seen in May 1998. The abundance of unripe fruits in November 1998 was because of *Acronychia pedunculata*, *E. munronii*, and a species of liana (Family Vitaceae). The species that contributed to the abundance of unripe fruits in January 1999 were *E. munronii, E. serratus, F. decipiens, Canthium dicoccum*, and *Cullenia exarillata* (the fruits of which are not eaten by the brown palm civets). The May 1999 peak in abundance of unripe fruits was due to *Antidesma menasu, C. exarillata, E. munronii*, and *P. ellipticum.* The temporal trend in abundance of unripe fruits was not significantly correlated between years (r_S = – 0.45, n = 12, P = 0.14, Table 4.1).

The abundance of unripe fruits was greater during the first part of the year (January to July) in 1999 than in 1998, similar to the pattern observed in the case of individuals with unripe fruits, while it was greater in 1998 during the latter part (August to December). When the entire year was considered, however, there was no statistically significant difference between 1998 and 1999 (Z = – 0.234, P = 0.81, Table 4.1).

4.4.4 Fruiting phenology: Ripe fruits

4.4.4.1 *Species with ripe fruits*

The number of species with ripe fruits varied between 3 and 9 species per month (Figure 4.3a). In 1998, the number of species producing ripe fruits was greater between August and December (7 – 9 species; 31.82% – 40.91% of the species monitored). In 1999, however, there were four bouts of fruiting with a large number of species bearing ripe fruits – January (7 species), March and April (8 and 9 species, respectively), August and September (7 and 9 species, respectively), and November and December (7 and 9 species, respectively).

In 1998, the number of species with ripe fruits was highest in September (9 species), followed by August and November (8 species in both months), whereas in 1999, the peaks were in April, September, and December (9 species in all the three months), followed by March (8 species) and August and November (7 species in both months). In the other months of 1998, the number of species with ripe fruits ranged between three and seven, the lowest being in February, June, and July. In 1999, five months had 4 – 6 species bearing ripe fruits. Overall, the number of species with ripe fruits was greater in all the months in 1999 except in August. October, and November, when the number of species with ripe fruits was greater in 1998.

The correlation between years in the temporal trend of number of species with ripe fruits was significant ($r_S = 0.59$, $n = 12$, $P < 0.05$, Table 4.1). There was no significant difference between years in the monthly number of species with ripe fruits ($Z = -1.853$, $P = 0.06$, Table 4.1). Among the monitored species, *Chrysophyllum lanceolatum* and *Syzygium zeylanicum* bore ripe fruits only in 1998, whereas *Canthium dicoccum* had ripe fruits only in 1999. Species other than *Dimocarpus longan* and *Tricalysia apiocarpa* and the ones mentioned above had ripe fruits in both years, although the pattern and duration of ripe fruit presence on trees varied between the two years.

4.4.4.2 *Individuals with ripe fruits*

There were a greater number of individuals bearing ripe fruits in 1999 than in 1998 in all months except November and December (Figure 4.3b). The major peak in 1998 was during November and December (5.16% and 6.69% of individuals in 4 ha, respectively), with *Antidesma menasu, E. serratus,* and *C.exarillata* (ripe fruits not eaten by the brown palm civet) contributing 15 – 25% of the fruiting individuals. Minor peaks in 1998 were observed in April (3.19%), and August (4.56%). In 1999, there was a relatively high number of individuals with ripe fruits between January and April, peaking in March (8.66%). Minor peaks were observed between June and August, and in December 1999.

The species influencing the major peak (March) in 1999 were *E. munronii, F. decipiens*, and *C.exarillata.* All the minor highs in 1999 were because of *E. munronii*, and to a smaller extent due to *A. menasu*, and *E. serratus* in different months. When the number of individuals bearing ripe fruits were compared, there were fewer trees overall in 1998 than in 1999. Within 1998, the months with the least number of plants bearing ripe fruits were in February (4 individuals in 4 ha, 0.61%), May, January, March, and June (12 individuals in each, 1.82%). May was the month with the least number of individuals bearing ripe fruits (27 individuals in 4 ha, 4.10%) in 1999.

The correlation between years in the temporal trend of number of individual trees and lianas with ripe fruits was not significant ($r_S = -0.30$, $n = 12$, $P = 0.35$, Table 4.1). The monthly number of individuals with ripe fruits in 1998 was significantly lower than in 1999 ($Z = -2.824$, $P = 0.005$, Table 4.1).

4.4.4.3 *Abundance of ripe fruits*

There was a greater abundance of ripe fruits in 1999 than in 1998 (Figure 4.3c), which corresponded with the number of individuals with ripe fruits. This difference was highly

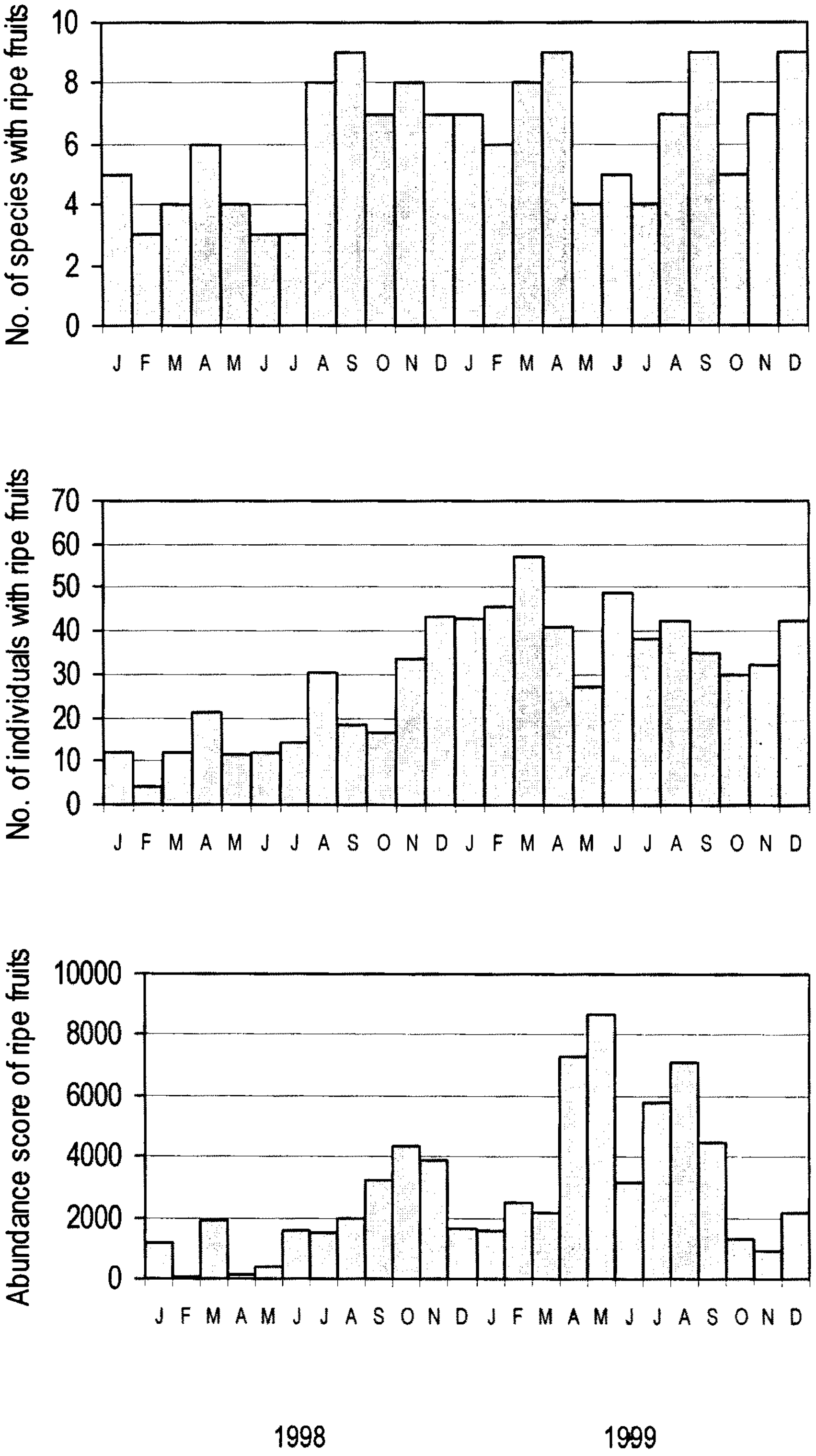


Figure 4.3: Fruiting phenology of ripe fruits of 22 brown palm civet food species in 4 ha in Sengaltheri, KMTR.

influenced by the synchronous mass fruiting of *E. munronii* (see section 4.4.7). In 1998, a peak in ripe fruit abundance was observed in the monsoon months between September and November, with the highest abundance in October (with over 4000 ripe fruits). This abundance was largely influenced by species such as *A. menasu, Acronychia pedunculata*, and *Nothopegia beddomei.* The second year had very high ripe fruit abundance between April and September, with the highest in May (> 8500 ripe fruits). The abundance of ripe fruits in April and August (> 7000 each) was largely because of *E. munronii*, and the peak in May was due to *E. munronii* and *A. menasu.* The months with least abundance of ripe fruits in 1998 were February and April (less than 200 ripe fruits), and November (less than 1000) in 1999. When these high density species were excluded, May 1999 had lower abundance of ripe fruits than November 1999.

The correlation between years in the temporal trend of the abundance score of ripe fruits was negative but not significant ($r_S = -0.50$, $n = 12$, $P < 0.10$, Table 4.1). The difference in the monthly abundance score of ripe fruits between the two years, although indicating fewer fruits in 1998, was not significant either ($Z = -1.883$, $P = 0.06$, Table 4.1).

4.4.5 Effect of rainfall and temperature

The monthly rainfall and the mean monthly minimum and maximum temperatures were significantly correlated between the two years ($r_S = 0.797$, 0.888, 0.874, respectively, $n = 12$, $P < 0.002$, Table 4.1 and Figure 4.4). The mean monthly rainfall was not significantly different between the two years (Table 4.1). The mean monthly rainfall was 19.03 cm (SE = 5.77) in 1998 and 18.58 cm (SE = 4.17) in 1999. The mean monthly minimum and maximum temperatures were significantly different between 1998 and 1999 (Wilcoxon $Z = -2.134$ and -2.118, respectively, $P < 0.05$). The mean minimum and the mean maximum temperatures were slightly lower in 1999 than in 1998. The mean monthly minimum temperature was higher in 8 months, and mean monthly maximum temperature was higher in all months, except April and September, of 1998 than in the corresponding months of 1999.

The flowering and fruiting patterns were not significantly correlated to the mean monthly rainfall of the corresponding months. The number of species in flower and the number of individuals with unripe fruits were significantly correlated to the mean minimum temperature ($r_S = 0.423$ and 0.456, $n = 24$, $P = 0.04$ and 0.02, respectively). The number of species flowering was also significantly correlated to the mean monthly maximum temperature ($r_S = 0.451$, $n = 24$, $P < 0.03$). The other indices of flower and fruit availability were not significantly correlated to the mean monthly minimum or maximum temperatures.

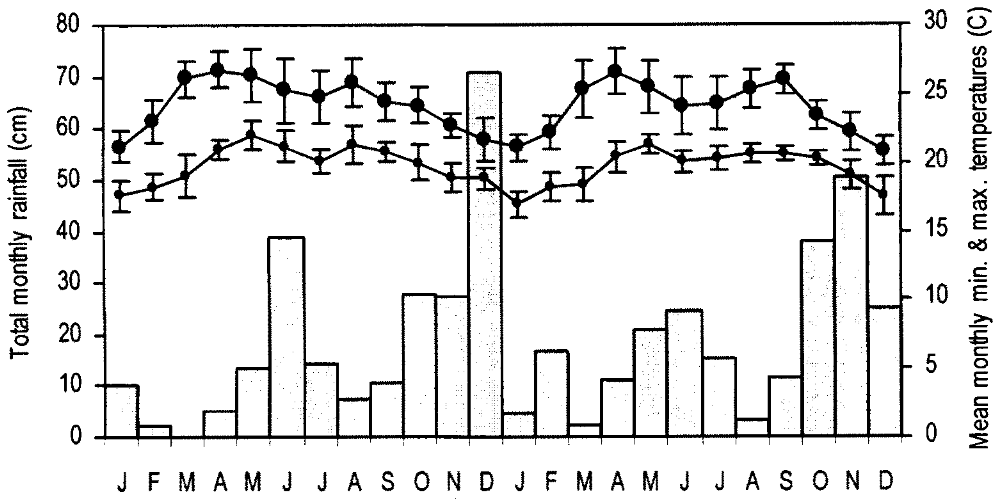
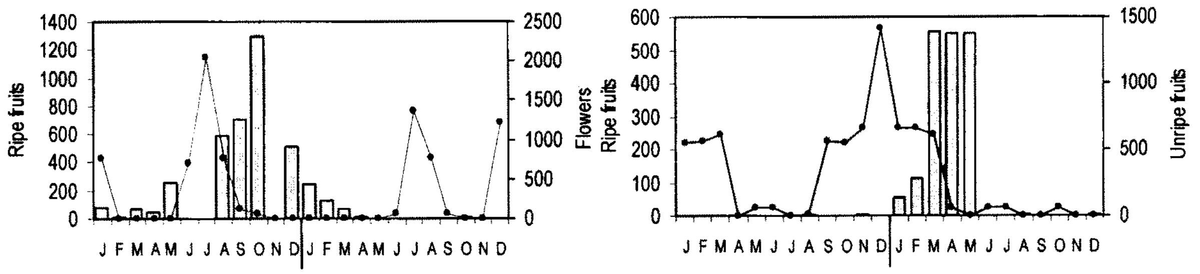


Figure 4.4: Rainfall and temperature (with error bars) in Sengaltheri, KMTR during 1998 and 1999.

4.4.6 Phenology of important food plant species

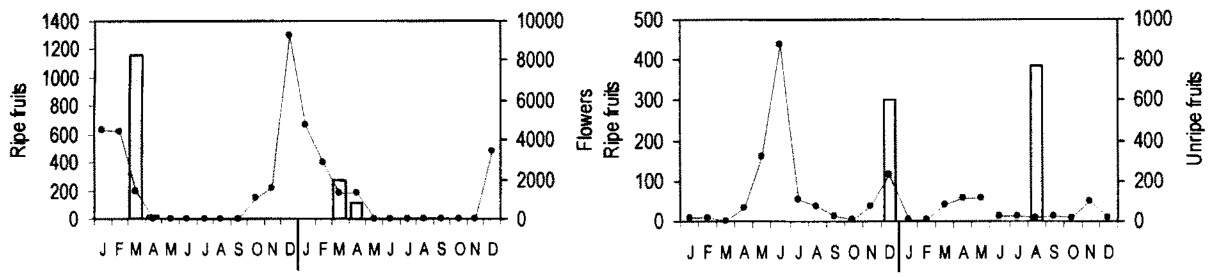
The 11 food species that were examined in detail for their flowering and fruiting phenology, were those that were identified as important species based on their occurrence in scats (see Chapter 3). These 11 fruit species, of the 24 species or species groups consumed, contributed to 64.51% of the diet in 1998, while in 1999, of the 43 species or species groups consumed, these 11 contributed 46.58% (Chapter 3). Of these, *Acronychia pedunculata* was the only species that produced ripe fruits twice a year—in two bouts (bi-annual), in both the years that the study was carried out (Figure 4.5a). Although *Ficus* spp. and *Elaeocarpus munronii* had long fruiting periods, they exhibited different fruiting regimes. While fruiting of *Ficus* spp. was more unpredictable, *E. munronii* produced fruits once in two years (biennial), although for several months. Among the annually fruiting species were *E. serratus, Diospyros sylvatica, Filicium decipiens, Artocarpus heterophyllus*, and *Gnetum ula*. Four of the important species that exhibited supra-annual rhythms producing ripe fruits biennially (major fruiting episodes occurring in alternate years) were *E. munronii, Holigarna nigra, Palaquium ellipticum*, and *Nothopegia beddomei* — all these produced <10% of the ripe fruits in one year as compared to the other (peak) year.

Acronychia pedunculata flowered during the south-west monsoon (June – September), and again at the end of the north-east monsoon (December, January) in both 1998 and 1999. Ripe fruits were produced both in the dry season (February – May), and towards the end of the south-west monsoon (August – September) continuing into the peak north-east monsoon



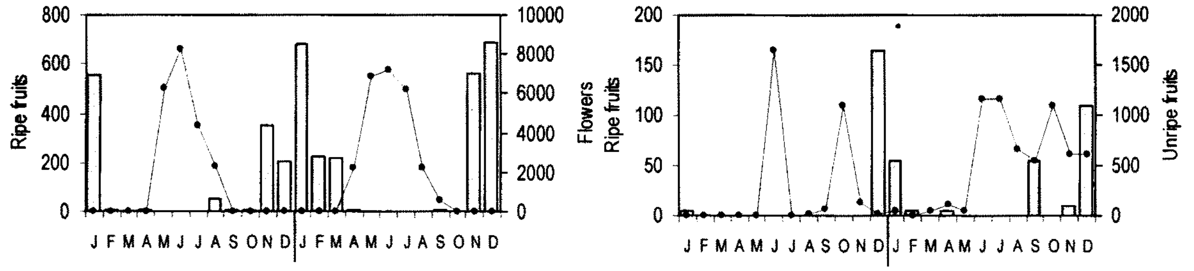
a) *Acronychia pedunculata*

b) *Ficus* spp.



c) *Filicium decipiens*

d) *Artocarpus heterophyllus*



e) *Elaeocarpus serratus*

f) *Gnetum ula*

g) *Diospyros sylvatica*

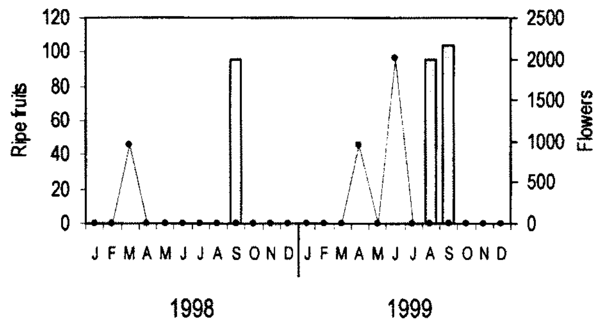
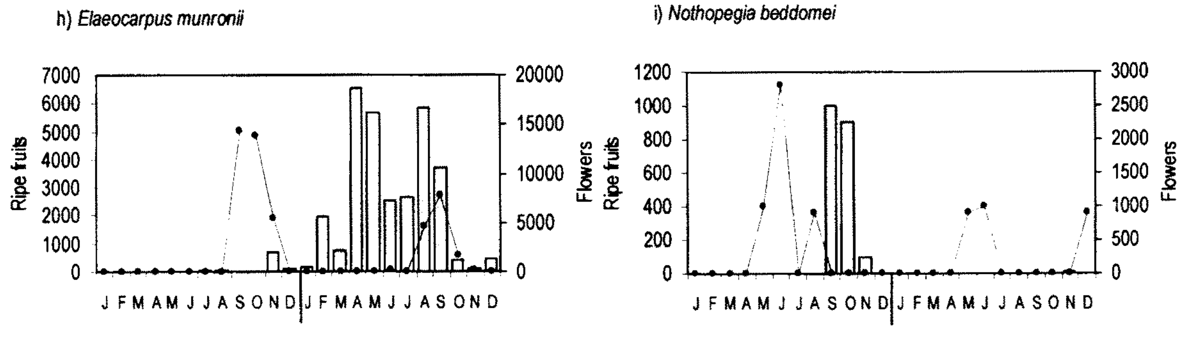


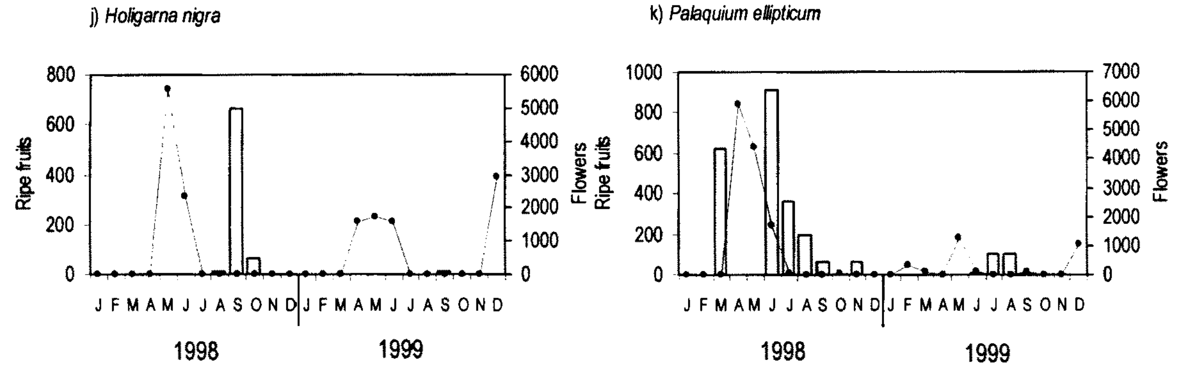
Figure 4.5: Fruiting phenology of eleven important species, indicating food availability for the brown palm civets per 4 ha in Sengaltheri, KMTR, during the study period 1998 – 1999 (a – k). (Bars denote ripe fruits, lines denote flowers or unripe fruits, as the case may be).

Figure 4.5 contd.



h) *Elaeocarpus munronii*

i) *Nothopegia beddomei*



j) *Holigarna nigra*

k) *Palaquium ellipticum*

(October and December, Figure 4.5a). This species was one of the major dry season resources, when the overall fruit abundance in the habitat was the least, as well as a resource during months of low rainfall. However, in 1998, the abundance of *Acronychia pedunculata* was greater in the end of south-west monsoon period. Overall, in 1999, there was a reduction in about 80% production of fruits while compared to 1998.

Although *Ficus* spp. fruited for many months in both the years, ripe fruits were seen only 1999 (Figure 4.5b). This was probably because of the short fruit ripening and depletion periods that these species have. The densities of the fig trees were also low in the study area (Table 4.2).

Among the annually fruiting species, *Filicium decipiens* and *Elaeocarpus serratus* were the main dry season resources. *F. decipiens* was highly seasonal, producing ripe fruits in the months of March and April in both the years (Figure 4.5c), although fruit production in 1999 was about 60% less than in 1998. Although *Artocarpus heterophyllus* bore unripe fruits through most of the year, ripe fruits were available during the north-east monsoon season in 1998 (August) and in the south-west monsoon period in 1999 (December, Figure 4.5d). This was, however, a resource that the civets probably "scavenged" on when the fruits fell to the ground, as these fruits are large and may be difficult for the civets to handle.

Elaeocarpus serratus, Gnetum ula, and *Diospyros sylvatica* also produced ripe fruits every year, although not in the same abundances (Figures 4.5e, f, g, respectively). Both *E.*

serratus and *D. sylvatica* produced fruits about 50% greater in abundance in 1999 than in 1998. *E. serratus* had a long fruiting period, that started towards the end of the south-west monsoon, continuing through the north-east monsoon into the dry season (August – April). *D. sylvatica*, on the other hand, had a short fruiting period between August and September. *G. ula* had a short fruiting period in the north-east monsoon season (December – January) in both the years, producing more or less equal amount of ripe fruits.

Elaeocarpus munronii was found to fruit supra-annually, with almost no fruiting in 1998 (3% of that in 1999), but producing ripe fruits in every month in 1999 (Figure 4.5h). The previous synchronous fruiting of this species in the study area was observed in 1997, prior to the commencement of systematic phenology monitoring. However, this species was not consumed in proportion to its overwhelming abundance in 1999 (see below). In contrast, *Nothopegia beddomei*, which was also supra-annual like *E. munronii*, produced ripe fruits towards the end of the south-west monsoon (September – November) in great abundance in 1998 (0.5% in 1999, Figure 4.5i). Both *Holigarna nigra* and *Palaquium ellipticum* were also species that produced ripe fruits in greater abundance in alternate years, both being higher in 1998 (Figures 4.5j and k, respectively). *H. nigra* bore ripe fruits towards the end of the south-west monsoon (August – October), being about 50 times more abundant in 1998 than in 1999. *P. ellipticum* was also a south-west monsoon fruiting species (June – September), that was over 100 times more abundant in 1998 than 1999. In 1998, some amount of ripe fruits was available in March and also in November.

To summarise, of these 11 species, 7 produced ripe fruits in both the years. Among these: (a) *Acronychia pedunculata, Elaeocarpus serratus*, and *Filicium decipiens* fruited during the dry season; (b) *A. pedunculata, E. serratus, Artocarpus heterophyllus*, and *Diospyros sylvatica* bore fruits towards the end of the south-west monsoon; (c) *E. serratus, Gnetum ula*, and *A. pedunculata* produced fruits during the north-east monsoon; and (d) *Ficus* spp. were fruiting sporadically throughout both the years. Of the remaining four, which exhibited biennial fruiting pattern, three species—*Holigarna nigra, Palaquium ellipticum*, and *Nothopegia beddomei*, produced fruits in great abundance in 1998. During most of 1999, *Elaeocarpus munronii* was the most abundantly available civet food species. The 1998 biennials were south-west monsoon fruits, while *E. munronii* produced fruits through 1999, peaking like the other biennials during April-May and through the south-west monsoon (August and September).

Most of the 22 species monitored for phenology produced ripe fruits for less than six months in two years (Figure 4.6). Of the 11 important species, *Artocarpus heterophyllus, Diospyros sylvatica*, and *Filicium decipiens* bore ripe fruits in two, three, and four out of the 24 months monitored, respectively. Both species of *Elaeocarpus* had ripe fruits for the longest period during the study—*E. serratus* for 15 of 24 months, and *E. munronii* for 16 months. *Gnetum ula, Ficus* spp., and *Palaquium ellipticum* had ripe fruits for 8, 9, and 10 months, respectively.

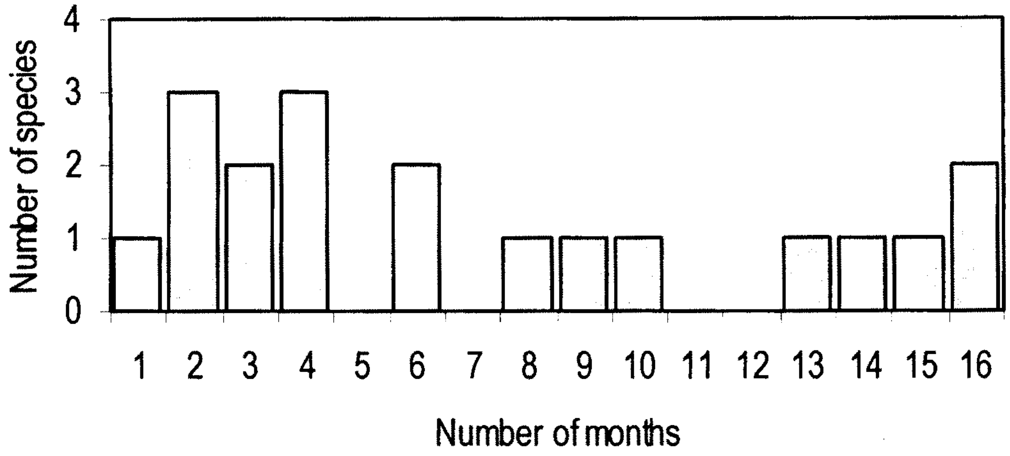


Figure 4.6: Frequency distribution of species with respect to the period of ripe fruit production over the two-year study period in Sengaltheri, KMTR.

4.4.7 Food tree density and distribution

A total of 24 species of food trees were represented in the 184 PCQ plots that were laid in various parts of the intensive study area, Sengaltheri. Density of these food tree species constituted about 38.5% of the total tree density in the study area. The most common were *Cullenia exarillata, Palaquium ellipticum, Holigarna nigra, Dimocarpus longan, Antidesma menasu,* and *Syzygium* spp. (10 – 40 individuals/ha in rainforest). There were 19 species of food trees within plantations (58.6% of 353 trees/ha; abandoned cardamom plantations that were used by some of the radio-collared civets; Chapter 5) as compared to 24 (53% of 714 trees/ha—estimates of tree densities from Chapter 5) within relatively undisturbed rainforests. The densities of food trees were lower in plantations than in the rainforests (207 *versus* 379 trees/ha, Table 4.2). Nine species found in the rainforests were absent in the plantations, and 3 that occurred in the plantations were not found in the rainforest plots. The densities of 11 food tree species were lower in the plantations when compared to that of rainforests, and that of four species was greater in the plantations.

Table 4.2: Density and distribution of food tree species (≥ 30 m GBH) of brown palm civet in Sengaltheri, KMTR.

Species	**Density (Total count)**			**PCQ Density/ha**		**Dispersion (variance to mean ratio)**
	Plot 1 (2 ha)	**Plot 2 (1 ha)**	**Plot 3 (1 ha)**	**Rainforest (n=116)**	**Plantation (n=68)**	
Artocarpus heterophyllus (AH)	25	1	2	9.23	11.69	1.02
Antidesma menasu (AM)	38	3	49	24.61	2.6	1.1
Acronychia pedunculata (AP)	2	8	7	15.38	1.3	1.32
Bischofia javanica (BJ)	4	5	0	3.08	1.3	1.73
Cullenia exarillata (CE)	40	0	25	39.99	33.78	1.38
Diospyros sylvatica (DS)	4	14	15	13.84	7.8	1.37
Elaeocarpus munronii (EM)	24	1	5	9.23	5.2	0.99
Elaeocarpus serratus (ES)	13	2	4	4.16	5.2	0.99
Filicium decipiens (FD)	10	23	9	12.30	0	1.25
Ficus spp. (Fig)	12	1	1	3.08	0	0.99
Holigarna nigra (HN)	32	9	12	24.61	7.8	1.19
Nothopegia beddomei (NB)	1	27	0	3.08	3.9	1.23
Dimocarpus longan (DL)	17	28	47	16.92	12.99	1.66
Palaquium ellipticum (PE)	32	1	5	15.38	28.58	1.51
Syzygium zeylanicum (SZ)	22	26	11	16.92	10.4	1.09
Tricalysia apiocarpa (TA)	0	0	3	0	0	1.44
Canthium dicoccum (CD)	4	1	3	4.61	0	
Chrysophyllum lanceolatum (CL)	1	3	1	0	0	
Viburnum punctatum				6.15	0	
Euonymus angulatus				4.61	0	
Syzygium mundagam				12.30	0	
Olea dioica				3.08	2.6	
Knema attenuata				1.54	0	
Gomphia serrata				1.54	0	
Caryota urens				1.54	0	
Syzygium jambolanum				15.38	3.9	
TOTAL	281	153	199	378.56	207.04	

Of 18 tree species monitored for phenological patterns (of the 22, the other 3 species were lianas, and the other, wild banana plants *Encete superbum*), 16 species were represented in the circular plots that were used to calculate the dispersion pattern of the species. None of these were uniformly distributed (Table 4.2), as their variance to mean ratio was not considerably lesser than one. Although none of the species had a variance-to-mean ratio of 1, seven species—*Artocarpus heterophyllus, Antidesma menasu, Elaeocarpus munronii, E. serratus, Ficus* spp., *Holigarna nigra* and *Syzygium zeylanicum*—had scores close to 1, implying that these food species were more or less randomly distributed. Highly clumped dispersion was not exhibited by any of the food tree species, although *Cullenia exarillata, Palaquium ellipticum, Filicium decipiens, Dimocarpus longan, Diospyros sylvatica, Acronychia pedunculata, Nothopegia beddomei, Bischofia javanica,* and *Tricalysia apiocarpa* showed more clumping than other species (variance-to-mean ratio ranging between 1.2 and 1.7; Table 4.2).

