IMPACT OF RAINFOREST FRAGMENTATION ON SMALL MAMMALS AND HERPETOFAUNA IN THE WESTERN GHATS, SOUTH INDIA

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EXECUTIVE SUMMARY

BACKGROUND

The Western Ghats in peninsular India is a biodiversity hot spot, primarily due to the tropical rainforest that it supports. Species richness and endemism are particularly high among plants, small mammals, amphibians, and reptiles. The forest in the Western Ghats has been severely fragmented due to human activities, especially clear felling for tea, coffee, and teak plantations during 1860 to 1950. Due to habitat fragmentation and high human densities, the Western Ghats is considered one of the 8 most threatened biodiversity hot spots of the world. The impact of habitat fragmentation differs among species depending on their biology, ecology and social behaviour. Species that are rare, endemic and habitat specialists are more adversely affected and tend to be lost faster than other species. Similarly, more complex and species rich habitats like the tropical rainforest are much more adversely affected than other habitats. This project aimed to assess the changes in the communities of amphibians, reptiles, murid rodents, shrews and small carnivores in the rainforest in the Western Ghats due to habitat fragmentation.

OBJECTIVES

In the first phase of the project (1996-2000) we attempted to understand the distribution and ecology of the target taxa in the continuous stretch of rainforest in Kalakad-Mundanthurai Tiger Reserve. The second phase (1997-2000) was a study in rainforest fragments in the Anamalai Hills. The specific objectives of the project were:

- To examine the community structure and ecology of the target taxa in relatively undisturbed forests in terms of *species richness, abundance,* and *relative abundance,* and factors governing them.
- To identify the nature and extent of changes in communities in forest fragments and habitat correlates of such changes.
- To identify implications for conservation and research.

STUDY AREAS

The Kalakad-Mundanthurai Tiger Reserve (KMTR) is at the southern extremity of the Western Ghats, and covers about 895 km^2 in area. The rainforests occur above 600 m. KMTR and the adjoining wildlife sanctuaries in Kerala State have about 400 sq.km of relatively undisturbed and continuous rainforests, one of the few such areas left in the Western Ghats. In KMTR, the sampling centered on three sites - Kannikatti (700 m), Sengaltheri (1,000 m), and Kakachi (1,300 m), which represented the altitude and climatic regime in the Reserve.

Anamalai Hills is a typical representative of the extent to which the rainforest has been lost and fragmented in the Western Ghats. Clear felling, initially for planting tea, began in the 1860's and continued up to the 1970's. Most of the remaining rainforest fragments falls either within the Indira Gandhi Wildlife Sanctuary, or in privately owned coffee and tea estates that almost entirely cover the Valparai valley. Nearly 30 such fragments were identified, of which 14 were selected for sampling, representing the variability in area, matrix around the fragment and disturbance levels. The fragments, in an altitudinal range of 700 m to 1,500 m, and ranged from 1 ha to 2,500 ha in area.

METHODS

Sampling methods included quadrat searches (for forest floor amphibians and reptiles), transects (for arboreal reptiles), stream surveys (for stream amphibians and reptiles), live trapping (murid rodents and shrews), and camera and track plots, radio-telemetry, plant phenology and vegetation plots (for small carnivores).

MURID RODENTS AND SHREWS

About 70 species of murid rodents, which include the rats, mice, voles and dormouse (Order: Rodentia, Family Muridae) occur in India of which 17 occur in the Western Ghats. Seven species of ground shrews (Order Insectivora; Family Soricidae) occur here, out of 26 species in India. Being small and specialized in their diet, murid rodents and shrews would be more sensitive to habitat fragmentation than many other mammals. Species richness and abundance of these two taxa were assessed by live-trapping using standard Sherman traps. In the Anamalai Hills, tea, coffee, and cardamom plantations, around or adjacent to the fragments were also sampled in order to identify dispersal-shy species and species not adversely affected by man-modified habitats.

- During a total of 9,613 trap-nights in KMTR, 204 individuals of 5 species were captured. *Mus famulus* and *Suncus etruscus* were seen in KMTR, but not trapped. A total of 71 individuals of 5 species were captured in 2,104 trap-nights in the matrix. In an earlier study (Kumar et al 1998), 572 individuals from 8 species were trapped during 10,595 nights of trapping in the forest fragments in Anamalai Hills.
- The capture rate in the continuous rainforest was low (2.14/100 trap nights). *Rattus rattus wroughtoni* (white-bellied wood rat) was the most abundant species in KMTR contributing to 80% of the captures, followed by *Platacanthomys lasiurus* (Malabar spiny dormouse, 9.8%), *Funambulus tristriatus* (Western Ghats striped squirrel, 5.9%), *Suncus* spp. (ground shrews, 3.4%), and *Mus* sp. (mouse, 0.5%). The shrews trapped in KMTR were *Suncus montana* and *S. murinus*. The sites from where the endemic dormouse was trapped had a greater canopy cover (c. 98%) and height (27 m), and more lianas and climbers (mean = 7.3), than sites without it.
- The forest fragments and the matrix in the Anamalai Hills had greater capture rates (3.5 and 5.4/100 trap nights, respectively) and more species than KMTR. Even though the capture rate of the white-bellied wood rat was greater in the fragments, its relative abundance was much lower than KMTR, due to the presence of other species. The structural changes in the murid and shrew community in fragments include the invasion of human commensals, loss of endemics, and changes in abundance. The loss of Malabar spiny dormouse, an endemic, is related to the loss of specific habitat features such as woody lianas, buttressed trees, and canopy cover and height. While shrews were associated with rocky areas and high litter depth, the white-bellied wood rat was ubiquitous in microhabitat selection.

SMALL CARNIVORES

Species, belonging to the mammalian Families Herpestidae, Viverridae, and Mustelidae, are commonly referred to as small carnivores. Small cats (Felidae) are sometimes included along with these species. Small carnivores form diverse assemblages in tropical forests, and are critical to the functioning of natural ecosystems because of the key roles that they play as predators, prey, and seed dispersers. Thirty species of small carnivores occur in India. The Western Ghats has 13 species: 4 civets, 4 mongooses, and 5 mustelids (including 3 species of otters).

- The brown palm civet, an arboreal frugivore and a major seed disperser, numerically dominated the small carnivore community in KMTR, forming about 88 % of the camera trap pictures. The most commonly sighted small carnivore during the daytime was the Nilgiri marten. The small Indian civet, brown mongoose, stripe-necked mongoose and leopard cat were also seen.
- Nearly 90% of the scats of the brown palm civet contained fruit remains. Over two years, they fed on fruits of 53 species, mostly trees and lianas. Due to intra- and inter-annual variation in the diet, no species formed >10% of the overall diet, although some species formed 25–75% of the diet in certain months. Most fruits were drupes or berries, with moderately thick and watery pulp. Fruits of nearly 53% of all the trees in the study area were eaten by the brown palm civet, showing its importance as a seed disperser.
- Changes in the small carnivore community in the rainforest fragments included a decline in their overall abundance, a decline in the absolute and relative abundance of the brown palm civet, and an increase in the terrestrial small carnivores (brown mongoose and small Indian civet). These changes were related to habitat features other than fragment area.
- In a fragmented landscape, conservation efforts should include the maintenance of relatively undisturbed and large tracts of remnant 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.

AMPHIBIANS

Out of the 219 species of amphibians in India, 120 species occur in the Western Ghats, with 93 endemics. A majority of these are found in the rainforest and almost all the endemics are confined to it. It is being increasingly realised that the amphibians, along with other lower vertebrates and invertebrates, might have considerable patchiness in their distribution. This patchy and restricted distribution makes them highly susceptible to extinction, and also has major implications in the context of habitat fragmentation.

- Thirtytwo species of amphibians were recorded from KMTR. The forest floor amphibians occurred as discrete clusters of 6 to 8 animals, with an overall density of 348 animals/ha, comparable to sites in south-east Asia and South America. The densities as well as species composition varied considerably among the three sites in KMTR. In Sengaltheri, the community was dominated by one species (*Rana temporalis*), which occurred in high densities. Even though densities were lower, the communities were more species rich in Kannikatti and Kakachi, the latter with

Micrixalus as the dominant genus.

- The spatial differences in community composition were more evident in the case of stream amphibians. The similarity in species occurrence and relative abundance was highest between stream segments within a drainage, followed by stream segments in different drainages, while stream segments in different hill ranges (Ashambu Hills and Anamalai Hills) had the lowest similarity. Thus, data from both forest floor and stream amphibians strongly suggest a turn over of species from one drainage to another. The hilly nature of the Western Ghats, the dependence of amphibians in the Western Ghats on streams for breeding, and even Pleistocene glaciation might all be reasons for the high turn over of species. This results in a low alpha or local diversity, but high beta and gamma, or regional diversity.
- In KMTR, litter depth, canopy cover and height, and soil temperature were important habitat features that affected the local distribution of different amphibian taxa.
- A total of 40 species were recorded from the rainforest fragments in the Anamalai Hills. Apart from area and time since isolation, habitat disturbance had a negative impact on the species richness in the rainforest fragments in the Anamalai Hills. Moreover, the densities of different genera were not correlated with fragment area but with different habitat features, especially disturbance. This indicates the need for active management of these remnant rainforest fragments and the intervening matrix in the Western Ghats.
- The occurrence of many species in a rainforest fragment depends on periodic recolonization from large undisturbed forest fragments in the landscape. The probability of recolonization is low due to the matrix of inhospitable tea plantations that surround many forest fragments. The scenario might change with the change in the dominant plantation crop.
- The large turn over of species indicates that the amphibian fauna in the Western Ghats has been poorly inventoried and that even small patches of forest might contain exclusive species. This is indicated by the discovery of several new species in this study, some of them confined only to a few forest fragments.

REPTILES

Out of nearly 490 species of reptiles reported from India, at least 197 occur in the Western Ghats, and about 130 of these are restricted to the rainforests. Some taxonomic groups show very high endemism, (*e.g.* all 33 species of uropeltids or shield tailed snakes, and 40 out of about 62 species of geckos, skinks and agamids).

- A total of 54 reptile species were recorded from KMTR. Geckos and skinks dominated the forest floor assemblage. Reptiles had an overall density of 112 animals/ha. There were major differences among the three sites in KMTR in overall density as well as those of the four taxa. Kannikatti and Sengaltheri had high densities, and were dominated by agamid lizards, while Kakachi had low densities and was dominated by skinks. The density of snakes was also higher in Kakachi, compared to the other two sites.
- The overall encounter rate of arboreal reptiles along transects was 1.94 animals/250 m, about 51% of which was of the gliding lizard (*Draco dussumieri*) and about 28% of

another endemic, *Calotes ellioti*. Snakes were the most species rich taxon (8 species), although only 38 individuals were sighted. Sengaltheri had greater species richness while Kannikatti had greater abundance in the arboreal reptile community. In both the leaf litter and arboreal assemblages, the high altitude site of Kakachi had a unique assemblage in terms of species richness, composition and abundance.

- Species richness of arboreal reptiles along transects in KMTR showed a unimodal relationship with altitude while abundance showed a linear decline with an increase in altitude. The abundance of agamid lizards showed a sharp decline with altitude, while geckos and skinks reached highest abundance and species richness at mid altitude, and snakes were more abundant in the higher altitudes. The similarity between transects in species occurrence and relative abundance also decreased with increasing difference in altitude. Thus altitude was a major determinant of reptile richness, composition and abundance, even at higher taxonomic levels.
- Forty species were recorded from the Anamalai Hills. Skinks and geckos dominated the forest floor assemblage, while agamid lizards dominated the arboreal assemblage. The density of floor reptiles in fragments (148 animals/ha) was greater than in KMTR, mainly due to an increase in non-endemic and generalist species. Although the encounter rate of arboreal reptiles in fragments (1.84 animals/250 m) was comparable to that in KMTR (1.94), there were major changes in species composition.
- Although species richness was highly correlated with fragment area, time since isolation was also an important factor. As in the case of the amphibians, the density of floor reptiles overall as well as that of individual taxon showed no correlation with fragment area, but was related to different habitat features, especially those that measured human disturbance. Unlike amphibians, however, disturbance had a positive effect on reptile abundance.
- Five of 14 species of agamid lizards in the Western Ghats were recorded from rainforest fragments. *Calotes elliotti* was the most dominant species in all fragments (40-45% of all agamids), while *C. rouxii*, a secondary forest species, was more common (22.6%) in small fragments. The relative abundance of two rainforest endemic species (*C. grandisquamis* and *C. nemoricola*) declined from the large (22%) to small fragments (7.5%), while that of the flying lizard (*Draco dussumieri*) was highest in the medium sized fragments (37.5%). *C. elliotti* was associated with a wide variety of microhabitats, probably the reason for its insensitivity to habitat fragmentation. In contrast, *C. grandisquamis* and *C. nemoricola* were associated with structurally complex vegetation with minimal human disturbance, explaining their decline in abundance in small fragments. The flying lizard was associated with areas with low tree densities and greater basal area.

CONSERVATION IMPLICATIONS

1. The patchy distribution of herpetofauna has important conservation implications. For example, protected areas in the Western Ghats need to enclose ecological gradients and drainage systems. Even forest fragments in hitherto un-surveyed drainage are likely to contain several undescribed species. This is evident from the discovery of several new species during this project and other recent studies, including a taxonomically unique amphibian species.

2. Even though there was a strong positive relationship between fragment area and species richness, due to the patchy distribution of many species fragments in a landscape together still retain a considerable number of endemics. Some of these are found nowhere else. The rainforest fragments in the Western Ghats are therefore of significant conservation value.
3. Since the abundance of many taxa respond to specific habitat features, rather than fragment area, it should be possible to manage fragments to retain such taxa. Specific measures would depend on the taxa and their conservation importance.
4. Since many forest fragments are privately owned and managed for production of cash crops under natural shade, conservation of many endemics in these fragments would depend on the integration of conservation and production goals through appropriate policies and other incentives. Many of the forest fragments require habitat restoration in order to support resident populations of species such as the brown palm civet.
5. Forest fragments are a dominant feature in the Western Ghats landscape, and are often surrounded by or adjacent to protected areas. Such forest fragments are often the stepping-stones for the dispersal and seasonal movement of medium and large sized mammals, birds, and a few reptiles within and between protected areas. The retention of these fragments is therefore critical to the conservation of such animals, apart from resident populations of several endemics.

RESEARCH IMPLICATIONS

1. The patchy distribution of amphibians and reptiles, and the turn over of species with drainage and altitude suggest that systematic surveys of drainages and altitude zones would discover several new species. The discovery of several new species in this project, and many more by others in recent years is an indication of this.
2. A systematic survey of lower vertebrates and small mammals in the Western Ghats is needed in order to identify gaps in their coverage in the protected area network.
3. Taxonomic uncertainties are a major handicap in the studies on amphibians, reptiles, murid rodents and shrews.
4. Privately owned rainforest remnants are critical to the conservation of several endemics as well as wide ranging species in a fragmented landscape. Management measures, appropriate policies and economic incentives that would promote conservation of such forest fragments need to be identified.
5. The data collected need to be examined in the context of landscape level processes which might add substantially to our understanding of the factors that govern the survival of species in forest fragments.

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CONTENTS

1 INTRODUCTION

1.1 BACKGROUND

Habitat fragmentation, a legacy of habitat loss due to human activities, is a major threat to conservation due to two major reasons. First, it leads to the fragmentation of contiguous, large populations into several, small and isolated populations. These small populations are prone to extinction from several threats that are well known (Soule 1986 for a review). Second, the habitat fragments decay in the long run due to changes in the macro- and micro- habitat conditions (Saunders *et al.* 1991 for a review). This process is often further aggravated by human activities. This decay reduces the populations of many species that the fragment can support in the long run. The impact of habitat fragmentation differs among species depending on their biology, ecology and social behaviour (Laurance 1991). For example, the consequences of population isolation depend on the density at which a species occur prior to fragmentation, and its ability to disperse between fragments. The impacts of habitat decay would depend on resource needs of the various species, and their sensitivity to macro and microhabitat changes. Resident species, which are often rare, endemic and habitat specialists, are more adversely affected and tend to be lost faster than other species. Similarly, more complex and species rich habitats like the tropical rainforest are much more adversely affected than other habitats.

The tropical rainforests of the Western Ghats (often also called the wet evergreen forests), a biodiversity hot spot, have been severely fragmented due to habitat loss in the last two centuries. It has been estimated that nearly 40% of the forest cover in the Western Ghats was lost between 1920 and 1990, with a 17 fold increase in the number of forest patches (Menon & Bawa 1997). This is, due to reasons mentioned above, a major threat to the long-term survival of many taxa, especially those that are species rich and endemic. This project aims to assess the loss of species and the changes in the communities of small mammals and herpetofauna in the tropical rainforests of the Western Ghats due to habitat fragmentation resulting from human activities. These are the vertebrate taxa among which species richness and endemism are the highest in the Western Ghats.

The montane rainforest (>1700 m) occurs in a naturally fragmented state and interspersed with montane grassland. This formation is many thousands of years old and not a result of human activities (Sukumar *et al.* 1993). This study did not cover rainforest fragments that form part of this formation.

1.2 OBJECTIVES

The specific objectives of the project are to (a) identify the factors that govern the species richness, distribution and relative abundance of small mammals and herpetofauna in the contiguous and undisturbed rainforest; (b) assess the nature and extent of loss of species and changes in the communities in small mammals and herpetofauna in fragmented rainforests; (c) identify the factors that cause these changes; (d) assess the efficacy of the protected area network in the long term conservation of the above taxa in the light of our findings; and (e) suggest measures for better management of small mammals and herpetofauna in fragmented rainforests.

1.3 ORGANISATION OF THE STUDY

The first phase of the field studies was an assessment of the species richness, distribution, and relative abundance of herpetofauna and small mammals in a contiguous rainforest in relation to several habitat parameters. This phase of the study was carried out in the contiguous and relatively undisturbed rainforests in the Kalakkad-Mundanthurai Tiger Reserve, during 1996-99. During the second phase in 1997-2000, small carnivores and herpetofauna were sampled in several rainforest fragments in the Indira Gandhi Wildlife Sanctuary. A comparison of these data among fragments and with the contiguous forest enabled us to identify changes in the communities of herpetofauna and small mammals and associated changes in habitat features. The final phase of the field studies was a rapid survey of the herpetofauna in some rainforest fragments in the State of Kerala in order to validate our findings.

1.4 ORGANISATION OF THIS REPORT

This report is organised in five sections and twelve chapters. The first section covers introduction, review of relevant literature, and a description of the study area and methods. The next three sections cover each of the major taxa that were covered - small mammals, amphibians and reptiles. The last section provides the results of the rapid survey of some rainforest fragments in the State of Kerala. For each major taxon, the species richness, distribution and abundance and factors affecting these are discussed in one chapter, followed by another chapter on the impact of forest fragmentation. For amphibians, one chapter is devoted to discuss the pattern of and factors affecting regional distribution.

2 STUDY AREA AND METHODS

2.1 WESTERN GHATS

The Western Ghats mountain range from almost the southern tip of India up to the River Tapti, covering a distance of 1600 km and area of about 160,000 sq.km. The rainforests in south India are presently confined to these mountains. In the last two centuries, especially the first half of the present one, vast stretches of rainforests were cleared for various purposes like industries, river valley projects, plantations and rehabilitation (Chattopadhyay 1985; Menon & Bawa 1997). While direct habitat loss and threats to the survival of many species were the immediate result, the remaining forest was also fragmented and insularized. More than 60% of the remaining rainforest occur as patches of a few hectares to 20 km^2. These patches vary in their ownership and extent of degradation through human impact.

These forests have a very rich and endemic flora and fauna. Of the 15,000 species of Angiosperms in India, 5000 are from the Western Ghats (Nair & Daniel 1986). About 60 genera, mostly monotypic, and 2100 species are endemic to the Western Ghats, mostly to the rainforests. The rest of India has only 84 endemic genera. Endemism and species richness are highest among the herpetofauna (Inger & Dutta 1986). About 75% of the nearly 120 amphibian and about 50% of the nearly 200 reptile species in the Western Ghats are endemic.

Richness among mammals is high with 137 species (Nameer *et al*. 2002), but only 12 are endemic. Among the smaller nonvolant mammals, the well known endemics are the lion-tailed macaque *(Macaca silenus)*, Nilgiri langur *(Presbytis johni)*, the Malabar civet *(Viverra civettina),* brown palm civet *(Paradoxurus jerdoni)*, Nilgiri marten *(Martes gwatkinsi)*, the spiny dormouse (*Platacanthomys lasiurus*), and two or three species of ground shrews (*Suncus spp.*). Some species are endemic at subspecies level: for example, the brown mongoose (*Herpestes fuscus fuscus*) and the stripenecked mongoose (*Herpestes vitiollis viticollis*), Western Ghats striped squirrel (*Funambulus tristriatus*), Travancore flying squirrel *(Petynomys fuscocapillus fuscocapillus)* and dusky striped squirrel *(Funambulus sublineatus sublineatus)*, all of which are also found in Sri Lanka.

Despite the extreme richness and endemism of the flora and fauna of the rainforest of the Western Ghats, no detailed studies have been carried out. Apart from species listings of various localities, the vegetation has been the subject of only very few studies (Pascal 1988). The endemic fauna has been even less studied, except for some mammalian species. Most of the studies on amphibians have been reports of one or a few species from specific localities (*e.g.* Daniels 1991; Sekar 1992a), species listings (Inger & Dutta 1986) or keys for identification (Daniel 1962; Sekar 1992b; Daniels 1992). The same is true for reptiles (Chari 1955; Murthy 1990; Ghate & Yazdani 1990; Karthikeyan 1991).

There have been only very few studies on the distribution, abundance, ecology, and conservation status of the small mammals of the Western Ghats. The lion-tailed macaque is the most studied (see Kumar *in press* for a review). These studies show that about 60% of the 4,000 lion-tailed macaques in the wild are isolated as small populations of less than 50 animals in patches of rainforest. The feeding ecology of Nilgiri langur (Oates *et al.* 1980) and the ecology and the impact of habitat degradation (Sunderraj in prep.) have been studied. The relative abundance of small carnivores in the Nilgiri

Biosphere Reserve has recently been assessed, with reference to different vegetation types and human disturbance, using scat abundance as an indicator (Yoganand & Kumar 1999). The Malabar civet, considered `extinct' (IUCN 1978), and rediscovered in 1987 (Kurup 1987), has now been reported from low land forests of the Malabar coast, but as patchily distributed and highly endangered small populations (Ashraf *et al.* 1993; Rai & Kumar 1993). The terrestrial murids (rats and mice) and ground shrews have recently been studied in the natural forest fragments in the higher elevations of the upper Nilgiris (Shankar 1998). During 1993-95, Kumar *et al*. (1997) examined the impacts of rainforest fragmentation on arboreal mammals (primates and squirrels) and murid rodents and shrews in the Anamalai Hills.