4.4.8 Food species availability and preference

The 21 species of food plants (excluding *C. exarillata*) that were monitored for phenology contributed nearly 74% and 57% to the diet of the brown palm civets in the years 1998 and 1999, respectively (data from 456 scats from Sengaltheri, Chapter 3).

The evenness of the available food species was significantly negatively correlated to the abundance of ripe fruits ($r_S = -0.481$, $n = 24$, $P < 0.02$), indicating that fewer species contributed highly to the abundance score during peak fruiting. As expected, the diversity and evenness of food species available monthly were significantly correlated ($r_S = 0.784$, $n = 22$, $P < 0.001$), while dominance (of the most dominant species, Berger-Parker index) was highly negatively correlated to both the diversity and evenness ($r_S = -0.932$ and -0.834, respectively, $df = 22$, $P < 0.001$). This implied that in months of lower food availability, a single species contributed substantially to the abundance of food. The number of species with ripe fruits was significantly correlated to the other measures of food availability, but not to diversity.

Of the indices of dietary diversity, there was a weak but significant correlation between the number of items in the scat and the number of species represented in them ($r_S = 0.420$, $n = 24$, $P < 0.05$). However, although the number of species in the diet was highly significantly correlated to the diversity in the diet ($r_S = 0.846$, $n = 24$, $P < 0.001$), the number of items was not significantly correlated to the diversity of species in the diet ($r_S = 0.005$, $n = 24$, $P > 0.1$). There was a negative relationship between evenness and the number of species in diet, that is, even when there was a greater number of species in the diet, fewer species contributed highly. This negative relationship was, however, not statistically significant. The evenness of the diet was inversely related to the number of items in the diet ($r_S = -0.697$, $n = 24$, $P < 0.001$). Dominance was negatively related to the number of species in the diet ($r_S = -0.598$, $n = 24$, $P = 0.002$), that is, when there were fewer species in the diet, one species was predominantly represented/eaten. As expected, the dominance of a single species in the diet was significantly greater in months with lower diversity ($r_S = -0.869$, $n = 24$, $P < 0.001$), and evenness ($r_S = -0.635$, $n = 24$, $P < 0.001$).

There was a significant correlation between the number of food species with ripe fruits available and the number of species that occurred in scats ($r_S = 0.437$, $n = 24$, $P < 0.05$). None of the other abundance and diversity measures of food availability was significantly correlated to any of the other indices of dietary diversity.

Although it seemed that most species were consumed to some extent whenever they were available, the Ivlev's electivity or preference index showed some species to be more preferred than others in each month (Table 4.3). When the index was calculated using

Table 4.3: Ivlev's electivity index for food species in Sengaltheri, KMTR. (Species codes expansions for trees are given in Table 4.2, EK – *Eleagnus kologa*, GU – *Gnetum ula*, MS – *Encete superbum*, and PK – Vitaceae sp.).

Species:	AH	AM	AP	BJ	CE	CL	DS	EK	EM	ES	FD	Fig	GU	HN	MS	NB	PE	PK	SZ	CD	TA
Jan-98		-1	0.966	-1	-1					0.776			0.99								
Feb-98			-1		-1		1			0.998		1	1		-1						
Mar-98			0.805	-1	-1	1	1			1	0.244	1	1			1	-1				1
Apr-98			-1		-1		1	-1		-1	-1		1		-1				-1		
May-98		-1	0.485	-1	-1	0.971	1								1						1
Jun-98		-1		-1	-1		1										0.06				
Jul-98				-1	-1	1			-1								0.589				
Aug-98		-1	-1		-1				-1	-1		-1		0.968			0.734		-1		
Sep-98			-1	-1			-1			-1				0.568		-0.21	0.415	-1	-1		
Oct-98		-1	-1	-1	-1					-1				0.945		0.124		0.996			
Nov-98		-1	1		-1				-1	-1		-1	1		0.998	0.9	-1	1			
Dec-98	0.993	-1	0.879		-1				-1	0.772		1	0.87		-1						
Jan-99			0.83		-1				-1	0.817		0.872	0.708		-1						
Feb-99			0.897		-1				-1	0.973		0.874	-1								
Mar-99			0.981		-0.54				-1	0.73	-1	-1			-1			-1			
Apr-99	1		0.99		-0.46	1		-1	-1	0.971	0.842	0.66	-1					-1			
May-99		-1				1	1		-1		1	0.681						-1			
Jun-99		-1		-1					-0.16			1					-1				
Jul-99		-1		-1		1			0.137			1		1			-1				
Aug-99	-1	-1		-1			-1		-0.06			0.955		1		1	0.346				
Sep-99			-1	-1			-1		-0.31	-1		1	-1	0.984	1	1	-1				
Oct-99		-1	-1	-1		1			-1			1			1			-1			
Nov-99	1	-1		1	-1				0.448	-0.35		1	0.976	1		-1		1		0.964	
Dec-99		-1	-1	-1	1				-1	-0.31		-1	0.532							0.585	
Pooled	0.991	-1	0.738	-0.72	-0.96	0.998	0.918	-1	-0.19	0.831	0.401	0.784	0.922	0.921	0.537	0.348	0.706	0.855	-1	0.848	1
Without CE	0.976	-1	0.432	-0.88	x	0.994	0.798	-1	-0.59	0.609	-0.06	0.516	0.807	0.804	0.116	-0.12	0.377	0.658	-1	0.644	1

utilisation data versus the availability of all the food species (including *C. exarillata* flower abundance), the preference reflected for other species was very high. This was because, despite being one of the most abundant food resources, *Cullenia* flowers were not commonly eaten. When the index was recalculated excluding *Cullenia*, the preference value for all the species changed, although relatively they remained more or less the same (Table 4.3). *Gnetum ula, Holigarna nigra, Diospyros sylvatica, Chrysophyllum lanceolatum*, and *Artocarpus heterophyllus* were some of the food species with higher preference values.

4.4.9 Species overlap

Over the two years, the overlap between two consecutive months in species composition of individuals with ripe fruits was significantly correlated to corresponding overlap in the abundance of ripe fruits ($r_S = 0.623$, $n = 23$, $P = 0.002$). Least species overlap in ripe fruit availability occurred in February – March, May – June, July – August, and November – December in 1998, and in January – February, and October – November in 1999 (Figure 4.7a). The species overlap between consecutive months in ripe fruit availability varied more during 1998 than during 1999, with the least overlaps or similarities occurring mostly at periods of changing seasons (Chapter 2). The lack of severe fluctuations in ripe fruit availability between consecutive months in 1999 was probably due to the year-round copious fruiting of *E. munronii*.

The periods of least similarity in the diet occurred between May – June, August – September, and October – November in 1998, and between February – March, May – June, and September – October in 1999 (Figure 4.7b). However, the species similarity in the diet was not significantly correlated to the similarity in food resource availability ($r_S = 0.338$, $n = 23$, $P = 0.115$). Dietary overlap between consecutive months, however, closely paralleled overlap between consecutive months in ripe fruit availability (individuals) in 1998 (Figure 4.7c). But in 1999, the overlap in diet and overlap in availability differed considerably between February and May, and September, corresponding to peaks in *E. munronii* fruiting (Figure 4.5h). *E.munronii* was not a preferred species of civets (Table 4.3). Therefore, when the above peak months were excluded from the analysis, there was a near significant ($P < 0.10$) positive correlation between overlap in diet of consecutive months and overlap in ripe fruit availability between consecutive months ($r_S = 0.426$, $n = 17$, $P = 0.088$, Figure 4.7c).

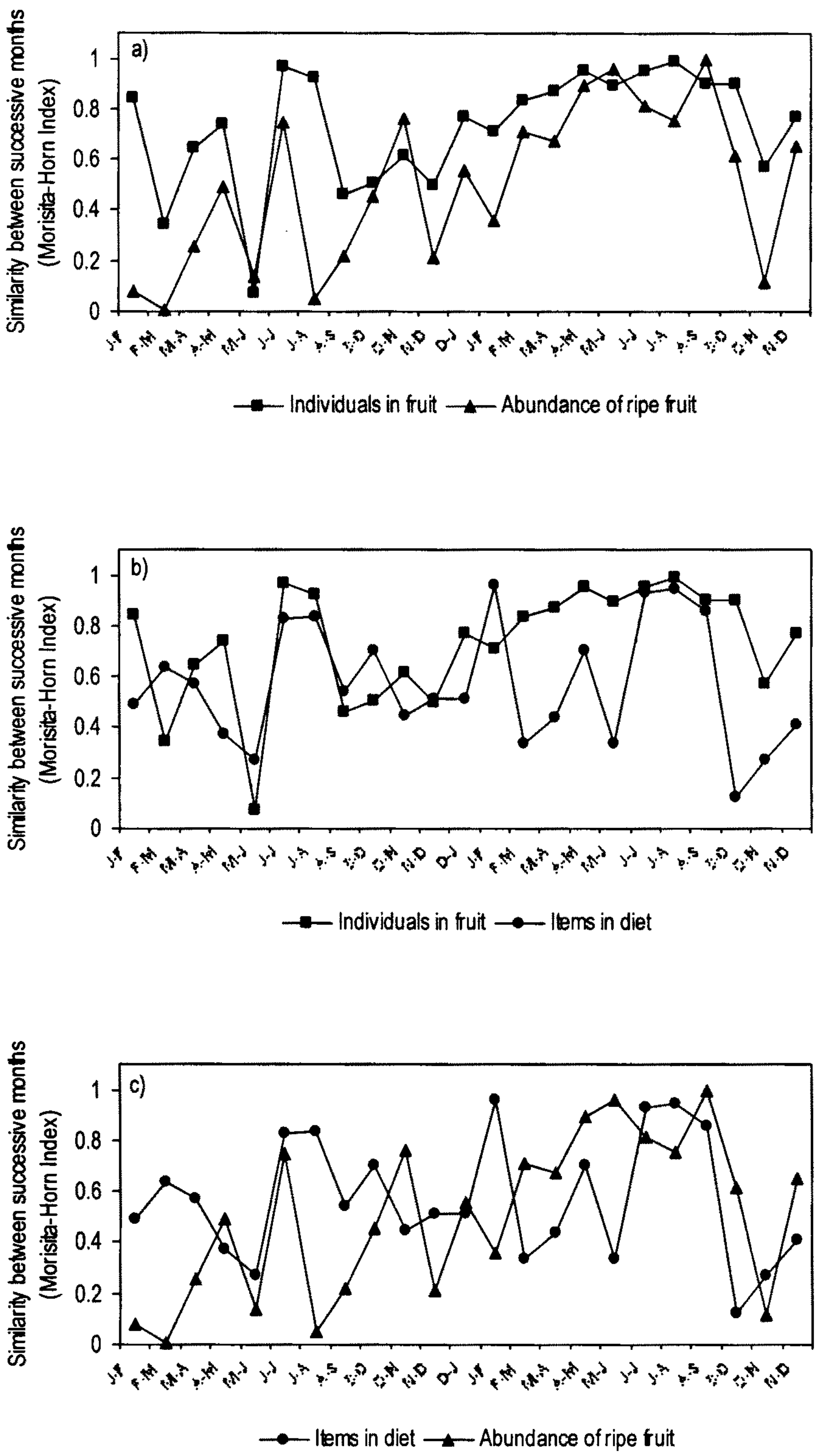


Figure 4.7: Comparison of Morisita-Horn Similarity index of food availability (number of individuals and abundance score of ripe fruits of 22 species in 4 ha) and items in diet (*n* = 456) in Sengaltheri, KMTR.

4.5 DISCUSSION

4.5.1 Flowering and fruiting phenology

Flowering and fruiting phenological patterns of civet food species exhibited clear peaks and troughs during the study period. The flowering pattern was bimodal, similar to that in Cocha Cashu, Peru (Terborgh 1986a), with the first peak between the late dry season and the early south-west monsoon being greater than the north-east monsoon peak. The ripe fruit production peaked during the late south-west and early north-east monsoons in 1998 and the dry season and the south-west monsoon periods in 1999. This suggests patterns similar to those described for other tropical forests, where fruit availability is highly variable in both space and time (Terborgh 1986a). In Sengaltheri, KMTR, the period of greatest availability of ripe fruit resources for brown palm civets was chiefly during the late south-west monsoon and the early north-east monsoon. These patterns were determined by varying combinations of species, number of individuals and abundances of flowers and fruits.

The pattern of flowering was similar to the patterns reported in some earlier studies, where water deficit has been identified to trigger flowering (Kinnaird 1992, Richards 1996, Corlett and LaFrankie 1998, Whitmore 1998, Chapman *et al.* 1999). In this study, temperature seemed to influence the number of species flowering, and the number of individuals with unripe fruits. Temperature and irradiance have been reported to influence flowering in many other tropical rainforests as well (van Schaik *et al.* 1993, Struhsaker 1997). Rainfall does not seem to have a direct influence on the phenological patterns, particularly in determining flowering (Bawa and Ng 1990). Long-term monitoring, and correlation and time-lag analyses with long-term weather data, may help in understanding and predicting fruit resource availability patterns.

Although the variation between months in the number of species flowering and fruiting of food plants was not very high (4 – 14 and 3 – 9 species with ripe fruits, respectively), there was high variation in the number of individuals and the abundance of flowers and fruits both within and between the years. This could be due to (a) variation in the densities of various food species in the plots, and (b) differences among species in flowering periodicity. There were also differences in the species bearing ripe fruits between the two years (1998 and 1999), with it being greater in the second year. However, a few species had a major influence on the differences in flowering and fruiting phenological activities between the two years. For example, the extended (and therefore diffused) abundance peak in the second year was mostly because of the mass flowering and fruiting of *Elaeocarpus munronii*. There was also a lower abundance of ripe fruits than unripe fruits, reflecting removal of ripe fruits between the two consecutive periods of monitoring. Terborgh (1986a) observed that in climates with two dry and two wet seasons, fruits were available throughout the year and scarcity was brief. This study area closely matches this kind of pattern, although the major seasons observed were one major dry period (January – April), and two major wet seasons (May – August and September – December), with a short dry spell in August and September (Figure 4.4). Unpredictability of fruit resource availability, however, may be a reason for the diffuse coevolution between plants and frugivores (Herrera 1982, Terborgh 1986b, Struhsaker 1997). Although, available throughout the year, most preferred species ("core-diet species") are highly seasonal, occurring in particular periods, usually not longer than 3 or 4 months (Fleming 1986). This probably is the reason for the diversity of fruit species, and the adaptability to a varying diet, including animal matter by the brown palm civet, just as seen in the diet of frugivorous bats in the Neotropics (Fleming 1986). Despite a large subset of fruit species being common to the diet of various frugivores (Ganesh and Davidar 2001), competition is reduced during times of food scarcity, by many species switching to exclusive diets (Fleming 1986, Stevenson *et al.* 2000), and the brown palm civet probably adopts the same strategy (Chapter 3 for the diversity of its diet).

The hypotheses proposed and tested by Gautier-Hion (1990), and reviewed by Terborgh (1990) and van Schaik *et al.* (1993) for factors other than climate (*viz.*, biotic factors) that are likely to influence patterns of fruit production are (1) competition avoidance hypothesis, (2) predator satiation hypothesis, and (3) optimal time of ripening hypothesis. Although I did not test any of the above directly, there may be weak evidence for the support of the second and third hypotheses. The data do not support the first, as there is unlikely to be much competition among arboreal frugivores in this study area. The arboreal, mammalian frugivore community is small, with about five to eight species of varying body size, with a variety of fruit species contributing to their diet (Chapter 3, Fleming 1979, Ganesh and Davidar 2001). Species like *Elaeocarpus munronii, E. serratus, Palaquium ellipticum*, and *Holigarna nigra* could be probable examples of species that support the predator satiation hypothesis, due to their "mass-fruiting" characteristic, which in the dipterocarps of south-east Asia is suggested to be driven by seed-predation in non-masting years (Janzen 1974, Yap and Chan 1990). The period between flowering and fruit maturation observed in this study (4 – 6 months) is similar to that reported for the phenological patterns of the overstorey trees in La Selva, Costa Rica (Frankie *et al.* 1974). The species producing ripe fruits in the south-west monsoon, like *Palaquium ellipticum, Elaeocarpus serratus, Diospyros sylvatica*, and *Nothopegia beddomei*, are likely to germinate during the favourable conditions of the north-east monsoon season, which is the stronger monsoon in the region. These are probable evidences for the third hypothesis of optimal time of ripening. However, there is likely to be a combination of factors influencing the phenological patterns, and the evidence for close evolutionary relationship between plants and their consumer species is diffuse at best (Herrera 1982, Gautier-Hion 1990). Exploration of species-specific ecology of plants will give a better knowledge of the dynamics of plant communities as well as their relationship with the frugivore, seed predator, and dispersal communities (Howe 1990).

4.5.2 Phenology traits of food species

There were no months without one of the important food species producing ripe fruits (> 13% of food species with ripe fruits in each month), although the abundance showed tremendous inter-annual variation. The food plants of the brown palm civet exhibited different periodicity of fruiting, such as supra-annual, annual, and sub-annual. Even among the food species that were monitored, there were subsets of species that produced fruits seasonally, and some that were more unpredictable.

Four of the 11 important species and one of the less preferred species fruited supra-annually, with at least three of them fruiting in intraspecific synchrony (*Palaquium ellipticum, Holigarna nigra*, and *Elaeocarpus munronii*). This can probably be equated to masting, which is commonly seen in temperate oaks and tropical dipterocarps, and is only recently being recognised as a pattern also shown by some fleshy-fruited species in the tropics (Janzen 1974, Yap and Chan 1990, Herrera 1998, Levey and Benkman 1999). Fruit abundance strongly influences animal abundance, distribution, and movement pattern (Gurnell 1996, Solórzano *et al.* 2000, Stevenson *et al.* 2000). Since the brown palm civets feed on a diverse set of species, masting plant species, while others are also available, is likely to have negligible impact on their ranging and movement (Chapter 5). However, further research and investigations into the impact of these supra-annually "masting" species on the movement and abundance of frugivores (seed dispersers and predators) in the long-term, would give a better insight into the impact of such plant strategies on their dispersal and regeneration.

Ficus spp. in South and South-east Asian tropical forests, and some members of Annonaceae and Myristicaceae in Gabon, have been identified as keystone resources (Leighton and Leighton 1983, Gautier-Hion and Michaloud 1989, Lambert and Marshall 1991, Kannan and James 1999). *Ficus* species occurred in many months, and did not exhibit any strictly seasonal pattern in fruiting. Assessing from its occurrence in the diet, it may be a keystone resource for the brown palm civet by being available in periods of low fruit availability, as reported from elsewhere for other species in the Western Ghats (Chapter 3, Kannan and

James 1997, 1999; Patel 1997). Also, recent studies have shown *Ficus* spp. to be more nutritive than previously considered (McKey 1975, Snow 1981, Borges 1993, Wendeln *et al.* 2000). However, *Ficus* spp. do not occur in high densities in the study area (Table 4.2, D. Mudappa *personal observation*, Ganesh and Davidar 1999). In this region, Ganesh and Davidar (1997) identified *Cullenia exarillata* to be a keystone resource. It was, however, not an important species in the diet of the brown palm civet. For the brown palm civets, species producing fruits annually, particularly those during the dry season, when fruit abundance is at its lowest, like *Elaeocarpus serratus, Acronychia pedunculata, Ficus* spp., and *Filicium decipiens* can be considered as key-stone resources, being more reliable food resources than copious flowering or fruiting, but less preferred species like *Cullenia exarillata, Elaeocarpus munronii*, and *Dimocarpus longan.*

4.5.3 Food tree density and distribution

The density and distribution of some of the food plant species is likely to determine the distribution and abundance of endemics like the lion-tailed macaque (*Macaca silenus*) and the brown palm civet. The tropical rainforests of Kalakad-Mundanthurai Tiger Reserve are known for their high diversity and endemism in plant communities (Ganesh *et al.* 1996, Parthasarathy 2001). The tree densities estimated for the study area (Ganesh and Davidar 1999, D. Mudappa *unpublished data*) were higher than those reported for some of the richest forests in the Neotropics (Whitmore 1998, Richards 1996). Most tropical plant species (particularly trees) are randomly distributed on large landscape scales, while they appear clumped locally (Richards 1996, Terborgh 2000). More than 50% of the trees within the plots were civet food species, although only half (11 species) contributed to a majority of them. Some among the most abundant tree species were not preferred diet species of the brown palm civet.

About 50% (9 species) of food tree species encountered in the sampling plots appeared to be clumped in distribution. While this may be so in the study area, they may be more randomly distributed when the larger area of the rainforests in the Western Ghats are considered. Also many of the common species in this region were mammal-dispersed (Ganesh and Davidar 2001).

Of the 55 species (including flowers and fruits) of plants consumed by the brown palm civet, 28 occurred in the PCQ plots sampled (of a total of 736 individuals). Most of the other food species, particularly the lianas, were rare in the study area. There were also differences in the densities of food plants between sites within the reserve. However, most of these species also occurred infrequently in the diet (Chapter 3). The 28 species accounted for 38% of the total tree density in the study area. There are few reports specifically mentioning the densities of food plant species of a particular species or taxa in tropical rainforests (Kinnaird 1992, Ganesh and Davidar 2001). Mammal dispersed tree species were found to be more common, although the number of avian frugivores in this region was about the same as the number of mammalian dispersers (Ganesh and Davidar 2001).

One of the consequences of differences in the densities and distribution of food plants in the study area is that the diet of the brown palm civet differed between sites. For instance, while *Semecarpus auriculata* and *Knema attenuata* were commonly eaten in Kannikatti, they did not occur in scats in the other sites (Sengaltheri and Kakachi), where these species were rare or absent. Clumped local distribution of food species would also mean that all animals may not have all the food species within their individual ranges. Even for otherwise territorial small carnivores like the common palm civet *Paradoxurus hermaphroditus*, home ranges have been shown to be influenced by the distribution of food plants, making them non-territorial when food is patchy or clumped in distribution (Joshi *et al.* 1995). This may, however, happen in an island system like where the study by Joshi *et al.* (1995) was carried out, but may not, in a relatively undisturbed forest with high food tree densities as in the present study, where the animals would occupy a range that ensures year-round availability of resources (Chapter 5). Also with a high diversity in diet—both plant and animal matter—the brown palm civet can sustain and maintain territories. This study area, one of the richest stands in the tropics, with high tree density (Foster 1982, Terborgh 1983, Ganesh *et al.* 1996, Ganesh and Davidar 1999, Divya Mudappa *unpublished data*), provides a diet breadth to the frugivores, including the brown palm civets, that makes them "extended specialists" as observed in the bats in the Neotopics (Fleming 1986).

4.5.4 Food species availability and use

The availability or abundance of ripe fruit was not the only factor influencing food choice in the brown palm civet. The choice of food species is also determined by other factors such as fruit traits or their nutritive content (Borges 1993). *Acronychia pedunculata, Filicium decipiens*, and *Elaeocarpus serratus* were important food species, occurring during the dry season when the abundance of ripe fruits was at its lowest, resulting in high-preference values for these species. The evidence for fruit choice comes from the observation that some species dominated the diet when the number of species consumed was lower than available. They consumed a greater number of species during times of low fruit availability, or they did not consume some species in proportion to their availability. A greater number of species were consumed usually in months when preferred food species were not available, and they were also eaten in more even proportions, providing evidence for resource tracking as in birds and other mammals (Leighton and Leighton 1983, Fleming 1992, Peres 1994). Even in months with very high abundances of *Elaeocarpus munronii*, many other species were eaten, and therefore *E. munronii* had a very low preference index value. These values, however, do not always indicate the preference as used by the animals. Although the brown palm civets were tracking fruit resources, their choice of food does not seem to be entirely influenced by abundance alone.

Although a large number of species with small fruits, mostly pulpy berries and drupes, were eaten (Chapter 3), they did not form the bulk when their absolute frequency of occurrence in the diet was considered (*e. g.*: *E. munronii vs. E. serratus*). Even in times of very low fruit availability, the brown palm civets do not migrate to other habitats or substantially increase their usually small home ranges (Chapter 5). Instead, they consume greater amounts of animal matter (invertebrates, Chapter 3) and also eat plant species that are not preferred otherwise. Similar behaviour of switching the diet has been observed in primates, bats, as well as some small carnivores like the pine marten (Fleming 1979, 1986; Peres 1994, Courts 1998, Jędrzejewska and Jędrzejewski 1998). Although strict species choice was not observed, it is obvious that the brown palm civets avoid some food species like the members of the families Lauraceae and Burseraceae, as noted in other frugivores (Fleming 1986), despite these families being abundant in rainforests (Ganesh *et al.* 1996, Kannan and James 1999). Having a generalist and flexible diet, the brown palm civets probably obtain a balanced diet by supplementing their core or preferred species with other opportunistically available species, as seen in frugivorous bats (Fleming 1986, Courts 1998). The diet of the brown palm civet and the use of available resources may be extrinsically based on the spatio-temporal variability of food resources and intrinsically on the nutritive content and fruit-size (or gape-width; Fleming 1986, Terborgh 1986a).

The diversity and abundance of plant species required for the year-round sustenance of the brown palm civet is particularly relevant to the conservation of this species in fragmented rainforests. Recent studies have predicted greater vagaries in patterns of flower and fruit production in the wake of the changes in global climatic rhythms, particularly in highly disturbed and fragmented landscapes (Corlett and LaFrankie 1998). Keeping in mind the intra- and inter-annual variation in plant food availability, and the differences in densities and dispersion of various species, protection of large areas of relatively undisturbed tropical rainforests is imperative for the conservation of the endemic brown palm civet.

4.6 SUMMARY

1. Year-round availability of flowers and fruits of 22 civet food species was observed in the relatively undisturbed rainforests of Sengaltheri, KMTR. A minimum of 3 species or 4 individual plants in flower or fruit, or 100 flowers or fruits, were available per 4 hectares in any given month. The dry season (February to May) was a period of low fruit availability in this site.
2. There was significant difference in the number of species, individuals, and abundance score of fruits between the two years (1998 and 1999). The fruiting peaks were highly influenced by synchronously fruiting species such as *Elaeocarpus munronii* and *Palaquium ellipticum*.
3. Fruiting of all the important species was staggered, such that at least one of them fruited in a given season. This was due to either the biannual species like *Acronychia pedunculata*, the annually fruiting species like the *Diospyros sylvatica*, or a biennial like *Holigarna nigra*. The south-west monsoon and the north-east monsoon were the seasons of high fruit availability, and this was probably due to the plant's fruiting strategy, such that seeds are produced and dispersed under optimal weather conditions.
4. The diversity of available food and diversity in the diet were not significantly correlated. There was dominance of a species in the diet when the diversity in the diet was low. This coincided with periods of increased food availability, and also indicated preference for particular fruits by the brown palm civets. In times of low fruit availability, the civets consumed a greater variety of food species in even proportions.
5. Over half of the trees in this region are civet food species. Therefore, even the clumped distribution of many of the food tree species was compensated by their high densities. Less than half the species are very abundant, while most others are relatively rare. However, most of the civets' preferred food species, such as *Holigarna nigra* and *Palaquium ellipticum*, are the more abundant species.
6. The variations in flowering and fruiting phenologies can partly be explained by temperature and rainfall. The fluctuations may be enhanced due to changes in global climate, particularly in disturbed and fragmented regions. In the light of this, and the importance of year-round fruit availability to highly frugivorous species like the brown palm civet, it becomes imperative to maintain relatively less disturbed rainforests with high plant diversity for their long-term conservation.

CHAPTER 5

HOME RANGE, ACTIVITY, AND DAY-BED CHOICE OF BROWN PALM CIVETS IN TROPICAL RAINFORESTS

5.1 INTRODUCTION

Although a member of the order Carnivora, the brown palm civet is highly frugivorous (Chapter 3). It is also predominantly nocturnal and arboreal in habit. Other than these basic features of the species, there is very little known about them. Many studies have been carried out on the larger carnivores like the lion (*Panthera leo*, Schaller 1972, Chellam 1993), tiger (*P.tigris*, Schaller 1967, Sunquist 1981, Karanth and Sunquist 1995), cheetah (*Acinonyx jubatus*, Caro and Collins 1987), jaguar (*P. onca*, Rabinowitz and Nottingham 1986), snow leopard (*P. uncia*, Fox *et al.* 1991, Chundawat 1992), Asiatic wild dog (*Cuon alpinus*, Johnsingh 1982, 1983), and the Indian wolf (*Canis lupus*, Jhala and Giles 1992, Jhala 1993), but very little information exists on small carnivores, particularly the viverrids of tropical Asia (Ewer 1998). It is evident from earlier studies that the area requirements of carnivores are not only influenced by resource availability and distribution, but also by their social systems (Sandell 1989). Range sizes in females are largely determined by food abundance, while that of males, at least during the mating season is determined by the distribution of females (Erlinge and Sandell 1986).

The technique of tracking animal using radio-transmitters has made it possible to at least gather some basic ecological information on many otherwise cryptic species (Kenward 1987, Harris *et al.* 1990, White and Garrott 1990, Rabinowitz 1991). Earlier studies on civets have shown them to range over fairly large areas (1 – 3 km², Rabinowitz 1991, Grassman 1998). These studies support the assumption of larger home ranges for males and bigger individuals, although the extent to which body size and sex influence home range is not clear due to small sample sizes. Rabinowitz (1991) also showed that the home ranges were smaller during periods of high rainfall with an increase in activity; Grassman's (1998) results exhibiting a converse trend. Joshi *et al.* (1995) suggested that the movement of predators and resource availability determined the ranging behaviour of common palm civets in Nepal. In this chapter, I discuss the factors influencing ranging and activity pattern, and day-bed choice of the brown palm civet in the relatively undisturbed rainforests of Sengaltheri, Kalakad-Mundanthurai Tiger Reserve, between April 1998 and December 1999. As the diet of brown palm civets comprises a diversity of plants, occurring in relatively high densities within the study area (Chapter 4), its influence on their ranging pattern was examined.

5.2 OBJECTIVES

Using radio-telemetry as a technique, which involved capturing, immobilising and radio-collaring of brown palm civets, I tried to answer the following questions pertaining to their ecology.

a. What are the home ranges sizes of brown palm civets? Can body size explain inter-individual differences? Do these civets exhibit territoriality?
b. How does food resource availability, rainfall, and season influence their ranging behaviour?
c. Does habitat quality determine the home range sizes?
d. What kinds of day-beds are used by civets, and what are the characteristics of these day-bed sites?
e. What are the basic activity patterns of civets and how are they influenced by food availability, habitat quality, and rainfall?

5.3 METHODS

5.3.1 Capture, immobilisation, and radio-collaring

The brown palm civets were captured using live animal Havahart traps, immobilised with a mixture of ketamine hydrochloride and xylazine hydrochloride, and fitted with radio-transmitters mounted on collars (Mudappa and Chellam 2001). Morphometric measurements of the animals were taken and ectoparasites collected prior to release. Scats in traps were collected and preserved for endoparasite examination. AVM P2RLM (AVM Inc.) activity transmitters were fitted around the neck of the animals.

The process of capture took an average of two weeks for each individual. This involved pre-baiting track-plots situated on trails, at sites where there were signs of animal movements (direct sightings or scat-marking). Banana was placed as bait on track-plots. Baiting was continued for three or four days, and shifted to another site if no animals consumed it. If the bait was consumed, a Havahart live trap (large racoon live animal cage trap 107 x 28 x 33 cm) was placed with both doors open on the track-plot and the baiting was continued until the animals were habituated to entering the trap. A week after the trap was placed on the track-plot, one of the doors was shut and baiting continued for 3 to 4 days prior to capture. Civets seemed to avoid traps placed randomly at the track plots without pre-baiting ($n = 12$ trapping sessions).

On the day of capture, the trap was set at dusk, and a radio-transmitter was attached to the door such that the capture of an animal would activate transmission of radio signals. Signals were monitored every 5 minutes from a nearby location and thus capture of an animal could be detected almost immediately. Within 30 minutes of capture, the animal was transferred into a box trap (30 x 30 x 30 cm) and brought to the field station. The animal along with the trap was weighed using a 10 kg Pesola hanging scale and the drug dosage calculated based on body weight. The animal was then immobilised with an intramuscular administration of a mixture of ketamine hydrochloride (KE, KETMIN 50, Themis Chemicals Ltd., Hyderabad, India) and xylazine hydrochloride (XY, XYLAZIN 2% solution, Indian Immunologicals, Hyderabad, India; following Palomares and Delibes 1992a, Palomares 1993b). A KE: XY ratio of 15:1.5 mg/kg body weight was administered into its hindquarters, using a hand-held 2 ml disposable syringe.

Approximately every 5 to 10 minutes, rectal temperature (for one individual) and respiration rate (for all individuals) were recorded. Time taken for lateral recumbency, induction (drug administration to lack of response to stimuli), sedation (induction to response to stimuli), and down time (lateral recumbency to complete recovery) were also recorded. During the handling of animals for fitting radio-collars, a sterile solution of methyl cellulose (MEZOL7, Syntho Pharmaceuticals Pvt. Ltd., Lucknow, India) was applied to moisten the eyes and prevent corneal ulcers.

5.3.2 Radio-tracking

5.3.2.1 *Mapping*

Due to the lack of maps of the required scale, on which known points could be marked and used for triangulation, existing trails within the study area were mapped. Starting from the base camp as the origin, trails were marked at 25 m intervals. Four major trails (each about 1.5 km long) and 4 minor trails (<500 m long), radiating in different directions from the base camp were mapped in the following manner. The compass bearing and slope between successive points were taken using a compass and a clinometer, respectively. Using these three parameters (distance, angle, and slope), the co-ordinates (x, y) of each point was calculated in metres (White and Garrott 1990, p. 49). Compass bearings during triangulation were taken from these marked points along trails.

5.3.2.2 *Triangulation*

Due to the elusive habits of brown palm civets, a combination of techniques needed to be used in order to understand even their basic ecology. The radio-collared animals were tracked on foot, and at least three locations per week were taken for each individual. The time when locations were taken was more or less equally distributed over all hours of day and night. To the extent possible, all radio-collared individuals were tracked according to this monitoring protocol. The number of locations, activity records, and day-bed sites obtained for each individual are given in Table 5.1. Usually two to five bearings were taken from known points 25 m to 100 m apart within a short period of 10–15 minutes. Locations of these individuals based on the bearings were estimated using maximum likelihood estimates in LOCATE II software programme (Version 1.6, 1990). The distance moved by an individual between two consecutive locations was also calculated. Location estimation errors were also calculated based on the standard deviation of the bearings estimated from the data. Locations with an error ellipse of >1 ha were excluded

Table 5.1: Number of locations, activity records, and day-bed sites of radio-collared brown palm civets in Sengaltheri, KMTR.

ID	**Period of tracking**	**Locations**		**Activity records**	**Day-beds**
		Inactive	**Active**		
K70	April–October 1998 & January 1999	54	67	1301	14
P80	May–September 1998	34	42	744	16
K82	May 1998	3	11	170	2
S84	June–December 1998 & April–June 1999	78	71	1166	14
B88	July–December 1998	45	49	763	10
BM76	February 1999	16	15	0	3
M94	June–December 1999	69	57	833	1

from analysis of home range estimation. All the remaining locations were used to estimate the home ranges, and these were not tested for autocorrelation, as the biological relevance of this is still debatable (Rooney *et al.* 1998, De Solla *et al.* 1999). Removal of autocorrelated locations could substantially reduce the already limited data set. A solution to overcome this problem is to increase the number of observations/locations. Home ranges were estimated using CALHOME programme (Kie *et al.* 1994). The various parameters estimated from radio-tracking data of brown palm civets were:

i. *Total home range* — 100% and 95% Minimum Convex Polygon (MCP) home range size (Mohr 1947).
ii. *Core area* — 60% Harmonic Mean (HM) method, and this indicated intensive use area within the total home range.
iii. *Monthly ranges* — 100% and 95% MCP and 60% HM monthly area estimates were obtained for each collared individual and was used to relate to food abundance and activity pattern. This was also used to estimate spatial and temporal overlap in home ranges, thereby determining the civets' territorial tendencies.
iv. *Activity range* — 100% and 95% MCP, and 60% HM area used during active periods
v. *Resting range* — 100% and 95% MCP, and 60% HM area used during inactive periods
vi. *South-west monsoon range* — 100% and 95% MCP, and 60% HM area used between June and September, as the largest number of individuals were tracked simultaneously during this period.
vii. *Distance travelled* — the average distance between two consecutive locations was calculated separately for each of the different subsets of locations (mentioned above).

Activity and resting ranges were estimated separately, for each individual, and comparisons made among them, to get a better insight into the movement and space use patterns of these animals (Palomares and Delibes 1992b).

For the five individuals tracked for more than three months, the home range sizes were examined in relation to their body size, average distance travelled during the period of tracking, and habitat parameters. Within individuals, changes in the home range centres and movement patterns based on monthly shifts in the area used within the range were estimated. The percentage overlap in the ranges of consecutive months for individuals and overlaps across individuals was measured using entire home range estimates. Overlaps were calculated by grid cell count method from the home range maps produced using CALHOME.

The relation between monthly ranges of individuals and the number of locations obtained (sample size) was tested using Spearman rank correlation (Siegel and Castellan 1988). In the case of individuals for which there was a significant correlation between the number of locations and the monthly range estimates, a maximum of 10 locations per month picked randomly were used to estimate the monthly ranges and these estimates were used for further analysis, thereby standardising it so as to make it comparable with other individuals. The monthly home ranges were correlated to the monthly average of distance travelled, rainfall, food availability, and activity patterns. To relate home range size to fruit availability and rainfall, a standardised index of monthly range size (S_{ij}) for each individual was calculated as:

$$S_{ij} = \frac{H_{ij}}{H_{i\,\mathrm{max}}}$$

where,

H_{ij} = monthly home range of individual *i* in month *j*,

$H_{i\,\mathrm{max}}$ = Largest monthly range recorded for individual *i*

This index, which can take a value of up to 1 for all individuals, corrects for inter-individual differences in monthly ranges while retaining the pattern of variation across months.

5.3.2.3 *Territoriality*

This was examined by calculating the extent of overlap in the home ranges — overall and monthly. Overlap in the overall home ranges was considered to be the spatial overlap (includes individuals that were not simultaneously tracked). The overlap in home ranges within particular months was considered to indicate temporal overlap. The degree of spatial overlap was estimated as percentage of overlapping grids in 100% MCP home range polygons, by the grid cell count method. Direct sightings and camera trapping results (Chapter 6) were also used to confirm the presence of other individuals within the ranges of the radio-collared civets.

5.3.3 Activity monitoring

5.3.3.1 *Diel-activity*

Twenty four-hour diel activity was monitored (Palomares and Delibes 1991) for all but one collared individual (BM76) once every month. Activity status was recorded by listening to signals for 60 second-bouts, at 10-minute intervals (15-minute intervals initially for one individual – K70). Active signals were transmitted at a faster rate than inactive signals. Three procedures were used to denote the activity within each 1-minute sample as described below.

i. Instantaneous sample: the activity status (active/inactive) was recorded at the 60th second of the minute;
ii. One-zero sample: the animal was considered active if there was any active pulse heard during the 1-minute (60 seconds) sample; and
iii. Classified activity: the activity was also classified as moving, foraging, resting, or grooming/shifting position within day-bed, based on the intervals of active and inactive pulses within the minute (Palomares and Delibes 1993). The activity was classified as moving if the activity pulse was continuous for a long period of time and contributed to more than 30 seconds within the sampling minute. The animal was noted to be foraging when the activity pulses were heard intermittently between inactive pulses. Resting was recorded when the entire minute had no active signals. When the active signals lasted for less than 5 seconds, the animal was probably engaged in other activities, especially grooming. This classification was based on observations made on radio-collared civets during their release and whenever they were observed in the field.

Due to small sample sizes, activity records were pooled across individuals and over the entire study period. Monthly and seasonal changes could not be explored due to the same reason, both within and across collared individuals. The activity monitoring data were used to calculate the proportion of records with activity within hourly time blocks. The percent time spent in various activities across months was related to the corresponding changes in food resource availability and rainfall.

5.3.4 Day-bed sites

5.3.4.1 *Homing-in and location of day-beds*

For each radio-collared civet, day-beds were located at least once a month by homing-in on resting sites during the day. These confirmed locations were also included in the estimation of the home ranges, particularly of the resting ranges. Locations taken just before sightings of collared individuals at night helped to confirm the accuracy of the triangulation procedure.

At each day-bed, the characteristics (*e.g.*: girth at breast height (GBH), tree height, canopy contiguity) of the day-bedding tree, and some habitat parameters such as canopy cover, presence and absence of liana, number of large trees in 5 m radius around the tree, were measured. These parameters were also measured for random trees located within the home range of the individual. The parameters were chosen as important variables for an arboreal species like the brown palm civet, as they are indicative of cover and contiguity for their arboreal movement. At a random location, the first tree in a PCQ plot (see section 5.3.6) that was >60 cm in GBH was treated as a random tree. The substrate used for day-bedding was identified and verified by watching the animal emerge from the day-bed at dusk. Non-parametric Mann-Whitney *U* test (Siegel and Castellan 1988) was used to test for significant differences between day-bed and random trees for nine variables (see Table 5.7). G test was used to test for differences in use of categorical variables (Zar 1999) such as type of day-bed, presence of climbers, branching pattern (horizontal – < 30°, oblique – > 30° and < 60°, and vertical – > 60°), and canopy shape of the trees (conical, semicircular, horizontal ellipse, and vertical ellipse/oval). Logistic regression was used to identify the parameters influencing the day-bed choice (Donázar *et al.* 1993, Gros and Rejmánek 1999).

5.3.5 Food resource availability

Since fruits are the major food of the brown palm civets in the study area (see Chapter 3), three phenology plots were established to monitor monthly variation in fruit resource availability (method modified after Chapman *et al.* 1994). Of the 45 identified food plants (trees and lianas), 22 were represented and monitored in these plots. A majority of these 22 species were commonly eaten (absolute frequency of occurrence in scats 74% in 1998 and 57% in 1999). One plot was 2 ha in area with 292 trees and lianas (> 30 cm) and two other plots, each 1 ha in area, contained 158 trees and lianas marked and monitored (see Chapter 4 for details). A maximum of 20 individuals of each common species and all the individuals of the rare or less common species in the plots were monitored. Between January 1998 and December 1999, the abundance of flowers, unripe fruits, and ripe fruits on each plant was recorded using a ranking system — 0 for none, 5 for less than 10 units (flowers or fruits), 55 for 11 – 100 units, 550 for over 100 units. However, for *Artocarpus heterophyllus* the score of 0 for none, 5 for less than 4 fruits, 55 for 5-8 fruits, and 550 for >8 fruits was used (see Chapter 4 for details).

Fruits of 21 species and flowers of one (*Cullenia exarillata*) in the plots represented food availability. Monthly food availability and abundance was estimated using three *indices* — (1) the number of species in flower or with ripe fruits, (2) number of individuals (trees or lianas) in flower or with ripe fruits, and (3) abundance score. Abundance score was calculated by summing the number of fruits across individuals and corrected using the tree density data for each species, in order to represent overall abundance in 4 ha. In this chapter, even *Cullenia exarillata* flowers are included in the estimation of food availability (unlike in Chapter 4).

5.3.6 Habitat quality

Habitat quality refers to those characteristics of the habitat that are likely to influence the reproduction and survival of a species. I do not have data to support the direct effect of the habitat characteristics on the above life-history parameters of civets. However, I assume that the features of habitat structure and resource distribution considered for analysis, influence the life-history traits of the species, and can be used as an index of habitat quality.

Total tree density and species richness, food tree density and food species richness, and basal area of the trees within the home ranges of five brown palm civets that were tracked for a period of at least 3 months, were estimated. Point-centred quarter (PCQ) method was used to estimate the above-mentioned habitat parameters (Krebs 1989), based on a minimum sample size of 20 random points within each home range. These were correlated to the total home range sizes and the average distance between successive locations of civets, using Spearman rank correlation (Siegel and Castellan 1988).

5.4 RESULTS

5.4.1 Capture and immobilisation

Seven brown palm civets (3 adult and 1 sub-adult male, 1 juvenile male, and 2 adult females) were captured on 10 occasions (including three recaptures) for the radio-telemetry study. Ten immobilisations of these individuals were carried out between April 1998 and June 1999 (Table 5.2). The individuals weighed between 1.2 kg and 3.5 kg. Apart from one female and a recaptured sub-adult male that had some injuries unrelated to capture, all individuals were in good physical condition. Nine immobilisations

Table 5.2: Morphometrics of the seven radio-collared brown palm civets in KMTR.

ID	Date of capture	Sex	Body weight (kg)	Head-body length (cm)	Tail length (cm)	Age class
K70*	02 Apr 98/06 Jan 99	M	1.6	48.0	40	Sub-adult
P80	02 May 98	M	2.6	54.0	44	Adult
K82	17 May 98	F	2.6	59.0	50	Adult
S84*	25 May 98/19 Apr 99	F	2.0	51.0	47	Adult
B88	02 Jul 98	M	3.2	52.0	46	Adult
BM76	30 Jan 99	M	1.2	46.5	41	Juvenile
M94*	14 Mar 99/18 Jun 99	M	3.5	61.5	48	Adult

* recaptured individuals

were made using a single dosage of 15 mg/kg body weight of KE and 1.5 mg/kg body weight of XY (Table 5.3). An additional dose of 18.2 mg KE and 1.8 mg XY was given to an adult female that was being immobilised for the second time in 11 months. Despite the additional dosage, unlike in the other immobilised individuals, complete relaxation of skeletal muscles was not attained and she remained only partially immobilised.

Table 5.3: Drug dosage, and time taken for each stage of immobilisation procedure of brown palm civets in KMTR (*n* = number of individuals for which the parameter was measured).

	Mean	**SD**	**Range**	**n**
Ketamine hydrochloride (mg) (KE)	36.45	10.98	18–52.5	10
Xylazine hydrochloride (mg) (XY)	3.65	1.1	1.8–4.25	10
Body weight (kg)	2.39	0.80	1.2–3.5	7
Time for lateral recumbency (min)	6.1	3.78	3–15	10
Induction time (min)	8.7	2.83	5–12	9
Sedation time (min)	77.6	29.83	43–132	10
Down time (min)	84.9	28.76	49–138	9

There were considerable inter-individual differences in response to the drugs administered. Time taken for each stage of immobilisation is given in Table 5.3. Recovery from immobilisation was gradual. Rectal temperature decreased very slightly from 38.9°C (13 min after drug administration) to 37.8°C (29 min after drug administration). The respiration rate did not show any particular pattern of change with time, and there was a lot of variation across individuals (Figure 5.1).

Spasmodic convulsions were not observed during immobilisation. Five individuals urinated, two vomited, and one defecated while recovering. No animal died or suffered any physical injury during capture, immobilisation, handling, or recovery. After complete recovery, all individuals were released at the capture site. The animals were released within 6 hr of capture (except for B88, which was released after 62 hr as it had been trapped in my absence and could be radio-collared only when I got back to the camp).

5.4.2 Home ranges

The overall home range sizes (HRS) estimated for the period (Table 5.4) varied between 6.3 ha and 56.3 ha for 100% MCP estimates (Figure 5.2). The 95% MCP area contributed to an average of 63% of the total home range estimate (100% MCP), and varied between 3.6 ha and 51 ha (*n* = 6). On an average (*n* = 5), one-fifth (18.6%) of the total home range formed intensively used or core areas (60% Harmonic Mean estimates).

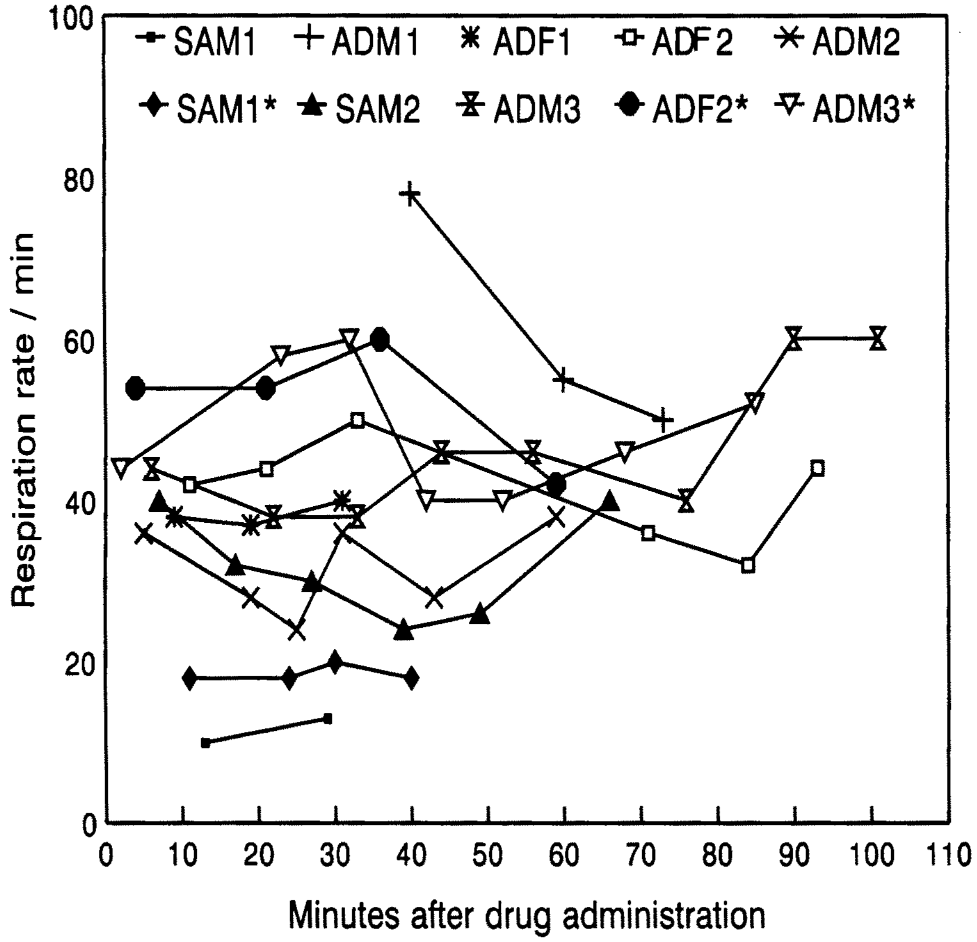


Figure 5.1: Respiration rates of immobilized brown palm civets during radio-collaring in KMTR. (SAM = sub-adult male, ADM = adult male, ADF = adult female, * signifies recapture).

The 100% activity range was, on an average, 13.6% smaller than the total home range. The activity core area was smaller than the total core area by about 2%, being about 17% of the total HRS. The 100% and 95% MCP resting range estimates were even smaller than the activity ranges by an average of about 40% and 50%, respectively, of the total home range. The resting core area was one tenth of the total home range.

The 100% MCP and the 60% HM (core area) of the southwest monsoon range were not much smaller than MCP and HM estimates of the total home range or the activity range (except for K70). However, the 95% MCP of the southwest monsoon range was about 50% of the total home range and smaller than the total activity range also. As there was considerable variation in the home range sizes of the collared brown palm civets, a brief description of the ranging and movement pattern of each individual is given in Appendix 3.

Usually, home ranges were greater when the animals were tracked for a longer period of time and located more often. Effort (number of locations or number of weeks of radio-tracking) and total home ranges were not significantly correlated ($r_s = 0.679$ and 0.643, $n = 7$ and $P > 0.05$ for 100% and

Table 5.4: Individual home range and core area estimates of brown palm civets in the rainforests of Sengaltheri, KMTR (100% and 95% MCP, and 60% HM estimates in hectares).

ID	Home range			Activity range			Resting range			SW monsoon range		
	100%	95%	60%	100%	95%	60%	100%	95%	60%	100%	95%	60%
K70	18.04	11.24	2.94	16.19	11.25	2.99	10.22	7.53	1.04	7.17	5.59	0.89
S84	17.55	9.92	3.79	14.35	10.11	3.92	11.16	8.66	2.03	13.1	8.39	2.58
P80	9.86	6.97	1.69	8.95	5.89	1.41	4.92	4.24	0.70	7.12	4.68	1.26
B88	56.31	50.94	10.82	43.21	39.61	8.38	48.04	41.23	6.98	51.71	41.56	9.18
M94	33.21	16.79	6.14	30.85	14.7	4.87	17.05	14.47	3.28	25.96	13.49	4.71
K82	6.27		0.16									
BM76	7.29	3.55	0.39									

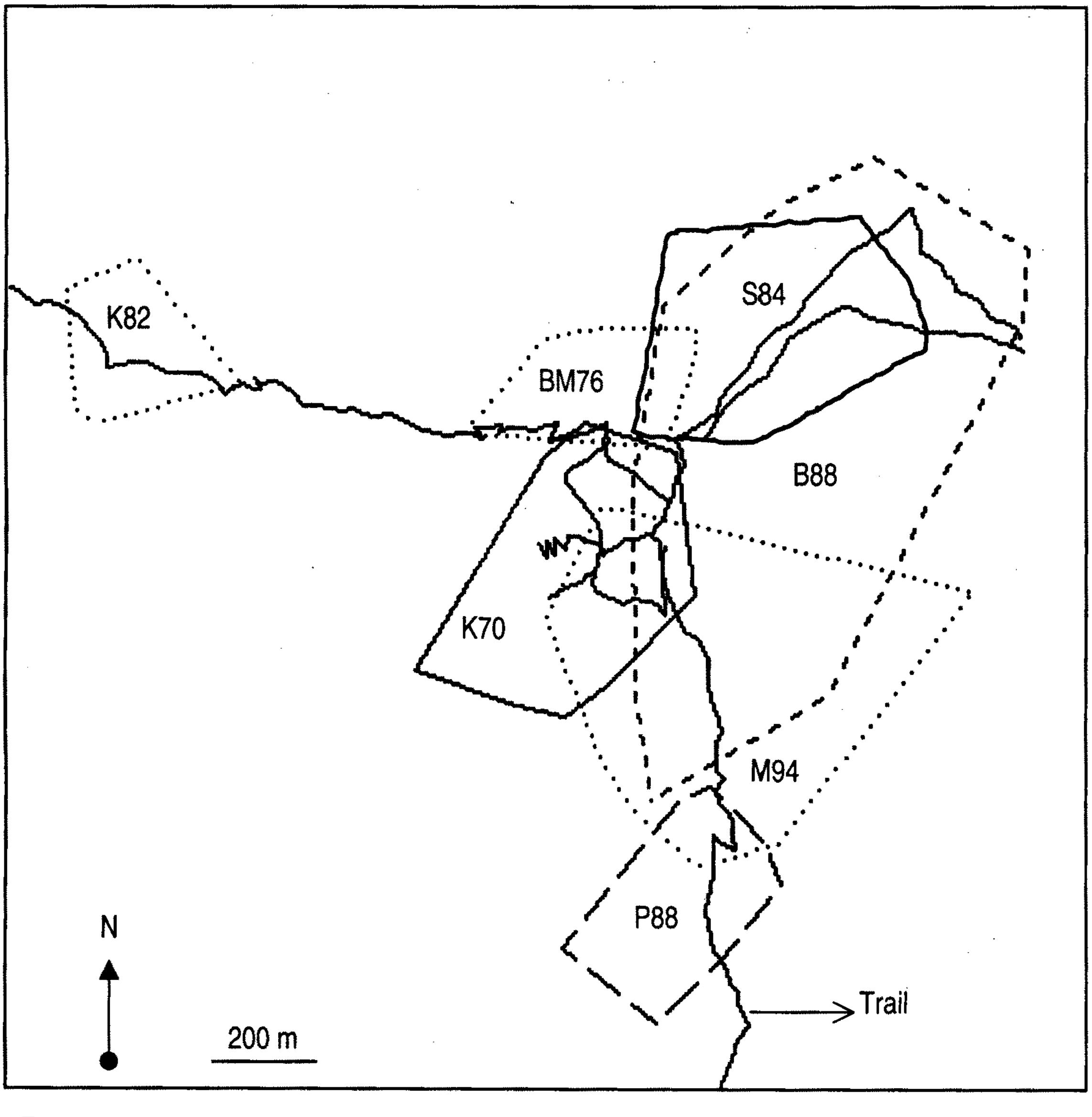


Figure 5.2: Home ranges of radio-collared brown palm civets in Sengaltheri, KMTR.

95% MCP, respectively; Figure 5.3), and therefore the home range size estimates were used as such for further analysis. Similarly, the monthly ranges of three of the five individuals tracked for more than three months were not significantly correlated to the number of locations in a month ($r_S = -0.359$, 0.100, and 0.414, $n = 5$, 5,and 7, and $P > 0.05$, for P80, B88, and M94, respectively) . However, it was highly significant for K70 ($r_S = 0.857$, $n = 8$, $P < 0.01$ for both 100% and 95% MCP) and S84 ($r_S = 0.87$ $n = 9$, $P < 0.05$ for 100% and 95% MCP), which were tracked for the longest period (Table 5.5). For these two individuals, when a set of 10 random locations were taken for months with more than 10 locations, the monthly ranges estimated using them were not significantly correlated to the number of locations ($r_S =$ 0.546 and 0.412, $n = 5$ and 7, for 100% MCP of K70 and S84, respectively, $P > 0.05$). These standardised home range estimates were used for correlation with other variables such as food availability and activity.

5.4.2.1 *Home range overlaps and territoriality*

Radio-tracking data suggest large spatial overlaps but very little or almost complete absence of temporal (in the same month) overlap between collared individuals. The only large spatial and temporal overlap was between adult male B88 and adult female S84. About 28.5% of B88's home range overlapped with 86.9% of S84's home range. About 31% of B88's home range also overlapped with 49% of the adult male M94, spatially. However, as they were not monitored simultaneously, temporal overlap in their ranges is not known. The spatial overlap between other individuals ranged between 0% and 32.5%. The female K82's range was completely independent of the other collared individuals, while the range of S84 was adjacent to that of K70, and P80's range was adjacent to that of B88 and K70 (Figure 5.2).

Unless there is evidence of active defence of any of the resources, the absence of temporal overlap does not substantiate the existence of territory maintenance. There were no observations of territorial defence during the study. The overlap in monthly ranges of the individuals that were monitored in the same months was calculated to estimate temporal overlap. The ranges of the adult male B88 overlapped with that of the adult female S84 in months of August, September, October, and November 1998. Although B88 ranged more or less in the region of K70's range, they overlapped only in one out of four months, that too slightly (<10%). With the exception of the adult male, B88, all the individuals used >50% of their range over the successive months that they were tracked (*e.g.*: S84, Figure 5.4). B88 shifted his range and activity centre during August 1998, as can be observed from Figure 5.5.

Opportunistic camera trapping between April 1998 and January 1999, within the home range of K70, detected only K70, until his death due to predation. Afterwards, pictures of the adult radio-collared male (B88) and an unidentified brown palm civet were obtained at the same station. K70, B88, M94, and an animal that was not collared, were all captured at the same site. A small Indian civet (*Viverricula*

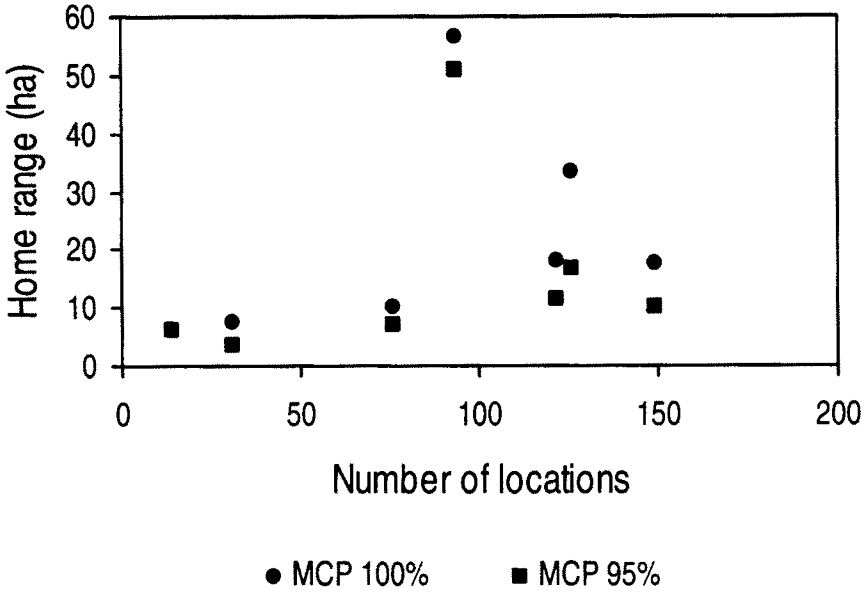


Figure 5.3: Home ranges of seven radio-collared brown palm civets in Sengaltheri, KMTR, in relation to number of locations.

Table 5.5: Monthly home ranges (100% MCP in ha) of the five radio-collared brown palm civets tracked for more than three months in KMTR. Number of locations in parentheses.

Month and Year	K70	S84	P80	B88	M94
April 1998	10.56 (32)	-	-	-	-
May 1998	8.48 (29)	-	6.08 (20)	-	-
June 1998	0.35 (5)	8.01 (22)	1.66 (21)	-	-
July 1998	0.67 (11)	4.80 (23)	2.69 (13)	14.11 (22)	-
August 1998	2.92 (7)	3.66 (16)	3.15 (13)	29.58 (20)	-
September 1998	5.56 (12)	11.37 (24)	3.45 (9)	17.93 (21)	-
October 1998	0.86 (4)	5.06 (19)	-	18.51 (19)	-
November 1998	-	3.32 (110)	-	6.75 (11)	-
January 1999	4.02 (21)	-	-	-	-
April 1999	-	2.62 (7)	-	-	-
May1999	-	9.91 (19)	-	-	-
June 1999	-	2.92 (8)	-	-	15.88 (8)
July 1999	-	-	-	-	7.20(14)
August 1999	-	-	-	-	7.19 (11)
September 1999	-	-	-	-	13.43 (24)
October 1999	-	-	-	-	16.21 (33)
November 1999	-	-	-	-	10.73 (17)
December 1999	-	-	-	-	10.37 (19)

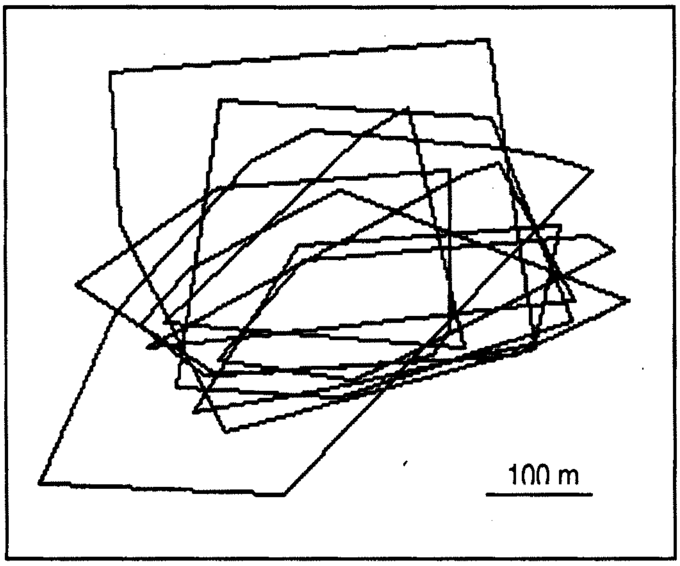


Figure 5.4: An example of spatial fidelity in ranging—superimposed 100% MCP ranges of eight months for adult female S84 in Sengaltheri, KMTR.