2.2 STUDY AREAS

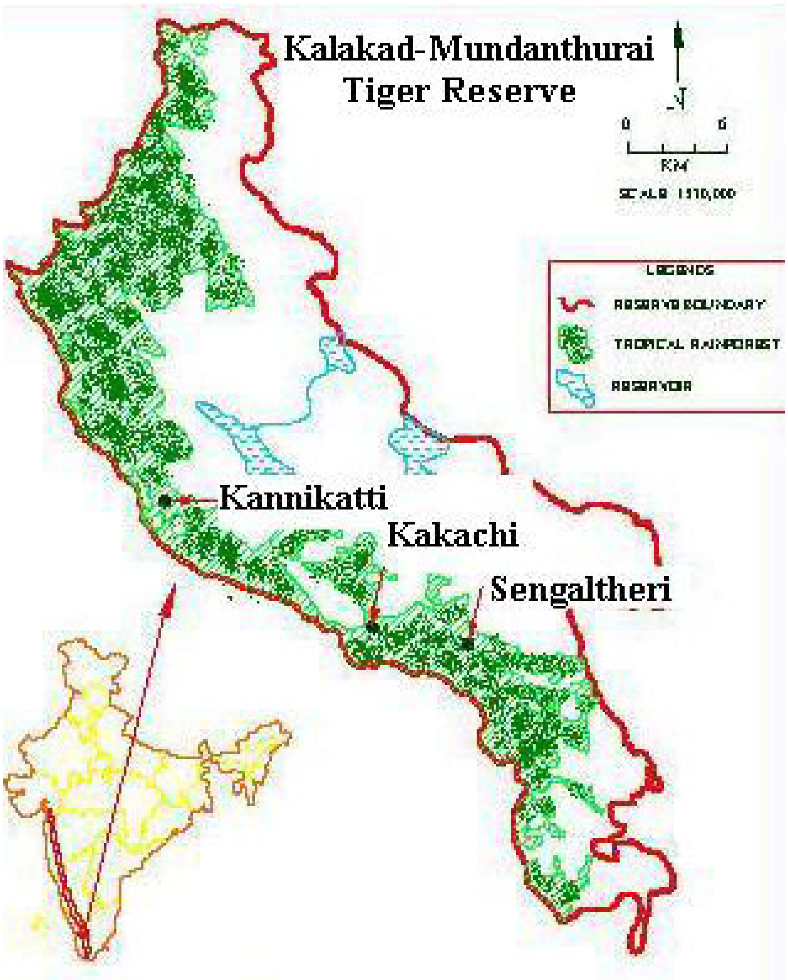
2.2.1 Kalakkad-Mundanthurai Tiger Reserve

2.2.1.1 Physical features 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 2.1), and extends over an area of about 895 km². 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 km² of relatively undisturbed and contiguous rainforests (Ramesh *et al*. 1997).

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 daytime 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, 1,040 m). The lowest temperature recorded in 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 dry month with less than 100 mm, while there is greater amount of precipitation in all the other months. Strong winds occur during the southwest 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 northeast monsoon. KMTR receives most of the rainfall during the northeast 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.

Figure 2.1. Kalakad-Mundanthurai Tiger Reserve showing the distribution of rainforest and the three study sites (Kannikatti, Sengaltheri, and Kakachi).



Within KMTR, we carried out sampling centred on three sites which represented the altitude, rainfall and temperature regime in the Reserve. 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. An abandoned cardamom curing house was renovated to serve as the permanent field camp. This site was surrounded by rainforests (800–1250 m) within an area of about 10–15 km 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 sampled from temporary camps, provided by the Reserve authorities.

2.2.1.2 Vegetation

Within the Western Ghats, the Kalakad-Mundanthurai Tiger Reserve has one of the largest remaining contiguous tracts of tropical rainforests spreading over 400 km² including the Ashambu range in the adjoining Kerala state (Ramesh *et al*. 1997). The mid-elevation (700

– 1400 m) rainforest classified as tropical wet evergreen forest (Champion & Seth 1968) falls under the *Cullenia exarillata* - *Mesua ferrea* - *Palaquium ellipticum* type which has about 43% plant endemism (Pascal 1988). At least 2000 of about 4000 flowering plant species found in the Western Ghats are believed to occur in KMTR (Nair & Daniel 1986; Ganesh *et al*. 1996). The type of vegetation varies along an elevational 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).

2.2.1.3 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. This could be due to the restricted area occupied by rainforests and their isolation from large tracts of rainforests in northeast India and southeast Asia. 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 (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).

2.2.2 Anamalai Hills

2.2.2.1 Physical features and climate

The Indira Gandhi (formerly Anamalai) Wildlife Sanctuary (10°12' and 10°54' N and 76°44' and 77°48' E) in Tamil Nadu is one of the largest sanctuaries in south India (Figure 2.2). Created in 1976, it covers an area of about 987 km². It is located mainly in the Valparai Taluk, but extends to Pollachi and Udumalpet Taluks of Coimbatore district and Kodaikanal Taluk of Dindugal District. It extends 45 km north-south, and 25 km east-west. It is about 90 km from Coimbatore city. Three major public roads from Pollachi town passes through the Sanctuary - the Pollachi-Chalakudi road through Valparai, the Pollachi-Parambikulam road through Topslip and the Pollachi-Munnar road through Udumalpet range. A network of roads connects Valparai town to various estate settlements.

Almost in the centre of the Sanctuary is nearly 180 km² of tea and coffee estates that are under private ownership, and in its centre is the Valparai Town. The Sanctuary is bordered in the south-west by Parambikulam Wildlife Sanctuary (287 km²), in the south by the Reserve Forest of Chalakudi Forest Division and Eravikulam National Park (97 km²), in south-east by Chinnar Wildlife Sanctuary (90 km²) all in Kerala State, and in the east mostly by the cultivated plains. These sanctuaries along with the Reserve Forest of Nelliyampathi Hills form a large conservation area for large and wide ranging species such as elephant, gaur, and tiger.

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

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

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

2.2.2.2 Vegetation

The natural vegetation in this area includes tropical rainforest, montane shola-grassland, moist deciduous, dry deciduous and thorn forests. The rainforest is found in an altitude of 600 m to 1,600 m, where *Cullenia-Mesua-Palaquium*, *Hopea-Mesua-Artocarpus*, and *Dipterocarpus-Anacolosa* associations occur (Pascal 1988). In this forest the trees obtain a height of about 30 m or more. In the higher elevations (>1,700 m), tropical montane forest occur with the following dominant tree species; *Gordonia obtusa, Michelia nilagirica, Ternstroemia japanica*, and *Eugenia* spp. Typically, these forests are interspersed with montane grassland, forming the shola-grassland complex. The lower elevations of the eastern slopes have mixed dry and moist deciduous forests, where *Tectona grandis, Terminalia bellerica, T. tomentosa, T. paniculata, Dillenia pentagyna* and *Lagerstroemia lanceolata* are the dominant tree species. The thorn forests occur mainly in the plains, east

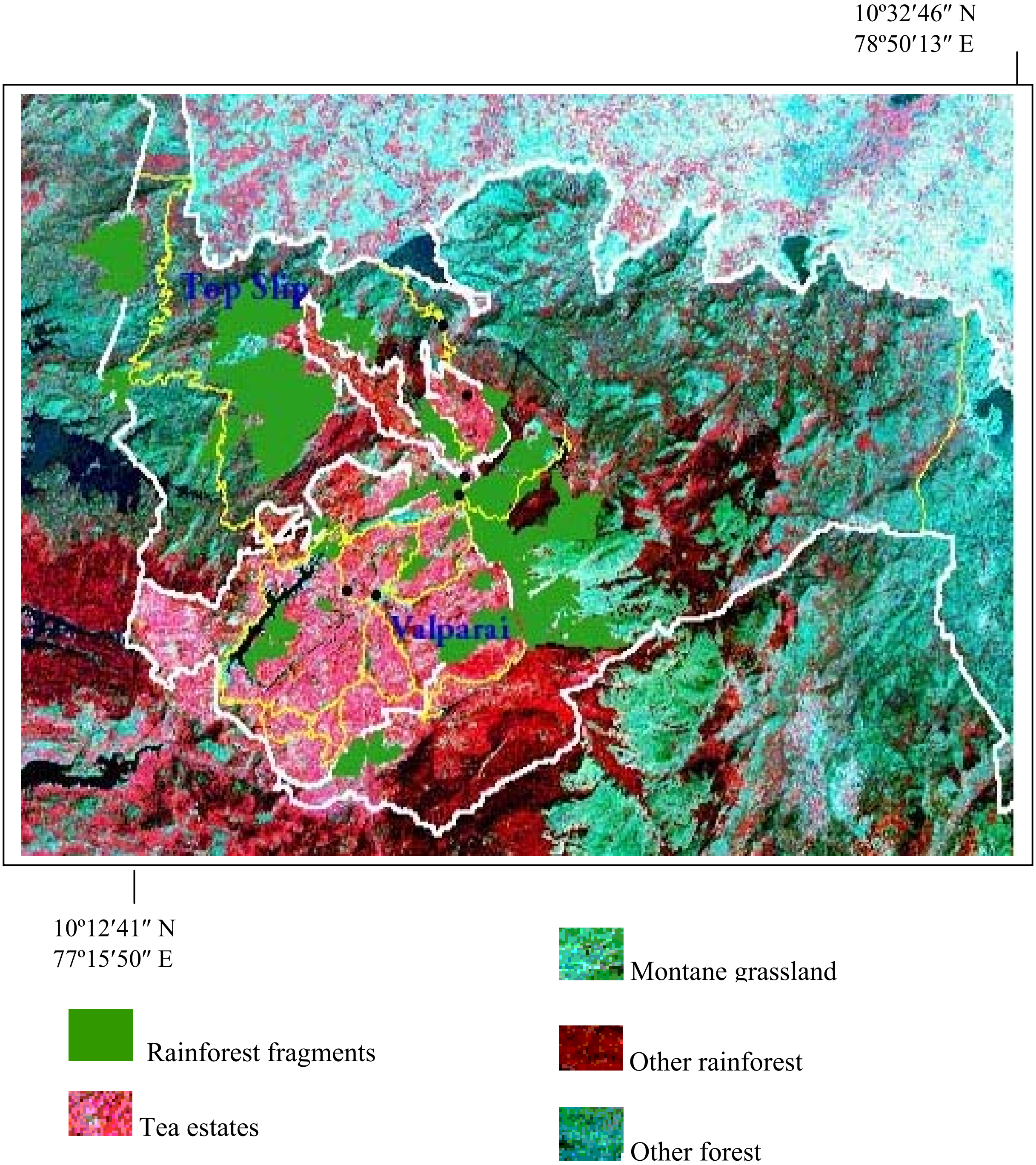


Figure 2.2. False colour composite (LISS-III) of the Anamalai Hills showing major vegetation types, and the rainforest fragments. The boundary of the Indira Gandhi Wildlife Sanctuary is also shown.

of the Sanctuary. The major tree species are *Acacia latronum, A. nilotica, A. ferrruginea, A. leucophloea, Zizyphus jujuba* and *Albizzia amara*. An extensive area has been planted with teak, mostly between 600 m and 1,000 m altitude. Estimates of area under major vegetation types are not available. Forest Department statistics in 1980s showed that rainforests covered about 80 km².

2.2.2.3 Fauna

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

In spite of its rich biodiversity, the Indira Gandhi Wildlife Sanctuary has received little research attention. Recent studies include the ecology, demography, and social behaviour of the lion-tailed macaque (see Kumar *in press* for a review), loris (Singh *et al.* 1997a), primate community ecology (Singh *et al.* 1997b), rodents (Chandrasekar-Rao & Sunquist 1996), hornbills (Kannan 1994; Mudappa & Kannan 1997) and amphibians (Saravanakumar 1995). In the adjoining Parambikulam Wildlife Sanctuary, there have been several studies on the large herbivores (Balakrishnan & Easa 1986) and giant squirrel (Ramachandran 1988).

2.2.2.4 Forest fragments sampled

Nearly thirty rainforest fragments ranging in area from less than one ha to over 2000 ha have been identified in the Anamalai Hills, especially in the Valaparai valley, by an earlier study (Kumar *et al.* 1997). The data available from this study was used to select 14 rainforest fragments for sampling small carnivores, amphibians and reptiles. These fragments represented the range of variability in terms of area as well as disturbance in rainforest fragments in the Anamalai Hills. Seven of these fragments were also sampled for murid rodents and shrews in 1993-95 (Prabhakar 1998). The details on these forest fragments are given in Table 2.1.

2.3 METHODS

Several methods were used to sample the different taxa that were the target of the study, as well as to measure features of the habitat. Since these are taxa specific detailed description of the sampling methods are given in different chapters. The methods included live trapping (for murid rodents and shrews), scat analysis, radio-telemetry, camera-trapping, track plots, night surveys, and vegetation and phenological studies (all for small carnivores), adaptive cluster sampling, transects, stream surveys, and measurement of micro-habitat features (for amphibians and reptiles).

Table 2.1. Characteristics of 14 rainforest fragments in Anamalai Hills that were selected for sampling small carnivores, amphibians and reptiles in 1997-2000 (data from Kumar *et al.* 1997)

Fragment	Area (ha)	Size class	Owner	Tree /ha	Canopy Ht (m)	Canopy Cover (%)	Basal Area sq.m (/ha)
Akkamalai shola	2500	VL	F	492	19	67	97.54
Manampoly	200	L	F	347	23	52	55.46
Sankarankudi	180	L	F	184	21	33	37.48
Andiparai shola	185	L	F	357	22	77	29.41
Iyerpadi church	50	M	F	403	17	59	43.90
Korangumudi Est.	35	M	P	161	17	23	37.82
Puthuthottam Est.	50	M	P	128	9	62	67.23
Tata Estate	24	M	P	93	25	56	11.01
Varattuparai-II	2	S	P	233	18	42	51.59
Varattuparai-III	4	S	P	182	10	21	20.29
Varattuparai-IV	1	S	P	127	9	18	8.01
Pannimedu	10	S	P	306	14	48	42.82
Urulikkal I	5	S	P	178	16	36	61.87
Urulikkal II	2	S	P	111	9	35	19.80

As in the case of sampling methods, a variety of statistical methods were used for analysis of the data. We have used parametric tests wherever we were satisfied that the necessary conditions for these tests have been met. Otherwise, we have used non-parametric tests. Besides, we have also used several tests (often simulation based) available on the internet that are applicable to specific situations. Details of these tests are given in the appropriate chapters. Most of the tests were carried out using SPSS Ver 8.0., on Windows 98.

3 MURID RODENTS AND SHREWS

3.1 INTRODUCTION

The nonvolant small mammals reported from the Western Ghats comprise of about 20 species of rodents and ground shrews. The taxonomy, distribution and habitat preferences of many rodents (Order: Rodentia), especially rats and mice (Family: Muridae), squirrels (Family: Sciuridae), and shrews (Order: Insectivora) in the Western Ghats are still unclear. Among rodents, the Malabar spiny dormouse *(Platacanthomys lasiurus), Millardia kondana, Mus famulus* and *Funambulus tristriatus* are endemic to the Western Ghats at the species level. The Travancore flying squirrel *(Petinomys fuscocapillus fuscocapillus)* is endemic at the subspecies level. At least one species of ground shrew, *Suncus dayi*, is also endemic.

Small mammals play a major role as seed dispersers, predators and prey in the ecosystem (Fleming 1975). Changes in their communities due to habitat fragmentation (*e.g.* see Malcom 1991) is, thus, likely to have a cascading effect. Studies on the small mammals, therefore important component of the project.

During 1996-97, we attempted to:

- Estimate the species richness and relative abundance of rodents and shrews in relation to habitat parameters in the contiguous rainforests in the Kalakad-Mundanthurai Tiger Reserve; and
- Estimate their abundance in the man-made vegetation surrounding rainforest fragments in the Anamalai Hills.

An assessment of the species richness and frequency of occurrence of rodents and shrews in the rainforest fragments in the Anamalai Hills had been completed in 1994-96 (Kumar *et al.* 1997), using methods comparable to those used in this study (see below). We did not repeat this effort, but have used the data from that study for comparisons.

3.2 METHODS

Rodents and shrews were sampled by live-trapping using standard Sherman traps, of 9 x 9 x 21 cm, in order to assess their species richness and relative abundance. The grid configuration and sampling effort were based on field trials in the first year of the project. Traps were set up on the forest floor in grids of 7 x 7 (49 traps) at 10 m intervals. Two grids were run simultaneously, for five consecutive days in each session. Traps were baited with a mixture of banana, grated coconut and groundnut. The traps were checked in the mornings and rebaited whenever necessary .The traps with captures were replaced. In KMTR, a total of 46 grids were laid in the three sites (Sengaltheri, Kakachi and Kannikatti), during a period of one year.

In KMTR, we also attempted trapping arboreal rodents, by placing standard Sherman traps at 2 m above ground on trees or lianas at 10 m intervals in a grid of 7 x 4 traps, and at 30 m intervals in 2 grids of 3 x 4 traps. Traps were also occasionally placed in areas around the base camp to record commensal species.

In the Anamalai Hills, rodents and shrews were sampled only in the tea, coffee, and cardamom plantations, surrounding or adjacent to forest fragments. We used the same grid size (7 x 7) as in KMTR. The sampled areas were between two fragments - the Akkamalai shola, which is about 20 sq.km in area, and Puthuthottam Estate.

The trapped animals were identified using reference books (Ellerman 1961; Biswas & Tiwari 1966), measured, marked by ear clipping and released. Unidentified animals were photographed, preserved and identified at the Zoological Survey of India, Pune by Dr. M. S. Pradhan. Relative abundance of animals is estimated as the number of animals captured/lOO trap- nights.

Several habitat parameters, with which the frequency of occurrence of rodents and shrews were hypothesized to be correlated, were measured in 5 m radius plots around five random trap stations in each grid, and all the trap stations with capture.

3.3 RESULTS

Live-trapping was carried out for a total of 9,613 trap-nights in the rainforest in KMTR during which 204 individuals of five species were captured, giving an overall capture rate of 2.12 animals/100 trap-nights. In the matrix in the Anamalai Hills, we captured 71 individuals of five species in 2,104 trap-nights, with a capture rate of 3.5 animals/100 trap-nights. In a total of 228 trap-nights of arboreal trapping in Sengaltheri, only three individuals were trapped five times, with a capture rate of 1.9 animals/100 trap-nights. All the captures in the arboreal traps were of *R. r. wroughtoni.* Since arboreal trapping did not yield any new species nor an increase in capture rates but involved a lot of time and effort, it was abandoned. Two species of rodents which were not trapped in the forests were trapped near and in the base camp at Sengaltheri during opportunistic trapping. These were a species of *Mus*, and the soft-furred field rat *Millardia meltada*. The latter especially was common in and around the base camp, which was surrounded by open grassy patch.

The five species trapped in KMTR were the white-bellied wood rat *(Rattus rattus wroughtoni),* the spiny dormouse *(Platacanthomys lasiurus),* a mouse *(Mus sp.*), a shrew *(Suncus sp.),* and the Western Ghats palm squirrel *(Funambulus tristriatus).* Of these, *R. r. wroughtoni* was the most abundant species, forming up to 80% of the captures, followed by *P. lasiurus* (9.8%), *F. tristriatus* (5.9%), *Suncus* sp. (3.4%), and *Mus* sp. (0.5%; Table 3.1). The matrix around the fragments (man-made vegetation) also had five species, in spite of considerably lower sampling effort; however, the spiny dormouse was absent in the matrix. *Golunda ellioti* was frequently captured in the coffee plantations.

A comparison was made of the result from contiguous forests in KMTR with that from forest fragments in the Anamalai Hills (Kumar *et al.* 1997). *F. tristriatus* was frequently sighted but only very rarely trapped in the Anamalai Hills. Excluding this species, only four species were recorded from KMTR (this included the only individual of a *Mus* sp. captured in Kakachi) compared to eight species recorded from forest fragments. The species that are widely distributed in India, often as a commensal to man, and reported from the fragments but absent in the contiguous forests of Kalakad were *Mus musculus, M booduga, Golunda elliotti, Vandeleuria oleracea* and *Rattus blandfordi. R. r. wroughtoni* was the most abundant species in both the places, with a relative frequency of 1.7% in Kalakad and 2.6% in the forest fragments. In the absence of other species, the relative frequency of this species was much greater in Kalakad (80%), compared to only 48.5% in forest fragments, and 21% in the matrix. The greater frequency of occurrence of all species together in the fragments is primarily because of the occurrence of several commensal species. While the endemic *P. lasiurus* was relatively more frequent in KMTR forming 9.8% of the captures, it was trapped only from the largest fragment, Akkamalai, in Anamalai Hills (0.06%). As a result of relatively few species in the contiguous forests and the dominance by *R. r. wroughtoni,* the diversity (as measured by Shannon- Weiner index) and evenness was considerably low compared to both forest fragments and the matrix around them (Table 3.1).

The similarity in species composition and relative frequency between the contiguous rainforests of KMTR and each of the seven forest fragment in the Anamalai Hills was estimated using the Morisita-Horn (M-H) index (Magurran 1988). This was then correlated with the corresponding Euclidean distance between contiguous forest and each fragment in three habitat parameters -tree density, basal area, and canopy cover, and the fragments and KMTR ranked in order of increasing area. The M-H index showed highest correlation with the area and the ranks of the fragment (Spearman rank correlation rs=0.90, n=7, $P < 0.05$). Thus the similarity in species composition between contiguous forest and forest fragment increased as the area of the fragment increased. The habitat parameters were highly correlated with the fragment area (ranks) (Kumar *et al.* 1997), and hence showed high correlation with similarity in species composition. The limited number of fragments from which data is available did not allow partial correlation or multiple regression for an assessment of the independent effect of habitat parameters on similarity in species composition. A scatter plot of M-H index against the area (rank) between fragments showed that the Kurangurnudi Estate and Puthuthottam Estate deviated considerably from the general relationship between these two variables. Both these estates had been severely logged just prior to the study and undergrowth considerably modified and planted with cardamom and coffee. It is thus very likely that in addition to area, habitat parameters can significantly alter the species composition of rodents and shrews.