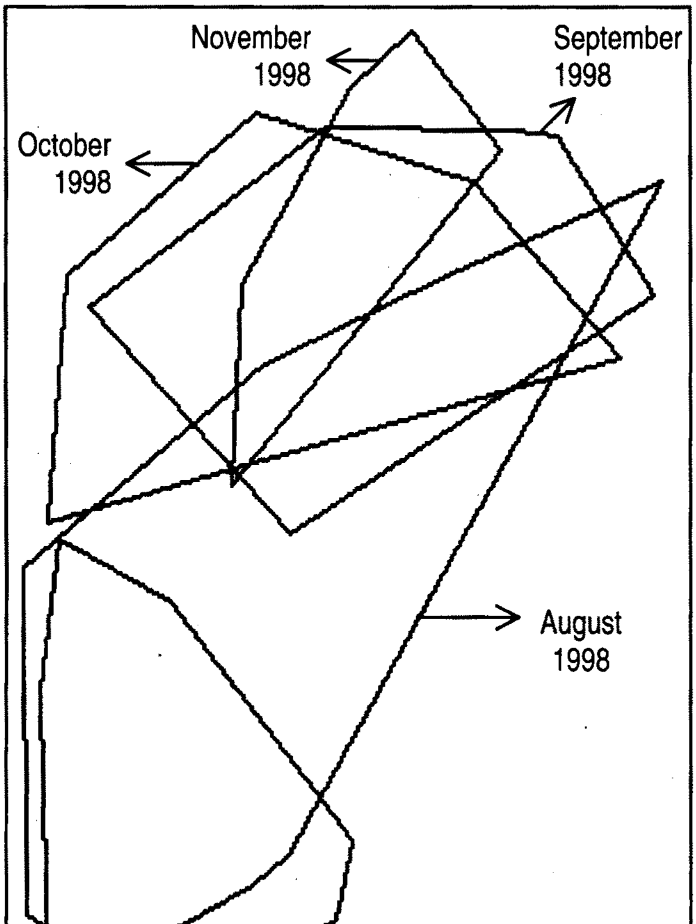


Figure 5.5: Home range shift exhibited by an adult male brown palm civet (B88) in Sengaltheri, KMTR.

indica) and a leopard cat (*Prionailurus bengalensis*) were also sighted within K70's home range, the former when K70 was alive and the latter after his death.

Camera trapping within the home range of P80 after the disappearance of his signals in September 1998, yielded pictures of a larger, male brown palm civet. The male brown palm civets, therefore, seem to exhibit territoriality. Within the home range of the female S84, camera trapping did not reveal the presence of any other individual. However, tracks of a brown palm civet, very small in size, were seen on track plots within her home range. During attempts to recapture S84, a young male weighing 900 g was captured. When the animal was being examined, a larger individual without a collar was sighted close by.

5.4.3 Activity pattern and distance travelled

5.4.3.1 *Activity pattern*

All the six healthy collared civets were distinctly nocturnal in their activity regime, exhibiting about 45% activity (one-zero sampling) over 24 hr. The activity was almost entirely confined to between 1800 h and 0600 h (Figure 5.6), over which period the average percentage of activity was 80% (SE = 1.56) using one-zero sampling, and 31% (SE = 3.17) using instantaneous sampling (Table 5.6). All further analysis was carried out using results from one-zero sampling because instantaneous sampling seemed to underestimate the activity and did not permit classifying different activities.

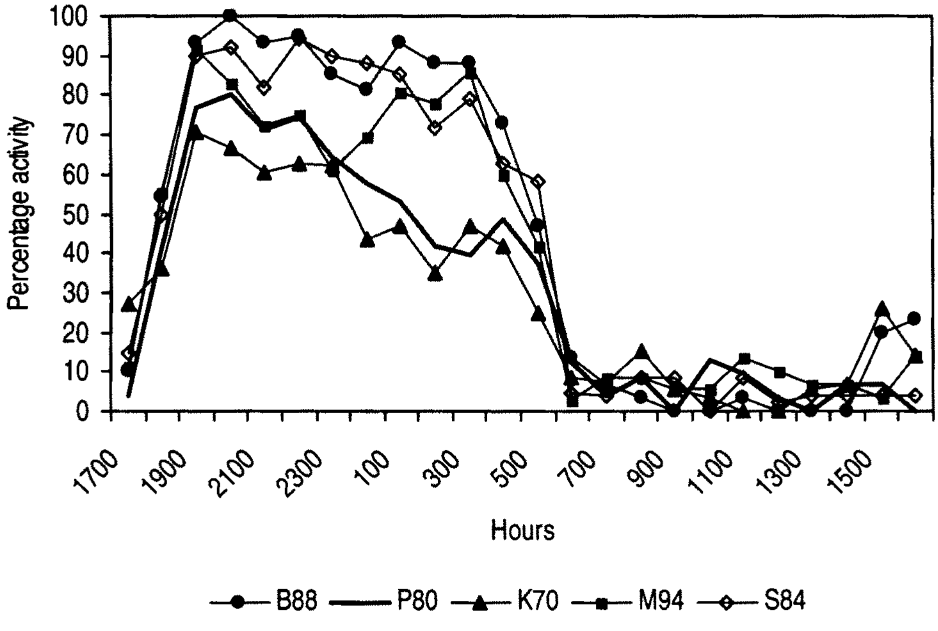


Figure 5.6: Diel activity pattern of radio-collared brown palm civets in Sengaltheri, KMTR.

Table 5.6: Nocturnal activity of the radio-collared brown palm civets as determined by the three different methods (n = number of months, * – 4, # – 8, ** – 10, percentage records with activity is given, SE in parentheses).

ID	n	One-zero	Instantaneous	% Moving	% Feeding	%Grooming
B88	5	84.00 (4.3)	27.30 (2.6)	20.04 (3.7)	54.62 (4.8)	9.30 (2.2)
M94	6	75.63 (3.6)	27.82 (2.3)	18.06 (2.9)	48.50 (3.5)	7.90 (2.1)
P80	5	80.28 (5.5)	43.53 (6.2)*	31.93 (3.2)*	44.75 (3.8)*	4.54 (0.7)*
S84	8	81.94 (3.1)	27.30 (4.5)	24.50 (4.0)	48.08 (4.3)	8.33 (1.5)
K70	9	76.81 (6.8)**	28.44 (7.8)	30.06 (7.3)#	39.24 (5.3)#	5.52 (1.5)

Activity showed a slight decline through the night—the proportion of records with activity was higher in the first four hours after sunset as compared to the first four hours before sunrise, although the activity showed a slight bimodal pattern. The civets spent a little over 50% of the time resting, mostly during the day, although even at night, they were found to exhibit short bouts of resting (20%). On an average, more time was spent foraging (includes feeding, 47%) than moving (25%). Active pulses were occasionally heard during daylight hours and these were probably due to bouts of grooming or repositioning of the animal in its day-bed site. Across months, standardised 100% MCP was significantly (weak) negatively correlated to the diel activity, percentage of records with activity during the night and those recorded as moving (r_S = −0.343, −0.471, and −0.361, n = 42, 46, and 43, P = 0.03, 0.00, and 0.02, respectively). Total home range (100% MCP) was, however, positively and significantly (weak) correlated to the percentage of records resting (r_S = 0.324, n = 46, P = 0.03). The standardised 95% MCP of monthly ranges was negatively correlated only to nocturnal activity (r_S = −0.416, n = 31, P = 0.02).

B88 was the most active, and the sub-adult K70 was the least active during the nights, among the five individuals with normal activity (Table 5.6). The injured female, K82, showed a diametrically opposite activity pattern. She was captured during the day (1030 h). Direct observations and activity monitoring showed that she was active during the day and rested at night (Figure 5.7). K70, the sub-adult male, also had some injuries when he was recaptured. During that period, he became active earlier than usual and was resting during the night (Figure 5.7). He reverted back to normal activity regime towards the end of the tracking period (January 1999).

5.4.3.2 *Distance travelled*

The average distance travelled between successive locations by the collared individuals varied between 93 m (n = 31 locations of BM76) and 273 m (n = 126 locations of M94). It was not significantly correlated to the sampling effort (number of locations obtained; r_S = 0.714, n = 7, P = 0.07), or body size (r_S = 0.667, n = 7, P > 0.10). The average distance travelled was positively and significantly correlated to total

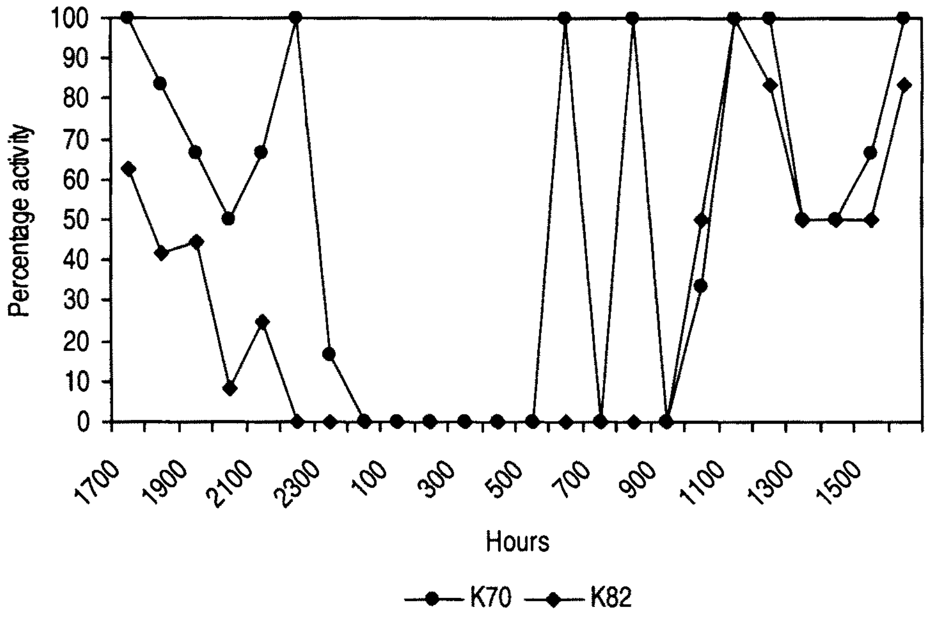


Figure 5.7: Unusual activity patterns exhibited by injured radio-collared brown palm civets in Sengaltheri, KMTR (K70 in Jan 1999, and K82 in May 1998).

home range sizes ($r_S = 0.821$, $n = 7$, $P = 0.02$). The average distance between resting locations was lower than the distance moved during the activity period (144 m, 161 m, and 105 m *vs* 182 m, 172 m, and 130 m, for K70, S84, and P80, respectively), with the exception of the two largest adult males (531 m and 229 m *vs* 501 m and 200 m by B88 and M94, respectively). B88 and K70 moved a greater distance, on an average, during the southwest monsoon period than when the entire tracking period was considered (285 m and 128 m as against 264 m and 125 m, respectively). The others moved slightly shorter distances during the rains (170 m as against 177 m).

5.4.4 Factors influencing home range sizes and activity

5.4.4.1 *Body size*

The inter-individual variation in home range size can be partly attributed to body size. Although not statistically significant ($r_S = 0.541$, $n = 7$, $P > 0.10$), there was a trend towards total home range size increasing with body size (Figure 5.8). The pattern was obscured due to the small range sizes of the two adults P80 and K82, and the larger than expected range size of the adult male B88 that exhibited a home range shift during the study (Figure 5.5, described in detail later in the text).

5.4.4.2 *Habitat quality*

Point centred quarter (PCQ) estimate of tree and food tree densities and basal area within the home range of each individual is given in Figures 5.9a and b. Total tree species richness was positively

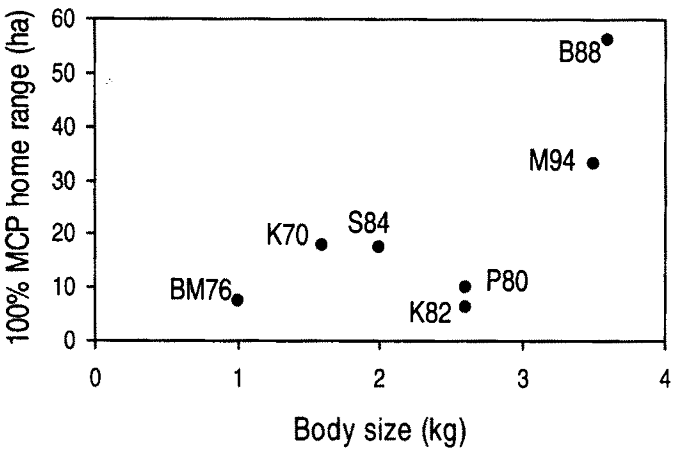


Figure 5.8: Relationship between body size and total home range size of brown palm civets in Sengaltheri, KMTR.

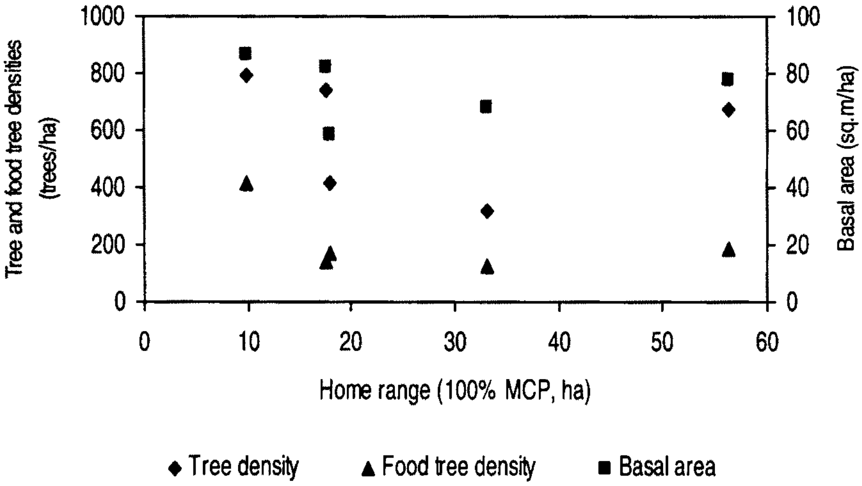


Figure 5.9a: Habitat quality in relation to the home ranges of the radio-collared brown palm civets in Sengaltheri, KMTR.

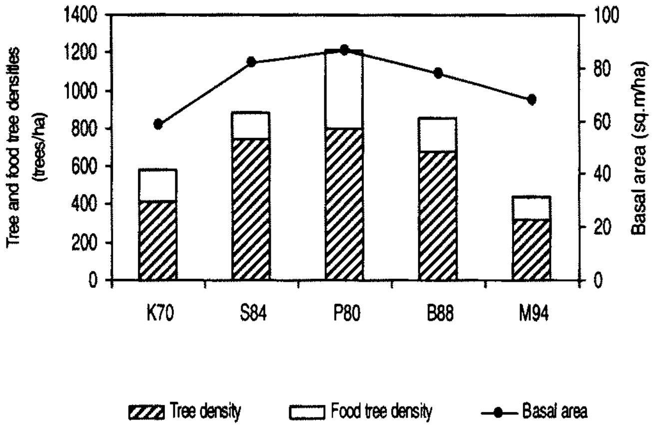


Figure 5.9b: Habitat quality in relation to the body size (increasing order) of the radio-collared brown palm civets in Sengaltheri, KMTR.

correlated with all the various home range estimates (overall, activity, resting and southwest monsoon; $r_S = 0.80$ for all, $n = 5$, $P < 0.10$), although it was not statistically significant.

The adult male (P80) with the smallest home range (9.86 ha) had the highest density of both food species and non-food tree species. The adult male with the second largest home range (M94, HR=33.2 ha), had the lowest food and non-food tree densities. However, it was compensated by trees of larger girth (basal area = 80 m^2/ha), which would reflect larger fruit crops and better canopy contiguity. The sub-adult (K70), which had a larger home range than the two adults (S84 and P80), was using a rather poor habitat in terms of tree density, but with slightly higher food tree density than in the range of S84 (Figure 5.9a, b). Therefore, it is likely that abundance of food tree species is one of the habitat factors determining the home range sizes of brown palm civets.

5.4.4.3 *Food resource availability*

In the study area, food availability showed considerable monthly and annual variation (Chapter 4). The highest number of food species available in 1998 was in August, and in 1999, in April. The number of food species producing ripe fruits was higher in the latter half of both the years (Figure 5.10). The months with the highest number of individual trees with ripe fruits were December in 1998, and March in 1999, and highest food abundance score was in October in 1998 and May in 1999 (Chapter 4, Figure 5.10).

The standardised 100% MCP and 95% MCP of monthly ranges were not significantly correlated to any of the three indices of food availability ($r_S < 0.063$ for species, individuals, and abundance score, $n = 50$, $P > 0.1$). M94 was the only individual whose home range size showed a significantly negative relation with the abundance score ($r_S = -0.764$, $n = 7$, $P < 0.05$). Neither different estimates of the home range areas nor the average distance moved by the individuals were significantly correlated to rainfall or the food availability indices. Percent feeding activity was significantly positively correlated to the average distance moved and food availability ($r_S = 0.505, 0.445, 0.510, 0.609$ for distance, species, individuals, and abundance score, respectively, $n = 41$, $P < 0.005$). The monthly percentage of records with moving as activity was significantly negatively correlated to average distance travelled, individuals with ripe fruits and abundance scores ($r_S = -0.435, -0.539$ and -0.610, respectively, $n = 43$, $P < 0.005$).

5.4.5 Day-bed site choice

All day-beds of brown palm civets located, with the exception of one, were on trees ($n = 60$). The civets used four kinds of substrate to roost in during the day: nests or dreys of Malabar giant squirrel (*Ratufa indica*), tree hollows, tree notches, and vine tangles. Dreys and tree hollows were most commonly used (Figure 5.11). The only resting site on the ground was in a patch of grassland, under a rock ledge. This was used by K70, who had suffered some injuries and was eventually predated by a python. Only one of

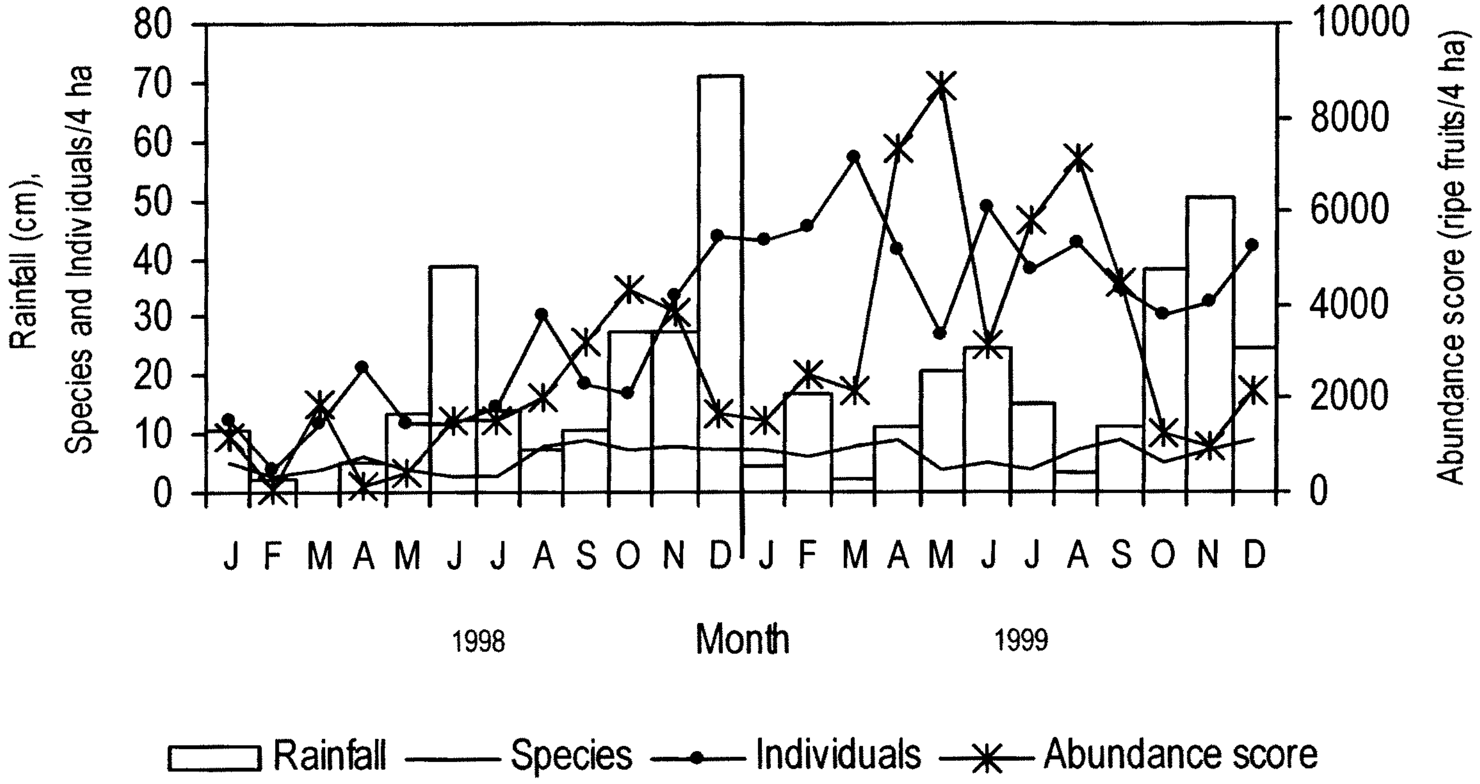


Figure 5.10: Phenological pattern of ripe fruit production, and rainfall in Sengaltheri, KMTR, between 1998 and 1999 — Indices of food availability for the brown palm civets.

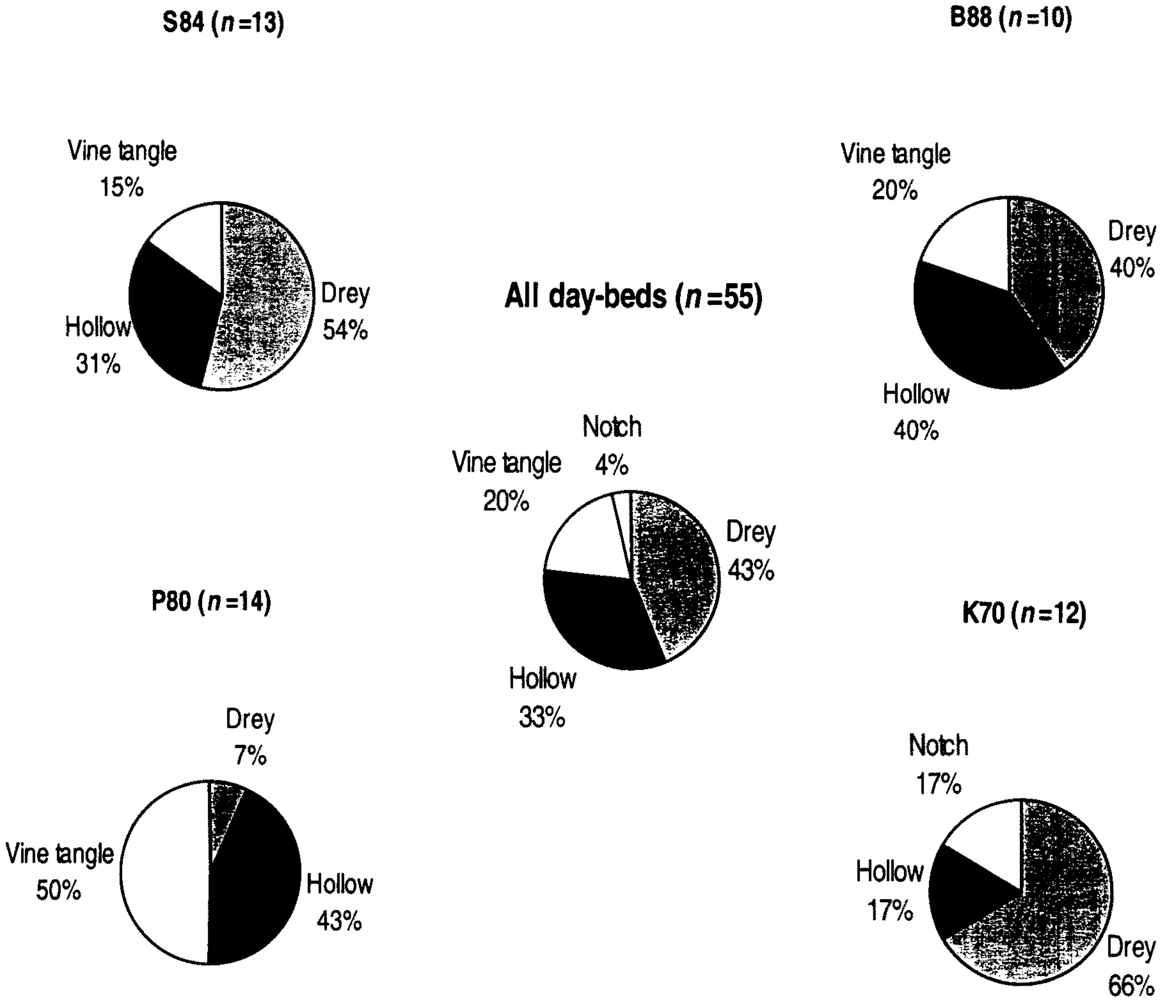


Figure 5.11: Day-beds used by the radio-collared brown palm civets in Sengaltheri, KMTR.

the collared individuals (K70) reused particular day-bed sites from 2 to 20 days continuously before shifting to another site. He also reused some of the sites intermittently. The other individuals rarely reused day-beds. During the night, the civets were found to exhibit short bouts of resting. On these occasions ($n = 3$), they were found resting on open branches.

Of the nine characteristics of the day-bedding site that were quantified and compared with those of the random sites using Mann-Whitney *U* tests, seven were significantly different at $P < 0.005$ and one at $P < 0.10$ ($n = 50$ day-bed sites and 70 random; Table 5.7). Moreover, a majority of the random trees (63 of 80 trees sampled) did not have any of the substrates that the civets were found to use commonly. Notches between branches, although likely to be present on all the trees, were not a commonly used day-bed substrate. There was a significant difference in the use and availability of the types of day-beds (squirrel nests, vine tangles, hollows; $G = 301.99$, $df = 3$, $P < 0.001$). Among random trees, 21% (17) had squirrel nests, vine tangles, or hollows, with the last two found more often than the former. In contrast, a majority of day-beds were Malabar giant squirrel nests (43%) or hollows (33%). Only two day-beds were in dead or partially dead trees.

Table 5.7: Comparison of the day-bed and random site characteristics of the brown palm civet in KMTR (Mann-Whitney *U* test, *n* = 50 and 79, respectively).

Variable	**Mean (± SE)**		**Mann-Whitney U (Z)**	***P***
	Random	**Day-bed**		
Girth at breast height (cm)	136 (±9.8)	233.2 (±16.2)	948 (–4.965)	0.000
Height of tree (m)	20.36 (±0.53)	22.0 (±0.57)	1338.5 (–3.091)	0.002
Height of first branch (m)	9.9 (±0.4)	10.9 (±0.70)	1824 (–0.732)	0.464
Canopy cover (%)	97.09 (±0.25)	96.52 (±0.34)	1622 (–1.708)	0.088
Canopy contiguity (number of directions with overlapping canopy)	3.79 (±0.23)	5.36 (±0.21)	1036 (–4.604)	0.000
No. of overlapping trees	3.21 (0.2)	5.0 (0.29)	1076.5 (–4.394)	0.000
No. of overlapping lianas	0.89 (0.29)	1.22 (0.17)	1406 (–3.126)	0.002
No. of trees > 20 cm girth/0.008 ha	7.33 (0.33)	9.6 (0.58)	1337.5 (–3.099)	0.002
No. of trees > 30 cm girth/0.008 ha	3.81 (0.19)	5.43 (0.33)	1172.5 (–3.932)	0.000

The branching patterns were significantly different between the day-bed trees and random trees ($G = 23.58$, $df = 5$, $P < 0.001$), with 71.15% of the day-bed trees with horizontal or horizontal-oblique primary branches in contrast to 57.5% with the same kind of branching pattern in the random trees. The canopy shape did not differ between the two ($G = 3.52$, $df = 3$, $P > 0.05$); semicircular canopy was the most predominant shape in both the random and day-bed trees. A significantly higher percent (51.92%) of day-bed trees had climbers growing on the main trunk, while less than 35% of random trees had climbers on them ($G = 7.23$, $df = 1$, $P < 0.01$). Logistic regression correctly classified about 75% of the day-bed and random sites. The variables that were selected as good predictors of day-bed sites were the girth at breast height (GBH) of the trees, canopy cover, canopy contiguity, and number of large trees in the sites (Table 5.8).

Table 5.8: The values of the variables selected to classify the brown palm civet day-bed and random trees: results of logistic regression.

Variable	**B**	**S. E.**	***P***
Girth at breast height	0.0072	0.0023	0.0014
Canopy cover	–0.2391	0.1011	0.0180
Canopy contiguity	0.4941	0.1462	0.0007
Large trees	0.3563	0.1404	0.0112
Constant	17.5668	9.5352	0.0654

5.5 DISCUSSION

5.5.1 Capture and immobilisation

Pre-baiting increased the probability of capture of the target species, the brown palm civet. It also seemed that the animals were not very agitated when captured, probably due to habituation to the trap. The dosage of 15:1.5 mg/kg body weight of ketamine (KE) and xylazine (XY) was found to be effective for successful immobilisation of wild brown palm civets. No fatal or other adverse effects were observed during the capture and immobilisation exercise. A mixture of KE and XY has been used in immobilisation of carnivores in the past. The dosage used varied from 5 mg of KE/kg and 1 mg of XY/kg body weight of racoons *Procyon lotor* (Deresienski and Rupprecht 1989), 4.2 mg of KE/kg and 6.5 mg of XY/kg in Egyptian mongoose *Herpestes ichneumon* (Palomares and Delibes 1992a), and 1.4–1.9 mg of KE/kg and 1.9–2.4 mg of XY/kg in African wild dogs *Lycaon pictus* (Osofsky *et al.* 1996). In these studies, the proportion of XY was lower or higher than reported here. The modified ratio of KE and XY mixture used in this study was based on trials on captive common palm civets and small Indian civets (*Viverricula indica*) and free-ranging common grey mongooses (*Herpestes edwardsii*) in India (R. Chellam, N. V. K. Ashraf, and R. Anand *personal communication*). Revival drug (yohimbine hydrochloride) was not used, as the immobilised animals did not exhibit any adverse responses to the XY and recovered from immobilisation gradually.

Although XY has been reported to decrease body temperature and respiration rate (Seal and Kreeger 1987), no consistent reductions in respiration rates were observed in this study, probably due to the small dosage of XY. A combination of KE and XY is known to counteract the adverse effects observed, if administered individually (Deresienski and Rupprecht 1989). The dosage of KE was comparable to that administered to viverrids in Africa (Maddock 1989). Therefore administration of KE and XY in combination seems to be safe and effective in the immobilisation of free-ranging brown palm civets.

5.5.2 Home range size

Body size, sex, resource availability, and habitat quality are some of the parameters that have been shown to influence the home range sizes in animals, particularly the carnivores (Sandell 1989). Body size and sex influence home range sizes, with larger and/or male individuals ranging over larger areas (Gittleman and Harvey 1982, Sandell 1989, Jędrzejewska and Jędrzejewski 1998). In conditions of greater resource availability and undisturbed habitats, animals tend to use smaller areas. However, social systems also have a major role to play in determining the home range use and territoriality, with males encompassing the ranges of more than one female. Individual variability in ranging and movement patterns are described in Appendix 3.