Twenty nine habitat parameters were measured in 5 m radius plots around all the traps that had a capture, and also around a few random traps. The habitat parameters were tested for difference between traps with and without captures using Mann-Whitney U test (MW). Kruskal-Wallis test (KW) was used to test for differences among the trap sites where the three most frequently captured species *(R.r.wroughtoni, P.lasiurus* and *Suncus spp.)* were trapped.

Table 3.1. The capture rate (CR=animals/100 trap nights) and relative frequency (RF=% out of total captured) of murid rodents and shrews estimated through live-trapping. The data for rainforest fragments in the Anamalai Hills taken from Kumar *et al.* (1997) are for 1994-96. NA = Data not available; ---= species absent

Species	Contiguous rain forest		Matrix around fragments		Rain forest Fragments	
	CR	RF	CR	RF	CR	RF
Rattus rattus wroughtoni	1.71	80.39	0.71	21.13	2.62	48.52
Platacanthomys lasiurus	0.21	9.81	---		0.06	1.11
Funambulus tristriatus	0.12	5.88	0.71	21.13	N.A.	N.A
Suncus spp.	0.07	3.43	0.38	11.27	1.52	28.15
Mus spp. (musculus?)	0.01	0.49	1.38	40.85	0.10	1.85

Golunda ellioti	---		0.19	5.63	0.05	0.92
Mus booduga	---		---		0.95	17.59
Rattus blandfordi	---		---		0.05	0.92
Vandeleuria oleracea	---		---		0.05	0.92
Number of species	5		5		9	
Overall capture rate	2.12		3.37		5.61	
Shannon-Weiner Index	0.7		1.4		1.0	
Evenness Index	0.4		0.8		0.7	
Trap nights	9,613		2,104		10,595	
Number of captures	204		71		594	

There was a significantly greater number of lianas, log cover, and lesser distance to lianas at traps with captures, and greater per cent of soil cover at traps without captures (MW U= l0599.5, 9732, 9646, 10604.5 respectively, $P<0.05$, Table 3.2). The number of boulders and distance to them were also significantly different.

There was a significant difference in the number of lianas and litter cover among the trap sites where the three species were trapped (KW, *df*=3, c^2 =13:26, and 10.87 respectively, Table 3.2). The mean canopy cover, canopy height, and number of lianas were much higher at trap sites where dormice were trapped. The distance to the lianas from the trap was also shorter. The spiny dormouse thus seemed to be associated with habitat features that are typical of rainforest. Trap sites at which the *Suncus spp.*

were trapped had greater number of boulders and buttressed trees, greater litter depth, and lower canopy cover. The Western Ghats palm squirrel was also associated with traps in m open areas. The trap sites at which the most abundant species, the white-bellied wood rat, was captured showed no significantly high or low values in any of the habitat parameters.

Table 3.2. Microhabitat preferences in murid rodents and shrews. The mean values of habitat parameters among (a) trap sites in which animals were captured and not captured; and (b) trap sites in which one of the three species was captured. *=significant difference (at *P*<O.Ol), **=significant difference (at *P*<O.l).

Species	Canopy Cover %	Canopy ht (m)	No. Liana	No. boulders	No. Buttress	Litter depth	Soil Cover (%)
(a) Mann-Whitney U test							
With capture	97.12	26.46	*2.98	6.04	1.16	2.40	**3.56
Without capture	96.1	26.36	1.31	5.68	1.27	2.30	5.16
(b) Kruskal - Wallis Test							--
R.r. wroughtoni	**96.79	26.51	*2.35	5.40	**1.09	**2.4	
P. /asiurus	98.12	27.00	7.28	5.81	1.33	2.38	--
Suncus spp.	95.54	24.43	1.57	12.71	2.00	3.54	--

3.4 DISCUSSION

The data on murid rodents and shrews show that there is an increase in their species richness and overall abundance due to the fragmentation of rainforests. This is due to the invasion of fragments by commensal and widely distributed species such as *Mus* spp. and *Gollunda ellioti.* This invasion is perhaps facilitated by the presence of large human settlements near most of the fragments, matrix (consisting of coffee, tea, cardamom and other fruit bearing trees) around the fragments, and habitat disturbance (such as logging, lopping, and removal of undergrowth) that fragments are often subjected to. In contrast, the areas where trapping was done in KMTR were away from human settlements, had no extensive man-made vegetation nearby, and have also remained relatively undisturbed. Another major difference between the contiguous forests and forest fragments was the low diversity and evenness in the former due low species richness and dominance by *R. r. wroughtoni.* As the area of the fragment increased, however, the species composition became more similar to the contiguous forest. Kumar *et al.* (1997), however, found that the relationship of species richness and abundance with fragment area and other habitat parameters might be non-linear reaching a peak at medium sized and moderately disturbed fragments. The matrix surrounding the fragments mostly support only the generalist or commensal species that often invade forests fragments. The matrix around the fragment might thus be a barrier to the dispersal of some species. Among the three species that were caught in sufficient numbers in KMTR, the spiny dormouse was associated with habitat features that are typical of rainforests such as lianas, greater canopy height and canopy cover, and shrews were associated with boulders and buttressed trees. The most common species, *R. r. wroughtoni,* was not associated with any habitat features.

4 SMALL CARNIVORES

4.1 INTRODUCTION

4.1.1 Diversity, distribution, and disturbance

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 (Rabinowitz & Walker 1991; Ray & Sunquist 2001, Chapter 4). Most carnivores are widely distributed, but occur in intrinsically low densities in most regions (Voss & 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 *et al.* 1997). Small carnivores, many of which are of habitat generalists, are usually positively affected by moderate disturbance (Johns 1983; Oehler & Litvaitis 1996). However, these carnivores play significant roles in the habitat as predators, prey, and seed dispersers (Herrera 1989; Rabinowitz 199), and therefore fragmentation may affect the dynamics of the ecosystems when the carnivore community is altered or disturbed (Crooks & 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 & Umapathy 2000), few examine distribution-abundance patterns in the face of habitat alteration. Heydon & Bulloh (1996) specifically studied the impact of logging on civets in Borneo, where they found them to persist, albeit in lower abundance, in selectively logged forests.

Species that are particularly negatively impacted due to fragmentation 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; Goosem & Marsh 1997; Medellín & Equihua 1998). Species-rich groups such as butterflies and non-volant mammals are more sensitive to the surrounding matrix (Bierregaard *et al.* 1992). 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 & Leighton 1983; Johns 1988; Struhsaker 1997; Umapathy & Kumar 2000). Disturbed rainforest fragments are also highly susceptible to invasions by 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 & Litvaitis 1996; Travaini *et al.* 1997; Crooks & Soulé 1999).

In India, the distribution and conservation status of small carnivores is inadequately known. This is the first study examining the impact of rainforest fragmentation on small carnivores.

4.1.2 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, we attempted to assess the impact of rainforest fragmentation on them in the Anamalai Hills. As the Western Ghats contain a species-rich carnivore community, we also tried to assess the direction of change in the small carnivore community in the fragmented landscape in the Anamalai Hills, in comparison with their relative abundance 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. 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 behavioural response and abundance vary among species (Zielinski & Stauffer 1996; Foresman & Pearson 1998). However, there is still a gaping lacuna in our knowledge about small carnivores in tropical forests.

Here, we 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.

4.2 OBJECTIVES

The following questions regarding the distribution and relative abundance of small carnivores are dealt with:

- What is the community composition of small carnivores in the relatively undisturbed rainforests of KMTR? What is their relative abundance?
- What is the extent and nature of change in the relative abundance of small carnivores in the fragmented rainforests of the Anamalai hills?
- What is the distribution of the brown palm civets in the fragmented landscape in the Anamalai Hills?
- How are differences in habitat structure and resource availability related to the size and disturbance of the fragments?
- What are the habitat and site correlates that determine the occurrences of small carnivores in a fragmented landscape?

4.3 MATERIALS AND METHODS

4.3.1 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 & Kumar 1999). They are the small Indian and the brown palm civets, the stripe-necked and the brown mongooses, and the leopard cat. The endemic Nilgiri marten, and the widespread small-clawed and common otters represent the Family Mustelidae. 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).

4.3.2 Survey methods

4.3.2.1 Track plots

The small carnivores in KMTR and Anamalai Hills 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 Anamalai Hills, the number of track plots laid was relative to the size of the fragments. The track plots were checked and rebaited if necessary in the mornings. The distribution of sampling effort in the fragments is given in Table 4.1.

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.

4.3.2.2 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 aluminum 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 aluminum foil was connected by a thin cable of about 2 m length to the electronic shutter release. The circuit was completed between aluminum foil layers as they came into contact through the perforations when an animal stepped on the pad.

Table 4.1. List of rainforest fragments sampled in Anamalai Hills, 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 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. 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. In KMTR, camera-trapping was carried out between October 1996 and December 1999 (Table 4.2) and between January and May 2000 in the Anamalai Hills.

In the Anamalai Hills, camera-trapping effort varied in proportion to the size of the fragments (Table 4.1). 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.

4.3.2.3 Direct sightings

Night walks were carried out both in KMTR and in the Anamalai Hills. During these night walks, 1.5 km were covered on an average through rainforests at a moderately slow pace. The understory 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 valley in the Anamalai Hills, 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.

Table 4. 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 order to collate information on small carnivores in KMTR, all sightings by the research group (five researchers and one trained assistant) during the study period (June 1996 – December 1999) were pooled together. All the small carnivores sighted during drives and walks by night and day in the Anamalai Hills (January 2000 – May 2000) are reported. For Anamalai Hills, 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 Anamalai Hills was calculated as a sum of the time spent in each fragment. Each fragment was visited 3 to 5 times during the day, and an average of four hours per visit was spent in each.

4.3.3 Habitat structure measurement

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.

4.3.4 Food tree density and distribution

Total tree and brown palm civet food tree densities (>30 cm GBH), 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 Anamalai Hills. For Varagaliar, tree and food tree densities, and basal area were derived from Ayyappan and Parthasarathy (1999). A total of 184 plots (736 trees) distributed in various parts of Sengaltheri (KMTR) was used to estimate densities. For lianas, density was estimated from total counts in the 4 ha.

The spatial 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.

4.3.5 Data analysis

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. The effects of lure and altitude for the data from KMTR were analysed using the chi-square test (Siegel & Castellan 1988). Lure was used in all the track plots and at all camera-trap stations in the Anamalai Hills, 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 Anamalai Hills, success rates pooled across rainforest fragments were used to correlate with habitat and site parameters, using Spearman rank correlations. 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 Anamalai Hills. 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.

4.4 **RESULTS**

4.4.1 Track plots

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 4.1). 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 4.3). 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).

In the Anamalai Hills, the overall success rate in the fragments was about 32.2% (95 of 295 trap-nights, Figure 4.2), with the brown palm civet contributing to 50.5% (n = 48), the small Indian civet to 21.1% (n = 20), and unidentified small carnivores excluding brown palm civet to 28.4% (n = 27, the latter two combined as one in Figure 4.3). The success rate ranged between 8.0% in Tata Finley, one of the small-sized fragments, to 46.7% 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.

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

4.4.2 Camera-trapping

4.4.2.1 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 4.1). 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 4.1). Three species were photo-trapped: the brown palm civet , the small Indian civet , and the brown mongoose. 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; χ^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%). Traps with lure (n = 85 days) had a significantly greater success rate (57%) than the traps without lure (12.8%, n = 27, χ^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.

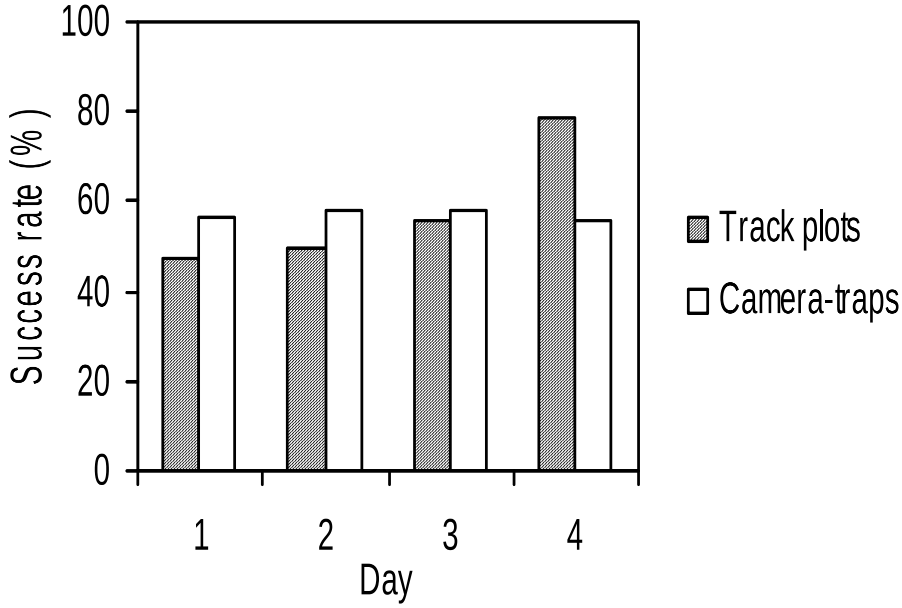


Figure 4.1. Success rates over four days of baited track plots (*n* = 263) and camera-trapping (*n* = 105) carried out in KMTR between 1996 and 1999).

4.4.2.2 Anamalai Hills

Camera-trapping success in the rainforest fragments of the Anamalai Hills was significantly lower than in KMTR, with a success rate of 16.8% (*n* = 95 trap-nights) as against 37.5% in KMTR (*n* = 112, χ^2 = 10.88, *df* = 1, *P* < 0.001, Figure 4.2). However, even in the Anamalai Hills, 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 (χ^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 4.3). Although the brown mongoose was photo-trapped a greater number of times in the Anamalai Hills than in KMTR, and the small Indian civet fewer times, the differences were not statistically significant (χ^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.

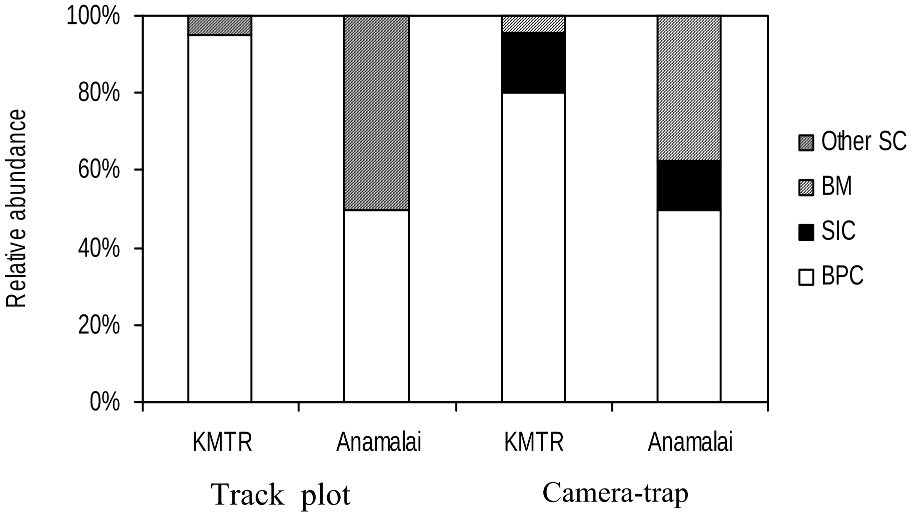


Figure 4.3: Relative abundance of small carnivores (SC) using track plots and camera-traps — comparison between KMTR and the Anamalai Hills.

4.4.3 Direct sightings

4.4.3.1 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 4.2). 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/km, 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 Anamalai Hills, 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 4.2). 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. 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.

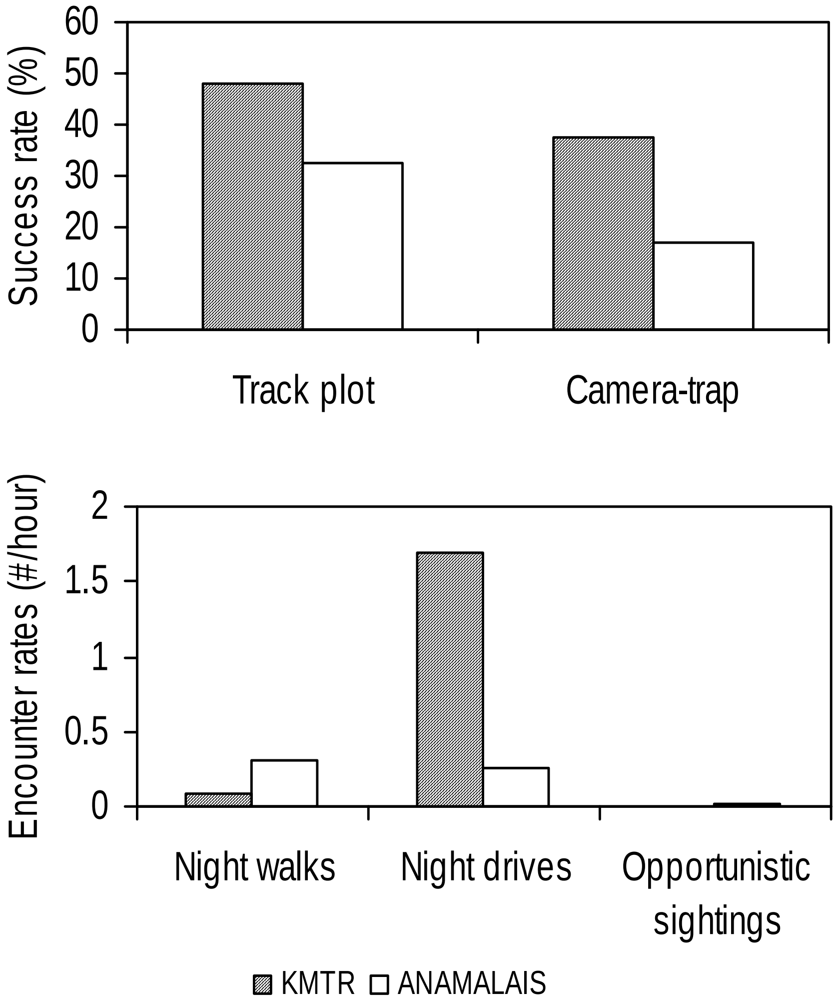


Figure 4.2. Comparison of success and encounter rates of small carnivores between KMTR and the Anamalai Hills using different methods.

4.4.3.2 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. On seven night drives, we covered 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 4.2) or 0.09 animals/km. Leopard (*Panthera pardus*), porcupine, and sambar were also seen during these drives.

In the Anamalai Hills, 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). We 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 4.2). 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.

4.4.3.3 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 4.2). 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).

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

4.4.4 Determinants of small carnivore occurrence

4.4.4.1 Comparison of habitat features in KMTR and Anamalai Hills

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 Anamalai Hills were lower than any of the rainforest sites in KMTR (Table 4.3). 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 4.3).

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 4.4 and 4.5, and Table 4.4). 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 4.5).

4.4.4.2 Influence of site and habitat features on occurrence

The frequency of occurrence (per cent) of the small Indian civets in the track plots in the Anamalai Hills 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 (Table 4.6).

There were no significant differences (χ^2 test) among fragments of varying size classes or disturbance levels 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 camera-trapping success of brown palm civet was significantly different between sites of varying size classes (χ^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 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 overstory 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. Among these food trees, *Cullenia exarillata*, *Holigarna nigra*, and *Palaquium ellipticum,* were the most frequently occurring overstory species, while *Antidesma menasu* was the most common under-story species. Fifty percent of the food plants represented in these PCQ plots had a density of over 10 trees per hectare.

4.4.4.3 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) as compared to 24 (53% of 714 trees/ha) within relatively undisturbed rainforests. The densities of food trees were lower in plantations than in the rainforests (207 *versus* 379 trees/ha, Table 4.7). 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 4.3. Habitat structure measurements of different sites in the undisturbed rainforest of KMTR, and rainforest fragments in the Anamalai Hills (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)

Table 4.4. Spearman rank correlation values between site and habitat parameters of the rainforest fragments in the Anamalai Hills (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

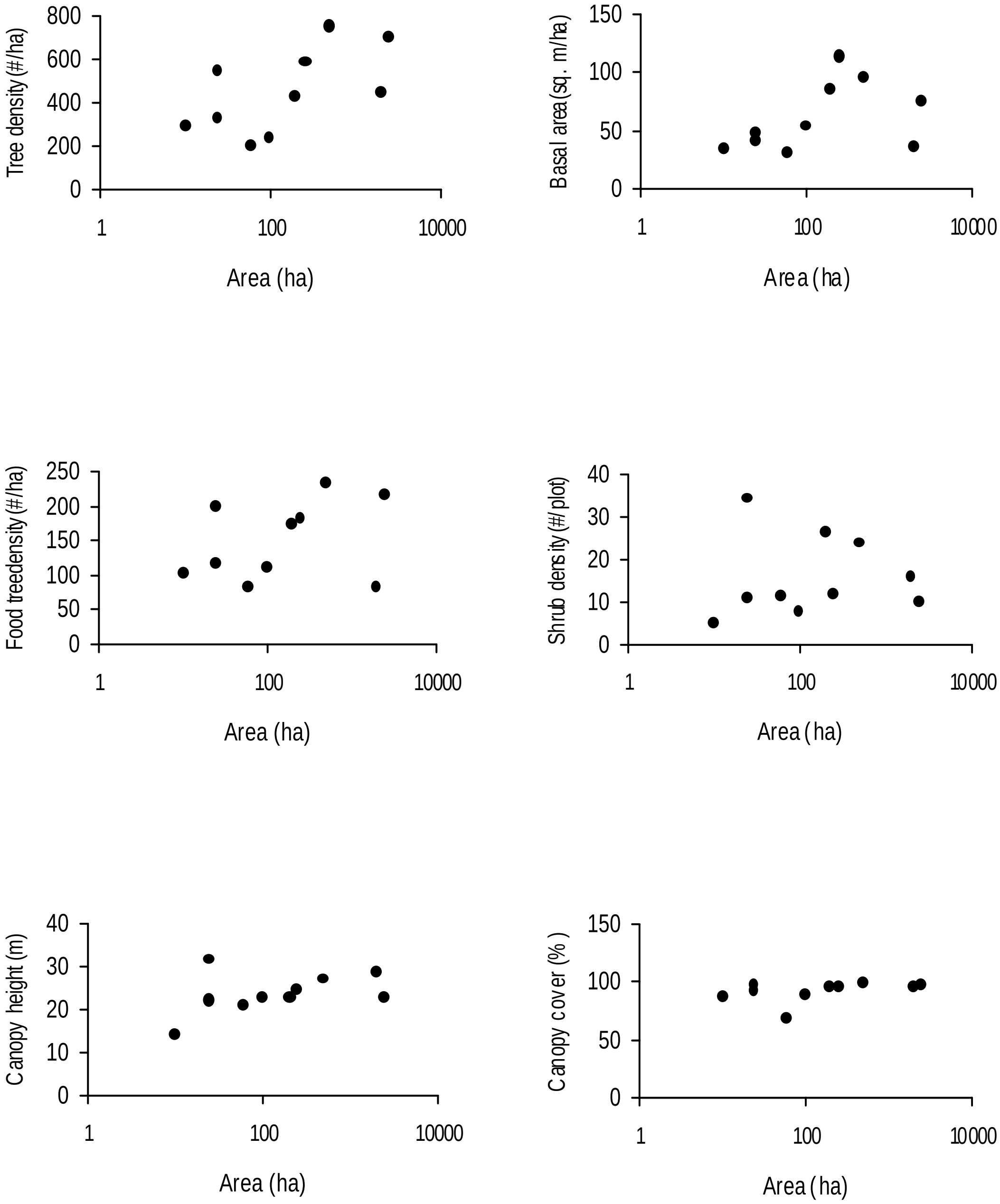


Figure 4.4. Relationship between the area of the rainforest fragments (in logarithmic scale) and habitat attributes in the Anamalai Hills.

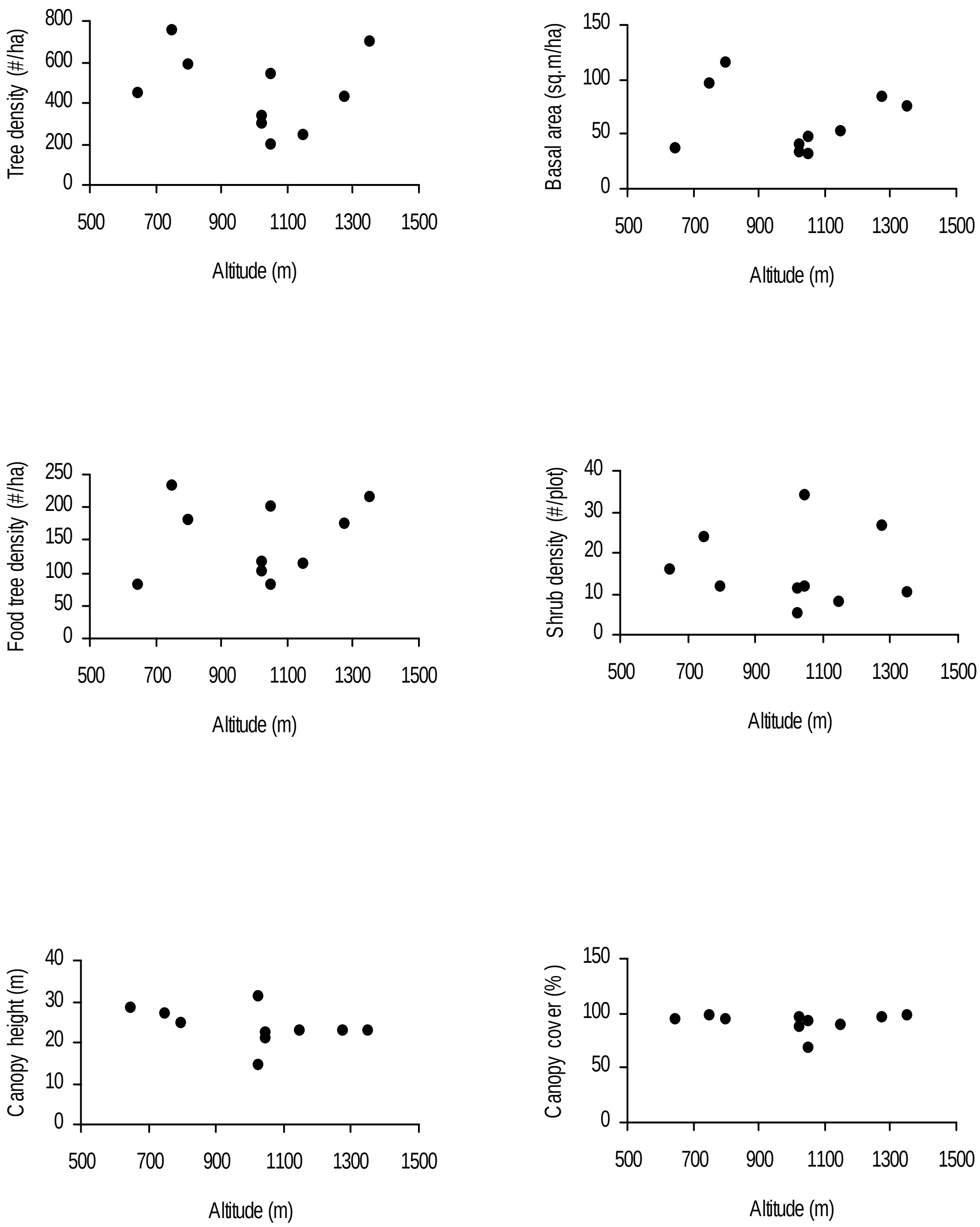


Figure 4.5. Relationship between altitude and habitat attributes in the rainforest fragments in the Anamalai Hills.

Table 4.5. Spearman rank correlation amongst habitat parameters of the rainforest fragments in the Anamalai Hills (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	0.60*	0.29	0.78***	0.64**	0.69**
Canopy height		0.20	0.32	0.01	0.36
Shrub density			0.45	0.31	0.35
Tree density				0.77***	0.71**
Food tree density					0.72**

Table 4.6. Spearman rank correlation between site and habitat parameters with small carnivore occurrence indices in the rainforest fragments in Anamalai Hills (n = 10, * – significance at 0.1, ** – significance at 0.05 levels).

	Track plot			Camera-trap			
	BPC	SIC-M	All	BPC	SIC	BM	All
Area	–0.26	0.70**	0.05	–0.24	0.18	0.17	–0.16
Altitude	0.64*	–0.01	0.50	0.15	0.09	0.29	0.54*
Canopy cover	–0.35	0.33	–0.28	–0.33	0.17	0.33	–0.12
Canopy height	–0.60*	0.23	–0.61*	–0.22	0.09	–0.39	–0.50
Shrub density	0.34	–0.16	0.26	0.19	0.35	–0.25	0.03
Tree density	–0.16	0.36	0.04	–0.17	0.17	0.31	0.06
Food tree density	0.29	0.23	0.34	0.05	0.22	0.32	0.43
Basal area	0.15	0.43	0.12	–0.05	0.61*	0.17	0.25
PC1	–0.02	0.40	0.10	–0.08	0.26	0.28	0.16
PC2	–0.53	0.14	–0.59*	–0.03	0.00	–0.55*	–0.50

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

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 as their variance to mean ratio was not considerably lesser than one (Table 4.7). 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 4.7).

Table 4.7. 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	

4.4.4.4 Influence habitat variables on success rates

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 (Figure 4.6). Cluster analyses based on habitat parameters grouped fragments mainly by disturbance level, and to a lesser extent, size of the fragment (Figure 4.7). 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 Anamalai Hills is given in Table 4.8.

4.5 DISCUSSION

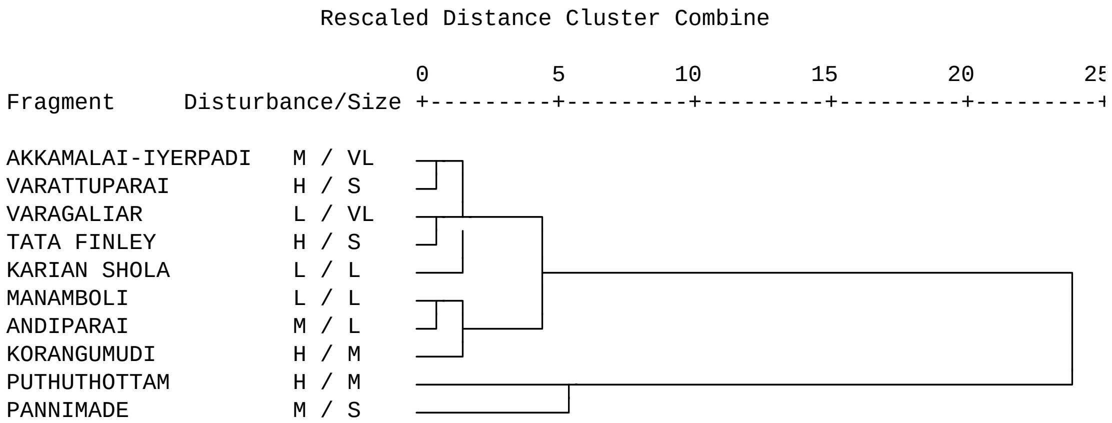
4.5.1 An evaluation of small carnivore survey methods

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 & Pearson 1998) than other indirect methods, as identification of species did not pose a problem. However, relative abundance estimates must therefore be treated as approximations.

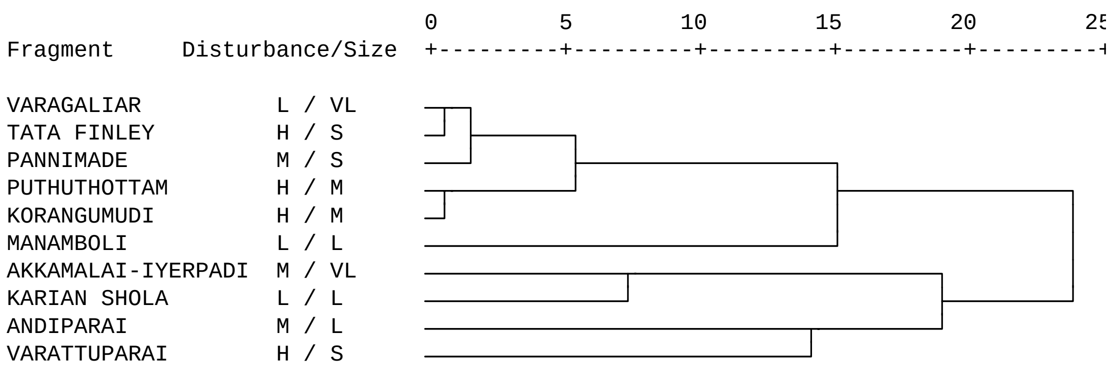
Night walks provided few sightings in the rainforest fragments, and fewer in the undisturbed rainforest. This may, however, be due to the much denser foliage and forest stand in the undisturbed forests than in the degraded fragments. Spotlighting was not an effective method of sampling rainforest small 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, has yielded better estimates of the relative abundances of small carnivores. The use of a combination has been proposed earlier (Zielinski *et al*. 1996; Foresman & Pearson 1998; Mudappa 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.

BROWN PALM CIVET

Dendrogram using Average Linkage (Between Groups)



SMALL INDIAN CIVET AND BROWN MONGOOSE



ALL SMALL CARNIVORES

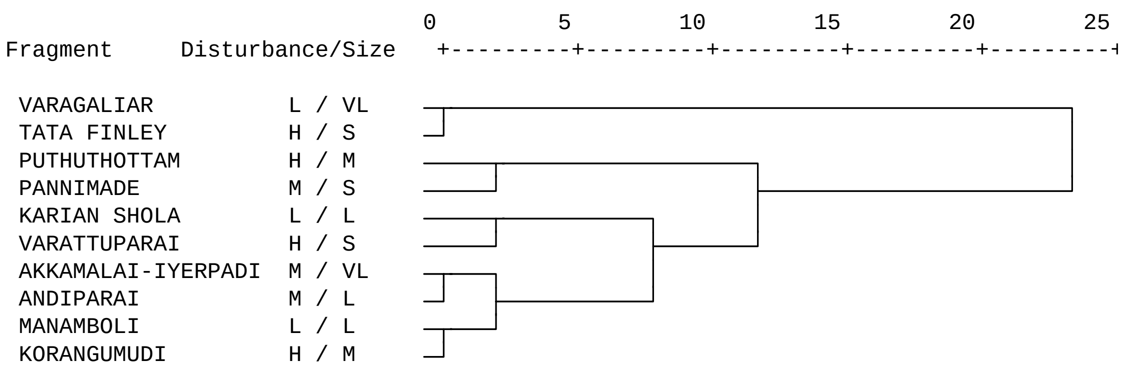


Figure 4.6. Hierarchical cluster of rainforest fragments in Anamalai Hills based on success rates at track plot and camera-trap stations. Disturbance levels: H – high, M – medium, L – low; Size class: VL – very large, L – large, M – medium, S – small.

Dendrogram using Average Linkage (Between Groups)

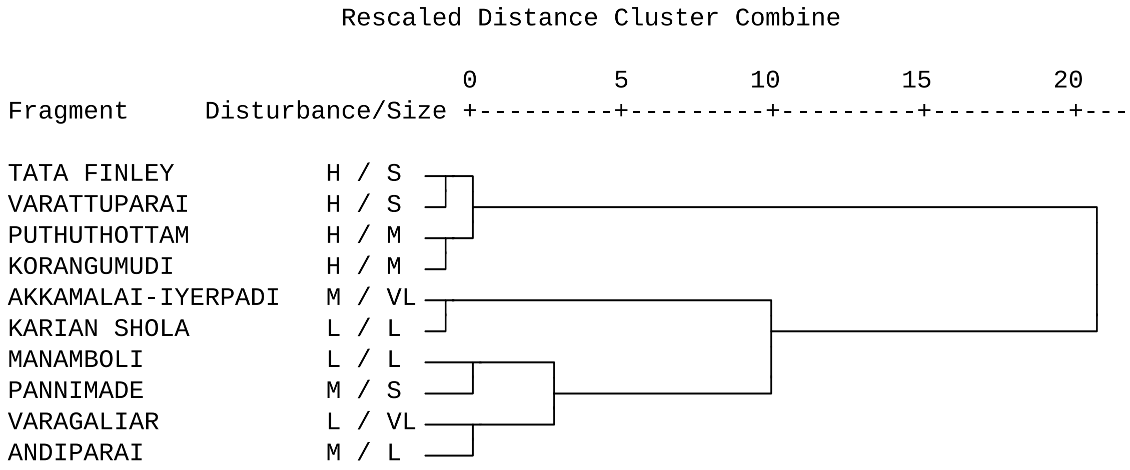


Figure 4.7. Cluster diagram of rainforest fragments in Anamalai Hills based on six habitat parameters (canopy cover, canopy height, tree density, food tree density, shrub density, and basal area). Disturbance levels: H – high, M – medium, L – low; Size class: VL – very large, L – large, M – medium, S – small.

Table 4.8. Occurrence of rainforest small carnivores in KMTR and fragments in the Anamalai Hills, 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
Kalakad-Mundanthurai Tiger Reserve	*	*	*		*	*	*
Anamalai Hills							
Akkamalai (10° 22.015’ N / 76° 59.956’ E)	*	*		*			
Varagaliar (10° 25.070’ N / 76° 51.940’ E)	*	*	*	*		*	
Karian Shola (10° 28.561’ N /76° 49.992’ E)	*	*	*	*		*	*
Manamboli (10° 20.877’ N / 76° 53.949’ E)	*	*				*	
Andiparai (10° 23.646’ N / 76° 59.608’ E)	*	*	*	*	*		*
Puthuthottam (10° 20.468’ N / 76° 58.025’ E)	*	*	*	*			
Korangumudi (10° 18.836’ N / 76° 54.543’ E)	*						
Tata Finley (10° 20.920’ N / 76° 56.053’ E)	*						
Pannimade (10° 17.774’ N / 76° 53.693’ E)	*						
Varattuparai (10° 21.351’ N / 76° 55.797’ E)	*						

BPC – Brown palm civet, SIC- Small Indian civet, BM – Brown mongoose, SNM-Stripe-necked mongoose

The methods used were not without drawbacks (reviewed in Smallwood & 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 & 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 & 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.

4.5.2 Relative abundance of small carnivores

The higher success rates in track plots (48%) and camera-trapping (37.5%) in KMTR than in the Anamalai Hills (32.2% success in track plots and 16.8% in camera-traps) probably indicate higher abundance 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 Anamalai Hills. 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 abundance across regions and habitats. The lower encounter rate of the small Indian civet in direct sightings in KMTR, may not reflect actual abundance, 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 Anamalai Hills. 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 Anamalai Hills. 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 Anamalai Hills. 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 Anamalai Hills). Although not strictly comparable, this may suggest that the more omnivorous mongooses are more common in drier areas, with their abundance 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 Anamalai Hills, in contrast to more than three-fourths in KMTR. The major factor affecting its distribution in KMTR was altitude. In the Anamalai Hills, 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 understory, 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 & 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 Anamalai Hills. However, this may indicate that habitat parameters *per se* cannot predict the occurrence of small carnivores as noted in other studies (Smallwood & Schonewald 1998).

4.5.3 Influence of habitat matrix in fragmented landscape

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 abundance 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 & 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 understory, these species, being chiefly terrestrial animals, are least likely to be affected (Wilkie & 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 & 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 & Turner 1997), particularly by the more terrestrial species.

4.5.4 Impact of habitat fragmentation and disturbance

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 & Davidar 1999; D. Mudappa *unpublished data*) were higher than those reported for some of the richest forests in the Neotropics (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 is considered. Also many of the common species in this region were mammal-dispersed (Ganesh & 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 (*e.g.* Ganesh & 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 & 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. 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 (Terborgh 1983; Ganesh *et al*. 1996; 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).

In this study, rainforest fragments in the Anamalai Hills 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 & 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 & 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 abundance 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 abundance 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 & Bulloh 1996), 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 & 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 (Johns 1988, but also see Fimbel 1994, and Ferrari & 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 & Diego 1995; Heydon & 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 & Kumar 2000). 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 to meet the annual requirements of the species. With the exception of fragments with coffee in the understory, 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). Most of the fragments were less than 100 ha in area, and this could explain the lower abundance 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.

4.6 SUMMARY

- A combination of methods that included track plot, camera-trap, and spot-lighting (night walk and drives) surveys, and opportunistic sightings, provided reliable estimates of the occurrence and relative abundance of small carnivores in tropical rainforests of the Western Ghats.
- The overall success rates in track plots and camera-traps was lower (32.2% and 16.8%, respectively) in the rainforest fragments of the Anamalai Hills than in the relatively undisturbed forests of KMTR (48% and 37.5%, respectively).
- The brown palm civet was the most frequently occurring small carnivore in both KMTR and in the fragments in Anamalai Hills. 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.

- 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.
- 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.
- 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.

5 FOREST FLOOR AMPHIBIANS IN CONTIGUOUS FORESTS

5.1 INTRODUCTION

The rainforest floor is rich in organic matter due to the high litter fall rate, and also has a high moisture level throughout the year, and low fluctuations in temperature (Richards 1996). These conditions are ideal for a rich assemblage of amphibians. The high structural complexity in rainforest is another factor that leads to a diverse amphibian community (Duellman & Trueb 1994). Amphibians have high species richness and endemism in India, with two major centres of distribution; north-east India and the Western Ghats. It is in the latter that amphibian species richness and endemism are highest. Out of the 216 species in India, 120 species occur in the Western Ghats, with 93 endemics. Species richness and endemism are notable among some taxa *e.g.* 14 of 16 species of limbless amphibians (Caecilians) 29 out of 35 species of *Rhacophorus* or gliding frogs, and 35 out of nearly 50 species of Ranids. A majority of the species is found in the rainforest and almost all the endemics are confined to it. The amphibians in India are beginning to be studied in detail (Dutta 1997), and species are being discovered even now. Many species remain single locality records, dating back to 100 years. The taxonomic status of many species, such as the species belonging to the genus *Philautus* and caecilians, are even now far from clear. The life history, micro habitat preference, and the factor affecting the distribution of most species are unknown. Only two studies (Inger *et al.* 1987; Daniels 1992) attempted to identify the factors that govern their distribution and have presented conflicting theories. It is being increasingly realised that the amphibians, along with many of the reptiles and other lower vertebrates and invertebrates, might have considerable patchiness in their distribution. This patchy and restricted distribution makes them highly susceptible to extinction. A recent assessment based on the revised IUCN criteria showed that nearly 57% of the amphibians in India are threatened, with the Western Ghats having the highest number (49) of threatened species (Kumar *et al.* 1998). This patchy distribution also has major implications in the context of habitat fragmentation.

Apart from a short study (Inger *et al.* 1987), there have been no studies on the distribution, abundance, and species richness in amphibians, and factors affecting these in the Western Ghats. An understanding of these aspects was necessary in order to develop a framework within which the impacts of habitat fragmentation could be examined. It is also of considerable importance in ecology. The goal of the study of amphibians in the contiguous rainforests in KMTR was to gain an understanding of these aspects. The specific objectives were to:

- Examine the variation in the distribution, abundance and species richness in relation to microhabitat features of the rainforest; and
- Examine the variation in the abundance and species richness in relation to macrohabitat features such as altitude and drainage.

In order to examine the above aspects we divided the amphibian community into those which reside primarily in the forest floor, and those which are found in the streams. These two communities were sampled separately. The latter is discussed in Chapter 7.

5.2 METHODS

5.2.1 Sampling

5.2.1.1 Adaptive cluster sampling

We began sampling forest floor amphibians and reptiles using the traditional quadrat sampling. The very large proportion of quadrats without any animals (more than 50%), and very low abundance in the others proved a major constraint in data analysis. Therefore, we decided to use adaptive cluster sampling (Thompson 1991) to sample the herpetofauna in the forest floor. Amphibians were sampled in several randomly laid 5m x 5m quadrats. If an animal was sighted in one of these quadrats (called primary quadrats), additional quadrats of the same dimensions (called secondary quadrats) were searched on four sides of the primary quadrat. If any of these quadrats had animals, further quadrats were laid around them until the quadrats with animals were bound or surrounded by quadrats without animals. The quadrats with the animals then become a cluster. If the primary quadrat did not have any animals, the sampling was carried out in the next randomly selected primary quadrat. The search procedure in a quadrat followed Inger (1994). Various substrate such as leaf litter, tree buttress, tree trunk, shrubs, fallen log, and rocks were intensively searched up to a height of two metres by two persons. The sampling was carried out between 0700 and 1100 hrs, and 1400 hrs and 1730 hrs.