The brown palm civets ranged over areas between 3.6 ha and 51 ha (95% Minimum Convex Polygon, MCP, Figure 5.2, Table 5.4), over the period of tracking as given in Table 5.1. This is considerably smaller than the 1.1 km^2–17 km^2 reported for similar-sized civets in south and southeast Asia (Rabinowitz 1991, Grassman 1998, Kumar and Umapathy 2000). The mean monthly home range of 6.72 ha (range 0.35 – 29.58 ha) is also small compared to that of the common palm civet *Paradoxurus hermaphroditus* in Nepal and Borneo (14.1 ha and 23 ha, respectively, Joshi *et al.* 1995, Yoneda *et al.* 1998b). The small home ranges observed for the brown palm civets in this study can probably be attributed to the resource-rich habitat (tropical rainforest) that they inhabit. This region has an almost year-round food availability for this highly frugivorous species (Chapter 3). Since this species is predominantly frugivorous, its ranging behaviour can be compared only with species of similar habits, and is not suitable for comparison with more carnivorous mustelids, herpestids, and felids, even though they may be of similar body size.

The largest brown palm civet monitored (B88), an adult male, had the largest home range of 57 ha (Figure 5.2). In addition to the influence of body size, his larger home range could partly be attributed to a range shift in August 1998. Body size alone does not account for differences in home range size among individuals. The sub-adult male, K70, had a larger home range (18 ha) than two larger adults, the male P80 (9.7 ha) and the female S84 (12 ha; Figure 5.2). The larger home range size of K70 may have been a consequence of him occupying a more disturbed and poorer habitat patch than the others. The range of M94 was the second largest and can be attributed to his sex, size, and also the poorer habitat quality (Figure 5.9a, b).

Most carnivores are territorial, and actively defend territories against conspecifics either for food resources or (during the mating season) for mates (Lockie 1966). They also use scent marking and defecation to mark territories (Palomares 1993c). This could be particularly true for the more carnivorous of the species. The civets, particularly the members of the sub-family Paradoxurinae, comprising the palm civets, also possess scent glands, and may use them in territorial scent marking (Ewer 1998). Moreover, they are frugivorous, and the patchy distribution of their food plants and seasonality in the fruit abundance is likely to influence their ranging, movements, and territoriality. Patchy or clumped distribution of food resources has resulted in non-territorial behaviour in the common palm civets in Nepal (Joshi *et al.* 1995). Data from this study suggest territoriality in brown palm civets, particularly among males. Like in other carnivores, the home range of a male (B88) which exhibited a shift in his range, overlapped almost completely the range of an adult female (S84). This shift and large overlap might have been influenced by reasons other than the occurrence of other individuals or food resources in the vicinity (see Sandell 1989).

5.5.3 Activity pattern

Radio-collared brown palm civets showed a predominantly nocturnal activity regime, with injured animals becoming diurnal probably to avoid aggression from conspecifics. Shift in activity pattern (nocturnal to diurnal) seems to occur among injured/sick animals consistently. Other studies on civets also match this species in its general activity pattern (Rabinowitz 1991, Grassman 1998). Rabinowitz (1991) observed an increase in activity during the wet season despite a reduction in home range sizes, while Grassman (1998) noted an opposite trend. No consistent monthly trends were seen across individuals during this study, which may be because the habitat structure and food availability varied within each individual's home range.

In times of greater availability of fruits, the percent of records with moving activity was lesser while the distance travelled was greater. However, the civets spent more time foraging and feeding. Distance travelled was directly correlated to food availability, but inversely related to the percent of moving activity records. This could imply that the animals had to move longer distances between food resource patches, which can be supported by the food tree distribution that was observed in the study site (Chapter 4). However, when in a patch with abundant food resources, the civets seemed to be maximising their foraging and feeding, and moving less. This implies that food availability determined the distance moved by the civets, and most of the time spent was on feeding.

The bimodal activity can be explained by the increase in feeding bouts and movement to food patches just after dusk, and movement towards day-beds just before dawn. Many species have been shown to be bimodal, by being most active immediately after they come out of their resting sites and just before they get back into them (Rabinowitz 1991). Joshi *et al.* (1995) reported the civets to day-bed in suitable sites close to the food patches. However, in this study, there were probably preferred resting sites, as indicated by the smaller resting ranges than the activity ranges for most individuals, due to which the civets went back to those sites after the feeding and other activities at night. The percentage of activity recorded during this study is more or less similar to that of other small carnivores (Rabinowitz 1991, Palomares and Delibes 1992c, 1994; Ray 1997, S. C. Austin *unpublished* ms), which have been shown to be active between 40% and 55% of the time. Activity as shown by other studies are likely to be affected by the abundance of food, temperature and climate (Rabinowitz 1991, Joshi *et al.* 1995). Palomares and Delibes (1994) have, however, shown body mass and distance moved to be highly positively correlated to percent activity.

The activity observed in the brown palm civets is not strictly comparable to other small carnivore studies, as the methods and analyses used by them are not given explicitly in the published literature. Instantaneous sampling, although apparently the most commonly used method, may underestimate activity. This is because, even an individual involved in a clear bout of activity such as feeding, may by chance produce an inactive pulse on the instantaneous/sampling second and be labelled as inactive. While the one-zero sampling followed in this study does probably overestimate the amount of activity in brown palm civets, it enabled further classification of the kind of activity the animals engaged in. This classification could be reliably used to correlate activity to food availability and other factors, and therefore provide a better understanding of the ecological implications of their activity rhythm.

5.5.4 Factors influencing home range and activity

Body size had a positive influence on home range sizes, activity, and average distance moved. Part of the differences in the home range sizes could be attributed to the differences in the quality of the habitats occupied by various individuals, although food tree abundance *per se* did not seem to directly influence the trend. Food availability did not significantly influence the home range sizes (except for M94), but did suggest a positive correlation with the amount of time spent feeding and foraging. Rainfall did not strongly influence either the home range sizes or the activity patterns of the radio-collared brown palm civets.

Rabinowitz (1991) observed the animals to shift home range centres from resource poor habitat (dry deciduous dipterocarp forests) to mixed deciduous forests in times of low fruit availability. Other natural disturbances like fire and floods are also likely to influence home range sizes, activity centres, and activity patterns. During times of low food availability, some large and small carnivores have been shown to exhibit a shift in their dietary habits from frugivory to insectivory and carnivory. Even during months of low food availability and abundance, the brown palm civets did not show changes in their ranging pattern, but consumed a greater variety of fruits as well as more invertebrates (Chapter 3).

5.5.5 Day-bed choice

It is evident from the inactivity or resting ranges being smaller than the total or activity range that the animals prefer some parts of their home ranges to rest in during the day. Being an arboreal species, they not only forage on the trees, but also rest on them, both during the day as well as at night. They seem to exhibit a clear preference for the nests of the Malabar giant squirrel. This is the first report of the use of squirrel nests as rest sites among the tropical small carnivores. There is evidence of pine marten (*Martes martes*), a mustelid, using squirrel nests in the temperate forests of Poland (Zalewski 1997). Despite the relatively more frequent presence of tree hollows in the study area, they were probably not suitable in terms of inner dimensions for use by the brown palm civets. The higher frequency of reuse of some of the sites by K70 is probably a reflection of the poorer *quality* of the habitat patch he ranged in, and the relative paucity of suitable day-bed sites.

5.6 SUMMARY

1. Pre-baiting for capturing using Havahart live-animal traps, and a dosage of 15:1.5 mg/kg body weight of a mixture of ketamine and xylazine were found to be useful methods for successful capturing, immobilisation, and radio-collaring of brown palm civets.
2. The brown palm civets were found to range over areas of 6 ha to 57 ha (100% MCP estimate). Among the small carnivores studied thus far, this species seems to have the smallest ranges. Body size was only weakly positively related to home range sizes. Civets seem to have a choice of resting areas within their ranges. A combination of habitat characteristics that ensures a year-round resource availability probably influences the home range sizes of this species. The individual with the smallest home range (P80) also had the highest tree and food tree densities within its range. Similarly, the sub-adult male (K70), which ranged over a larger area than expected, was using a poorer habitat in terms of tree density. One of the individuals (B88) exhibited a shift in its range, and it seems likely that factors other than habitat quality influenced this observed shift. The monthly ranges were weakly influenced by food availability.
3. The brown palm civets were strictly nocturnal in their activity rhythm. The injured animals exhibited a shift to diurnal activity. Activity pattern was not significantly influenced by body size, age, or sex. This could however be due to the small sample sizes. There seemed to be a significant increase in foraging and feeding activity in times of greater food availability. The distance travelled was inversely proportional to food availability, probably indicating patchy distribution of food resources. Activity was, however, not directly influenced by rainfall.
4. The brown palm civets day-bedded on trees. They predominantly used the nests of the Malabar giant squirrels, vine tangles, tree hollows, and notches. The day-bedding trees were larger (GBH), and taller (height) than the random trees. These trees also had greater canopy contiguity and number of overlapping trees and lianas than the random trees. The number of large trees in the plot was also higher at day-bed sites.
5. Although the brown palm civets seem to have relatively smaller area requirements, it is necessary that these areas have high tree and food tree densities. Canopy contiguity is also an important feature of the brown palm civet habitat. These characteristics of their ecology and area requirements have to be taken into account while planning their conservation, particularly in disturbed and degraded rainforest habitats.

CHAPTER 6

RAINFOREST FRAGMENTATION AND SMALL CARNIVORES IN THE SOUTHERN WESTERN GHATS

6.1 INTRODUCTION

6.1.1 Diversity, distribution, and disturbance

In India, the distribution and conservation status of small carnivores is inadequately known. Within India, the Western Ghats is one of the *hotspots* or high diversity areas for many plant and animal taxa (Myers *et al.* 2000), including the small carnivores. The Western Ghats is one of the hotspots with the highest human population density (Cincotta *et al.* 2000), and continues to suffer large-scale habitat degradation and fragmentation (Menon and Bawa 1997). Very little was known of the effects of this large-scale habitat alteration in the form of fragmentation on the plant and animal community composition and also species persistence (particularly that of endemics and habitat specialists), until a few recent studies (Prabhakar 1998, Umapathy and Kumar 2000, Vasudevan 2000, Ishwar 2001). This is the first study examining the impact of rainforest fragmentation on small carnivores in India.

Tropical rainforests contain diverse carnivore assemblages that are structured by the diversity and abundance of prey, and also by the presence of insects and fruits, which are highly abundant or renewable resources like insects and fruits (Rabinowitz and Walker 1991, Ray and Sunquist 2001, Chapter 4). Most carnivores are widely distributed, but occur in intrinsically low densities in most regions (Voss and Emmons 1996). Many carnivores, particularly those with large body-size and area requirements (Terborgh 1974), or those with specialised habits (Laurance 1990) are vulnerable to habitat loss, disturbance, and fragmentation (Johns 1983, 1988, Laurance 1997). Small carnivores, a majority of which are of generalist habits are, however, usually positively affected by moderate disturbance (Johns 1983, Oehler and Litvaitis 1996). However, these carnivores play significant roles in the habitat as predators, prey, and seed dispersers (Herrera 1989, Rabinowitz 1991, Chapter 3), and therefore fragmentation may affect the dynamics of the ecosystems when the carnivore community is altered or disturbed (Crooks and Soulé 1999).

Despite the recognition of the importance of carnivores in the ecosystem, an understanding of their roles and the correlates of their persistence or disappearance following habitat changes is lacking. Although there have been a few detailed studies of small carnivores in

South and South-east Asia (Joshi *et al.* 1995, Rabinowitz 1990, 1991, Grassman 1998, Kumar and Umapathy 2000), few examine distribution-abundance patterns in the face of habitat alteration. Heydon and Bulloh (1996) specifically studied the impact of logging on civets in Borneo, where they found them to persist, albeit in lower abundances, in selectively logged forests.

Habitat loss and fragmentation are major threats facing many wildlife areas (Whitmore 1997). Studies on rainforest habitat fragmentation in many tropical countries have shown area to be a major factor influencing changes in plant and animal occurrences and densities (Lovejoy *et al.* 1986, Laurance 1994, Struhsaker 1997, Laurance *et al.* 1998, Laidlaw 2000, Umapathy and Kumar 2000), however, small, isolated forest fragments are also repositories of tropical biodiversity (Turner and Corlett 1996). Species that are particularly negatively impacted are those with specialised habitat requirements and/or those with large home-ranges (Laurance 1990, Chiarello 1999). The persistence of a species is also dependent on its ability to use modified habitats (Laurance 1991, Lindenmayer and Lacy 1995, Goosem and Marsh 1997, Medellín and Equihua 1998). Species-rich groups such as butterflies and non-volant mammals, are more sensitive to the surrounding matrix (Bierregaard *et al.* 1992, Hill *et al.* 1995). In contrast, many species of frugivorous and folivorous birds and mammals may increase in abundance due to the increase in some food resources associated with the openness of the habitat following disturbances (Leighton and Leighton 1983, Johns 1988, Struhsaker 1997, Umapathy and Kumar 2000). Disturbed rainforest fragments are also highly susceptible to invasions by the more widespread and generalist species at the cost of the restricted endemics and specialists, altering the composition of the community (Palomares *et al.* 1995, Oehler and Litvaitis 1996, Travaini *et al.* 1997, Kurki *et al.* 1998, Suarez *et al.* 1998, Crooks and Soulé 1999).

6.1.2 Surveying small carnivore populations

An understanding of the basic ecological requirements of a species enables one to assess the impact of habitat changes on its distribution and abundance. Having studied the area, habitat, and food requirements of brown palm civets in a relatively undisturbed site (KMTR, Chapters 3, 4, and 5), I attempted to assess the impact of rainforest fragmentation in Anamalais on them. As the Western Ghats contain a species-rich carnivore community, I also tried to assess the direction of change in the small carnivore community in the fragmented landscape in Anamalais, in comparison with relative abundances of these species in KMTR.

Most small carnivores are rare, nocturnal, solitary animals, often inhabiting areas where detection is difficult because of dense vegetation. As a consequence, assessments of their occurrence and abundance, based on direct sightings are difficult or almost impossible. Indirect signs such as scats may help to establish occurrences of small carnivores, but is unreliable due to the difficulties in accurately identifying scats of all species. Attempts to identify small carnivore (particularly viverrid) scats to species level using thin layer chromatography (TLC) of extracts of bile acids from the scats, have not been successful (A. Kumar *personal communication*, and *personal observation*). Quinn and Jackman (1994) have also shown that the presence of bile acid in the faeces is highly dependent on a carnivorous diet and therefore, with most viverrids being omnivorous, and the palm civets being predominantly frugivorous, TLC may not be a reliable method for identifying scats to the species level. Local people living in the species' habitats do not sight many of the small carnivores, and thus even cursory knowledge of the natural history of these taxa is scanty. An assessment of the occurrence, distribution, and abundance of these small carnivores therefore remains a daunting task, especially when the community is species-rich. Such studies may require the use of a combination of methods because the behaviour, responses, and abundances vary among species (Raphael and Barrett 1981, Zielinski and Kucera 1995, Zielinski and Stauffer 1996, Foresman and Pearson 1998).

Many field methods have been used and tested to survey large mammals and birds in terrestrial environments (Verner 1985, Bibby *et al.* 1992, Karanth and Sunquist 1992, Buckland *et al.* 1993, Caro 1999). Surveys of cryptic small carnivores, however, face several methodological and logistical difficulties. In addition, rapid short-term surveys encounter problems such as the limitation of time, failure to detect rare or cryptic species, or often so few sightings that little meaningful interpretation of the data is possible. In recent years, survey methods have been established for temperate small carnivores (Zielinski and Kucera 1995), and methods to interpret presence-absence data have also been suggested (Zielinski and Kucera 1995, Sargeant *et al.* 1998, Foresman and Pearson 1998, Stander 1998, Carroll *et al.* 1999, Strayer 1999). However, there is still a gaping lacuna in our knowledge about small carnivores in tropical forests.

Here, I discuss the results of the surveys carried out using a combination of methods, in order to assess the extent and nature of change in the occurrence and relative abundance of the small carnivores in two major and contrasting rainforest landscapes in the southern Western

Ghats. The two regions were the relatively undisturbed rainforests of Kalakad-Mundanthurai Tiger Reserve (KMTR) and the fragmented rainforests of the Anamalai hills.

6.2 OBJECTIVES

In this chapter, the following questions regarding the distribution and relative abundance of small carnivores are dealt with:

a. What is the community composition of small carnivores in the relatively undisturbed rainforests of KMTR? What are their relative abundances?
b. What is the extent and nature of change in the relative abundances of small carnivores in the fragmented rainforests of the Anamalai hills?
c. What is the distribution of the brown palm civets in the fragmented landscape of Anamalais?
d. How are differences in habitat structure related to the size and disturbance of the fragments?
e. What are the habitat and site correlates that determine the occurrences of small carnivores in a fragmented landscape?

6.3 MATERIALS AND METHODS

6.3.1 Study species

The Western Ghats hill ranges in south-western India have at least 17 species of small carnivores (excluding members of the Family Canidae but including Felidae), of which eight are found in tropical rainforest habitats (Mudappa 1998, Yoganand and Kumar 1999). They are the small Indian and the brown palm civets, the stripe-necked and the brown mongooses, and the leopard cat. The Family Mustelidae is represented by the endemic Nilgiri marten, the small-clawed and the common otters. The otters represent the aquatic small carnivores in the rainforests. The brown palm civet and the Nilgiri marten are endemic to the Western Ghats at the specific level, while the stripe-necked and the brown mongooses are endemic at the sub-species level (these species being also found in Sri Lanka, Chapter 1).

6.3.2 Study sites

In KMTR, in an area of about 250 km^2, four sites were selected, ranging in altitude from 650 m to 1300 m asl. The sites were Kannikatti (650 – 1000 m), Koovapatti (750 – 850 m), Sengaltheri (800

– 1250 m), and Kakachi (1200 – 1300 m). The three sites, excepting Koovapatti, are rainforests. Koovapatti is a small strip of riverine forest, extending from the Sengaltheri forests into the wooded grasslands. These four sites were surveyed between June 1996 and August 1999. The Mundanthurai plateau (around 8° 40' 45" N, 77° 20' 59" E), containing dry deciduous and riparian forest types that are contiguous with the Kannikatti rainforests, was also sampled in order to document the species occurring in dry deciduous forests adjacent to rainforests.

In Anamalais, ten rainforest fragments of varying sizes (8 ha to 2500 ha) and disturbance regimes were sampled between January and May 2000. For some analyses, the fragments were pooled into size classes as (1) small, ≤ 25 ha; (2) medium, 26 – 199 ha; (3) large, 200 – 499 ha; and (4) very large, ≥ 500 ha. Some preliminary analysis indicated that most vegetation parameters were not good indicators of the disturbance levels in the fragments, as the disturbances were many, and the resilience of the fragments and vegetation differed based on factors such as area, distance to human settlements, and streams, as also shown by the long-term studies in Kibale (Struhsaker 1997). Most of the large fragments were protected as part of the Indira Gandhi Wildlife Sanctuary by the Tamil Nadu Forest Department, while the small- and medium-sized fragments were under private ownership.

6.3.3 Survey methods

6.3.3.1 *Track plots*

The small carnivores in KMTR and Anamalais were surveyed using a combination of methods—a) track plots, b) camera trapping, and c) incidental observations and direct sightings. Track plots were laid by clearing the leaf litter from the forest floor in an area of about 1 m x 0.75 m. Fine soil was sprinkled over this region, and a combination of baits (banana, dry fish, meat scraps, and carnivore lure) was placed on the track plot. These were usually set along existing forest trails or beside streams. In the undisturbed forests (KMTR), track plots were also used to determine the presence of the target species and therefore baiting was continued for a maximum of 15 days, or until the bait was eaten by a small carnivore. In KMTR, the track plots were set for a period of 24 hr and checked for tracks once—usually in the morning—before resetting. In the Anamalais, the number of track plots laid was relative to the size of the fragments. They were set up in the evenings and checked 12 – 14 hours later (in the mornings), as the plots were likely to be disturbed due to daytime human activity within these fragments. As most of the target species were nocturnal, this sampling strategy was not likely to affect the results. The track plots were run for only one night in one station. The distribution of sampling effort in the fragments is given in Table 6.1.

Table 6.1: List of rainforest fragments sampled in Anamalais, their attributes, and effort in each (size class in parentheses: VL – very large, L – large, M – medium, and S – small).

	Fragment name	Area (ha)	Altitude (m)	Matrix*	Disturbance level	Camera -trap nights	Track plot nights	Hours spent
1	Akkamalai-Iyerpadi Complex	2500 (VL)	1250-1500	T, G, SF	Low	15	60	28h 45m
2	Varagaliar	2000 (VL)	650-800	DD	Low	15	20	8h 20m
3	Andiparai	200 (L)	1250	T, SF	Medium	10	30	13h 45m
4	Manamboli	200 (L)	800	T, C, DD	Low	10	30	12h 05m
5	Karian Shola	500 (L)	750	B, DD	Low	10	30	16h 15m
6	Korangumudi	50 (M)	1000	C, T, H, R	High	10	30	10h 55m
7	Puthuthottam	100 (M)	1000	T, C, H, E	High	10	30	16h 50m
8	Varattuparai	8 (S)	1100	T, C, SF, R	High	5	20	9h 35m
9	Tata Finley	25 (S)	1000	C, T, E, H, R	High	5	25	10h 35m
10	Pannimade	10 (S)	1100	C, T, R	Low	5	20	11h 15m

* T – tea plantation, G – grasslands, SF – secondary forests, DD – dry deciduous forest, C – coffee plantation, B – Bamboo, R – reservoir, H – human habitation, E – eucalyptus plantation

The tracks on the plots were distinguished as those of 1) brown palm civet, if they were plantigrade prints with five digits clearly visible, 2) small Indian civet, if there were imprints with four digits only, 3) small Indian civet or brown mongoose, if the prints had four digits and occasionally claw marks, and 4) unidentified small carnivore, when the tracks were clearly that of a small carnivore based on the shape and size, but could not be distinguished further.

6.3.3.2 *Camera-trapping*

Each camera-trap consisted of a fixed-focus 32 mm Yashica camera (with electronic shutter release, flash, and auto-winder), and a pressure pad. The pressure pad consisted of two sheets of aluminium foil (30 cm x 45 cm) separated by a 0.5 cm thick sponge (foam) with several perforations, and enclosed in a water-proof air pillow. The aluminium foil was connected by a thin cable of about 2 m length to the electronic shutter release. The circuit was completed between aluminium foil layers as they came into contact through the perforations when an animal stepped on the pad. Ten camera-traps were used in the study.

The cameras were placed a minimum of 250 m from each other on existing forest trails, or near streams or fruiting trees, where there was spoor of small carnivores. The pressure pad was placed on the ground and covered with a thin layer of soil and baited with banana, dates and chicken scraps, and occasionally dry fish and wild fruits. Commercial lure for carnivores (Cat Passion, Weasel Lure, Feline Essence, or Skunk and Opossum Lure) was used on many occasions.

Table 6.2: Details of camera-trapping efforts between October 1996 and March 1997 in four sites in KMTR.

Sites	Stations	Trap-days	Trap-days with lure	Trapping success (%)
Kakachi	5	19	19	73.7
Sengaltheri	23	44	38	40.9
Kannikatti	13	34	13	20.6
Koovapatti	8	15	15	20.0

In KMTR, a camera-trap was run for a period of 1 to 9 days at one station. Traps were checked every morning, and the frame number, presence of tracks, use of bait, and any other indication of a small carnivore or another animal's visit were recorded. The traps were kept functional through the day and night in KMTR. Camera-trapping was carried out between October 1996 and March 1997 (Table 6.2), in order to make a preliminary assessment of the occurrence and distribution of small carnivores in the contiguous, undisturbed rainforests of KMTR, prior to the radio-telemetry study. It was carried out intermittently during the entire study period also (August 1996 to December 1999) to: 1) assess the distribution of the brown palm civet and the other small carnivores in various vegetation types and altitudes, 2) to identify or confirm the species visiting the track plots before capture for the radio-telemetry study, and 3) later, to determine whether other individuals occurred within the home-ranges of collared civets, in order to assess territoriality.

In the Anamalais, camera-trapping effort varied in accordance with the size of the fragments (Table 6.1). The camera-trapping was used to assess the occurrence of nocturnal small carnivores, and the cameras were therefore set up in the evenings and checked in the mornings. Each camera-trap was set at a new station every night. Camera-traps were set only at night as there was much human movement and activity involving fuel-wood collection and livestock grazing in the fragments during the day.

6.3.3.3 *Direct sightings: night walks, drives, and opportunistic sightings*

Night walks were carried out both in KMTR and in the Anamalais. During these night walks, 1.5 km were covered on an average through rainforests at a moderately slow pace. The understorey and the canopy were scanned and searched for eye shine or movements using spotlights (Novino 4-celled torches and Britelite Submersible Pro 5000 Series flashlight).

In Kakachi in KMTR, and the Valparai plateau in the Anamalais, surveys were also carried out at nights using a vehicle to avail of the available network of roads. All sightings of animals and parameters such as habitat type (as the roads passed through plantations also), and distance to the nearest rainforest, where relevant, were also noted.

In order to collate information on small carnivores in KMTR, all sightings by the research group (four researchers, including the author, and one trained assistant) during the study period (June 1996 – December 1999) were pooled together. All the small carnivores sighted by the author during drives and walks by night and day in the Anamalais (January 2000 – May 2000) are reported. For Anamalais, sighting records by research colleagues, even outside the study/survey period have been used to prepare the small carnivore species list of each fragment.

The effort was calculated as the total time spent in field by a team of field biologists (four researchers and a trained assistant in KMTR), with each spending an average of six hours in the field, for 20 days a month. This was calculated for the number of months that each of them spent in the field during the study, and the total time was further grouped into number of hours spent during the day and night separately. The time spent in Anamalais was calculated as a sum of the time spent in each fragment. Each fragment was visited 3 – 5 times during the day, and I spent an average of four hours per visit.

6.3.4 Habitat structure measurement

Total tree and civet food tree densities, and basal area were estimated using the point centred quarter (PCQ) method (Krebs 1989) both in KMTR and all the rainforest fragments, except Varagaliar in the Anamalais. For Varagaliar, tree and food tree densities, and basal area were derived from Ayyappan and Parthasarathy (1999). Habitat structural parameters such as canopy height, canopy cover, and shrub density were estimated from measurements taken at 25 points within the study sites, which were spaced at intervals of 50 m. Canopy height was measured using a clinometer or a range finder, canopy cover was measured using a spherical densiometer, and shrub density was estimated by counting the number of woody stems (< 10 cm in girth) within 2 m radius plots at each of these 25 points.

6.3.5 Data analyses

As the sampling regimes followed in the two study areas were different in certain aspects, such as the number of days sampled in one station, area sampled, and time of the day/night sampled, I used chi-square (χ^2) tests (Siegel and Castellan 1988) to examine the comparability of the data from the two areas. *Success rate* was calculated as percent successful track plot or camera-trap days. A trapping day was considered successful only if at least one track of a small carnivore was observed or a photograph obtained. Multiple pictures of the same species on the same night at a trap were taken as a single incidence. Direct sightings either during drives through the study sites, or during walks within them, were used to calculate encounter rates for a given effort for each species. For this analysis, days on which tracks were present on the plots, even if photographs were not taken, were considered as success.

Most of the track plots set in KMTR were during the pre-baiting phase, prior to capturing animals for radio-collaring. Therefore, only the first two days of all track plot effort were used for estimation of success rates. The results of the first two days for track plots, and all the days for camera-trapping in KMTR, were compared with the results from Anamalais. The effects of lure and altitude for the data from KMTR were analysed using the chi-square test (Siegel and Castellan 1988). Lure was used in all the track plots and at all camera-trap stations in the Anamalais, as lure was shown to be effective in attracting small carnivores (Mudappa 1998).

The two main indices of abundance used in this chapter are the success rates in track plots and camera-traps, and encounter rates based on direct sightings. The indices of abundance were calculated either by pooling across species and sites, or for individual species pooled across sites. For track plot data, the two species categories considered are brown palm civet and other carnivores, while for camera-traps, the categories are brown palm civet, small Indian civet, and brown mongoose.

For Anamalais, success rates pooled across rainforest fragments were used to correlate with habitat and site parameters, using Spearman rank correlations. Inter-variable correlations of habitat parameters were also tested, and the data reduced to fewer factors using Principal components analysis (PCA, Pielou 1984). These factors were in turn correlated to the success rates using Spearman rank correlation (Siegel and Castellan 1988) in order to test for significant influence of habitat parameters on the occurrences of small carnivores. Secondary information based on presence-absence data supplemented the other methods, in determining the community composition of small carnivores in fragments of varying sizes and levels of disturbance in the Anamalais. Hierarchical cluster analysis was used to assess the similarity or relatedness between various fragments based on: 1) success rates due to brown palm civet, 2) success rates due to small Indian civet, 3) success rates for all small carnivores, and 4) habitat parameters.

6.4 RESULTS

6.4.1 Comparability of results between KMTR and the Anamalais

In KMTR, there was no significant difference in success rates between the first and the second day, in both, track plots ($\chi^2 = 0.96$, $df = 1$, $P > 0.05$) and camera-traps ($\chi^2 = 0.017$, $df = 1$, $P > 0.05$, Figure 6.1). However, there was a significantly higher success rate in track plots on the third and fourth day in KMTR than on the preceding two days ($\chi^2 = 7.875$, $df = 3$, $P < 0.05$, Figure 6.1). Success rates and relative abundances were comparable between KMTR and Anamalais, despite the track plots and camera traps being set only once at a station and that too only at night in Anamalais, as 1) there was no significant increase in success due to "pre-baiting" on the second day in KMTR, and 2) all the small carnivore captures in both track plot and camera trap methods in KMTR were only at night.

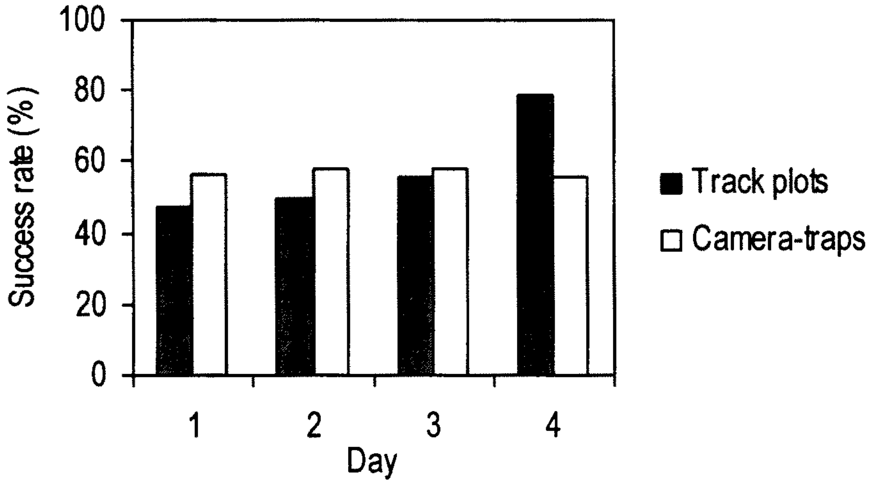


Figure 6.1: Success rates over four days of baited track plots ($n = 263$) and camera-trapping ($n = 105$) carried out in KMTR between 1996 and 1999.

6.4.2 Track plot success in undisturbed and fragmented rainforests

In KMTR, a total of 177 track plots were laid in Sengaltheri (day 1 =100, day 2 = 77) between June 1996 and December 1999. The average success rate in the first two days together was about 48%

(Figure 6.2). About 95.2% of the small carnivore visitation was by the brown palm civet. Small Indian civet and other small carnivore tracks occurred rarely (4.8%, Figure 6.3). The other animal tracks (56.5%) that were observed were that of wild boar (*Sus scrofa*), sloth bear (*Melursus ursinus*), mouse deer (*Moschiola meminna*), and rodents (mostly white-bellied wood rat *Rattus rattus wroughtoni* at night, and Western Ghats striped squirrel *Funambulus tristriatus* during daytime).