For the purpose of analyses we define the term network to be an aggregation of quadrats with amphibian sightings. The following characteristics of the network were estimated from adaptive cluster sampling:

- The number of primary quadrats with animals: This is indicator of the abundance of networks.
- Network size: The number of quadrats in a network, as index of the area occupied by a cluster of animals.
- Species richness in a network: As an indicator of species richness in the area.
- Density in a network: The abundance of animals in a network, controlling for area of the cluster: expressed as the number of animals/quadrat.
- Species composition: The percentage of animals in a taxon out of the total number of animals recorded from quadrats.

Density in the area was mean of the densities in the networks, including primary quadrats without animals (density of zero).

$d=(\Sigma w_i)/N$, where N=number of primary quadrats

$w_i=j/n$, where w_i=density in a network, j=frogs in all the quadrats n in the network together

The variance associated with density (**d**) is expressed as a unbiased estimator of variance (Thompson et al. 1992), by the equation

$$\text{var } d = \frac{(Y - N) \sum_{i-1}^{n} (w_j - d)^2}{YN (N - 1)}$$

where, **Y**=the total number of quadrats in the sampling universe *i.e.* the total number of quadrats that could be possibly laid within 0.5 x 2 km (1 km^2) of the target area that was sampled, and **N**= the number of primary quadrats laid in the area.

Species composition is percentage of animals in a taxon out of the total number of animals recorded during the sampling.

The three sites (Sengaltheri, Kakachi and Kannikatti) were sampled with a stream as the reference point in each of these areas. An approximate area of one sq.km was identified as the target area for adaptive cluster sampling. Adaptive cluster sampling covered the summer and south-west monsoon seasons of 1997. The north-east monsoon in KMTR was covered using quadrat sampling in 1996. Several habitat parameters were recorded from the quadrats that reflected the physiography, vegetation, ground cover, and climatic conditions within it (Table 5.1).

Table 5.1. Habitat variables that were measured in the 5 m x 5 m quadrats used for sampling amphibians and reptiles.

Variable	Measurement
Canopy height (m)	Clinometer and visual estimation to the top layer of leaves
Canopy cover (%)	Canopy densiometer reading at the centre of the plot
Ground cover (%)	Litter, grass and rock; visual estimation
Shrubs (number)	No. along a 1 x 5 m belt within the plot
Herbs (number)	No. along a 1x 5 m belt within the plot
GBH (cm)	Girth at breast height of trees (>20 cm)
Presence/absence of	Liana, bamboo, tree hollow, water, snag, buttressed tree, burrow, and rattan in the plot
Light intensity	Measured with a lux meter at the centre of the plot
Fire (presence/absence)	Evidence of recent fire in the plot
Distance to water (m)	Distance to the nearest water source (up to 500 m); visual estimation
Slope	Visually categorised into flat, gentle, medium or steep slope
Altitude (m)	Measured with an altimeter
Soil temperature (°C)	Mean of measurements at 4 corners of the plot and centre, using a digital thermometer
Air temperature (°C)	Mean of measurements at 4 corners of the plot and centre, using a digital thermometer
Soil moisture	Soil thermometer
Soil pH	Soil pH meter
Leaf litter depth (cm)	Measured with a ruler at four corners of the plot and the centre
Fallen logs	Presence/absence, girth, and state of decay in three categories

5.2.1.2 Opportunistic sampling

This was recording of species seen while not conducting systematic sampling, and not recorded or rarely recorded by other methods. Sometimes such sightings resulted from searches in microhabitats that were rarely encountered.

5.2.2 Data analysis

Discriminant function analysis (DFA) was used in order to identify the microhabitat variables that influence the occurrence of various genera, since sightings of many species were few. The group centroids of different genera obtained from the first two discriminant functions were used to produce a biplot.

The microhabitat measures that were used for the analysis were: herb density, shrub density, canopy cover, litter cover, rock cover, root cover, canopy height, total girth at breast height for the quadrat, number of trees, number of large rocks, number of very large rocks, total girth of fallen logs, number of fallen logs, soil temperature (in), litter depth (in cm), soil moisture (in a scale of 0 to 10) and number of trees with buttresses.

5.2.3 Species identification

Species identification was based on published keys (Boulenger 1890; Daniel 1963a & b, 1975; Daniel & Sekar 1989) and by taxonomists if needed.

5.3 RESULTS

5.3.1 Local distribution (network characteristics)

A total 403 quadrats were sampled during north-east monsoon (October-December 1996), and 648 quadrats during adaptive cluster sampling during summer and south-west monsoon (February-May 1997 and June to October 1997, respectively). Data from quadrat sampling during the north-east monsoon revealed that the abundance of amphibians was very low and variance high (mean = 0.37/quadrat, variance = 0.55, N = 403). There was also a steep decline in the occurrence of amphibians with increasing distance from the stream (Figure 5.1a). The number of species per quadrat also decreased sharply with increasing distance from streams (Figure 5.1b).

The data from adaptive cluster sampling showed that amphibians were distributed in discrete clusters in the forest floor. Only 50% of the primary quadrats (N = 102) had amphibians. In 48 networks that were sampled, the network size varied considerably, from 1-14 quadrats, with a mean of 4.1 (SE ± 0.48) and a median of 3.00. Only 30 % of the clusters had a network size of one quadrat, while 53% had three or more quadrats (Figure 5.2a). The number of amphibians in a network varied from 1 to 42, with a mean of 7.8 (SE ± 1.23) animals and a median of 5.00 (Figure 5.2b). As expected, the number of amphibians in the network was highly correlated with network size ($r_s = 0.925$, N = 48, $P < 0.001$). The density of amphibians in a network varied from 1 to 4 animals per quadrat, with a mean of 1.62 (SE ± 0.37) and a median of 1.50. Thus, amphibians on an average occurred as clusters of about seven animals occupying an area of about 100 sq. m.

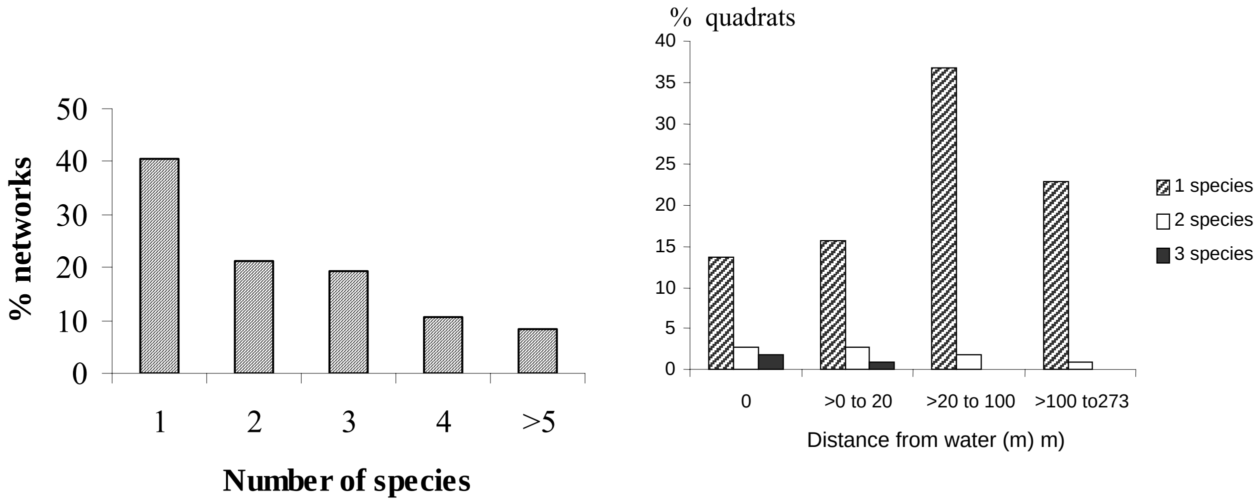


Figure 5.1 (a) Percentage of quadrats with amphibians, and (b) Number of species in quadrat, with increasing distance from water in KMTR during 1996-97 north east monsoon.

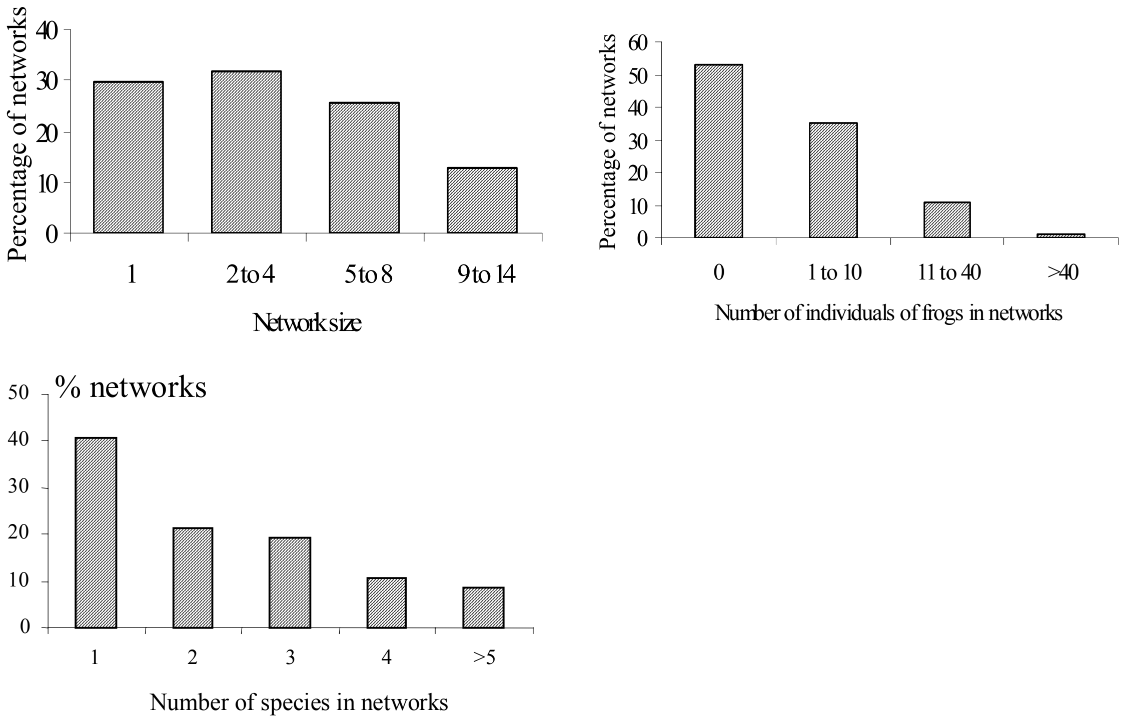


Figure 5.2. (a) The number of quadrats in a network; (b) The number of frogs in a network; and (c) The number of species in a network.

Amphibians occurred as multi-species assemblages in these networks. Only 40% of the networks had one species, 21% had two species and 39% had more than two species with a maximum of nine species (Figure 5.2c). The species richness in a network increased with the network size, but reached an asymptote at about four quadrats.

Some of the network characteristics differed among the three sites and between the two seasons. The occurrence of networks (% of primary quadrats with amphibians) was not different among three sites (χ^2 = 2.03, *df* = 2, *P* = 0.45) when seasons were pooled, and between seasons (χ^2 = 0.323, *df* = 1, *P* = 0.65) when sites were pooled. Network size did not differ among sites (Kruskal-Wallis oneway analysis of variance, KW, χ^2 = 3.08, *df* = 2, *P* = 0.215). Even though the seasonal differences were not significant for each site, when sites were pooled, network size in south west monsoon (mean = 5.23, SE ± 0.76) was significantly larger than in summer (mean = 2.92, SE ± 0.52; KW, χ^2 = 5.61, *df* = 1, *P* < 0.02). Moreover, network size was larger in south-west monsoon in all the sites (Figure 5.3a).

The difference among sites in species richness in a network was not significant in summer (KW, χ^2 = 0.53, *df* = 2, *P* = 0.76), but significant in south-west monsoon (KW, χ^2 = 13.96, *df* = 2, *P* < 0.001, Figure 5.3b). None of the networks in Sengaltheri had more than two species, while 62.5% of the networks in Kakachi and 33.4% in Kannikatti had > 3 species (up to a maximum of 7 and 6 species, respectively). When pooled across seasons also, Kakachi had the highest number of species per network (mean = 3.12, SE ± 0.49), followed by Kannikatti (mean = 1.89, SE ± 0.33) and Sengaltheri (mean = 1.77, SE ± 0.2; KW, χ^2 = 6.13, *df* = 2, *P* < 0.05). Number of species in a network did not vary between seasons when sites were pooled (KW, χ^2 = 0.45, *df* = 1, *P* = 0.5).

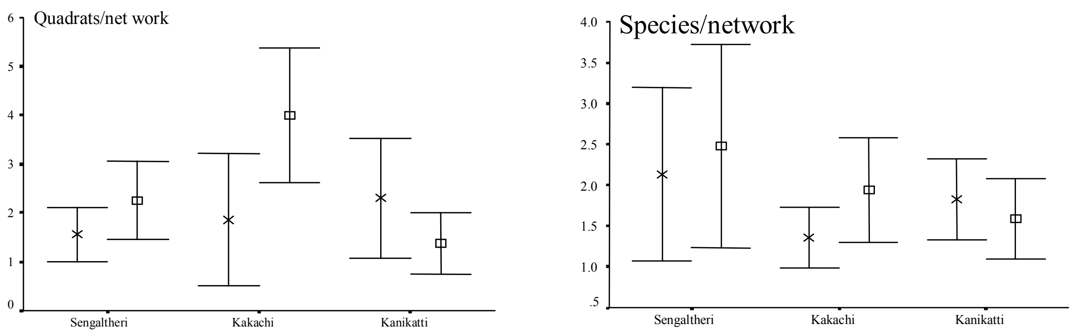


Figure 5.3. Variation in (a) network size (b) number of species per network in three sites during 1997 dry and south-west monsoon seasons in KMTR. × indicates mean for summer; □ indicates mean values for south west monsoon

Amphibian densities in a network were not different among sites when seasons were pooled (KW, χ^2 = 2. 89, *df* = 2, *P* = 0.235) or between seasons when sites were pooled (KW, χ^2 = 0.046, *df* = 2, *P* = 0.83).

5.3.2 Density and composition

During quadrat sampling 509 amphibians from 18 species were recorded. A majority of the species was rare and only few were common; 16 out of 18 species had < 50 individuals. The two remaining species *Micrixalus fuscus* and *Rana temporalis* had 113 and 250 individuals respectively. The density for all species and sites together was 0.87 animals per quadrat of 25 sq.m (variance= 0.012), or 348 animals/ha. Estimation of species densities was not possible since many occurred infrequently. Analysis is therefore based on genera, *viz*. *Bufo* (2 species), *Indirana* (3 species), *Micrixalus* (3 species), *Rana* (1 species: *R.temporalis*), *Ramanella* (1 species: *R.montana*), and *Philautus* (4 species). *Rana* was the most abundant (0.399 animals/quadrat), followed by *Micrixalus* (0.215). The densities were considerably lower for *Philautus* (0.097), *Indirana* (0.041), *Ramanella* (0.031) and *Bufo* (0.014).

There were considerable differences among the three sites in overall density as well as the densities of different taxa. Thus, Sengaltheri had considerably higher density (1.27 animals/25 sq.m) than Kannikatti (0.65) and Kakachi (0.91). This was primarily due to the high density of one species, *R.temporalis* (1.128), in Sengaltheri, compared to Kannikatti (0.366) and Kakachi (0.116). This species was also the most common species in Kannikatti, while in Kakachi *Micrixalus* was the most common taxa.

Overall, the dominant species were *R.temporalis* (43% of all individuals) and *M.fuscus* (21%). There was, however, considerable difference among the three sites in the relative abundance of different taxa. *R.temporalis* clearly dominated (84%) the amphibian community in Sengaltheri. Both *Micrixalus* (45%) and *Philautus* (32%) were dominant in Kakachi. In Kannikatti, *R.temporalis* (48%) and *Philautus* (25%) were the dominant taxa (Figure 5.4).

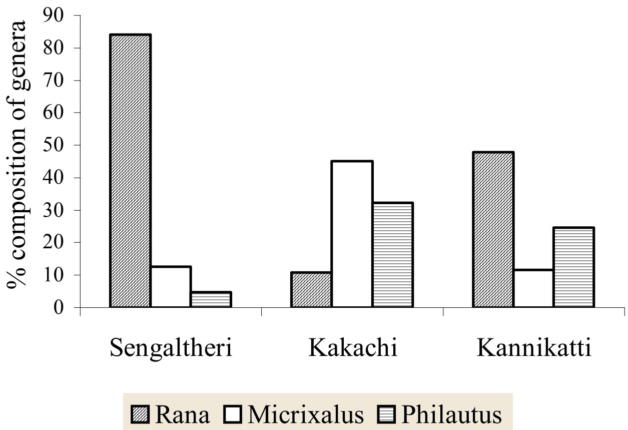


Figure 5.4. Percentage composition of three genera of amphibians in three sites during 1997 dry and south-west monsoon seasons in KMTR.

Micrixalus fuscus was the most dominant species of the genus and was common in all three sites. *M.saxicola* occurred only in Kakachi and Kannikatti. An unidentified *Micrixalus* species was found only in Kakachi. *Indirana brachytarsus* was the dominant species of the genus in all the three sites. Since *I.beddomi* and *I. brachytarsus* had striking morphological similarities and *I.beddomi* occurred infrequently, it was difficult to quantify their relative abundance in the sites. However, the latter occurred more frequently than *I.diplosticta*. In the genus *Philautus, P.variabilis* was the most common in all the three sites. *P.charius* was found only in Kakachi, the remaining two species were shared between Kakachi and Kannikatti.

5.3.3 Multispecies assemblages

The more abundant genera (specifically *Rana*) were found in single genus networks while the rare genera occurred in multigeneric networks ($\chi^2 = 5.388$, $df = 1$, $P < 0.05$). Nearly 38% (N =26) of the networks in which *Rana temporalis* occurred were single species networks, and 43% of the animals (N=205) were seen in monospecific networks. In contrast, in the genus *Micrixalus* only 12% (N=25) of the networks in which it occurred were single species ones, and only 5% (N=94) of the animals of this genus was seen in monogeneric clusters. Among other rare genera only one network out of 22 had a single species occurrence. About 35% (N=17) networks containing *Philautus* and 70% (N=10) containing *Indirana* had more than one species in them.

5.3.4 Microhabitat association

The data from primary quadrats were used to identify the microhabitat variables that influenced the occurrence of different taxa of amphibians, using discriminant function analysis. The quadrats without amphibians were also included in the analysis and are marked in the biplot for reference. In this analysis 8 out of 18 microhabitat variables showed significant difference in their group means on the first five functions (Wilk's Lambda 0.444, $\chi^2 = 184.39$, $df = 90$, $P < 0.00$, Table 5.2). The first and second functions explained 63.6% and 17% of the variance, respectively. Habitat variables that had a loading of >0.4 on these two functions were used to draw inference from the analysis (Table 5.3).

Table 5.3. Test of equality of group means through discriminant function analysis of microhabitat variables that described the separation of quadrats with different genera and those without amphibians in KMTR. The DF1 and DF2 are 5 and 234 respectively.

Habitat variable	Wilk's Lambda	F	Significance
State of decay of plots	0.93	3.506	0.004
Soil temperature (°C)	0.716	18.545	< 0.001
Soil moisture	0.933	3.342	0.006
Canopy height (m)	0.888	5.897	< 0.001
Litter depth (cm)	0.874	6.744	< 0.001
Very large rocks	0.939	3.021	0.012
Rock cover	0.931	3.466	0.005
Herb density in 5 sq m	0.891	5.708	< 0.001

The discriminant functions analysis showed that the genera *Rana, Micrixalus, Philautus, Bufo,* and *Indirana* occurred in different microhabitats (Figure 5.5). The quadrats without amphibians did not separate on the first axis. However, the second axis separated these quadrats (*i.e.,* low litter depth and high rock cover). *Rana temporalis* was distinct in its occurrence on the soil temperature gradient in the rainforest floor. It was usually found in higher soil temperatures and under shorter canopy heights than other species. *Indirana* occurred in high litter depth areas, while *Micrixalus* and *Philautus* occurred in quadrats that were less rocky, had greater leaf litter depth and low soil temperature.

Table 5.4. Structure matrix of discriminant function analysis of microhabitat variables that described the separation of quadrats with different genera and those which did not have any amphibians in KMTR. The cell values are the factor loadings of different functions that were derived through the analysis.

Habitat variable	Functions				
	1	2	3	4	5
Soil temperature (°C)	-0.799				
Canopy height (m)	0.446				
Litter depth (cm)		-0.652			
Very large rocks		0.514			
Large rocks		0.514			
Rock cover		0.429			
Litter cover			0.447		
Herb density in 5 sq m				0.522	
Number of buttress trees				0.464	
Total girth of fallen logs (cm)					-0.492

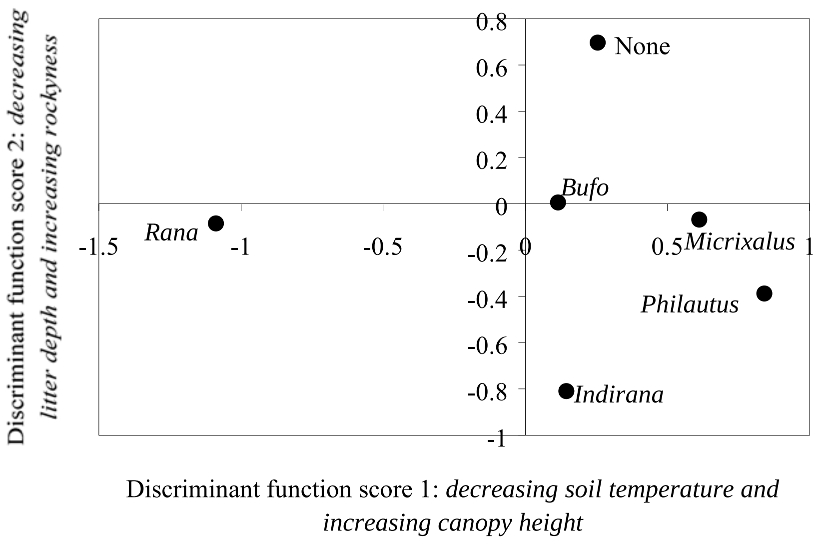


Figure 5.5. The association of amphibian genera with the first two discriminant functions, for quadrats sampled during 1997 dry and south west monsoon seasons in KMTR. The origin of the biplot is the global mean of the data set.

5.3.5 Species richness

During this study only 32 species of amphibians were recorded from the KMTR (Appendix I) using all methods. This included at least seven new records for the region and even more for the Reserve. *Rhacophorus clacadensis* recorded in this study was the first record after its description by Ahl in 1927. *Bufo beddomi, B. microtympanum* and *Micrixalus saxicolous* were first records for the Reserve.