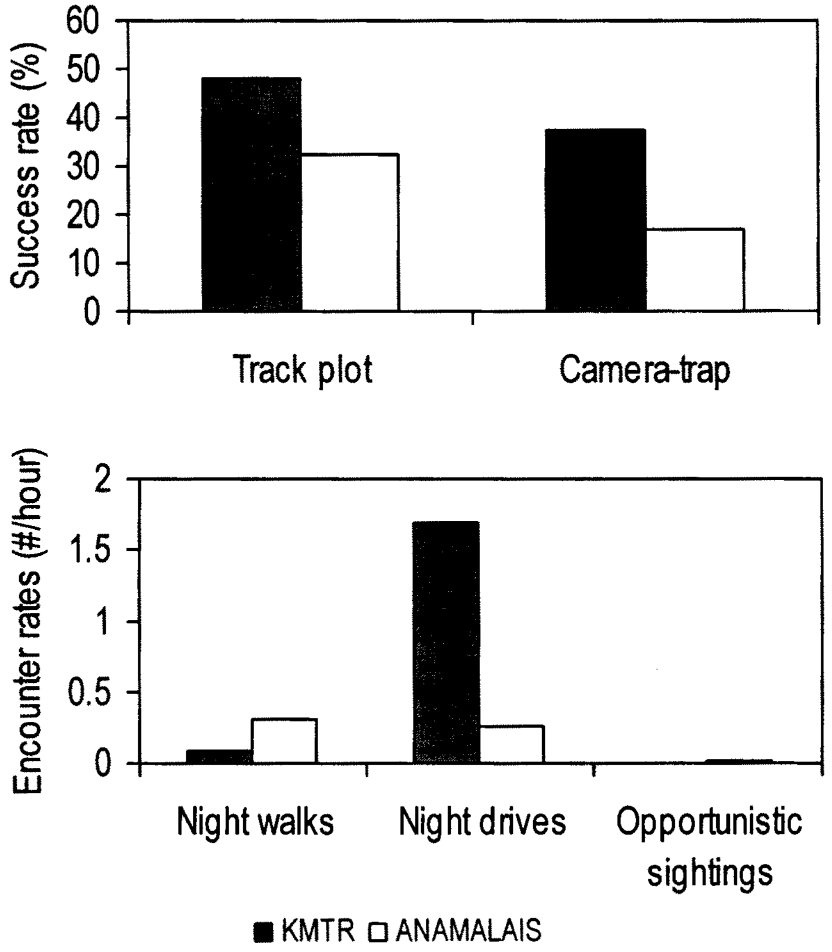


Figure 6.2: Comparison of success and encounter rates of small carnivores between KMTR and the Anamalais using different methods.

In the Anamalais, the overall success rate in the fragments was about 32.2% (95 of 295 trap-nights, Figure 6.2), with the brown palm civet contributing to 50.5% (*n* = 48), the small Indian civet 21.1% (*n* = 20), and unidentified small carnivores excluding brown palm civet 28.4% (*n* = 27, the latter two combined as one in Figure 6.3). The success rate ranged between 8.0% in Tata Finley, one of the small-sized fragments, to 46.67% in Korangumudi, a medium-sized fragment.

The other mammal species recorded on the track plots were porcupine (*Hystrix indica*), mouse deer, lion-tailed macaque (*Macaca silenus*), and some rodents.

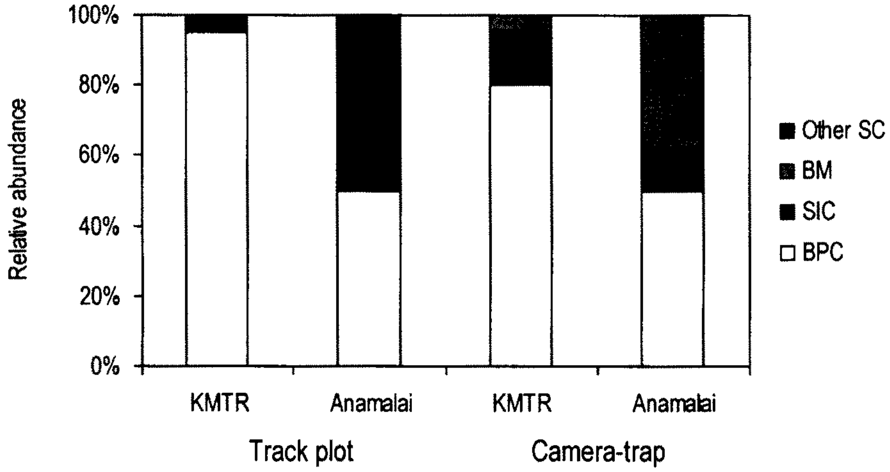


Figure 6.3: Relative abundances of small carnivores (SC) using track plots and camera-traps — comparison between KMTR and the Anamalais.

There were significantly higher rates of visitations by small carnivores to the track plots in KMTR than in the rainforest fragments of Anamalais ($\chi^2 = 11.73$, $df = 1$, $P < 0.001$). Success rate was higher in KMTR than in the Anamalais for both the brown palm civet ($\chi^2 = 48.44$, $df = 1$, $P < 0.001$) and for other small carnivores (small Indian civet and mongooses together, $\chi^2 = 14.61$, $df = 1$, $P < 0.001$).

6.4.3 Camera-trapping

6.4.3.1 *Kalakad-Mundanthurai Tiger Reserve*

Camera-traps were set at 49 different stations for a total of 112 trap-days, with each session lasting for a period of 1 – 9 days in four sites within Kalakad-Mundanthurai Tiger Reserve (Table 6.1). Lure was used on 85 days. Twenty four stations (nine each in Sengaltheri and Kannikatti, and six in Koovapatti) failed to attract any small carnivore. At least one small carnivore was photo-trapped on 37.5% of the trap-days (Figure 6.2). Three species were photo-trapped: the brown palm civet , the small Indian civet , and the brown mongoose (Plate 1). One station in Kakachi had all three species, and five stations (in Sengaltheri and Kakachi) had two species, either over the same night (*n* = 4) or session (*n* = 5). In Sengaltheri and Kakachi, all three small carnivores were photo-trapped, while in Koovapatti two species (small Indian civet and brown palm civet) and in Kannikatti only one species (brown palm civet) was photo-trapped. Kakachi had the highest trapping success of 73.7% (*n* = 19 trap-days), followed by Sengaltheri with 40.9% (*n* = 44), Kannikatti with 20.6% (*n* = 34), and Koovapatti with 20% (*n* = 15; $\chi^2 = 16.94$, *df* = 3, $P < 0.001$). The brown palm civet was photo-trapped on 37 days, accounting for about 88% of the success, the small Indian civet on seven days (16.7%), and the brown mongoose on two days (4.8%; values corrected for multiple species on a trap-day in Figure 6.3). Traps with lure (*n* = 85 days) had a significantly greater success rate (57%) than the traps without lure (12.8%, *n* = 27, $\chi^2 = 19.48$, *df* = 1, $P < 0.001$).

In Mundanthurai, three out of eight trap-nights were successful, photo-capturing the common palm civet (*Paradoxurus hermaphroditus*). In KMTR, it was clear that the brown palm civets occurred only in tropical rainforests and rarely in riverine patches contiguous with and close to them. The non-target species photo-trapped were the mouse deer, sloth bear, and white-bellied wood rat.

6.4.3.2 *Rainforest fragments in Anamalais*

Camera-trapping success in the rainforest fragments of the Anamalais was significantly lower than in KMTR, with a success rate of 16.8% (*n* = 95 trap-nights) as against 38.8% (*n* = 49, $\chi^2 = 8.45$, *df* = 1, $P < 0.001$) on day 1 in KMTR, and 37.5% overall (*n* = 112, $\chi^2 = 10.88$, *df* = 1, $P < 0.001$, Figure 6.2). However, even in the Anamalais, brown palm civet was the most frequently photo-trapped small carnivore, contributing to 50% of the success (8 trap-nights), but occurred at a significantly lower rate than in KMTR ($\chi^2 = 15.30$, *df* = 1, $P < 0.001$). Brown mongoose was the second most frequently photo-trapped species of small carnivore (37.5%), followed by the small Indian civet (12.5%, Figure 6.3). Although the brown mongoose was photo-trapped a greater number of times in the Anamalais than in KMTR, and the small Indian civet fewer times, the differences were not statistically significant ($\chi^2 = 2.84$ and 2.12, respectively, *df* = 1, $P > 0.05$). The camera-trapping success was highest in Puthuthottam, a medium-sized fragment, and in Pannimade, one of the small fragments. There were no photo-captures of small carnivores in Varagaliar, the largest fragment at low elevation, and in Tata Finley, one of the smallest fragments. The non-target species that were photo-trapped were the Indian porcupine, sloth bear, wild boar, mouse deer and white-bellied wood rat.

6.4.4 Direct sightings

6.4.4.1 *Night walks*

Twenty five night walks (32 hr 35 min) on forest trails were carried out in the three rainforest sites in KMTR between November 1996 and September 1997. The time spent on each walk was a little over an hour on an average (ranging between 40 min and 165 min), covering a distance of at least 1 km per hour. The number of walks and their durations varied among the three sites in KMTR: Kakachi – 18 hr 15 min over 15 walks, Sengaltheri – 4 hr 45 min over 3 walks, and Kannikatti – 9 hr 35 min over 7 walks. During these walks, three small carnivores — one brown palm civet in Kannikatti, and two small Indian civets in Kakachi were sighted. The encounter rate was 0.09 animals/hour (Figure 6.2). Large brown flying squirrel (*Petaurista philippensis*), mouse deer, sambar (*Cervus unicolor*), black-naped hare (*Lepus nigricollis*), Asian elephants (*Elephas maximus*), and a few species of owls were also seen during the night walks.

In the dry deciduous forests of KMTR, the encounter rates of common palm and small Indian civets were 0.19 and 0.07 animals/kilometre, respectively (Mahesh Sankaran *personal communication*). The other small carnivores sighted in this vegetation type in KMTR were the common grey mongoose (*Herpestes edwardsii*), ruddy mongoose (*H. smithii*), jungle cat (*Felis chaus*), and rusty-spotted cat (*Prionailurus rubiginosus*).

In the Anamalais, 12 night walks were carried out (13 hr 10 min) in seven rainforest fragments. Time spent in a walk ranged between 30 and 140 minutes, depending on the size of the fragment. Four brown palm civets were seen during these night walks, resulting in an encounter rate of 0.30 animals/hour (Figure 6.2). The brown palm civets were sighted in the larger fragments, Akkamalai and Andiparai. Small carnivores were sighted in other fragments also, although not during the night walks (see section 6.4.4.3 on opportunistic sightings). There were more sightings of species such as the large brown flying squirrel, mouse deer, sambar, and gaur (*Bos gaurus*) in the rainforest fragments. Barking deer (*Muntiacus muntjak*) was also sighted once.

6.4.4.2 *Night drives*

Most of the rainforest areas in KMTR were not accessible by road. Therefore night drives were confined to areas around Kakachi, where the roads passed through both rainforests and tea estates. I went on seven night drives, covering a distance of 100 km, in 5 hr 15 minutes. One brown palm civet, 7 small Indian civets, and 1 leopard cat were seen, giving an encounter rate of

1.7 animals/hour of drive (Figure 6.2) or 0.09 animals/km. Leopard (*Panthera pardus*), porcupine, and sambar were also seen during these drives.

In the Anamalais, due to the extensive spread of plantations (tea, coffee, *Eucalyptus*, cardamom), and settlements, there was a good network of roads, most of which were through tea plantations. Very small sections of the rainforest fragments were covered during the drives. The drives were conducted either early in the mornings (0530 h to 0630 h) or late in the evenings (1830 h to 2400 h). I covered a distance of 281.5 km over 11 hr 40 min (8 h at night and 3 h 40 min in the morning). During these drives, one brown palm civet and two small Indian civets were encountered, with an encounter rate of 0.26 animals/hour or 0.01 animals/km (Figure 6.2). Both the small Indian civets were seen at the edge of the tea estates, close to human settlements, while the brown palm civet was seen at a rainforest fragment edge. The only other mammal seen during the drives was black-naped hare.

6.4.4.3 *Opportunistic sightings*

These sighting records exclude those accounted for in the night walk and drive methods, and of radio-collared individuals. Over the 9486 day hours and 2754 night hours that were spent in fieldwork (by five persons) in the rainforests in KMTR, 16 small carnivore sightings were recorded during the day and 23 at night (Figure 6.2). These included the Nilgiri marten *Martes gwatkinsi* (11), brown mongoose (4), otters (2), and leopard cat (1) sightings during the day, and the brown palm civet (9), small Indian civet (4), otters (4), leopard cat (3), and brown mongoose (2) sightings at night.

The most frequently sighted small carnivores were the Nilgiri marten during the day, and the brown palm civet at night (encounter rates = 0.001 and 0.003 animals/hour, respectively). Descriptions of the habits and other incidental observations of the small carnivores seen in KMTR are given in Appendix 4.

In the Anamalais, of the nearly 500 hours (including 138 hr 5 min within the fragments) of time spent in field surveys during the day in the Anamalais, I sighted brown palm civet once (early in the morning) and stripe-necked mongoose 5 times (in groups of 1 to 3 individuals, totalling 8 individuals). The encounter rate of the stripe-necked mongoose was 0.016 animals/hour.

6.4.5 Determinants of small carnivore occurrences in rainforests

6.4.5.1 *Comparison of site and habitat parameters between KMTR and Anamalais*

With the exception of the very large fragment, Akkamalai, and the large Karian Shola fragment, the tree densities of all the other rainforest fragments in the Anamalais were lower than any of the rainforest sites in KMTR (Table 6.3). Basal area in the forest fragments was significantly positively correlated to both tree and food tree densities (r_S = 0.709 and 0.768, respectively, n = 10, P < 0.02). Andiparai, Manamboli, and Karian Shola had higher basal area (84 m^2/ha, 114 m^2/ha, and 96 m^2/ha, respectively) than sites in KMTR. The average canopy height varied among sites, particularly in the rainforest fragments, with it being the lowest in Varattuparai (11 m) and the highest in Tata Finley (31 m). Canopy cover varied between sites (68% – 98%), and Puthuthottam (89%) and Korangumudi (68%) had lower cover than the other fragments (Table 6.3). Among the fragments, only the tree density was significantly correlated to the area (r_S = 0.632, n = 8, P = 0.05). None of the other variables were, however, significantly correlated to either fragment area or altitude (Figures 6.4a and 6.4b, and Table 6.4).

Table 6.3. Habitat structure measurements of different sites in the undisturbed rainforest of KMTR, and rainforest fragments in the Anamalais (SE in parentheses).

Sites	**Tree density (#/ha)**	**Basal area (m^2/ha)**	**Canopy height (m)**	**Canopy cover (%)**	**Shrub density (#/12.57 m^2)**
Kakachi	850.97 (61.3)	79.23 (6.8)	23.83 (0.7)	93.68 (0.8)	20.77 (2.4)
Sengaltheri	760.47 (43.9)	81.07 (10.3)	20.92 (0.9)	93.84 (0.9)	19.26 (2.7)
Kannikatti	628.64 (79.4)	72.23 (7.1)	24.38 (1.2)	94.66 (0.6)	15.66 (2.0)
Akkamalai	697 (5.0)	52.49	22.65 (1.4)	97.70 (0.5)	10.20 (0.6)
Varagaliar	446	36.26	28.56 (1.4)	94.68 (0.7)	15.76 (1.7)
Andiparai	431 (4.4)	84.49	22.66 (1.8)	96.24 (0.7)	26.32 (2.9)
Manamboli	582 (5.8)	114.41	24.54 (1.1)	94.96 (1.4)	11.64 (1.1)
Karian Shola	755 (7.6)	95.86	27.00 (0.7)	98.20 (0.2)	23.84 (2.4)
Korangumudi	196 (1.9)	31.25	20.74 (2.1)	68.24 (3.2)	8.83 (1.2)
Puthuthottam	239 (2.4)	52.49	22.70 (1.9)	89.00 (1.3)	7.88 (0.8)
Varattuparai	295 (7.6)	33.47	11.11 (2.2)	95.65 (0.9)	3.73 (0.8)
Tata Finley	331 (5.6)	40.31	31.32 (1.9)	96.32 (1.2)	11.04 (0.9)
Pannimade	534 (13.7)	47.48	22.43 (1.8)	92.48 (0.8)	34.16 (3.0)

Canopy cover was significantly correlated to tree and food tree densities, and basal area (r_S = 0.782, 0.640, and 0.685, respectively, n = 10, P = 0.01, 0.05, and 0.02, respectively, Table 6.5). Principal components analysis (PCA) was used to summarise changes in six vegetation variables, by combining inter-correlated variables. PCA extracted two factors (with Eigen values >

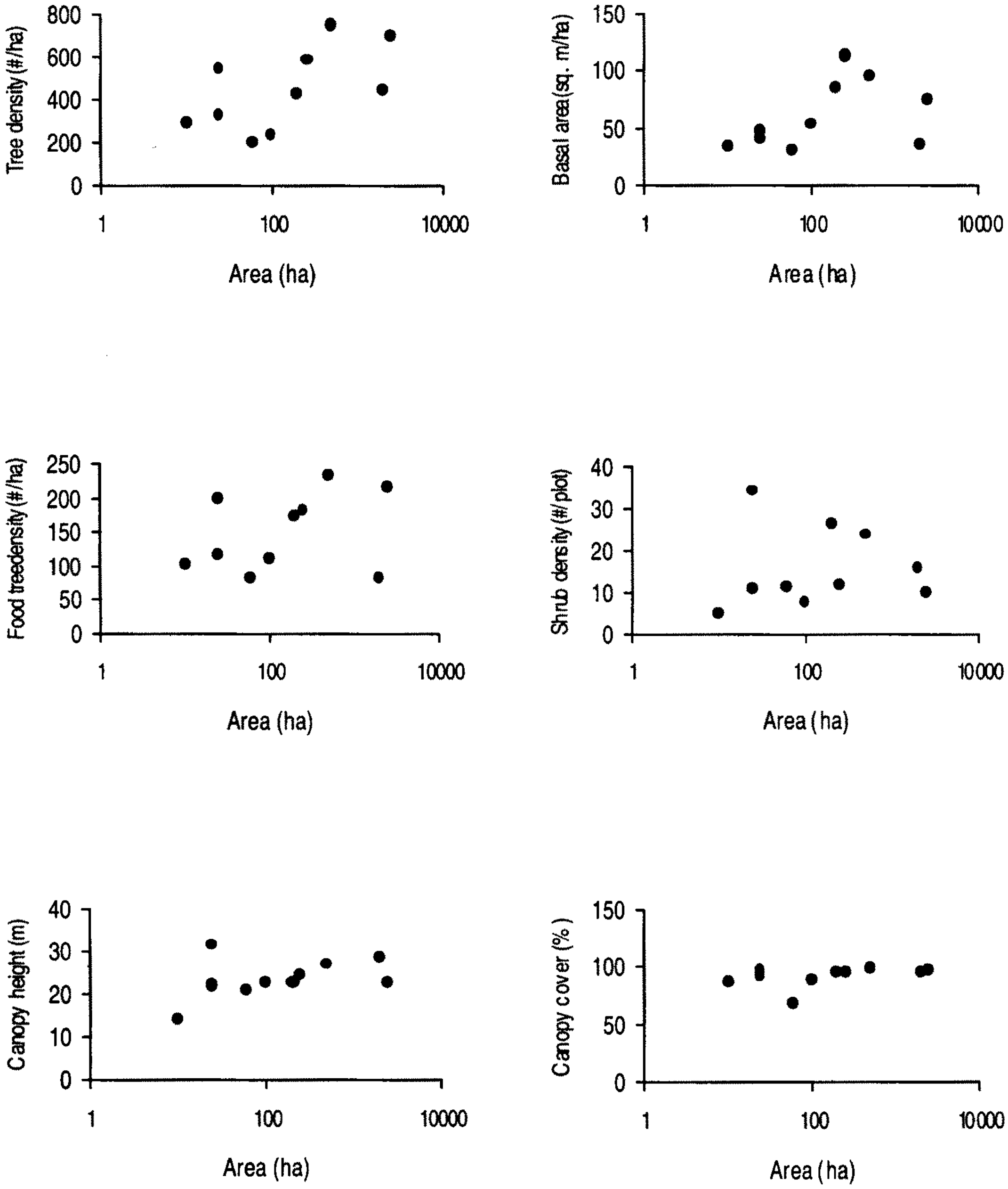


Figure 6.4a: Relationships between the area of the fragments in hectares (in logarithmic scale) and habitat attributes in the Anamalais.

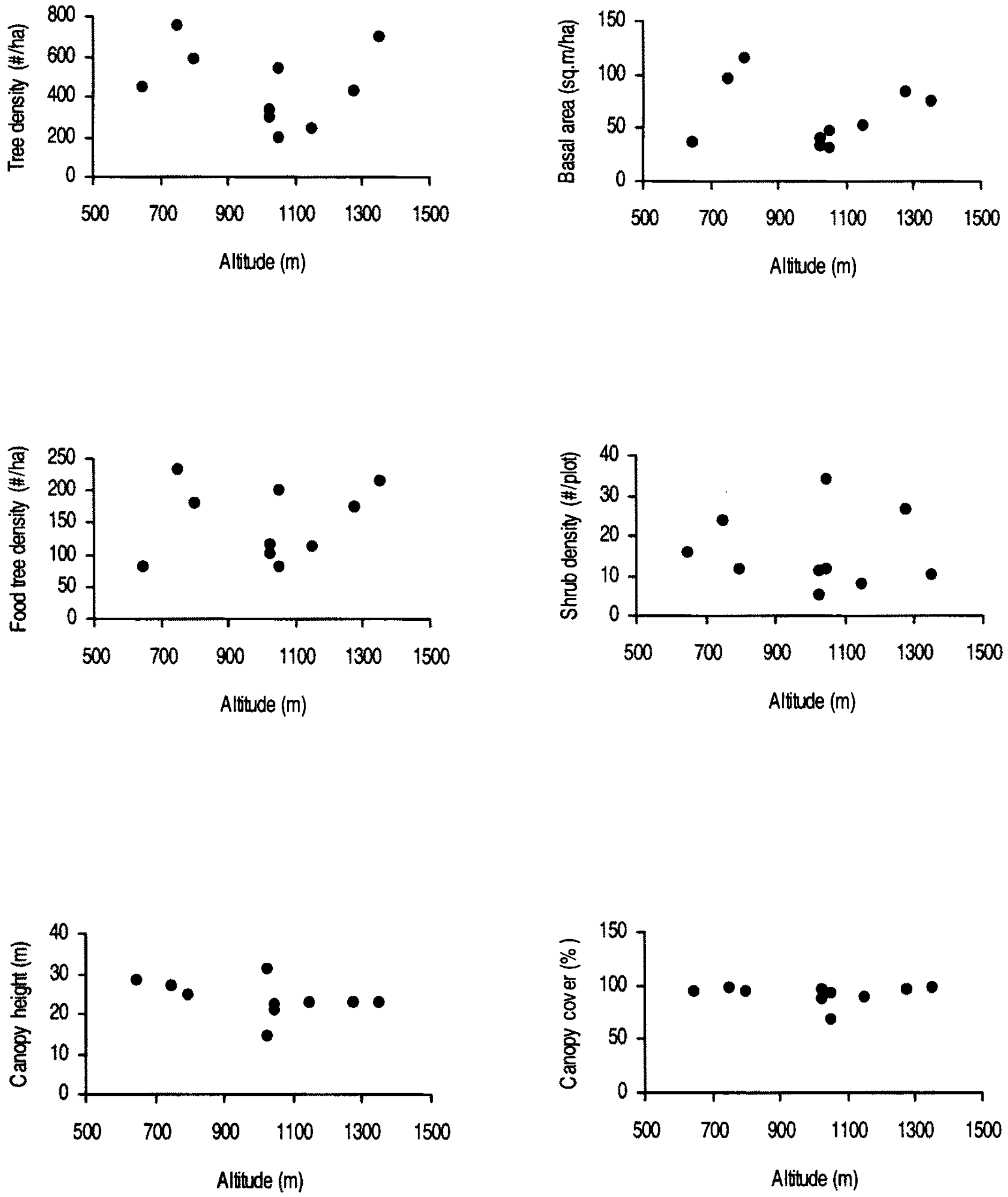


Figure 6.4b: Relationships between altitude and habitat attributes in the fragments in the Anamalais.

Table 6.4: Spearman rank correlation values between site and habitat parameters of the rainforest fragments in the Anamalais ($n = 10$, * – significance at 0.1, ** – significance at 0.05 levels).

	Canopy cover	**Canopy height**	**Shrub density**	**Tree density**	**Food tree density**	**Basal area**
Area	0.578*	0.401	0.201	0.632**	0.287	0.523
Altitude	-0.061	-0.506	-0.177	-0.220	0.328	0.055

1) that accounted for 74.3% of the variance in the data. PC1 or the first factor (explaining 56.4% of the variance) represented canopy cover, tree and food tree densities, and basal area. Since these correlations were positive, sites with higher PC1 values had higher tree and food tree density, basal area, and canopy cover. PC2 or the second factor (explaining 17.9% of the variance) was related only to canopy height, also indicating that sites with higher PC2 values have taller canopy.

Table 6.5: Spearman rank correlation amongst habitat parameters of the rainforest fragments in the Anamalais ($n = 10$, * – significance at 0.1, ** – significance at 0.05, *** – significance at 0.01 levels).

	Canopy height	**Shrub density**	**Tree density**	**Food tree density**	**Basal area**
Canopy cover	0.600*	0.285	0.782***	0.640**	0.685**
Canopy height		0.200	0.321	0.006	0.358
Shrub density			0.455	0.311	0.345
Tree density				0.768***	0.709**
Food tree density					0.720**

6.4.5.2 *Influence of site and habitat parameters on success rates*

The frequency of occurrence (per cent) of the small Indian civets in the track plots in the Anamalais was significantly correlated to area of the fragments ($r_S = 0.702$, $n = 10$, $P = 0.02$), while that of the brown palm civet was weakly correlated with altitude ($r_S = 0.642$, $n = 10$, $P = 0.05$), similar to the pattern observed in the undisturbed rainforests of KMTR (Mudappa 1998). None of the other small carnivore success rates were significantly correlated to any of the habitat parameters, either independently or when the PC factors were considered (Table 6.6).

There were no significant differences (χ^2 analysis) among fragments of varying size classes or disturbance levels (Table 6.1) in the success rates of either individual species or of all small carnivores pooled, in both track plot or camera-trap method. The only exception was that

Table 6.6: Spearman rank correlation between site and habitat parameters with small carnivore occurrence indices in the rainforest fragments in Anamalais (n = 10, * – significance at 0.1, ** – significance at 0.05 levels).

	Track plot			Camera-trap			
	BPC	**SIC-M**	**ALL**	**BPC**	**SIC**	**BM**	**ALL**
Area	–0.262	0.702**	0.049	–0.235	0.175	0.166	–0.16
Altitude	0.642*	–0.009	0.495	0.152	0.088	0.291	0.54*
Canopy cover	–0.353	0.336	–0.280	–0.330	0.174	0.330	–0.12
Canopy height	–0.608*	0.232	–0.608*	–0.220	0.087	–0.385	–0.50
Shrub density	0.347	–0.159	0.267	0.193	0.348	–0.248	0.03
Tree density	–0.164	0.361	0.036	–0.165	0.174	0.303	0.06
Food tree density	0.297	0.231	0.339	0.055	0.219	0.305	0.43
Basal area	0.152	0.434	0.122	–0.055	0.609*	0.165	0.25
PC1	–0.024	0.379	0.097	–0.083	0.261	0.275	0.16
PC2	–0.535	0.141	–0.578*	–0.028	0.000	–0.550*	–0.50

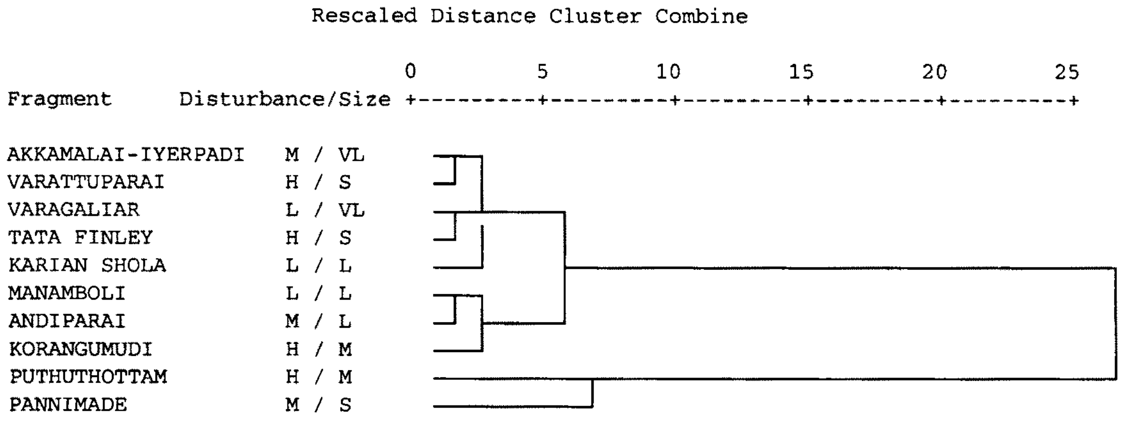
BPC – Brown palm civet, SIC-M – Small Indian civet and mongooses, SIC – Small Indian civet, BM – Brown mongoose, ALL – all small carnivores

camera-trapping success of brown palm civet was significantly different between sites of varying size classes ($\chi^2 = 11.36$, $df = 3$, $P < 0.001$) with success being highest in medium-sized fragments (25%) as compared to small (20%), large (16.7%), and very large (10%) fragments.

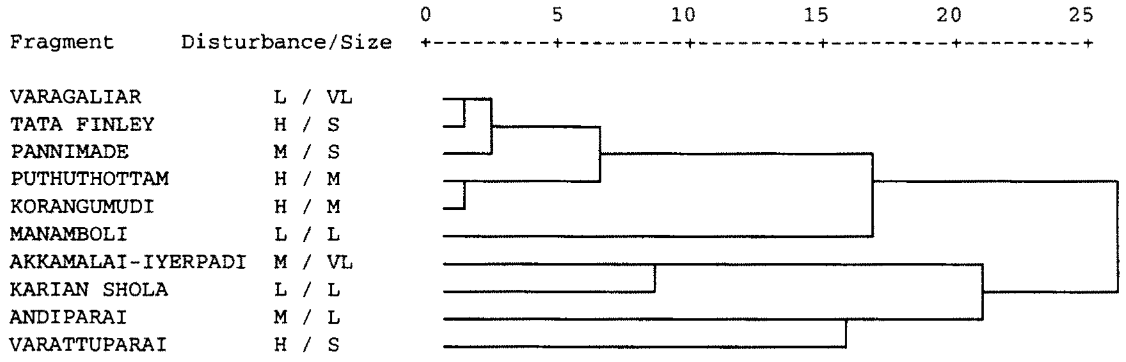
The similarity among fragments in habitat parameters did not match the similarity in the success rates at the track plots and camera-trap stations, either when considered as different small carnivore species groups or when pooled (Figures 6.5a and 6.5b). Cluster analyses based on habitat parameters grouped fragments mainly by disturbance level, and to a lesser extent, size of the fragment (Figure 6.5b). Tata Finley was most similar to Varattuparai, both being less than 25 ha and highly disturbed. Korangumudi exhibited highest similarity with Puthuthottam, both being medium-sized fragments and also highly disturbed (least canopy cover and tree densities). Akkamalai and Karian Shola, Manamboli and Pannimade, and Varagaliar and Andiparai, showed high similarity with each other and grouped to form a separate cluster. These fragments are large, with the exception of Pannimade, and are also included within the Sanctuary boundaries and protected by the Tamil Nadu Forest Department. These have minimal disturbances and relatively good forest stands. However, clustering of the rainforest fragments based on the success rates of small carnivores at track plots and camera traps did not correspond to the clusters based on habitat parameters. Small carnivore occurrence in undisturbed rainforests of KMTR and in the fragments of Anamalais is given in Table 6.7.

BROWN PALM CIVET

Dendrogram using Average Linkage (Between Groups)



SMALL INDIAN CIVET AND BROWN MONGOOSE



ALL SMALL CARNIVORES

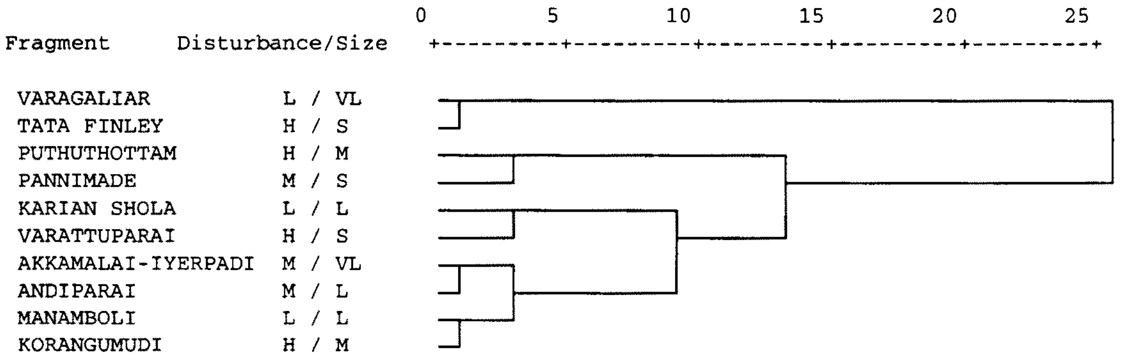


Figure 6.5a: Hierarchical cluster of rainforest fragments in Anamalais based on success rates at track plot and camera-trap stations. Disturbance levels: H – high, M – medium, L – low; Size class: VL – very large, L – large, M – medium, S – small.

Dendrogram using Average Linkage (Between Groups)

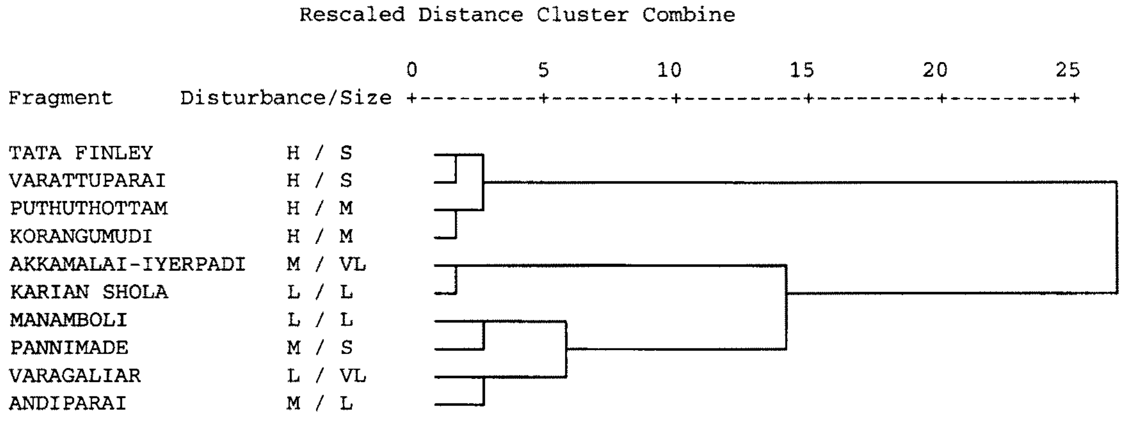


Figure 6.5b: Cluster diagram of rainforest fragments in Anamalais based on six habitat parameters (canopy cover, canopy height, tree density, food tree density, shrub density, and basal area). Disturbance levels: H – high, M – medium, L – low; Size class: VL – very large, L – large, M – medium, S – small.

Table 6.7:Occurrence of rainforest small carnivores in KMTR and fragments in the Anamalais, based on all methods including secondary data (BPC – Brown palm civet, SIC –Small Indian civet, BM – Brown mongoose, SNM – Stripe-necked mongoose, NM – Nilgiri marten, LC – Leopard cat).

Site	BPC	SIC	BM	SNM	NM	OTTER	LC
KMTR	*	*	*		*	*	*
ANAMALAIS							
Akkamalai (10° 22.015' N and 76° 59.956' E)	*	*		*			
Varagaliar (10° 25.070' N and 76° 51.940' E)	*	*	*	*		*	
Karian Shola (10° 28.561' N and 76° 49.992' E)	*	*	*	*		*	*
Manamboli (10° 20.877' N and 76° 53.949' E)	*	*				*	
Andiparai (10° 23.646' N and 76° 59.608' E)	*	*	*	*	*		*
Puthuthottam (10° 20.468' N and 76° 58.025' E	*	*	*	*			
Korangumudi (10° 18.836' N and 76° 54.543' E)	*						
Tata Finley (10° 20.920' N and 76° 56.053' E)	*						
Pannimade (10° 17.774' N and 76° 53.693' E)	*						
Varattuparai (10° 21.351' N and 76° 55.797' E)	*						

6.5 DISCUSSION

6.5.1 An evaluation of small carnivore survey methods

The methods followed during this study in the southern Western Ghats, provided enough data, for the first time, to describe patterns of small carnivore distribution in rainforest landscapes. While the data collected from the track plot method could be used to definitively ascertain the occurrence of one species (the brown palm civet) in the fragmented rainforests, it also provided an understanding about the occurrence of the other viverrids and herpestids. The camera-trap method was more reliable as shown in other studies as well (Foresman and Pearson 1998) than other indirect methods, as identification of species did not pose a problem. In cases of animals with distinct marks like the tiger, camera-trapping can even be used to identify individuals and estimate densities (Karanth 1995, Karanth and Nichols 1998) or indices of abundance (Zielinski and Kucera 1995, Yoneda *et al.* 1998b). However, the assumption of equal trappability across species may not hold true despite the similarity in the size, distribution, and other habits of the small carnivores. Relative abundance estimates must therefore be treated as approximations.

Night walks provided few sightings in the rainforest fragments, and fewer in the undisturbed rainforest. This may, however, be due to the much denser foliage and forest stand in the undisturbed forests than in the degraded fragments. Spotlighting was not an effective method of sampling rainforest small carnivores. Spotlighting has been reported to be ineffective even for surveys of other nocturnal small mammals like the greater glider *Petauroides volans* (Lindenmayer *et al.* 2001). A combination of different methods used systematically, as in this study, have yielded better estimates of the relative abundances of small carnivores. The use of a combination has been proposed earlier (Zielinski and Kucera 1995, Zielinski *et al.* 1996, 1997; Foresman and Pearson 1998, Mudappa 1998, Sargeant *et al.* 1998). Occurrence of scats can also be used as an index of small carnivore abundance, but this was not feasible in this study, due to logistic difficulties.

The methods used were not without drawbacks (reviewed in Smallwood and Schonewald 1998). Camera-traps are expensive and may cause technical problems in adverse weather, such as the wet and humid conditions often encountered in rainforests. The probability of theft was high in fragmented habitat due to constant human movement, and therefore sampling had to be restricted to the night hours. In the track plot method, as mentioned earlier, species identity was a problem, which can be overcome by a very good knowledge of tracks of different species. Also much effort had to be discarded due to the track plots being washed away in heavy downpours. Covered track plots could be an alternative, although it may deter some of the species (Foresman and Pearson 1998). Night walks and spot-lighting provided very few sightings of the target species in the dense rainforests relative to the effort invested as compared with other methods. This method has, however, been used in Borneo to study the impact of logging on civets (Heydon and Bulloh 1996). No single method can be used to understand and study the ecology of a species, and better results are obtained when multiple methods are used to supplement one another.

6.5.2 Relative abundances of small carnivores in the southern Western Ghats

The higher success rates in track plots (48%) and camera-trapping (37.5%) in KMTR than in the Anamalais (32.2% success in track plots and 16.8% in camera-traps) probably indicate higher abundances of small carnivores, particularly civets, in undisturbed rainforests. Greater success rate was due to visitations by the brown palm civet, a species that seems to be more common than previously believed (Ashraf *et al.* 1993). The second-most abundant species as recorded by these methods was the small Indian civet in KMTR, and the brown mongoose in the Anamalais. The small Indian civets were recorded from open areas, grasslands, and plantations within the rainforests in KMTR. This species, widely distributed (also occurring in dry deciduous and dry thorn forests) throughout south and south-east Asia, seems to occur in more or less similar abundances across regions and habitats. The lower encounter rate of the small Indian civet in direct sightings in KMTR, may not reflect actual abundances, as it could have been a result of poorer visibility in the denser forest vegetation cover in the relatively undisturbed forests.

The brown palm civet was relatively the most common (0.003 animals/hour) of nocturnal small carnivores in both KMTR and the Anamalais. Among the diurnal small carnivores, Nilgiri marten seemed to be more common (0.001 animals/hr) than the mongooses, in KMTR. The stripe-necked mongoose was never sighted in KMTR (although there are unconfirmed reports of the species from Kakachi), while it was the most frequently sighted small carnivore (0.016 animals/hour) in the Anamalais. This could be because of availability of their favoured habitat, namely small streams and marshes, that criss-cross the plantations. They also seem to be more abundant in dry- and moist-deciduous forests. These estimates are comparable with the estimates of small carnivore encounter rates reported by Kumar (2000) for the Anamalais. The abundance estimates of mongooses were higher in Ruhuna National Park, Sri Lanka (Santiapillai *et al.* 2000; 0.7 stripe-necked mongooses/km^2) when compared to the southern Western Ghats (0.016

animals/hour in the Anamalais). Although not strictly comparable, this may suggest that the more omnivorous mongooses are more common in drier areas, with their abundances increasing in disturbed rainforest fragments as compared to relatively undisturbed rainforests like in KMTR.

Although relatively the most abundant species in both the study sites was the brown palm civet, it contributed only to half the success in Anamalais, in contrast to more than three-fourths in KMTR. The major factor affecting its distribution in KMTR was altitude. In the Anamalais, however, apart from altitude, none of the habitat parameters showed any significant role in determining the abundance of brown palm civet, although the medium-sized fragments had greater success rates. This may be partly because these medium-sized fragments had plantations of coffee (the fruits of which are consumed by civets) in the understorey, and had also retained some of the native, rainforest trees (food species of brown palm civets) as shade. However, these are very highly disturbed fragments, whose long-term survival is questionable. Similar to results of studies on the impact of disturbances on other mammals (Johns 1983, 1988; Oehler and Litvaitis 1996, Travaini *et al.* 1997), there seemed to be a slight increase or no significant change in the abundance of terrestrial and more omnivorous-carnivorous species like the mongooses and small Indian civet in fragments. In contrast, there was a significant reduction in the occurrence of brown palm civets in the fragments compared to KMTR, probably due to its arboreal and predominantly frugivorous nature. The clustering of the rainforest fragments was based on habitat parameters, grouped in accordance with disturbance levels and size classes, but did not correspond with the clustering of the rainforest fragments based on the success rates of small carnivores at track plots and camera traps. This could partly be due to low success rates in the Anamalais. However, this may indicate that habitat parameters *per se* cannot predict the occurrence of small carnivores as noted in other studies (Smallwood and Schonewald 1998).

6.5.3 Influence of habitat matrix in fragmented landscapes

An interesting observation during the study was that none of the small carnivores seemed to have disappeared completely from the fragmented landscape, although otters may be confined only to fragments with large streams and rivers. Although the small carnivores persist, they occur in altered relative abundances with relatively fewer brown palm civets than mongooses and small Indian civets. This can be greatly influenced by the matrix surrounding the fragments if they provide cover for movement between fragments and food resources for the animals (Laurance 1991, 1994; Laurance *et al.* 1997). Species like the Nilgiri marten and the brown palm civet were confined to rainforest fragments, while the mongooses and the small Indian civet were frequently sighted even in the matrix of tea, *Eucalyptus*, coffee, and cardamom plantations. Most often, changes in the landscape are coupled with the establishment of a network of roads, which results in high mortality of terrestrial species due to roadkills (Kumara *et al.* 2000a). The changes in relative abundance may also partly be due to the increase in abundance of small mammal prey in the fragments (Prabhakar 1998, Umapathy and Kumar 2000), which is conducive for the more common and widespread, and more omnivorous species like the mongooses and the small Indian civet. Since there is cover in the understorey, these species, being chiefly terrestrial animals, are least likely to be affected (Wilkie and Finn 1990). These species are also omnivorous and insectivorous. There might be a slight increase in the abundance of leaf-litter invertebrates in moderately disturbed habitats, providing additional resources for these generalist and adaptable species (Didham 1997, Ray and Sunquist 2001). In contrast, the arboreal and predominantly frugivorous brown palm civet suffers from fragmentation because of its inability to survive in a matrix of plantations devoid of continuous tree cover and sufficient diversity of fruit resources. Larger relatively undisturbed patches of forests within the landscape can also act as source pools for recolonisation of other degraded sites (Corlett and Turner 1997), particularly by the more terrestrial species.

6.5.4 Impact of habitat fragmentation and disturbance on small carnivores

In this study, rainforest fragments in the Anamalais were observed to have lower abundance of small carnivores than the relatively undisturbed rainforests of KMTR. While there was a decrease in the overall success rate and in the occurrence of brown palm civet, the brown mongoose was photo-trapped a greater number of times in the fragments than in KMTR. This is the first study examining the impact of fragmentation on small carnivores and therefore the changes observed in these sites cannot be compared with studies in other areas. However, very similar results have been reported from studies on impact of selective logging on civets in Borneo (Heydon and Bulloh 1996). Although all the nine species of civets persisted in the logged sites in Borneo, there was a significant reduction in their overall abundance. The groups most affected were predominantly carnivorous (insectivorous) subfamilies of Viverrinae and Hemigalinae (Heydon and Bulloh 1996). Even Lambert's (1992) study of the impact of logging on birds in Borneo indicated insectivorous birds to be the most affected. However, in this study, the highly frugivorous brown palm civet seems to be the most affected.

If Heydon and Bulloh's (1996) findings can be generalised, then the species to be most affected in the southern Western Ghats would be the Nilgiri marten and the leopard cat, which are predominantly carnivorous, or the small Indian civet and the mongooses, which are insectivorous. The Nilgiri marten and the leopard cat are rare in the rainforests fragments (based on secondary information), despite the increase in the small mammal abundances both in the fragments and in the surrounding matrix (Prabhakar 1998, D. Mudappa *unpublished data*). On the contrary, the insectivorous small Indian civet and the mongooses do not seem to be negatively affected in this region. This could be because of the observed increase in small mammal abundances in the fragmented sites (Prabhakar 1998, D. Mudappa *unpubl. data*), and also probable increase in ground and leaf-litter arthropods along the edges and in disturbed fragments (Didham 1997). Clear evidence has been established between carnivore and prey abundances in the temperate regions (Hanski *et al.* 1991). Data on the abundance of invertebrates from the study fragments and landscape matrix are lacking. Although a few earlier studies have shown that many habitat specialists, especially those with narrow dietary habits have declined with disturbance (Heydon and Bulloh 1996, 1997), studies of invertebrates and other vertebrate prey species have indicated increases in disturbed habitats (Didham 1997, Malcolm 1997a,b; Ishwar 2001). This ambiguity and lack of direct evidence on the effect of prey abundance on small carnivores in tropical forests, makes the interpretation of small carnivore abundance difficult.

Studies in Africa and south-east Asia have reported civets and other omnivorous species to increase in abundance in slightly disturbed or logged habitats (Johns 1983, Wilkie and Finn 1990). Among other rainforest mammals studied, highly frugivorous and folivorous primates are faced with major reduction in food species due to logging and associated disturbances in many regions (Leighton 1982, Johns 1988, but also see Fimbel 1994, and Ferrari and Diego 1995). In south-east Asia, however, as the logged species are usually non-food species, the primates have been found to persist and in some cases (folivores) increase in abundance in logged forests. Studies from other tropical rainforests have shown that where many food species are logged for timber, the impacts could be negative for the species with narrow or specialised dietary habits (Johns 1988, Ferrari and Diego 1995, Heydon and Bulloh 1997, Struhsaker 1997). Similarly, in the present study, where the rainforests have been fragmented, the major problems are the reduction in forest fragment area, and continuing disturbances. Fuel wood collection is rampant and all species (food and non-food) are removed. The endangered primates like the Nilgiri langur

(*Trachypithecus johnii*) and the lion-tailed macaque have survived, probably due to their relatively long life-spans, and in some cases, availability of alternative food resources (Umapathy and Kumar 2000, Kumara *et al.* 2000b, Singh *et al. in press*). Persistence of species like the Nilgiri marten and brown palm civet can probably be attributed to similar reasons.

Fragmentation seems to have some degree of negative impact on the abundance of brown palm civets, and not on the other small carnivores that could be reliably studied. One of the major changes in the rainforest fragments is the indiscriminate cutting and removal of all trees for local use as fuel wood. The brown palm civet, which was recorded to be predominantly frugivorous, feeding on at least 53 species of fruits, would require a year-round supply of preferred food resources. Fourteen species of fruits, along with invertebrates and vertebrates, were identified as crucial resources (Chapter 3) to meet the annual requirements of the species. With the exception of fragments with coffee in the understorey, most others not only have very low food tree densities, but also harbour many exotics that bear fruits not usually eaten by the civets. Moreover, in order to meet their daily resource (food and day-bedding site) requirements, civets may have to range over a wider area in fragments than in undisturbed rainforests (a maximum of about 60 ha, Chapter 5). Most of the fragments were less than 100 ha in area, and this could explain the lower abundances of this species. Also, unless the fragments are surrounded by suitable habitats that can be used to range wider, these populations would be isolated.

A recent study of the impact of fragmentation on bats has shown small, canopy species to be the most negatively affected, and this is in turn related to their inability to use the surrounding matrix (Cosson *et al.* 1999). The brown palm civet, a more arboreal and predominantly frugivorous species, seems to persist in the rainforest fragments, but their long-term survival hinges on the presence of canopy cover and contiguity, and food tree species in the fragments. Large tracts of undisturbed rainforest at altitudes greater than 800 m should be considered as strongholds for the conservation of this endemic small carnivore. However, a complete picture of the impact of rainforest fragmentation on small carnivores cannot be obtained based on a one-time survey. Regular, systematic monitoring, using a combination of methods (such as track plots, camera-traps, and scat counts) is likely to give a more reliable picture of the trends in their populations. This would help in planning management steps to be taken for conserving small carnivores, particularly the endemics that appear to be more affected by habitat alteration and degradation. These management steps may include protection and where necessary and feasible, planting food tree species in highly disturbed fragments, better protection for more promising, larger tracts of forests, and continued monitoring of the status of small carnivores.

6.6 SUMMARY

1. A combination of methods that included track plot, camera-trap, and spot-lighting (night walk and drives) surveys, and recordings of opportunistic sightings, provided reliable estimates of occurrences and relative abundances of small carnivores in tropical rainforests of the Western Ghats.
2. The overall success rates in track plots and camera-traps was lower (32.2% and 16.8%, respectively) in the rainforest fragments of the Anamalais than in the relatively undisturbed forests of KMTR (48% and 37.5%, respectively).
3. The brown palm civet was the most frequently occurring small carnivore in both KMTR and in the fragments in Anamalais. Brown palm civet occurrence was positively correlated with altitude. In KMTR, more than 88% of the success rate was due to brown palm civet, in both track plots and camera-traps, and this was significantly higher than the 50% in the rainforest fragments.
4. The brown and stripe-necked mongooses and small Indian civet were photo-trapped and sighted more often in the rainforest fragments than in the relatively undisturbed rainforests of KMTR. These species occurred in slightly disturbed or open areas within KMTR.
5. None of the habitat structural variables were significantly correlated to the success rates. However, the occurrence of food-tree species in some of the fragments is probably what determines the persistence of the highly frugivorous species like the brown palm civet even in highly disturbed fragments.
6. It is suggested that relatively large and undisturbed tracts of rainforests at higher altitudes, with a complete array of plant food resources and animal prey base would help in the long-term conservation of the Western Ghats endemics such as the brown palm civet and the Nilgiri marten.

TO CONCLUDE...

I will attempt to highlight the results dealing with the ecological needs of the brown palm civet, its role in the ecosystem, and the impact of rainforest fragmentation on small carnivores in the Western Ghats. Implications for the conservation of small carnivores in the Western Ghats are also discussed.

- The brown palm civet is a highly frugivorous species. Availability and abundance of ripe fruits varied between years, and civets adapted to fluctuations in fruit resources by feeding on a diverse range of species (55 species recorded during the study). Its year-round frugivorous diet is supplemented with much invertebrate and vertebrate food. The brown palm civet is a key mammalian seed disperser in the tropical rainforests of the Western Ghats by virtue of it being predominantly frugivorous, consuming a diverse array of species, and dispersing seeds without damage, unlike other sympatric, arboreal mammals in the region. It could play a major role in restoration of degraded rainforest patches along the Western Ghats.

- Among the small carnivores studied thus far, this species has the smallest ranges (6 – 57 ha). Body size and habitat quality, in terms of the number and species of food trees available, determine the area requirements of the species as in other carnivores. In the undisturbed rainforests of KMTR, 53% of the trees were food species. Although many species were clumped in distribution, their availability was high due to their abundance. Moreover, at least 3 to 6 civet food species were in fruit at a given time, and their small home range is a result of the resource-rich habitat they occupy. The brown palm civets also require day-bedding trees with high canopy contiguity and large trees in the vicinity. Although they ranged over small areas in undisturbed forests, they are likely to require larger areas in degraded and disturbed fragments. They may also face competition from other widespread and more omnivorous species like the small Indian civet in degraded and fragmented landscapes.

- A combination of methods that includes track plot, camera-trap, and spot-lighting (night walk and drives) surveys, and opportunistic sightings, can provide reliable estimates of occurrences and relative abundances of small carnivores in tropical rainforests, as shown by this study in the Western Ghats. Overall success rates were lower in the rainforest fragments of the

Anamalais than in the relatively undisturbed forests of KMTR. The brown palm civets are not as rare as they were thought to be. The brown palm civet was the most frequently occurring small carnivore in both KMTR and in the fragments in the Anamalais. However, they were more common in the undisturbed forests. Brown palm civets also occurred more frequently at higher altitudes. The mongooses and the small Indian civet, which are more omnivorous in their diet, were more common in the fragmented landscape of Anamalais. The common palm civets, which occur in the drier habitats surrounding the rainforests, may invade highly degraded, and open rainforest habitats, in a manner similar to that seen in birds and other small mammals, thereby competing with the brown palm civet.

- Structural parameters of the habitat cannot be used to predict the occurrence of small carnivores. At the scale of a habitat patch, the occurrence of food-tree species determines the persistence of highly frugivorous species like the brown palm civet even in severely disturbed fragments. At a larger scale, the occurrence of large tracts of rainforest in the landscape may also enable persistence in fragments through colonisation and dispersal events. It is suggested that relatively large and undisturbed tracts of rainforests at higher altitudes, with a complete array of plant food resources and animal prey base would help in the long-term conservation of the Western Ghats endemics such as the brown palm civet and the Nilgiri marten. As much rainforest in the Western Ghats occurs as fragments, increasingly so in recent times, it is necessary to target efforts into conservation of such vulnerable small carnivores even in small fragments as they can contain populations of these species. This can be achieved by a combination of protection and restoration efforts in degraded fragments.

- Little information exists on the small carnivores of the Western Ghats. It is time that more attention is paid to these diverse and elusive creatures to understand their importance in the ecosystem and their conservation status. Research on the ecology and behaviour of all small carnivores needs to be encouraged. Protection of large tracts of undisturbed habitats and key resources in disturbed areas will help in the conservation of small carnivores. This study is just a first step in understanding the ecology of a small carnivore. As mentioned earlier, they are a diverse group, and therefore, the requirements of this species cannot be used to predict that of the other small carnivores. Most of them, like the Nilgiri marten occur in very low abundances, and are likely to become rarer due to fragmentation and habitat loss. Research on this species will throw light on the adaptations of an otherwise temperate genus to tropical habitats. Surveys and studies of the distribution and occurrence of the Malabar civet, which is believed to be highly endangered or nearly extinct, have to be carried out. Research on the ranging pattern and feeding habits of the brown palm civet in rainforest fragments, including an assessment of their role in seed dispersal and recovery of rainforest vegetation in disturbed fragments, would be valuable. Another critical need is the estimation of abundances and distribution of small carnivores along the Western Ghats. This could be attempted using a combination of survey methods as used in this study, which forms a benchmark for the initiation of comprehensive long-term conservation monitoring program of small carnivores in the region.

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Appendix 1. The percent occurrence of seeds and other remains in scats of the brown palm civet in the tropical rainforests of Kalakad-Mundanthurai Tiger Reserve (1996–1999, *n* = 1013 scats collected from Kakachi, Kannikatti, and Sengaltheri; Sengaltheri only in 1998–99, *n* = 456 scats).

Species/items	**1996** (*n* = 116)	**1997** (*n* = 287)	**1998** (*n* = 222)	**1999** (*n* = 388)	**Sengaltheri**	
					1998 (*n* = 176)	**1999** (*n* = 280)
Acronychia pedunculata	0.00	9.67	9.30	4.24	10.1	5.16
Annonaceae sp.	0.00	0.00	0.00	0.05	0.00	0.00
Antidesma menasu	0.00	0.16	0.00	0.00	0.00	0.00
Artocarpus heterophyllus	10.3	1.26	0.66	1.01	0.50	0.95
Bentinckia codapanna	0.00	1.33	0.20	0.23	0.00	1.44
Bischofia javanica *	0.00	0.00	0.32	0.43	0.00	0.43
Calamus sp. (L)	0.00	0.28	0.20	0.00	0.33	0.00
Canthium dicoccum	0.00	0.00	0.00	3.35	0.00	3.35
Caryota urens	0.00	0.00	0.60	0.69	1.00	0.69
Chrysophyllum lanceolatum	4.39	2.26	2.34	3.52	2.32	3.10
Cullenia exarillata	0.00	0.93	0.00	1.14	0.00	1.63
Dimocarpus longan *	0.00	2.22	0.00	0.00	0.00	0.00
Diospyros sylvatica	1.11	2.51	7.82	0.69	8.34	0.69
Diospyros sp. 2	0.00	4.05	0.00	0.00	0.00	0.00
Elaeocarpus munronii	10.5	16.3	0.00	12.10	0.00	12.7
E. serratus *	0.00	3.04	6.13	9.45	6.58	9.76
Eleagnus kologa (L)	0.00	0.28	0.00	0.00	0.00	0.00
Embelia sp. (L)	0.00	2.88	0.16	0.24	0.33	0.24
Ensete superbum (S) *	2.85	1.19	3.25	1.07	2.76	1.07
Erycibe wightiana (L)	0.00	0.00	0.00	0.34	0.00	0.37
Euonymus angulatus	0.00	0.00	0.00	0.69	0.00	0.69
Fagraea ceilanica	0.00	1.19	0.00	1.46	0.00	1.77
Ficus spp.*	4.34	3.02	1.60	9.31	1.53	9.09
Filicium decipiens *	0.00	0.37	0.60	1.67	1.00	1.67
Gnetum ula (L) *	0.00	7.53	7.31	1.68	8.04	1.62
Holigarna nigra *	23.1	0.99	9.86	4.11	9.86	4.26
Knema attenuata	0.00	1.54	0.00	0.00	0.00	0.00
Lepisanthus decipiens	0.00	0.00	0.00	1.13	0.00	0.00
Liana sp. 1 (L)	0.00	0.00	0.00	1.97	0.00	1.97
Ligustrum perrottetii	0.00	0.00	0.00	0.69	0.00	0.69
Nothopegia beddomei *	19.2	0.00	3.33	0.50	3.46	0.53
Olea dioica	0.00	0.00	0.00	0.75	0.00	0.75
Palaquium ellipticum *	0.00	3.72	14.4	0.37	15.1	0.15
Pandanus sp. *	0.00	4.72	0.00	0.82	0.00	0.84
Pinanga dicksoni	0.00	0.16	0.00	0.00	0.00	0.00
Rutaceae sp. (L)	0.00	1.89	0.00	0.00	0.00	0.00
Sapotaceae sp.	0.00	0.00	0.00	0.75	0.00	0.69
Semecarpus auriculata	0.00	0.65	0.00	3.63	0.00	0.00
Solanum sp.	0.00	2.22	0.00	0.65	0.00	0.68
Strychnos colubrina (L)	0.00	0.00	0.00	4.25	0.00	4.25
Strychnos sp. 2	0.00	0.00	0.00	0.05	0.00	0.00
Syzygium cumini/mundagam	0.00	0.00	0.00	0.37	0.00	0.45
Syzygium zeylanicum	5.93	0.48	0.00	0.00	0.00	0.00
Tricalysia apiocarpa *	0.00	0.00	2.11	0.00	1.15	0.00
Viburnum punctatum *	0.00	0.00	0.00	0.99	0.00	1.30
Vitaceae sp. (L) *	0.00	0.00	2.84	0.97	2.84	0.43
Zizyphus sp.	0.00	10.00	0.00	0.05	0.00	0.36
Banana (P)	0.00	0.00	1.21	0.42	1.42	0.42
Eletteria cardamomum (P)	0.00	0.09	0.00	0.12	0.00	0.15
Coffea arabica (P) *	3.96	4.52	4.73	4.26	5.24	4.56
Psidium guajava (P)	0.00	0.00	1.96	1.34	1.96	1.34

Species/items	**1996** (*n* = 116)	**1997** (*n* = 287)	**1998** (*n* = 222)	**1999** (*n* = 388)	**Sengaltheri** **1998** (*n* = 176)	 **1999** (*n* = 280)
Grass	1.42	0.58	1.02	1.01	1.02	0.95
Unknown plant matter	9.63	2.67	3.51	1.21	2.33	1.16
Other mammalian hair	0.00	0.70	3.00	1.80	3.26	1.98
Malabar spiny dormouse	0.00	0.28	2.24	0.06	0.00	0.06
Crab	0.88	0.91	0.00	0.11	0.00	0.00
Insects	1.42	2.08	7.46	11.00	6.23	12.1
Millipede	0.71	0.56	3.45	2.76	2.52	3.06
Centipede	0.00	0.00	0.25	0.00	0.25	0.00
Feather	0.41	0.00	0.20	0.00	0.33	0.00
Scales	0.00	0.00	0.00	0.06	0.00	0.06
Snail	0.00	0.00	0.00	0.06	0.00	0.06
Bees wax	0.00	0.09	0.00	0.00	0.00	0.00
Unknown animal matter	0.00	0.62	0.00	0.05	0.00	0.00

* Species viable even after ingestion by brown palm civets, L – liana.

Appendix 2. Characteristics of species eaten and not eaten by brown palm civets in KMTR.