Tree frogs and caecilians contributed most to the new records for the region. While at least 13 out of 25 (52%) tree frogs of the rainforest of the Western Ghats were recorded, only 16 out of 62 (26%) stream and forest floor amphibians and 3 out of 14 (22%) of the caecilians were recorded.

5.4 DISCUSSION

5.4.1 Local distribution

The nature of amphibian distribution on the forest floor has not been examined in any tropical areas, therefore, a comparison of the results from this study is not possible. Although estimates of network characteristics are sensitive to the size of the quadrat, comparisons among species, sites and seasons reveal interesting patterns in the distribution of floor amphibians. They have a clumped distribution, with the numerically dominant species occurring in single species groups and the rarer species occurring in multi-species groups. The clumps or networks sharply decline in occurrence with increasing distance from water sources, primarily streams. Similar patterns have been observed in Malaysia (Inger 1969).

5.4.2 Density and composition

The density of amphibians in KMTR was 0.87 animals/25 sq.m or 3.48 animals/100 sq.m in the rainforest in a 20 m zone from the streams (but not including streams). Density was much lower (0.37animals/quadrat), when the area beyond 20 m from streams was included. Density estimates are available from only few other tropical forests for comparison. In Bornean lowland rainforest the density is considerably less at 15 animals/100 sq.m (estimated from Lloyd *et al.* 1968). Densities in Central American (Heatwole & Sexton 1966; Scott 1976) and South American rainforests (Allmon 1991) range between 2.3 and 15.6. It has been hypothesized that mast fruiting of dipterocarp trees in Thailand causes unpredictability in resources through the fallen fruits and seeds for insects, thereby reducing the abundance of reptiles and amphibians (Inger 1980). Such unpredictable mast fruiting has not been reported from the Western Ghats where the dominance by dipterocarps is also low. The greater abundance of amphibians in South American rainforests compared to Southeast Asia have been attributed to differences in the soil nutrients based on their age (Allmon 1991), even though causal mechanisms are not known. The litter fall rates are greater in South America than Southeast Asia (Bray & Gorham 1964) and Western Ghats (Singh 1985). Resultant differences in litter insect abundance could cause differences in amphibian abundance. A similar pattern should also occur among other insectivores such as the reptiles, shrews, and birds; however such data are not available for a comparison. Another reason might be a greater density of streams in the flat terrain in the Amazon forests, or greater retention of soil moisture either due to the flat terrain or higher rainfall.

The differences among the three sites within KMTR show that the amphibian density and composition can vary markedly over short distances within apparently the same vegetation type. There were major differences among the three sites, although a few species dominated the community overall as reported from other tropical rainforests (Duellman & Trueb 1994). Kakachi had the highest number of species per network as well as overall, and a more even community than the other two sites. Sengaltheri, which had the least number of species per network as well as overall, was dominated by one species, (*Rana temporalis*). Sengaltheri was at the eastern edge of the Western Ghats receiving most of its rainfall, which is lower than the other two sites, from north-east monsoon. Community composition in other rainforest areas is poorly known to make a comparison.

5.4.3 Amphibian microhabitats

The variables such as soil moisture and temperature, canopy height, leaf litter depth and rockiness could discriminate among quadrats with different genera. Leaf litter depth is an important microhabitat feature in which several herpetofaunal species share their niches (Inger *et al.* 1987). *Rana temporalis*, the largest forest floor frog (mean snout vent length = 56.55 mm; SE=2.98; N=24), was associated with low litter depth and canopy height, and higher soil moisture and temperature adjacent to streams. This might explain their lower abundance in the other sites which had greater annual rainfall, greater canopy height, and greater litter depth. The low abundance of this species in Kakachi (altitude 1300 m) might be also related to lower soil temperature. This factor does not, however, explain its lower abundance in Kannikatti at lower altitude (700 m). The genera *Indirana, Philautus* and *Micrixalus* occurred more or less in similar microhabitats. *Micrixalus fuscus*, the most common among three species of the genus, was however was found in the same areas as *R.temporalis*. While *M.fuscus* was active during the day and rested at night, *R.temporalis* was active during the night. *R.temporalis* has a wide range of diet including other frogs (Karthik & Vasudevan, unpublished data). At the generic level, *Indirana* and *Philautus* had similar preferences for litter depth and rockiness, but differed on the soil temperature-canopy height gradient. However, some species of these genera were found together or with other genera rather than alone. It should also be noted that an examination of microhabitat selection might be more relevant at the species rather than at generic level. Low sample sizes, however, preclude such an analysis.

5.5 SUMMARY

Adaptive cluster sampling served as better technique to estimate density of amphibians in the forest floor. It increased the number of sightings of amphibians and provided new descriptors of the amphibian community such as, network size, mean number of species per network and density per network. Amphibians in the rainforest floor were few in numbers, with a density of 148 amphibians per hectare. They were mostly found multispecies networks comprising of 6 to 8 amphibians in a cluster. Amphibian densities were comparable to that of southeast Asia. Comparison of worldwide estimates of density reveals that for the Old World rainforests it was several times lower than in the New World rainforests. It was hypothesised that the differences could have some about because of the difference in the litter fall rates in these regions of the world. There was no significant variation in abundance and species richness across seasons and sites. Sengaltheri had the least number of species among the three sites and it was hypothesised that the disturbance due unpredictable rainfall influenced the amphibian community in this site. Amphibian sightings were associated with increasing litter depth and decreasing rockyness. *Rana temporalis* was differentiated from other species in inhabiting areas with higher temperature and under lower canopy heights. The diversity of amphibians in KMTR was comparable to that of Bornean forests. The species richness in any locality was low (about 8 to 12 species) but the in entire hill range there were 40 species of amphibians. Similar species richness has been observed in other hill ranges in the Western Ghats. There was about 40 % turnover of species from one site to the other in KMTR. It is hypothesised that the high species richness and endemism in the Western Ghats could be due to high beta and gamma diversity.

6 AMPHIBIANS IN RAINFOREST FRAGMENTS

6.1 INTRODUCTION

Amphibians are among the taxa likely to be most adversely affected by rainforest fragmentation and the microclimatic and other habitat changes that follow. This is because of their dependence on soil and atmospheric moisture, canopy and litter cover, and water bodies either at the larval stage or as adults (see Chapter 5). These habitat features are very often severely altered following fragmentation (see Saunders et al 1991). The patchy distribution of many species (see Chapters 5 and 7), makes then even more vulnerable. The patchy distribution, probably due to drainage effect, also makes it likely that forest fragments might have species not found in the larger fragments. Therefore, amphibian community in a fragmented landscape may show less nestedness, a property of biological communities that has been examined extensively in the context of habitat fragmentation (Patterson & Atmar 1986). However, their poor dispersal ability promotes nestedness.

The response of amphibians to habitat fragmentation is often diverse, perhaps reflecting the diverse life histories that they have compared to many other taxa. Fragment area, presence and permanency of wetlands, distance to large forest area, and friendly matrix are among the factors that govern the occurrence and abundance of species, as well as overall species richness (see Marsh & Pearman 1997; Vos & Chardon 1998; Gascon *et al.* 1999; Kolozsvary & Swihart 1999).

The major objectives of the study on amphibians in the rainforest fragments were:

- To examine the variation in network characteristics, density, species richness and composition among forest fragments, in relation of habitat features of the forest fragments, and comparison with the contiguous forests in KMTR;
- To examine the extent of nestedness of the amphibian fauna in the rainforest fragments.

6.2 METHODS

6.2.1 Sampling

Amphibians in forest fragments were sampled using adaptive cluster sampling, stream surveys and opportunistic records. Data on species richness in forest fragments come from all methods, while other parameters are estimated from adaptive cluster sampling. Data from stream sampling was used to examine species turn over (Chapter 7).

Unlike in KMTR, adaptive cluster sampling was not restricted to riparian zone since some small fragments did not have streams. Instead, all fragments were sampled at random distances from the edge. Laying quadrats at random distances along a randomly chosen compass bearing ensured this. In total, 436 primary, 202 secondary quadrats and about 300 boundary quadrats that did not have any amphibians were searched. The number of quadrats sampled was proportional to the area of the fragment. In addition to the habitat parameters recorded in KMTR (Table 5.1), the distance from the nearest edge to the primary quadrat was also recorded. The sampling covered three seasons between November 1997 and January 1999.

6.2.2 Data analysis

6.2.2.1 Comparison of species richness between KMTR and forest fragments

Due to major differences between the two hill ranges in species richness and composition (see below), the comparison of the structure of amphibian communities was primarily restricted to fragments within Anamalai Hills. The number of species per quadrat (MSPQ) was used as a surrogate for comparison of species richness in KMTR and the Anamalai Hills. MSPQ was the number of species in a network divided by network size. Primary quadrats without amphibians had a MSPQ of '0'. Fragments were grouped as large (150-2500 ha), medium (10-149 ha), and small (<10 ha). Then sites in the rainforest of KMTR were selected with comparable altitude range and MSPQ was calculated. The comparable site for large fragments in KMTR was Kakachi, for medium sized fragments it was all three sites pooled together, and for small fragments it was Sengaltheri. Bootstrapping (using SIMSTATW 4.2) was used to resample the data and develop a distribution of MSPQs for different size class of fragments and comparable sites in KMTR. The number of quadrats re-sampled was kept constant at 20, and 3000 iterations were conducted. The results are represented graphically.

6.2.2.2 Nestedness

Nestedness refers to the tendency of the more depauperate communities in habitat isolates to form subsets of richer communities (Patterson & Atmar 1986; Patterson 1987; Cutler 1991; Atmar & Patterson 1993; Quinn & Harrison 1988). An island system that shows complete nestedness of fauna has greater predictability of extinction (Atmar & Patterson 1993). However, ordered extinction from a nested fauna depends on the following assumptions (Atmar & Patterson 1993):

- The fragmented habitat was once whole and populated by a single common source biota;
- The fragmented habitat was initially uniform in the heterogeneity of habitat and the remnant fragments have similar heterogeneity;
- There is no significant environmental gradients across fragments which promote species turnover; and
- All species are equally isolated in fragments.

The program NESTED (Atmar & Patterson 1995) was used to test for nestedness. Species records from all sampling methods were used to develop species incidence matrix for 13 fragments. One fragment (Varatuparai 4) did not any amphibians and was excluded from analysis.

6.2.2.3 Community structure in fragments

A principal component analysis of the habitat variables did not result in a major data reduction. Therefore, the habitat correlates of community structure are examined with reference to the original set of habitat variables though simple linear correlation. Non-linear curves are accepted as better fits only when there was a better correlation as well as a reduction in probability values. We also explored the effect of time since isolation, this information coming from Congreve (1940) and discussions with biologists and planters in the area. Multiple regression was used to examine the cumulative effect of area and time since isolation. Seasonal variation is not examined due to small sample sizes. However, network characteristics and densities for each fragment were estimated as the mean of seasonal means thereby accounting for seasonal variation in sample sizes.

6.3 RESULTS

6.3.1 Network characteristics

The number of quadrats sampled in a fragment varied from 13 to 110, in proportion to fragment area (mean=45.57, SD=28.63). The number of frogs recorded in a fragment varied from 0 (Varattuparai 4) to 167 (mean=36.63, SD=45.59). Overall, only 21.2% of the primary quadrats (*i.e.* the occurrence of networks) had amphibians. In the 13 fragments with amphibians, the percentage of primary quadrats with amphibians or network occurrence varied from 9.34% to 44.44%. The mean network size in a fragment varied from 1.75 quadrats to 12.75, with an overall mean of 4.15 quadrats (SD=2.86). One fragment (Sanakarankudi) had large networks. The mean number of animals in a cluster in a fragment varied from 1.75 to 41.75 (overall mean=7.89, SD=10.42). The mean number of species per network (excluding Varattuparai 4) varied from 0.09 to 0.61, with a mean of 0.30 (SD=0.17).

None of the above network characteristics were significantly related to fragment area (Table 6.1), the correlation varying between 0.36 and 0.50. Network occurrence was positively related to root cover (r=0.67) and canopy height (r=0.53) and negatively to two variables that measured disturbance, number of cut saplings and cut trees in the quadrat (r=-0.62 and 0.63, respectively).

6.3.2 Species richness

Overall, 40 species were recorded for all fragments and sampling methods together (Appendix I). The number of species in the 13 fragments varied from 1 to 15 (mean=7.54, SD=4.96). The species richness in the fragments increased as a function of the area of the fragment (R^2 = 0.617, df = 13, P < 0.001, Figure 6.1a). The time since isolation of the fragments had a better quadratic fit (R^2 = 0.794, F = 21.16, P = 0.0002) than linear (R^2 = 0.577, F = 16.34, P = 0.0016) with the number of species (Figures 6.1b). Isolation, after controlling for area, showed a nearly significant relationship with species richness (Partial correlation: r = 0.464, N = 11, P = 0.111).

Table 6.1. Pearson correlation (r) of species richness, network variables and overall density of forest floor amphibians with habitat variables in 13 rainforest fragments in the Anamalai Hills.

TOTSPP=No. of species from all methods.**PERQSEAS**=% of quadrats with amphibians, mean of three seasons; **MCLUS**=Mean network size; **MINDCLUS**=Mean individuals/quadrat; **MSPP=**No. of species per quadrat; **DENSEAS=**Density (/25 sq.m; mean of three seasons.

	TOTSPP	PERQSEAS	.MCLUS	MINDCLUS	.MSPP	.DENSEAS
Area (log)	.8880**	.4687	.3696	.4822	.5016	.4666
No. of herbs	.7488**	.3484	.2936	.3993	.3841	.2509
No. of shrubs	.1115	-.2365	-.1997	-.1668	-.2492	-.3053
Canopy cover	.5789*	.1239	.2827	.1685	.1894	.0496
Litter cover	.5344*	.2065	.4716	.2838	.3226	.2197
Root cover	.7610**	.6680**	.4586	.4446	.7091**	6126*
Grass cover	-.5593*	-.2927	-.3370	-.2259	-.3521	-.1602
Canopy cover	.6377*	.5342*	.6292*	.5871*	.6347*	.6273*
Dist. to edge	.7681**	.2980	.1025	.2083	.2875	.201
No. cut sappling	-.6824**	-.6247*	-.2275	-.2857	-.6159*	-.3891
No. cut trees	-.7874**	-.6335*	-.2453	-.3055	-.6264*	-.3989
No. of tress	.4998	.2725	-.1959	-.1886	.2280	-.1190
No. of logs	.5596*	.3636	-.0247	.0023	.2968	.0389
Atmos. temp.	-.4477	.2100	.0699	.1029	.1980	.2133
Soil temp.	-.4559	.1662	.0837	.1729	.1398	.2620
Litter depth	.3344	.4489	.7083**	.5162	.5522*	.5726*
Soil moisture	.6343*	.0840	.2633	.2990	.1313	.1607
No. buttress	.5945*	-.0018	.0801	-.0527	.0928	.0072

* - Signif. LE .05 ** - Signif. LE .01 (2-tailed)

MSPQ in fragments of different size classes were lower than those observed in comparable sites in the KMTR (MW U: 'large fragments', Z = 4.174, n1 = 189, n2 = 102, P < 0.001; 'medium fragments', Z = 4.599, n1 = 160, n2 = 24, P < 0.001; 'small fragments', Z = 4.017, n1 = 82, n2 = 24, P < 0.001). The MSPQ for large fragments did not vary much from that in KMTR. However, MSPQ in the other two size classes were considerably lower (Figure 6.1d).

6.3.3 Density

The density of amphibians in fragments, excluding Varattuparai 4, varied from 0.09 animals/25 sq.m to 1.12 animals/25 sq.m, with a mean of 0.38 (SD=0.28). However, neither the overall density nor that of different genera was correlated with fragment area (Figure 6.1c; Table 6.2). Overall density was significantly and positively correlated with root cover (r=.61, P<0.05), canopy cover (r=.63, P<0.05) and litter depth (.57, P<0.05).

Among the major genera, the densities of *Bufo* and *Ramanella* were not correlated with any habitat variables, the correlation with litter depth being the highest in both genera (r=0.42 and 0.47, respectively, *P*>0.05). The density of *Indirana* was positively correlated with canopy height (r=.69, *P*<.01) and canopy height (r=.71, *P*<0.01), while that of *Micrixalus* was positively correlated with root cover (r=.84, *P*<0.01), tree density (r=.66, *P*<0.01) and number of fallen logs (r=.61, *P*<0.05) and negatively with two variables that measured human activities- density of cut saplings (r=.71, *P*<0.01) and cut trees (r=.77, *P*<0.01). The density of *Philautus* was negatively correlated with litter cover (r=-.57, *P*<0.05). Thus, the overall density and that of three genera were correlated with habitat variables other than fragment area.

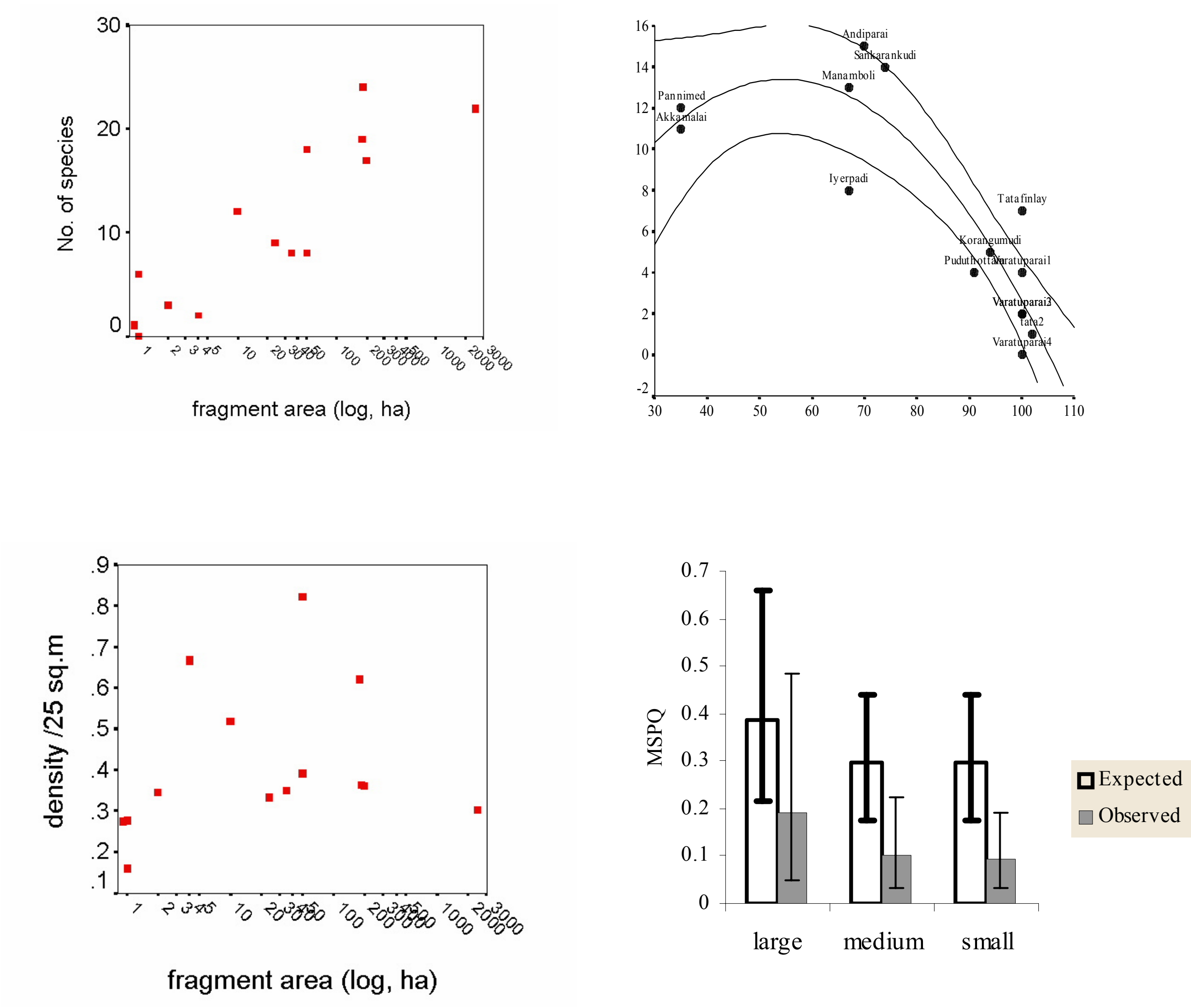


Figure 6.1. Species richness in relation to (a) fragment area, and (b) years since isolation of the fragment; (c) amphibian density in relation to fragment area; (d) species richness per quadrat (5 m x 5m) in three fragment size classes; expected value is the density in Kalakad-Mundanthurai Tiger Reserve.

Table 6.2 Pearson **r** of densities of 5 dominant genera with habitat parameters in 13 rainforest fragments.

	DBUFO	DINDRI	DMICRI	DPHILA	DRAMAN
LNAREA	.0672	.3347	.5112	.2844	.1915
HERBS	.0275	.2588	.3313	.0002	-.0382
SHRUBS	-.1236	-.2317	-.0423	-.1894	-.2972
CANCOV	-.1395	.2510	.3970	-.5055	-.0563
LITTERCO	.0885	.4131	.4864	-.5702*	.1200
ROOTCOV	.3418	.4298	.8365**	.0555	.3172
GRASCOV	-.0752	-.2298	-.5003	.2454	.1490
CANOPYHT	.2900	.6921**	.5282	-.2418	.5045
DISTEDGE	-.1570	.0471	.4930	.2800	-.0819
CUTSAP	-.2451	-.1346	-.7047**	-.3072	.1030
CUTTREE	-.2020	-.2079	-.7662**	-.1278	.0250
NTREE	-.0181	-.2632	.6616**	-.1238	-.5012
NLOGS	.0505	-.1526	.6144*	.0757	-.3206
TEMPATM	.3308	.1261	-.2315	.3851	.1019
SOILTEMP	.3690	.1362	-.3401	.4819	.2660
LITTEDEP	.4217	.7141**	.4060	-.2773	.4648
SOILMOIS	-.1040	.1755	.3480	-.2509	.2092
TREEBTR	-.1342	.1010	.4099	-.2952	-.1422

6.3.4 Species composition

Although 27 species of forest floor amphibians were recorded, the abundance of most species were low. For all fragments together, less than 10 individuals were recorded for 16 species, more than 100 individuals were recorded for only one species (*Indirana beddomei).* Between 11 and 20, and 41 and 60 individuals were recorded for 3 species each, and between 21 and 40 individuals were recorded for 4 species. The pattern was the same when fragments were grouped into three area classes (>200 ha-large, 100-199 ha-medium, and <100 ha-small). However, the percentage of species in the higher abundance classes was greater in the large fragment, and lowest in the small fragments, showing the frequency distribution becomes more uneven as fragments become smaller (Figure 6.3).