#	Species (Eaten), dispersers	Plant form	Fruit type	Fruit size* (cm)	Pulp	Pulp dryness	Colour	Odour	Resin	Seed type	Shape of seed	# of seeds	Seed size* (cm)
1	*Filicium decipiens* 1,2,3	Tree	Drupe	1.25/ 0.9	M	M	Purple	N	N	Soft	Ovoid	1	1/ 0.8
2	*Dimocarpus longan* 2,3	Tree	Arillate nut	1/1	M	W	R-Br	N	N	Stony	Globose	1	0.8/ 0.8
3	*Gnetum ula* 2,3	Liana	Drupe	2.75/ 2.25	T	D	Purple	N	N	Stony	Ovoid	1	2.25/ 1.5
4	*Elaeocarpus serratus* 1,2,3,4	Tree	Drupe	2.5/ 2.25	T	W	Green	Y	N	Stony	Ovoid	1	2/ 1.5
5	*E. munronii* 1,2,3,4	Tree	Drupe	1.5/0.9	M	M	Purple	Y	N	Stony	Ovoid	1	1.2/ 0.6
6	*Chrysophyllum lanceolatum* 2	Tree	Berry	4/4	T	W	Yellow	N	Y	Stony	Ellipsoid	3-5	2/ 1.25
7	*Palaquium ellipticum* 2	Tree	Drupe	3.5/ 2.25	T	W	Green	N	Y	Soft	Ellipsoid	1	2.5/ 1.25
8	*Holigama nigra* 2	Tree	Drupe	3/1.5	T	W	Green	N	Y	Soft	Ellipsoid	1	2.5/ 1.25
9	*Semecarpus auriculata* 2,3	Tree	Drupe	1.5/1	T	W	Orange-red	N	Y	Soft	Globose	1	1/ 0.5
10	*Knema attenuata* 1,2,3	Tree	Arillate	2.75/ 2.25	T	W	Red	N	N	Stony	Ovoid	1	2.3/ 1.6
11	*Bischofia javanica* 1,2,3	Tree	Berry	1/0.9	T	W	Brown	N	N	Soft	Ovoid	3-5	0.4/ 0.2
12	*Artocarpus heterophyllus* 2,3	Tree	Sorosis	30/25	T	W	Green/ yellow	Y	Y	Stony	Ovoid	1/ many	2.5/ 2.25
13	*Embelia basaal* 2, 1?	Liana	Drupe	1.5/1.5	M	M	Brown	N	N	Stony	Globose	1	0.75/ 0.75
14	*Diospyros sylvatica.* 1 2,1?	Tree	Berry	2/2	M	M	Green-Yellow	N	N	Stony	Ellipsoid	4-7	1.2/ 0.6
15	*Diospyros* sp. 2 2, 1?	Tree	Berry	4/4	T	M	Brown	N	N	Stony	Ellipsoid	3-5	3/ 2.5
16	*Tricalysia apiocarpa* 2,1?	Tree	Berry	1/0.75	Thin	W	Yellow-or.	N	N	Soft	Ellipsoid	2	0.9/ 0.7
17	*Canthium dicoccum* 2,1?	US-tree	Drupe	1.75/ 1.25	M	M	Green	N	N	Stony	Ovoid	1	0.8/ 0.5
18	*Acronychia pedunculata* 2	US-tree	Drupe	1.5/1.5	T	W	Green	Y	N	Stony	Globose	1	1/ 1
19	*Antidesma menasu* 1,2,3	US-tree	Berry	<0.5/ 0.5	M	W	Pink	N	N	Soft	Ovoid	2/ many	0.25/ 0.25
20	*Ficus* Spp. 1,2,3,4	Tree	Syconus	0.5-3.5/ 0.5-3.5	T	W	Yellow-Green	N	N	Soft	Globose	Many	0.1/ 0.1
21	*Fagraea ceilanica* 2	Tree	Berry	5/2.5	T	W	Green	N	N	Soft	Ovoid	Many	0.5/ 0.3
22	*Ensete superbum* 2,4	Shrub	Berry	8/2.5	T	W	Yellow-green	N	N	Stony	Angled	Many	0.5/ 0.5
23	Rutaceae sp.	Liana	Berry	<1	T	W	Blue-green	Y	N	Stony	Ellipsoid	Many	0.3/ 0.2
24	*Bentinckia codapanna* 2	Tree	Drupe	2/2.25	M	W	Red	N	N	Stony	Globose	1	1.75/ 1.75
25	*Caryota urens* 2	Tree	Berry	2/2.25	M	W	Green	N	N	Stony	Ellipsoid	2	1.75/ 1
26	*Pinanga dicksoni* 2	US-tree	Drupe	1/0.75	M	D	Green	N	N	Soft	Ovoid	1	0.75/ 0.5
27	*Pandanus* sp. 2,4	Shrub	Sorosis	10/8	Thin	W	Green	N	N	Soft	Ellipsoid	Many	3/ 0.4
28	*Calamus* sp. 2,3	Liana	Arillate	1/0.5	Thin	W	Yellow-green	N	N	Stony	Ovoid	1	0.8/ 0.4
29	Vitaceae sp. 2	Liana	Berry	2/2	T	W	Yellow-green	N	N	Soft	Pyriform	3-5	0.75/ 0.4
30	*Syzygium* spp. 1,2,3,4	Tree	Drupe	1/0.5-0.75	M	M	Purple	N	N	Stony	Ovoid	1	0.75/ 0.5
31	*Nothopegia beddomei* 2,3	US-tree	Drupe	1/1.25	M	W	Yellow	N	Y	Soft	Ovoid	1	0.75/ 1
32	*Ligustrum perrottetii* 1,2	US-tree	Drupe	0.75/ <0.5	M	W	Purple	N	N	Soft	Ellipsoid	1	0.5/ 0.4
33	*Lepisanthus decipiens* 2	US-tree	Arillate	3.5/3	M	W	Green	N	N	Soft	Ovoid	1-2	1.25/ 1
34	*Strychnos* sp. 1,2	Liana	Berry	1.5/ 1.5	T	W	Green	N	N	Stony	Discoid	4-6	1/ 1
35	*Erycibe wightiana* 2,1?	Liana	Drupe	1.5/1	M	W	Black	N	N	Soft	Ovoid	1	1.2/ 0.75

#	Species (Not Eaten), dispersers	Plant form	Fruit type	Fruit size (cm)	Pulp	Pulp dryness	Colour	Odour	Resin	Seed type	Shape of seed	# of seeds	Seed size (cm)
1	*Cryptocaria bourdillonii* 1	Tree	Drupe	1.5/1	M	W	Purple -black	Y	N	Stony	Ovoid	1	1.4/ 0.9
2	*Cullenia exarillata* 3	Tree	Capsule arillate	10/10	Thin	D	Green	N	N	Stony	Ellipsoid	10-12	3/ 2.5
3	*Harpullia arborea* ?	Tree	Capsule arillate	2/4	Thin	D	Red	N	N	Stony	Ovoid	2	2/ 2
4	*Aglaia* sp. 3	Tree	Aillate	1.5/ 1.25	Thin	W	Brown	N	Y	Soft	Ovoid	1-2	1.4/ 1
5	*Mangifera indica* 3	Tree	Drupe	7/5	T	W	Green	Y	Y	Stony	Ellipsoid	1	5/3
6	*Hydnocarpus alpina* 3,4	Tree	Berry	5/5	T	D	Brown	N	N	Stony	Globose	Many	1.5
7	*Litsea glabrata* 1,3	Tree	Drupe	2.5/ 1.75	M	W	Pink-red	Y	N	Soft	Globose	1	1.25
8	*Myristica dactyloides* 1,3	Tree	Capsule Arillate	4/2.5	Thin	W	Yellow Brown	N	N	Stony	Ovoid	1	3.8/ 2.4
9	*Symplocos macrocarpa* 1	Tree	Drupe	3/2.3	T	W	Blue	N	N	Stony	Ovoid	1	2.5/ 1.25
10	*Alseodaphne semecarpifolia* 1	Tree	Drupe	3/1.5	M	W	Purple	Y	N	Stony	Ovoid	1	2.8/ 1.3
11	*Cinnamomum* sp. 1	Tree	Drupe	1/0.5	M	M	Purple	Y	N	Soft	Ovoid	1	0.8/ 0.4
12	*Calophyllum austroindicum* ?	Tree	Drupe	1.25/1	M	M	Green	N	N	Stony	Ovoid	1	1/ 0.75
13	*Holigama amottiana* ?	Tree	Drupe	2/1.5	M	M	Green	N	Y	Soft	Ellipsoid	1	1.75/ 1.25
14	*Ormosia travancorica* ?	Tree	Pod	5/2.5	A	D	Brown	N	N	Stony	Globose	1	1.25/ 1.25
15	*Syzygium mundagam* 1,4	US-tree	Drupe	2.5/2.5	T	W	Green-pink	N	N	Soft	Globose	1	2.3/ 2.3
16	*Xanthophyllum flavescens* 3,4	US-tree	Drupe	1.25/ 1.25	M	W	Green	N	N	Soft	Globose	1	1.2/ 1.2
17	*Mastixia arborea* 4	Tree	Drupe	3.5/2	M	W	Purple -black	N	N	Stony	Ellipsoid	1	3.1/ 1.8
18	*Casearia rubescens* 1,3?	Tree	Capsule arillate	2/1	Thin	W	Orange-red	N	Y	Soft	Angled	6-8	0.25/ 0.25
19	*Neolitsea* sp. 1	Tree	Drupe	2.25/2	M	M	Purple	Y	N	Soft	Ovoid	1	2.1/ 1.9
20	*Canarium strictum* 1	Tree	Drupe	4/2.5	M	W	Purple	Y	N	Stony	Ellipsoid	1	3.6/ 2.1
21	*Scolopia crenata* ?	Tree	Berry	2/2?	M	M	Green	N	N	Stony	Globose	2-6	1.5/ 1.5
22	*Eugenia thwaitesii* ?	US-tree	Berry	1/1	M	M	Green-pink	N	N	Soft	Globose	1	0.9/ 0.9
23	*Beilschmedia gemmiflora* 1	Tree	Drupe	4/2	T	W	Purple	Y	N	Stony	Ovoid	1	3.4/ 1.6
24	*Elaeocarpus tuberculatus* 4	Tree	Drupe	3.5/2.5	T	W	Green	N	N	Stony	Ellipsoid	1	3/2
25	*Mesua ferrea* 4?	Tree	Capsule	5/5	T	D	Green	N	Y	Stony	Globose	1-4	4/4
26	*Vepris bilocularis* 3	Tree	Drupe	0.75/ 0.5	T	W	Green	Y	N	Stony	Ovoid	1	0.25/ 0.25
27	*Epiprinus mallotiformis* 4?	US-tree	Capsule	2/1.75	M	M	Green-grey	N	N	Stony	Globose	3	0.5/ 0.5
28	*Glycosmis pentaphylla* 1,3,4?	Shrub	Drupe	1/1	M	W	Pink	Y	N	Soft	Globose	1	0.75/ 0.75
29	*Agrostistachys borneensis* ?	US-tree	Capsule	2/1.5	M	M	Green	N	N	Stony	Globose	5-8	0.4/ 0.4
30	*Connarus wightii* ?	Liana	Follicle	2.5/1	Thin, arillate	D	Red	N	N	Stony	Ovoid	1	1/1?

Disperser: 1 = birds, 2 = civets, 3 = lion-tailed macaque, 4 = others, ? = not known; * fruit and seed size measured as length/width.

Appendix 3

INDIVIDUAL ACCOUNTS OF THE RADIO-COLLARED BROWN PALM CIVETS IN SENGALTHERI, KMTR

K70—sub-adult male

He was tracked for eight months. His total home range size was 18.04 ha (100% MCP) and 11.24 ha (95% MCP). His ranging area during the period of activity was 16.2 ha and 11.25 ha (100% and 95% MCP), while the inactive/resting range was about 10.2 ha (Fig.2). The core home area was c. 2.9 ha (60 % HM). Although there was considerable overlap between his activity range and the inactive/resting range, the difference in sizes indicate the use of particular parts of the range to day-bed/rest. The average distance moved between two consecutive locations by K70 was 126 m, and the distance moved during active periods was greater (182 m) than the average distance between resting/inactive locations (144 m). This individual was re-captured to replace the old collar, and then was found to have some wounds. During this phase of tracking, he was found to be active earlier during the day than usual, and was once found to be resting under a rock ledge on the ground. An Indian python (*Python molurus*) predated upon this animal. The home range of B88 partially overlapped with K70 in the month of August 1998. A part of his home range also spatially overlapped with that of M94.

P80—adult male

This individual was tracked for a period of four-and-a-half months. He ranged over an area of about 10 ha. His resting range size was about half of his entire range (4.9 ha), and his activity range (8.95 ha) was only slightly smaller than his entire range size. 1.4 ha formed the core of his range. He had the smallest core area when compared to the other collared animals in the study. His average movement between locations was about 104 m, and like in others, the average distance moved during active periods was greater (130 m) than average distance between the consecutive inactive locations (105 m). On an average, he moved the least during the southwest monsoon (98.5 m). The transmitter of this individual ceased working prematurely and he could not be located thereafter or be recaptured. P80's home range spatially overlapped only with that of M94.

S84—young adult female

She was radio-tracked for a period of eight and a half months, initially for 6 and then recaptured after 3 months and re-collared (to replace the old one) and followed for two-and-a-half months more. She had a smaller home range (17.55 ha) than that of the sub-adult K70. She had one of the larger core areas (as a proportion of the total HRS) of 3.8 ha probably due to the presence of lower food tree species within her range. Her home range was completely overlapped by that of the adult male

B88. Her resting range was also larger when compared to that of the other individuals. The average distance between her locations was 154.7 m, with both the activity distance and the average distance between resting locations being larger (172.4 m and 161.3 m respectively). She moved the shortest distance during the southwest monsoon (143.8 m). Her home range also partially overlapped with that of BM76, a juvenile male. Both times her transmitters stopped working prematurely. When she was recaptured in April 1999, she seemed to have littered as her nipples were swollen (one very prominently so).

B88—adult male

He had the largest home ranges of all the radio-tracked brown palm civets (four-and-a-half months). This was mainly due to an almost complete range shift about 2 months after he was collared. His range of 56.3 ha overlapped entirely that of the adult female S84. They were also located very close to each other both during the day and night in the month of September. His activity range had two centres and his resting range (48 ha) was larger than his activity range (43.2 ha). The average distance moved by him was much larger than the other individuals (263.9 m), and his activity and resting ranges were highly, positively correlated to the average distance moved (r_S=0.909, df=5, p<0.01). His range also overlapped with that of K70 (both spatially and temporally) and with M94 (spatially alone). He was captured at the same site as K70. He was the only animal that exhibited a prominent range shift during the study.

M94—adult male

He was tracked for a period of six months in 1999. His tracking period did not overlap with that of the other collared individuals. He was captured the first time in March 1999, but he dropped his collar the very next day. He was recaptured two and a half months later and re-collared. He occupied the area encompassing an old, abandoned cardamom plantation. Therefore, the relatively large area of 33.2 ha that he occupied could be related to his sex, body size, as well as a relatively disturbed habitat, with lower tree densities than the other ranges but compensated by very large trees (greater basal area than in the other ranges). His resting range (17.05 ha) was only half that of his activity range (30.85 ha). He used some parts of the range of K70 (after K70's death). The average distance moved by him either during the activity period (200.3 m), or between resting sites (228.8 m) or in the southwest monsoon (267.3 m) was not very different from each other, although the distance moved during the southwest period was the largest unlike for other animals.

K82—adult female

An adult female, K82, was located only 14 times during the two weeks that she could be monitored.

She used an area of 6.3 ha (N=14) during this period. She differed from all the other individuals in her activity rhythm by being diurnal. She was captured during the day and was found to be active over most of the day and resting at night. She had a number of injuries when captured (inflicted earlier, presumably due to intra- or inter-specific aggression and unrelated to the capture itself) and was generally in poor condition. Her activity rhythm change was probably a result of that. After 20 days, she disappeared and her signal was not heard although a thorough search was carried out. Three months later, her skeletal remains were found intact in a rock crevice. The animal had presumably succumbed to her injuries.

BM76—juvenile male

This was the smallest brown palm civet that was collared, but was followed for a very short period of time as he dropped his collar within a month. In the one month that he was tracked, he ranged over an area of 7.3 ha, and had a core range of 0.4 ha. My suspicion was that he was still a dependent and stayed with his mother. Once when he was homed-in on, another larger, uncollared individual fled out of the hollow that BM76 was resting in. His home range slightly overlapped with that of S84, B88, and K70. During this period, the distance moved by him between the consecutive locations was very small (average = 93 m).

Summary

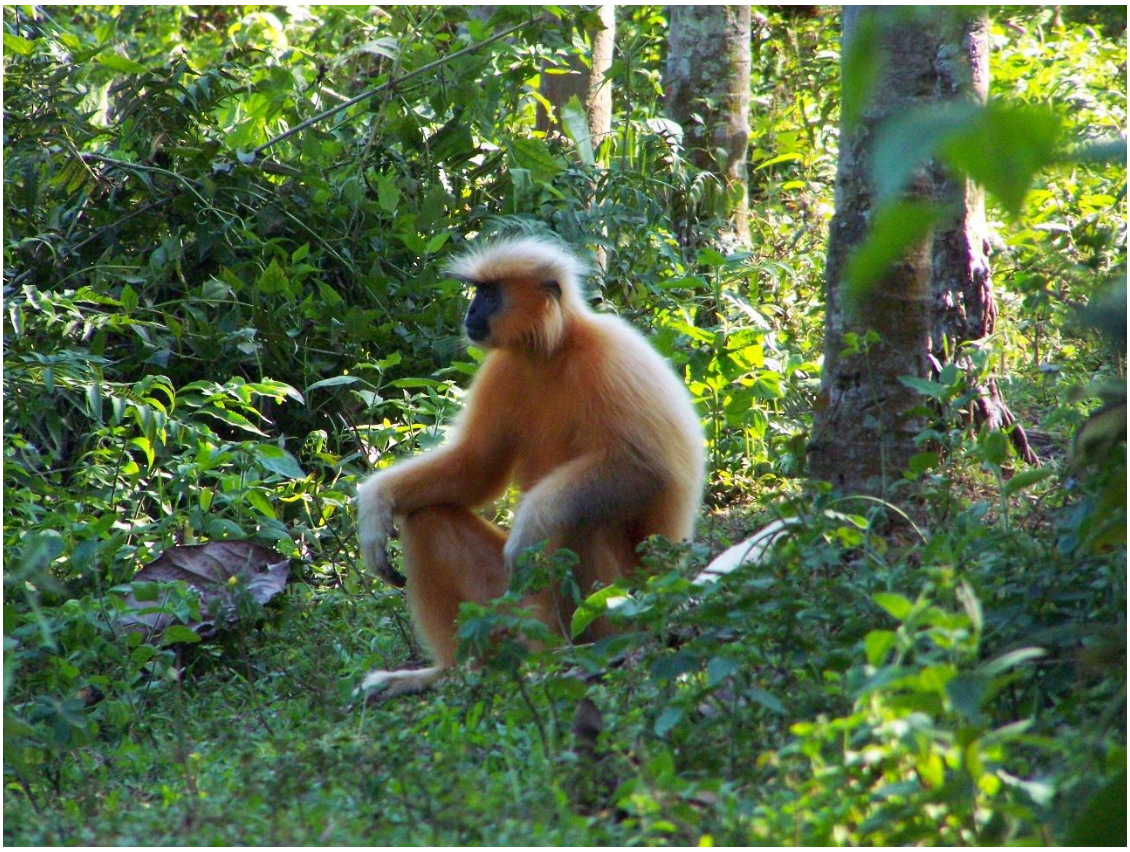
Summary

Golden langur (*Trachypithecus geei*) is an endangered and endemic leaf-eating monkey of Eastern Himalaya. The distribution of the southern population of India is restricted to small, isolated fragments. The langur is a forest specialist yet shows some extent of behavioural plasticity which helped them to continue to exist in degraded and altered habitats. Anthropogenic activities like logging, agriculture, human settlements, road and railway networks and other infrastructure built-ups resulted in habitat loss and fragmentation of its habitat that has pushed the species to explore human habitation, rubber plantation and other matrix patches which eventually make them vulnerable to threats like electrocution, dog attack and poaching. Though these negative impacts prevail, still the Golden langur persists in the forests of Chakrashila WLS and Abhaya RP. Chakrashila WLS retain a relatively stable population and also shows slow growth than in rubber plantation where a high fluctuation of population density has been observed over the few decades. Rubber plantations are an important part in connecting fragments and providing corridors for the Golden langur. These plantations are the preferred corridor and refuge of the langurs because of their tall height and continuous canopy cover which provide protection and keep the area at a lower temperature.

The group size of Golden langur depends on habitat conditions and resource availability. Forest core groups had a smaller mean group size than forest edge and rubber plantation groups. In forest edge, the group had the option to access more diverse food plants since edges are ecotones where diversity is always expected to be higher than either core inside or completely outside. The Golden langur group could access both forest plant species and species which are cultivated or grown in the home garden. To explore such diverse food plant species, nearby groups also look for the opportunity to get access to the resources. To defend territory from conspecific, groups in edges are expected to be larger. Larger group sizes are also benefitted during vigilance due to more individuals. On the other hand, groups in the rubber plantation maintained larger group sizes due to high population density to avoid intergroup conflicts by forming a few larger groups than many smaller groups. In forest core areas folivores like Golden langurs can form larger groups since leaves are evenly distributed and food cannot be a factor to limit group size. Yet in a habitat where there is no choice to access exotic food plant species or scrambled competition is not required, group sizes are small, as small groups are more socially stable and less prone to intragroup conflicts. Golden langurs give births throughout the years but maximum in monsoon. In a moist and mixed deciduous forest, leaves are more abundant during monsoon, which can provide calory requirement during gestation period or compensate for the energy loss in the post gestation period. The immature survival rate was high since infanticide is not common in Golden langurs and these fragments also have fewer predators.

In the three habitat types of Golden langur, the tree cover and species composition were different. Forest edge and forest core had more similarities than the rubber plantation. Basal area in forest core was found less because of less abundance of matured trees since the area is disturbed to some degree by selective logging. On the other hand, forest edge includes many cultivated plant resources resulting in densely distributed moderately matured trees. Rubber plantation has more basal area compared to the tree density since rubber is the predominant species planted uniformly and have more girths. The number of plant species consumed by forest core group, forest edge group and rubber plantation group are not very different in species number but species composition. Food plant species are different in the rubber plantation than forest edge and forest core. The forest edge group can access the plants in the village which adds some other food plant species to their diet. To maintain the microbial environment for food fermentation in the forestomach, colobines need to eat a substantial quantity of leaves. Forest core group and edge group consumed leaf in high quantity during pre-monsoon season when new foliage is usually more abundant. For fermentation of the leaves, they also need more resting time than travelling. The group in rubber plantations spent more time on locomotion to access the scarcely distributed patches of food resources by minimising resting time compared to the other two groups. The dispersion and abundance of food influenced the daily activity pattern including ranging behaviour. Comparison of seasonal and annual mean day path length and home range size of Golden langur in three different habitat conditions suggest an increased day path length and home range size in the more disturbed area. Home-range use was highest in the rubber plantation group followed by forest edge and forest core group. Seasonal variation in size and space of home range is observed in the three groups. The habitat condition and food availability affect their ranging pattern. In the rubber plantation, food plant availability is less and patchily distributed, which forces the Golden langurs to travel more and expand their home range over the other two groups.

The social organisation and ecology of Golden langurs is dependent on food resources and roosting trees available in the habitat and continuity of the forest patches in the habitat. The comparative study of Golden langur shows the relationship between habitat type and activity and ranging pattern. Group size is another factor that influences the space used to access more resources by increasing travel time for foraging to reach the patchily distributed isolated food resources. The adjustment of annual and seasonal budget and daily activity patterns of Golden langurs in different habitats with variable size and disturbance gradient suggests that fragment size and habitat characteristics influence the activity and ranging pattern. Though the species has some degree of plasticity to adapt in degraded and altered habitat, for the persistence of viable population the remaining natural habitats need to be protected. As a long-term conservation strategy, the fragments need to be connected through the regeneration of required plant resources for effective migration and gene flow.



(Male Golden langur monitoring from the ground)

Appendix 4

OBSERVATIONS OF SMALL CARNIVORES IN KMTR, WESTERN GHATS, INDIA

When conventional methods of estimations of either their numbers or occurrences of small carnivores do not give comprehensive results, casual or opportunistic sightings have to be used as supplementary data to deduce their behaviour and habits. This, therefore is a compilation of all the direct sightings (during casual walks and drives) in Kalakad-Mundanthurai Tiger Reserve, of non-radio collared small carnivores. All the sightings are not necessarily by me. Sightings by my research colleagues were also recorded in detail. Most of the observations are from the three sites within the reserve that were surveyed intensively—Kannikatti, Sengaltheri, and Kakachi—between May 1996 and December 1999.

Observations

We had a total of 14 sightings of brown palm civet, 12 of Nilgiri marten (*Martes gwatkinsi*), 10 of small Indian civet (*Viverricula indica*), 4 of leopard cat (*Prionailurus bengalensis*), 4 of brown mongoose (*Herpestes fuscus*), and otters were seen eight times.

Almost all the sightings of **brown palm civet** were after dusk/sunset. Only once, we found an injured animal during the day by the road. During the radio-telemetry study, it was observed that the animals which were strictly nocturnal, became diurnal when injured or ill.

Of the 14 sightings, we once saw two individuals together on the same tree (in July 1998). All the other sightings were of solitary individuals. Seven sightings were of animals on trees or lianas. They were either moving (4), resting (2), or calling (1). Though they are predominantly arboreal, observed moving long distances along the canopy, they were often seen on the ground, as the success in trapping and camera-trapping (done on the ground) suggests. They did not move away when they were sighted on trees or liana (*i.e.*, above ground). However, they usually disappeared without a trace when seen on the ground. Two of the sightings was of trapped, un-collared, non-target individuals within the home ranges of the collared animals. Smaller individuals (< 1 kg body weight) were sighted between August and January. Once, when a young male (900 g) was trapped (in May 1999), we saw yet another individual very close by on a tree. Sighting of unmarked individuals within the territories of collared male and female brown palm civets was not uncommon. They were easily attracted to track plots baited with banana. Two of the sightings were near such baited track plots.

The colour variation among individuals was very high. It ranged from being a uniform dark brown to grizzled, and even rarely golden. Animals both with and without a white tail tip were seen. This species vocalises. The call of the brown palm civet is a prolonged, loud and shrill moan. Very often, more than one call was heard. The calls were most frequently heard at night after August and until December. The call was either a single long, moan, or sometimes had two notes. The calls echoed in the valley.

The brown palm civet was the most frequently seen small carnivore. It is probably not as rare as it was previously believed to be, at least in relatively undisturbed rainforests. They were most common (based on camera-traps, scats, and direct sightings) at altitudes above 1000 m, although they were seen in lower altitudes (700 m) of Kannikatti also. Being a highly frugivorous and arboreal species, habitat/rainforest fragmentation is likely to have adverse effects on their abundance.

The **small Indian civet** was sighted very rarely within the rainforest. They were mostly seen near the garbage dump close to base camp, or in and around tea plantations (Manjolai Estates, Bombay Burma Trading Corporation) within the tiger reserve. They were not photo-trapped frequently in the rainforests, but were the most photo-trapped species in grasslands and in a riverine patch (Koovapatti, 850 m) which had a narrow connectivity to the rainforests of Sengaltheri. Brown palm civet was also photo-trapped in this site, although only once, unlike in the rainforests where it was the most common. Nine individual small Indian civets were sighted 10 times during this period, all at night, including one sighting in a dry deciduous forest (Mundanthurai, 200 m). This individual was observed for nearly fifteen minutes, when it was feeding on insects on the ground, and was seen scent marking on the shrubs. Small Indian civets are also nocturnal, but unlike the brown palm civets, seem to forage on the ground, and are more insectivorous.

The **brown mongoose** is relatively rare. It was photo-trapped only twice, both times at night. They were sighted either late in the evening or at night. Fresh droppings of the brown mongoose were seen in the mornings. They also frequented garbage dumps near one of our base camps. They liked to feed on groundnuts which were used to bait rodents during the study. They could be approached closely. They preferred the groundnuts, and did not eat the bananas and boiled chicken egg, placed along with it. An individual that was feeding on the bait, gave a guttural growl when approached, and left the place only after eating all the groundnuts.

The brown mongoose has a bushy, conical tail. The feet are black and the pelage a dark brown. This species was sighted only in or close to rainforests within KMTR. In contrast, the **ruddy mongoose** *H. smithii* was a common species of the dry deciduous forests. They were often seen in pairs and sometimes even in groups of four or five animals on the Mundanthurai plateau (Mahesh

Sankaran, *personal communication*). They are a lighter brown in colour, with a tinge of rufous on the ventral side and a black tip to the tail. The tail tip is usually held up. They seem to be more diurnal than the brown mongoose.

The **Nilgiri marten** was seen often in KMTR. This reserve is probably a strong hold for the species. We had 12 sightings over the 3½ years in KMTR. It has been previously seen at altitudes as low as 350 m (in moist deciduous forests adjoining wet evergreen forests in Srivilliputtur, Justus Joshua *personal communication*). In KMTR, they have been sighted between 550 m and 1350 m. Five of the 12 sightings were of pairs. Four times they were seen on trees—twice moving, and the other two times resting. They were also seen feeding on or chasing mouse deer (*Tragulus minima*). Once it was seen chasing a monitor lizard (*Varanus bengalensis*). When encountered, they usually gave a spitting snarl and moved away. The paired individuals were seen in the months of September, and between December and February.

They were mostly black in colour, with a pale to orange-coloured throat patch. Their gait is typical of the weasel members. They could easily be mistaken for the Malabar giant squirrel (*Ratufa indica*) that occurs in these forests because of their colour and size. However, the Nilgiri marten has a short black tail that is not as bushy as that of the giant squirrel. Once, in order to avoid us, a marten entered a tree hollow, out of which glided a large brown flying squirrel (*Petaurista philippensis*). All the sightings of marten were between 0630 h and 1800 h. They were seen near streams on four occasions. These animals are probably more wide ranging and carnivorous than the brown palm civets. Attempts to capture them using live chicken, rodents, or fruits failed, although they seem to be as common as the brown palm civets. They are known locally as *mara nai* or tree dog and sometimes as *kombu kuduka* as they are believed to hang below a branch in wait of prey. No ecological study of the species has been so far carried out.

Otters were seen eight times. Four times they were seen in pairs, once in a group of four, and the other sightings were of solitary individuals. Only twice they were seen walking on the trail by the river. The other sightings were of animals swimming or feeding in the rivers. Three of the sightings were during the day. One of these was of a pair feeding (probably on fish) in a pool in a river early in the morning (0630 h), and another of a pair under a rocky outcrop, giving an alarm call (probably on seeing us at 1130 h). Otter spraints were common along the streams in the reserve. The species could not be identified decisively. The smooth coated otter (*Lutrogale perspicillata*) occurs in the reservoirs and rivers (Karaiar and Servalar) in the drier parts of the reserve.

We had five sightings of four **leopard cats** over the study period. Three of the sightings were during the night, all in rainforests. They seem to be relatively rare. The individual seen during the day was seen twice, on consecutive days. It had a cloudy left eye, and could therefore be identified. It was seen resting on a trail at about 1745 h and again the next morning at 0900 h, about 250 m from the previous sighting. These animals also probably switch their activity rhythms and become diurnal like the brown palm civets, when injured.

Other carnivores in the rainforests are the leopard, dhole, tiger and sloth bear. In the drier forests, the small Indian civet was the most common small carnivore sighted, followed by the ruddy mongoose and the common palm civet *Paradoxurus hermaphroditus* in Mundanthurai (Mahesh Sankaran *personal communication*). Jungle cat *Felis chaus* and rusty spotted cat *F. rubiginosus* were seen on a few occasions in the wooded grasslands of Thalaiyanai, at the base of the Kalakad hills.