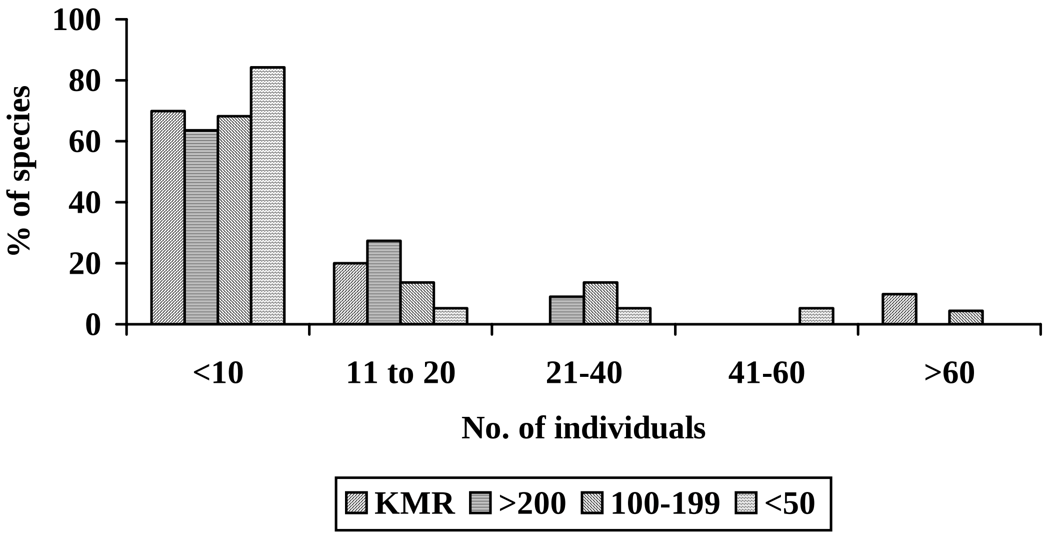


Figure 6.3. Frequency distribution of individuals recorded in each amphibian species in Kalakad-Mundanthurai Tiger Reserve (KMTR) and in three fragment size classes (>200, 100-199, and <50, ha) in the Anamalai Hills.

The relative dominance of genera varied considerably among the three fragment size classes (Figure 6.4). Thus, *Philautus* was the most common genus in the large fragment (41.77%) followed by *Micrixalus* (36.71%) and *Indirana* (17.72%). In the medium sized fragments, *Indirana* (57.82%) was the most common genus, followed by *Philautus* (20.75%) and *Micrixalus* (11.22%). In the small fragments, *Philautus* was the most common (35.25%), *Indirana* (30.94%) the second most common, followed by *Ramanella* (12.95%). Over the three fragment size classes, *Indirana* was the most dominant (35.49%), followed by *Philautus* (32.59%) and *Micrixalus* (19.33%).

The relative abundance of different genera of all fragments together as well as of each size class varied considerably from that of KMTR. One of the most notable differences was the lack of the genus *Rana* in the forest fragments, while this genus (with only one species, *R.temporalis*) dominated in KMTR overall, and in two sites. In contrast the most dominant genus in the fragments, *Indirana*, formed only 5.1% of the animals in KMTR. Similarly, *Philautus* which was the second most abundant genus for all fragments together and the most dominant genus in the small (35.35%) and large (41.77%) fragments formed only 11.8% in KMTR overall. This genus was most common in Kakachi (28.0%), and relative very rare in Kannikatti (8.7%) and Sengaltheri (1.3%). *Micrixalus* the third most common genus in fragments (19.33%) was the second most common in KMTR overall (25.2%), and in Sengaltheri (5.9%) and Kannikatti (25.2%), and the most dominant in Kakachi (55.8%). Thus, although there were considerable differences among the fragment size classes and among the sites in KMTR, the lack of *Rana* and the dominance of *Indirana* and *Philautus* are overriding features in the fragments in the Anamalai Hills.

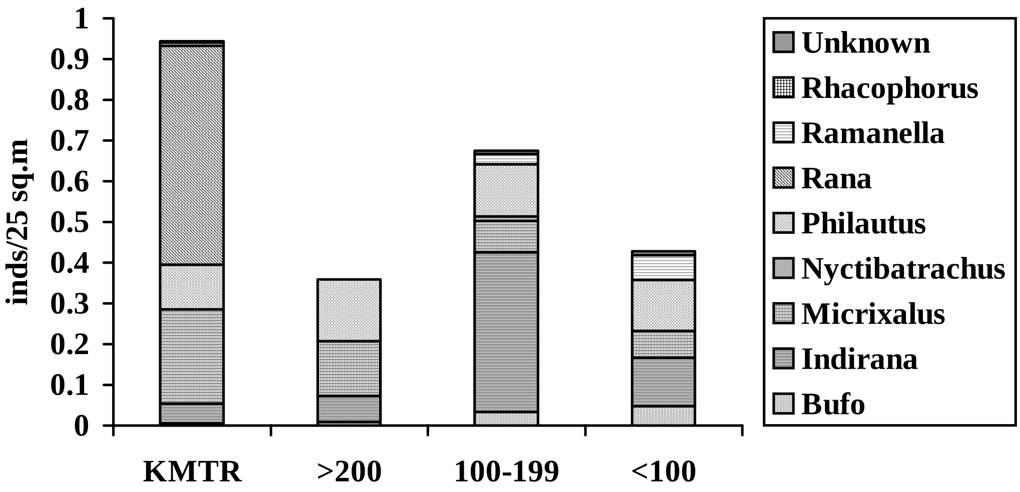


Figure 6.4. The density (/25 sq.m) of different amphibian genera in Kalakad-Mundanthurai Tiger Reserve, and three fragment size classes (>200, 100-199, and <50, ha) in the Anamalai Hills.

6.3.5 Nestedness

The matrix used for the analysis using NESTED program had 31 species in 13 fragments. This matrix was significantly nested ($T = 14.81°$, $P<0.001$). The area of the fragment and the rank of hospitality of the fragment had a strong positive relationship (r = 0.924, N = 13, $P < 0.001$).

6.4 DISCUSSION

6.4.1 Species richness and density

A positive relationship between species and fragment area has been reported in many taxa, and also in reptiles in the same area (see Chapter 9). The drastic reduction in number of species per quadrat (MSPQ) in forest fragments compared to KMTR shows that the decline in species richness happens not only for the fragment as a whole, but even at each location within (see also Yiming *et al* 1998). The relationship with fragment area does not provide a causal explanation to the variation in species richness since several habitat variables covary with fragment area (see also Vos & Chardon 1998). The relatively large unexplained variance in species richness reflects this. In fact, amphibian response to habitat fragmentation depends on the availability of specific habitat features rather than to area *per se*. For example, the availability of wet lands and their permanency (Kolozsvary & Swihart 1999), nature of matrix around the fragment (Gascon *et al* 1999), distance to the nearest large patch and nature of understory (Marsh & Pearman 1997) are all factor reported to influence the survival of amphibians in habitat fragments.

Fragment and the degree of isolation were correlated. This was expected since the process of fragmentation reduced size of the habitat and also simultaneously increased the distance to the nearest large patch. Further, the smallest extant fragments were those that were also the first to get fragmented. Since size and degree of isolation of the fragment were related they were used as independent variables in separate models predicting the number of species of amphibians.

6.4.2 Nestedness

Several island habitats and fragments have nested fauna although total nestedness is rare. In amphibians, nestedness have been reported in islands (Yiming *et al* 1998) whereas pond amphibians show greater nestedness if species are grouped by their microhabitats (Hecnar & M'Closkey 1997). The amphibian fauna in the fragments in the Anamalai Hills also appeared to be strongly nested, even though statistical test of nestedness is problematic (see Methods section). This nestedness is spite of the possibility of patchy distribution of many species and consequent differences among fragments in the original fauna. However, some species showed significant departure from nestedness, and these species might represent those which had patchy distribution. The patchy distribution could result from drainage effect (See chapter 7), or the occurrence of specific microhabitats only in smaller fragments. In the absence of information on microhabitat preferences at species level, it is not possible to examine the deviations of some species from nestedness.

The nested pattern in fauna could appear through passive sampling, nestedness of microhabitats, or through ordered extinction (Cutler 1991). It is important to rule out the possibility of passive sampling before exploring a causal explanation (Andren 1994; Worthen 1996). Since the abundance of species was not related to the number of fragments that they occupied, it is unlikely that passive sampling could have caused nestedness. Few studies have explored the effect of nested habitats or subdivision of habitat on the fauna (Cook & Quinn 1995). Calme & Desroches (1999) demonstrated that nested microhabitats best predicted nestedness of bird species in a peatland archipelago. Due to the lack of information on microhabitat preferences at a species level it is not possible to examine this aspect here.

Deviations from system temperature reflect the idiosyncratic site and species temperatures, and are indicative of the intrinsic nature of species or the site by forming outliers in the matrix. Andiparai, Akkamalai, Sankarankudi, Pannimed are idiosyncratic sites whose behaviour can be attributed to the ‘drainage effect’. This might have caused several unexpected absences and presences. The smallest fragment, Tata, was an ‘outlier’ where one species (*Rana aurantiaca*) was recorded when it was not expected. It was because this small fragment was close to the stream, when all other small fragments were far away from a stream. The species that occur on the temperature line are at the threshold of extinction. Based on this, the members of the genera *Micrixalus, Indirana* and *Nyctibatrachus* are likely to go extinct first from the rainforest fragments, if the size of the fragment were to decline. *Philautus charius, Bufo* sp., *Pedostibes tuberculosus, Bufo parietalis, Philautus sp., Micrixalus nudis, Limnonectes limnocharis, Polypedates pseudocruciger, Philautus temporalis, Philautus chalazodes* were the idiosyncratic species.

There is also growing evidence of enhanced nestedness due to frequent colonization in island fauna (Cook & Quinn 1995). Some core species such as *Bufo melanostictus* and *Limnonectes limnocharis* occurred as a fairly contiguous population in the landscape. They were poor discriminators of habitat quality, widely distributed and non-endemic species. In contrast, others (satellite species) occurred in discrete populations in the fragments. Some of these (*e.g. Indirana beddomi, I. brachytarsus, I. leptodactyla* and some *Philautus* species) survive in the landscape through recolonization after periodic extinction in the fragments, thus forming metapopulations (Hanski & Simberloff 1997). The survival of these species is most likely to be influenced by average distances between fragments. The remaining species in the community on the left of the matrix were rare and showed extreme site specificity (*e.g.* unidentified species of *Micrixalus* and *Philautus*). These may not respond to the degree of isolation. Their survival would be dependent on the remnant rainforest fragments in which they occur.

6.5 SUMMARY

Smaller fragments had fewer amphibian species in greater densities than in larger ones. It is speculated that the increase in the density of few 'common' amphibians was probably due to low interspecific competition and predation, which might have allowed their population to increase. Disturbance in the fragments influenced amphibian species richness even after controlling for area of the fragments. This suggests that other than decreasing area of the habitat, progressive decay of rainforest fragments can pose threat to several species of amphibians. If a large contiguous rainforest was fragmented then, the resulting fragments will have lower species richness than if the forest of the same were unfragmented. Fragmentation does cause a decline in the number of species of amphibians especially the 'rare' ones. The amphibian fauna in the rainforest fragments were significantly nested. Based on this, it was predicted that members of the genera *Micrixalus*, *Indirana* and *Nyctibatrachus* were likely to go extinct first from the fragments of the Anamalais, if the size of the fragment decreased. It is speculated that amphibians occur in discrete populations since majority of the landscape is dominated by an inhospitable habitat (tea plantations). The occurrence of species in a rainforest fragment may be governed by the probability of recolonization and extinction events. The probability of recolonization diminishes due to the intervening tea plantations between forest fragments.
Area, degree of isolation and habitat heterogeneity explained 77 % of the variation that was observed in the number of species in the fragments. The contribution by degree of isolation being the highest. There was quadratic relationship between time since isolation of the fragments and the number of species in them. This non-linear relationship puts forth a new paradigm to our knowledge on the effects of isolation on rainforest fragmentation in the Western Ghats. It is speculated that 'core area' in a fragment may be extremely small due to the 'edge effect'. The effective area habitable by amphibians in rainforest fragments might be far less than the area of the fragment.

7 STREAM AMPHIBIANS

7.1 INTRODUCTION

The amphibian fauna in the rainforest were divided into two groups (forest floor and stream dwelling) primarily because these two groups required different sampling methods (Chapter 5). Moreover, the streams in forest fragments were subject to a different suit of human disturbance, in addition to being influenced by factors such as selective logging, fuel wood removal etc. that happen away from the streams. A third reason to treat stream amphibians separately was that the stream segments formed ideal sampling units to examine the turn over of amphibian community from one site to another. That such a turn over is very likely became evident within a few months of sampling forest floor amphibians in KMTR (Chapter 5). Finally, streams are a very important microhabitat for many amphibians, especially for breeding, and subject to high seasonal variations due to monsoons. Compared to Amazonian forest, most Southeast Asian amphibians breed in streams or riparian areas (Zimmerman & Simberloff 1996). Seasonality in the amphibian community in rainforest is therefore best reflected in the stream amphibians.

The impact of rainforest fragmentation on stream amphibians has been examined little elsewhere, although this community might have been included in studies on amphibian community in general (*e.g.* Gascon *et a*l 1999; Parris & McCarthy 1999). On the other hand, there have been a few studies on the impact of habitat fragmentation in pond or wetland amphibians in North America (Hecnar & M'Closkey 1997; Kolozsvary & Swihart 1999) and Europe (Vos & Chardon 1998). The turn over of herpetofauna between hill ranges in the Western Ghats has been commented up on by Roux (1928) and Inger *et al.* (1987), but without quantitative data.

The major objectives of the study on stream amphibians were to examine:

- Changes in species richness, abundance and composition due to habitat fragmentation;
- The turn over of amphibian community with drainage.

7.2 METHODS

Amphibians along stream segments of second order were sampled using time-constrained search, in which the encounters of amphibians within a given time were recorded. The stream segments had a width of 8 m to 10 m. Surveys were made between 1830 hrs and 2300 hrs, by two persons walking abreast, on either side of the stream using a flashlight to locate amphibians. No active search was involved and hence there was no disturbance to the stream. Such nocturnal surveys are very effective for stream amphibians (Parris *et al* 1999). Each sighting was recorded with time and microhabitat description of the locality. Three drainages were sampled in each area, each of which had two stream segments (sites) permanently marked (Table 7.1).

Table 7.1. Sites for sampling stream amphibians in different drainages in Kalakad-Mundanthurai Tiger Reserve (Ashambu Hills) and Anamalai hills

Sampling sites	Altitude in m	Drainage	Hill range
Kannikatti 1 (KN1)	780	Tamarabarani	Ashambu
Kannikatti 2 (KN2)	740		
Sengaltheri 1 (S1)	990	Manimuthar	
Sengaltheri 2 (S2)	1010		
Kakachi 1 (KA1)	1200	Pambar	
Kakachi 2 (KA2)	1180		
Andiparai 1 (AD1)	1240	Kadamparai	Anamalai
Andiparai 2 (AD2)	1290		
Akkamalai 1 (AK1)	1360	Nadumalai	
Akkamalai 2 (AK2)	1370		
Manamboli 1 (M1)	880	Parambikulam	
Manamboli 2 (M2)	870		

Each stream segment was surveyed 3-4 times in KMTR and 2-4 times in Anamalai Hills in each of the three seasons. A total of 63 surveys were done in KMTR in 1997, and 51 in Anamalai Hills in 1998. Stream segments within fragments were classified into low disturbance (Akkamalai, Andparai and Manamboli) and high disturbance (Iyerpadi, Puduthotam and Shankarankudi) categories. In the former canopy and understory vegetation remained fairly intact and there was not much human activity upstream or around the stream segment sampled. The streambed was not silted and the boulders, covered with algae and moss, were firmly embedded in it. The high disturbance streams had a high human use around the stream, especially removal of fuel wood from the surrounding forests. Usually these streams were silted and had dense understory. The boulders were loose and sparsely covered by algae and moss.

7.2.1 Data Analysis

Since the data consisted of pseudoreplicates (*i.e.* repeat samples of the same stream segments) and true replicates (number of stream segments) were few, inferential statistical tests were not carried out. Instead, box plots, which furnish a measure of central tendency (the median line), dispersion (the length of the box and the whiskers), skewness (asymmetry of the upper and lower portions of the box and whiskers) and possible outliers, were used to compare the abundance and species richness of amphibians among sites and seasons.

Sorensen's index of overlap for species occurrence (Wolda 1981) was computed for 66 possible combinations of 12 sites. The overlap estimates were arrayed in a two-way matrix. In this matrix, 6 combinations represented overlap within drainage, 24 represented overlap between drainages, and 36 represented overlap between hill ranges. Similar matrices were developed for difference in altitude and distance between sites. The data were tested for differences in overlap within drainage, between drainages, among hill ranges using ANOVA.

Mantel Z statistic (Hemelrijk 1990) was used to test the significance of correlation of the matrix of species overlap with matrices of differences between sites in geographical distance and altitude in Ashambu hills (KMTR) and Anamalai Hills separately. The program MATSQUAR (Hemelrijk 1990) was used for this purpose. In each of these tests 10000 iterations were used to compute the statistic and one-tailed probability values. The index of species overlap for the two hill ranges was compared using the box plot.

7.3 RESULTS

7.3.1 Abundance and species richness

About 30 to 45 amphibians were encountered during each survey of a stream segment. The mean number of amphibians encountered per survey in KMTR was comparable to the high disturbance streams in the Anamalai Hills, while the low disturbance streams had fewer amphibians (Table 7.2). Although the mean number of species per survey was the same in both the hill ranges, the total number of species in the Anamalai Hills was twice as much as in KMTR. The two-fold increase in the number of amphibian species in the Anamalai Hills compared to KMTR was primarily due to the large representation by frogs of the genus *Philautus*. In KMTR, *Philautus* was not recorded at all during stream sampling. The only rhacophorid recorded during the survey in KMTR was *Rhacophorus clacadensis*. *Micrixalus* was more abundant in the streams of KMTR.

Table 7.2. Number of individuals and species of amphibians encountered in stream segments sampled between May 1996 and January 1999 in Kalakad-Mundanthurai Tiger Reserve and Indira Gandhi Wildlife Sanctuary.

	Number of amphibians			Number of species		
	Total	Mean*	SE ±	Total	Mean*	SE ±
KMTR	2776	44	2.68	10	5	0.15
Anamalais	1863	38	3.41	20	5	0.23
Low disturbance	925	33	4.36	18	5	0.3
High disturbance	938	45	5.2	16	5	0.36

* values rounded off to the nearest whole number

There was a large variability among seasons in number of amphibians and species recorded per survey. In KMTR, summer had more species per survey while north-east monsoon had fewer amphibians (Figure 7.1a & b). In the Anamalai hills, the north-east monsoon had more species and south-west monsoon had fewer amphibians per survey (Figure 7.2 a & b).

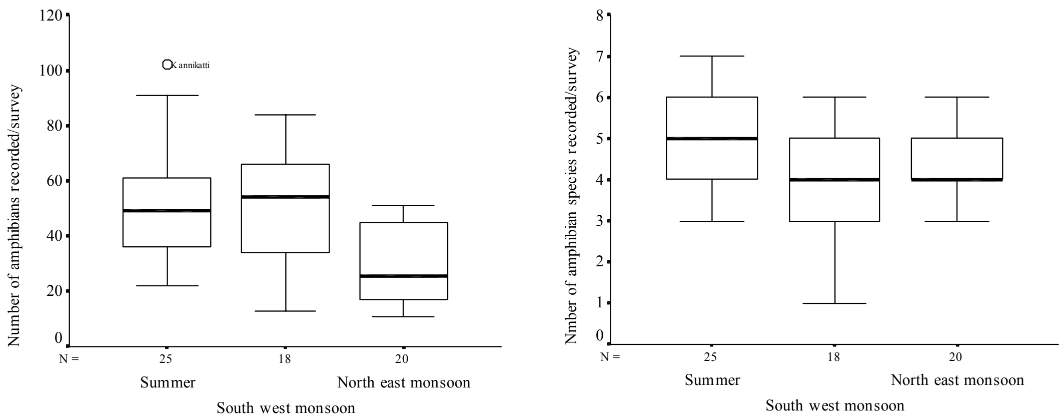


Figure 7.1. The variation in (a) the number of amphibians, and (b) amphibian species, seen in a river segment in rainforest in different seasons in Kalakad-Mundanthurai Tiger Reserve, during 1996-97.

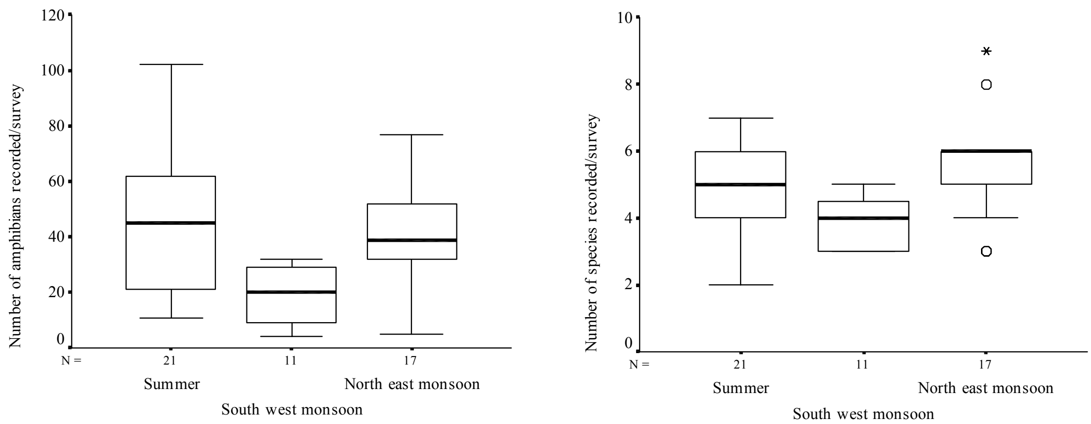


Figure 7.2. The variation in (a) the number of amphibians, and (b) amphibian species, seen in a river segment in rainforest in different seasons in Anamalai Hills, in 1998-99.

7.3.2 Species overlap: drainage and altitude effects

The overlap of amphibian species between pairs of stream segments (as measured by Sorensen’s index) was examined at three geographic scales – within drainage, between drainage and between hill ranges. The stream segments from different hill ranges had the least overlap of species, while segments within a hill range had a greater overlap and those within a drainage had the greatest overlap (ANOVA; F = 83.45, df = 65, P < 0.001; Tamhane’s post-hoc test, P < 0.001; Figure 7.3).

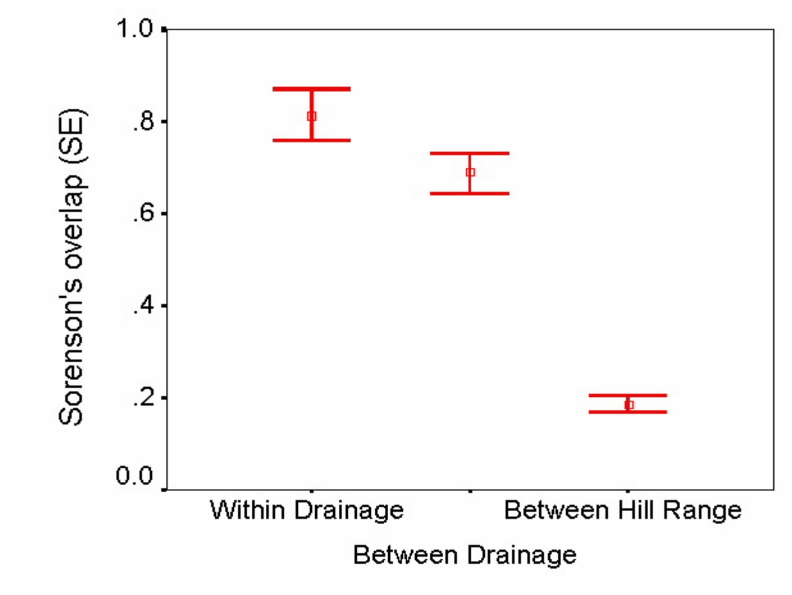


Figure 7.3. The overlap in species composition between streams within the same drainage, in different drainage (within the same hill range) and in different hill ranges (Ashambu Hills and Anamalai Hills).

The decrease in species overlap with increasing distance between stream segments was nearly significant both in KMTR (Mantel's R= 6207.5, one-tailed *P* = 0.066) and Anamalai Hills (R = 5619.5, one-tailed *P* = 0.056). Increasing difference between segments in altitude also caused a significant decrease in species overlap in KMTR (R = 5939.5, one-tailed *P* = 022) and Anamalai Hills (R = 5401.5, one-tailed *P* = 0.024). However, stream segments that were further apart were also separated to a greater extent in altitude in KMTR (R = 8799.5, one-tailed *P* = 0.014). When the effect of distance was controlled for, the negative correlation of the difference in altitude with species overlap was nearly significant in KMTR (Kendall's τ = -0.365, *P* = 0.061) and Anamalai Hills (τ = -0.297, *P* = 0.085). On the other hand, the effect of distance on species overlap within a hill range became insignificant when the difference in altitude was controlled for. Thus, stream segments in similar altitudes in a hill range had a high overlap in species occurrence.

However, the difference in altitude had no influence on species overlap between segments from different hill ranges (R = 12486, one-sided *P* = 0.419). Species overlap between streams was consistently lower in the Anamalai Hills than in KMTR (Figure 7.4).

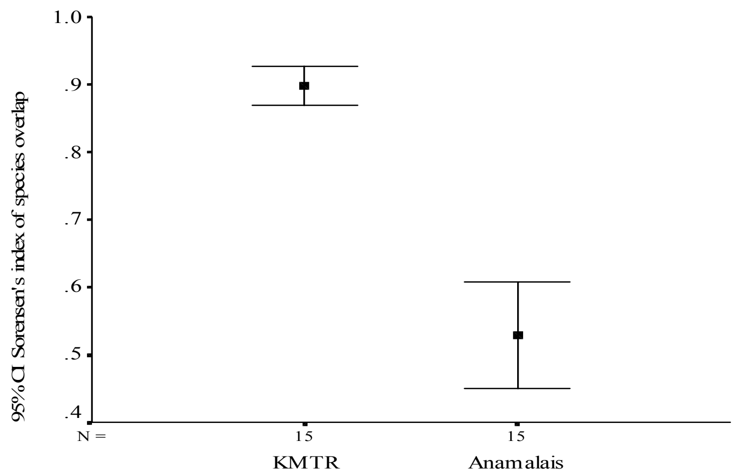


Figure 7.4. The difference between Kalakad-Mundanthurai Tiger Reserve (KMTR) and Anamalai Hills in the overlap (Sorensen's index) between streams in amphibian species composition.

7.4 DISCUSSION

7.4.1 Seasonal fluctuations in stream amphibians

Seasonal variation in the water level and flow has a major influence on the abundance of amphibians in streams since rains submerge most of the microhabitats of stream amphibians. However, since amphibians vary remarkably in their selection of breeding sites and life history (Zimmerman & Simberloff 1996), their response to seasonal flooding of their habitat might also vary. A few have adaptations to inhabit torrential streams (e.g *Nyctibatruachus*) and might continue to survive in the fast flowing streams. Some such as *Nyctibatrachus* migrate short distances and could be seen in the forest floor close to the stream. It is likely that some move away to patches of stagnant water that abound during monsoon in order to breed (e.g *Rhacophorus pseudomalabaricus*). On the other hand, some forest dwelling species such as *Pedostibes tuberculosus* in the Anamalai Hills and *Bufo beddomi* in KMTR reached the streams in large numbers to breed during this time of the year. Seasonal flooding might be an important factor in determining frog communities in torrential streams. It is likely that while some species which are resident in streams and numerically dominant (*e.g. Rana temporalis* in Sengaltheri and *Micrixalus* in Anamalai Hills) migrate away from streams during monsoon, some others migrate to the proximity of streams. This is probably why a reduction in amphibian abundance in peak monsoon in both hill ranges was not accompanied by an equivalent reduction in species richness.

7.4.2 Species overlap: local and regional

This study demonstrates that the overlap in species composition of amphibians in streams within a hill range is influenced by altitude. However, streams in different hill ranges have very little overlap in species composition, and altitude has no effect on it. The effect of streams belonging to different drainage *per se* (within the same hill range) on overlap in species composition is not clear. The streams sampled in KMTR finally drain into Tamarabarani and hence they are from the same drainage. However in the Anamalai Hills streams sampled belonged to three different drainage. The greater overlap in species composition between streams in KMTR compared to Anamalai Hills suggests a potential influence of drainage. This is also supported by data on forest floor amphibians in KMTR (see Chapter 5). Distance from stream was a major factor that influenced amphibian occurrences in the quadrats. Similar patterns have been shown for amphibians in the rainforest streams of Sarawak (Inger 1968). The Western Ghats is a linear habitat with steep slopes on the eastern and western aspects. The steep mountains bind the river valleys restricting dispersal over land. Dispersal through high order streams or rivers might be limited because many of these have very steep gradients and are torrential below 900 m. In fact, the steep terrain of the hills and the sharp gradients of rivers at mid elevations have been reported to be a major factor restricting the distribution of fish in the Western Ghats and Sri Lanka. Roux (1928) and Inger *et al.* (1987), using secondary data, have suggested that different hill ranges in the Western Ghats have different amphibian species composition. However, differences within hill ranges have not been examined till date.

If the amphibian dispersal is severely constrained due to their dependence on streams on the one hand, the terrain of the Western Ghats on the other, we could expect a turn over of species correlating with the order of drainage. Only 10 to 15 species were recorded, in any locality which comprised of a network of interconnected streams. Only 32 species were recorded for KMTR as a whole, and 40 for Anamalai Hills, with 10 species being common between these two hill ranges. Similarly, 30-40 species each have been reported for Nilgiri Hills (Easa *et al.* 1998). Species overlap among these four hill ranges remains to be estimated, however. Nonetheless, it seems very likely that the high species richness among amphibians in the Western Ghats is due to a high turn over of species from one drainage or hill range to another. If the overlap in species between hill ranges is as low as that between KMTR and Anamalai Hills, then the total number of amphibians in the Western Ghats is currently grossly under-estimated. This is partly borne out by discovery of about 8 new species during this study as well as others in recent years (Biju 2002).

Species turnover on an altitude gradient is well documented, including that of stream amphibians (Hynes 1970; p 383). The turnover of amphibians is probably due to changes in the microclimate along the altitude gradient, especially temperature which affects each taxon differently (Hynes 1970). In the Western Ghats on the eastern slope, lower altitudes receive lower rainfall than higher altitudes. The streams sampled in Sengaltheri in KMTR were located on the eastern slope and had a longer dry period than higher altitudes. This might be the major reason for the influence of altitude on species overlap in KMTR, rather than temperature. However, the low influence of altitude on species overlap in the Anamalai Hills where the streams belonged to different drainages, shows the overriding influence of drainage on species overlap.

A south-north gradient in plant species richness occurs in the Western Ghats, primarily determined by the length of the dry period, with the loss of species being more than the gain along the gradient (Pascal 1988). Even though rainfall and the length of the dry period might be important for amphibians, the fact that 30-40 species have been reported from different hill ranges across the Western Ghats does not suggest a gradient as in the case of plants. However, species lists are probably far from complete for many localities. Amphibian fauna in the Western Ghats seem to consist of some ubiquitous species (*e.g. Philautus spp.* and *Bufo melanostictus*), which are found in all hill ranges and drainage, and several others which are restricted to particular hill ranges or even drainages The breadth of the hill range might be an important factor determining the number of restricted species since it is correlated with the number of drainages. A higher number of species in the Anamalai Hills, despite severe habitat loss, is probably due to this reason.

This pattern is also against the latitudinal gradient which has been reported for many taxa. The two areas that were sampled do not have different rainfall regimes, and number of dry months in a year are the same (Pascal 1988). This precludes the possibility of rainfall influencing the species richness in the two hill ranges.

The turn over of species from one hill range to another is accompanied by replacement of one species by its ecological equivalent. Species such as *Nyctibatrachus aliceae* and *N.major*, abundant in the streams in KMTR, were absent in Anamalai hills. Their microhabitats were occupied by two other species of the same genus. This turnover of species contradicts patterns in amphibian communities in Bornean forests described by Inger & Voris (1993). In the Bornean streams that were far apart, the amphibian community was not any different from those that were nearby.

7.4.3 Species richness and turnover

It is interesting to note that long term studies in different hill ranges in the Western Ghats have all reported 30-40 species in a hill range *e.g.* Nilgiri hills (Easa 1998), Brahmagiri hills (Krishnamurthy 1999), Anamalai hills (this study), and Ashambu hills (this study). This study demonstrates that there is a turnover of species and changes in abundance even at local scales, from one drainage to another (the three sites fall under three drainages) within a hill range (in this case it is the Ashambu hills). The turnover is higher between drainages separated by greater distances, such as those between two hill ranges (between Ashambu hills and Anamalai hills). Amphibian distribution in the forest floor was largely restricted to the forest adjoining streams. The mountains flanking the valleys may restrict the dispersal of several species of forest floor amphibians across drainages. The influence of altitude on species diversity observed in other taxa (Nair & Daniel 1986; Daniels 1992), however, might hold good for amphibians at a local scale.

7.5 SUMMARY

There was no significant change in amphibian abundance in the wet evergreen forest streams, across sampling sites belonging to different drainages and across seasons. Species overlap in assemblages decreased with increasing distance between stream segments in different drainages. It also decreased with increasing difference in altitude between the stream segments sampled within two hill ranges. Streams within drainage had the greatest species overlap, streams between drainages had lesser overlap, and streams in different hill ranges had least overlap. The extent to which species overlapped between streams also varied in the two hill-ranges. Altitude influenced species composition within a hill range even after controlling for geographic distance between streams. However, sites in different hill ranges did not show any ‘altitude effect’. This finding has implications on the strategy that needs to be adopted for designating protected areas, if the rare and endemic amphibian fauna of the Western Ghats are to be conserved.

8 REPTILES IN CONTIGUOUS RAINFOREST

8.1 INTRODUCTION

The Western Ghats has about 200 species of reptiles, and 50% of them are endemic to this region. The rainforests in the Western Ghats have nearly 130 species of reptiles, with a majority being endemic. In spite of this high degree of endemism, the distribution and ecology of this rich reptile fauna have received very little research attention. Inger *et al.* (1987) carried out an intensive, but short-term, survey of in western Ashambu Hills to examine microhabitat features that influenced the distribution of herpetofauna. Bhupathy & Kannan (1997) conducted a survey of agamid lizards in Tamil Nadu part of the Western Ghats, and found considerable variation among hill ranges, habitat types, and altitude levels in the species richness and diversity.

It has long been recognized that species in a reptile assemblage are not randomly distributed in space either horizontally or vertically, but occupy discrete microhabitats (Heatwole 1977, 1982). Such information is lacking for the reptiles in the Indian sub-continent in particular, and tropics in general. Species diversity and habitat heterogeneity are correlated in some reptile taxa (Schoener 1974; Heatwole 1982; Toft 1985; Vitt 1996). Resource partitioning along food, time, temperature, altitude and habitat gradients has been documented (for reviews see Pianka 1973; Heatwole 1982; Toft 1985). Microhabitat separation has been shown among arboreal lizards in structurally complex habitats (Howard & Hailey 1999). Heyer (1967), in a study of herpetofauna in a 24 km long transect in Costa Rica, concluded that although the distribution of some species was limited by climatic factors, that of the others correlated with specific microhabitats. Pianka (1971) found that the most important variable influencing the number of lizard species in the Kalahari Desert was plant species diversity. Food may be an important factor limiting the distribution of snakes which are at the top of most food chains and are likely to be subjected to competition for food (Arnold 1972; Reinert 1993).

8.2 OBJECTIVES

Like the other target taxa of this study, the community structure of reptiles in the rainforest of the Western Ghats has not been studied in any detail. An understanding of this was necessary in order to examine the impact of habitat fragmentation. Therefore, the study on reptiles also started in the contiguous rainforest of the Kalakad-Mundanthurai Tiger Reserve, with the goal of understanding the community structure with reference to species richness, abundance and distribution. The arboreal reptile community in the rainforest consists of snakes (Families Colubridae, Elapidae and Viperidae), agamids (Agamidae) and geckos (Gekkonidae). The specific objectives of the study in KMTR were to:

- Determine patterns in the structure of reptile community in the contiguous rainforests of Kalakad-Mundanthurai Tiger Reserve, with reference to species richness, abundance and relative abundance; and
- Determine the influence of microhabitat and macrohabitat variables on the distribution of rainforest reptiles.

We divided the reptile community into forest floor community and arboreal community since these two communities demanded different sampling design.

8.3 METHODS

8.3.1 Forest floor reptiles

Forest floor reptiles were sampled using adaptive cluster sampling, which gives better estimates of the density of animals that show patchy distribution (see Section 5.2.1.1, for detailed methodology). The following parameters were estimated from this data:

- The number of primary quadrats with animals, an indicator of the abundance of clusters.
- Network size: The number of quadrats in a network, an indicator of the area occupied by a cluster of animals.
- Species richness in a network: An indicator of species assemblages in the area.
- Density: This is the mean of the densities in networks, including primary quadrats without animals (density of zero).
- Species composition: The percentage of animals in a taxon out of the total number of animals recorded from quadrats.

Several habitat variables were also measured in each quadrat (see Section 5.2.1.1.)

8.3.2 Arboreal reptiles

Six transects, each 250 m long and on a random compass bearing, were permanently marked around each of the three sites in (Sengaltheri, Kannikatti and Kakachi), by lightly clearing the undergrowth. Each transect was surveyed thrice in each of the three seasons, between June 1997 and May 1998. Thus each of the 18 transects was surveyed nine times. The average time taken to walk these transects was about 90 minutes. During the survey, two observers walked slowly along the transect scanning either side of the transect above the forest floor. All reptiles sighted were recorded, with details of the microhabitats and activity. This was a non-destructive search (*i.e.* it did not involve active turning over of litter, rocks/stones or the pulling apart of fallen logs as done in the quadrat search). Many of the reptiles were captured for positive identification and morphological measurements after which they were released at the site of capture. Reptiles seen on the forest floor were not recorded. Sightings of reptiles were generally restricted to 3 m on either side of the transect and up to a height of about 8 m. Surveys were carried out between 0800 hrs and 1300 hrs, when the atmospheric temperature varied from 19°C to 25°C.

Since reptile sightings were few and sampling effort was the same for all seasons, we pooled data across the seasons in order to estimate the following parameters from the above data:

- ***Reptile abundance in a transect:*** mean number of arboreal reptiles sighted in a transect during 9 replicates;

- ***Species richness in a transect:*** number of arboreal species recorded in a transect for all 9 replicates together;
- ***Species overlap:*** Sorensen's index of overlap between all pairs of transects (Index = $(2C/A+B)$ x100, where C = number of species common to two transects, A and B are number of species in transect A and B, respectively).

Several habitat variables reflecting the topography, vegetation, and climate were measured from 3 m x 3 m plots laid at 25 m intervals along each transect. Apart from this, similar 3 m x 3 m plots were laid at every point a reptile was sighted with the location of the animal as the centre, and similar habitat variables were recorded. Only the climatic variables were repeatedly measured, as the others were not expected to vary between seasons.

8.3.3 Data analysis

We used linear and quadratic models to examine the relationship among habitat and reptile community variables. The latter was selected as the best fit model only when an increase in R^2 was accompanied by a decrease in P value; otherwise, linear models were selected as the best fit. Discriminant function analysis was used to separate sampling plots with different taxa of reptiles.

8.3.4 Species identification

Voucher specimens were collected for all species. Species identification was based on published keys (Gunther 1864; Wall 1923; Smith 1933, 1935, 1943), and consultation with taxonomists, especially Drs. I. Das & S.K. Dutta.

8.4 RESULTS

8.4.1 Forest floor reptiles

8.4.1.1 Local distribution (network characteristics)

A total of 576 primary quadrats, 143 secondary quadrats and 310 edge quadrats were sampled three sites and seasons together. Seventeen species totaling 243 individuals were recorded by this method (Table 8.1). Only 91 (15.8%) of the primary quadrats had reptiles showing the low abundance of networks or clusters. Reptiles did not also form large clusters, since 80 networks (87.9%) were ≤ 2 quadrats in size (Figure 8.1a). The number of reptiles in a network varied from 1 to 7 with a mean of 2.78 (S.E=0.17) and a median of 2. More than half (58.2%) of the networks had ≤ 2 individuals (Figure 8.1b). Thus, the forest floor reptiles were not highly clumped in their distribution. The number of species in a network varied from 1 to 4, with only 5.5% networks recording >2 species and as much as 69.2% with only a single species. The forest floor reptiles, therefore, did not also form multi species assemblages (Figure 8.2).

Table 8.1. Forest floor reptile species and number of individuals recorded by adaptive cluster sampling in three sites in KMTR, (1997-98).

	Kannikatti	Sengaltheri	Kakachi	Total
Cnemaspis indica	26	32	2	60
C. ornatus	16	20	4	40
C. mysoriensis	0	2	0	2
Cnemaspis spp 1 (white belly)	3	1	0	4
Cnemaspis spp 3 (red eye)	1	0	10	11
Calotes ellioti	9	1	0	10
C. rouxii	0	1	0	1
Draco dussumieri	6	0	0	6
Mabuya beddomii	18	31	0	49
M. carinata	0	2	0	2
Scincella travancoricum	0	8	39	47
Ristella spp	1	1	1	3
Brachyophidum rhodogaster	0	1	0	1
Melanophidium punctatum	0	1	0	1
Ahaetulla nasutus	0	1	1	2
Hypnale hypnale	0	2	1	3
Trimeresurus malabaricus	0	0	1	1
Total	80	104	59	243

8.4.1.2 Density and composition

The overall density of forest floor reptiles was 0.28 animals/quadrat, with a variance of 0.001. Most species occurred in very low abundance with 10 (58.8%) of the 17 species represented by ≤ 5 individuals. Consequently, the analysis of community composition was done a higher taxa level, namely geckos, skinks, agamids and snakes. Geckos had the highest density (0.13 animals/quadrat), followed by skinks (0.12), while agamids (0.02) and snakes (0.01) occurred in very low densities.

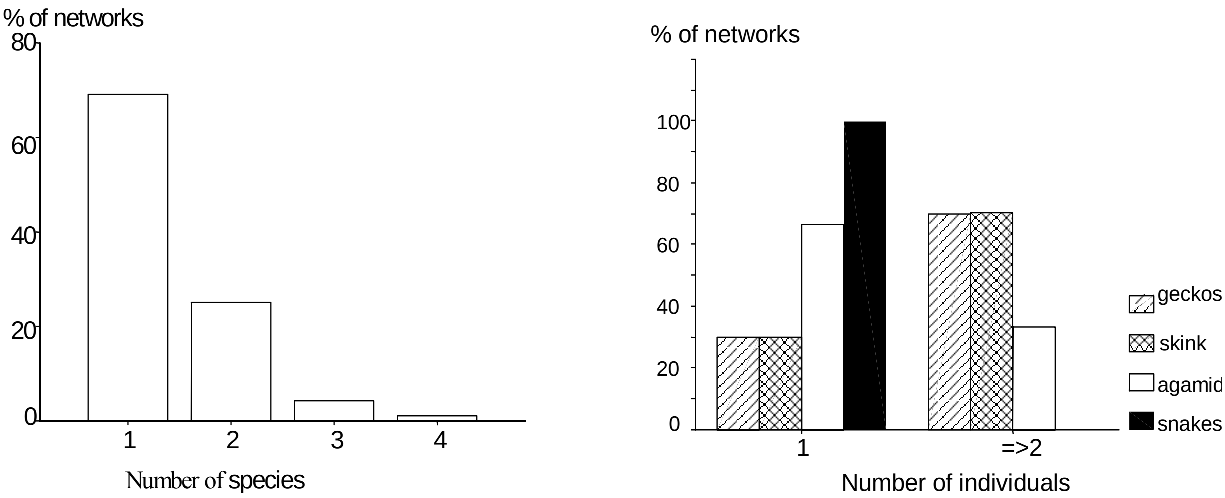


Figure 8.1 The frequency distribution of (a) number of quadrats in a network, and (b) the number of reptiles in a network, in KMTR.

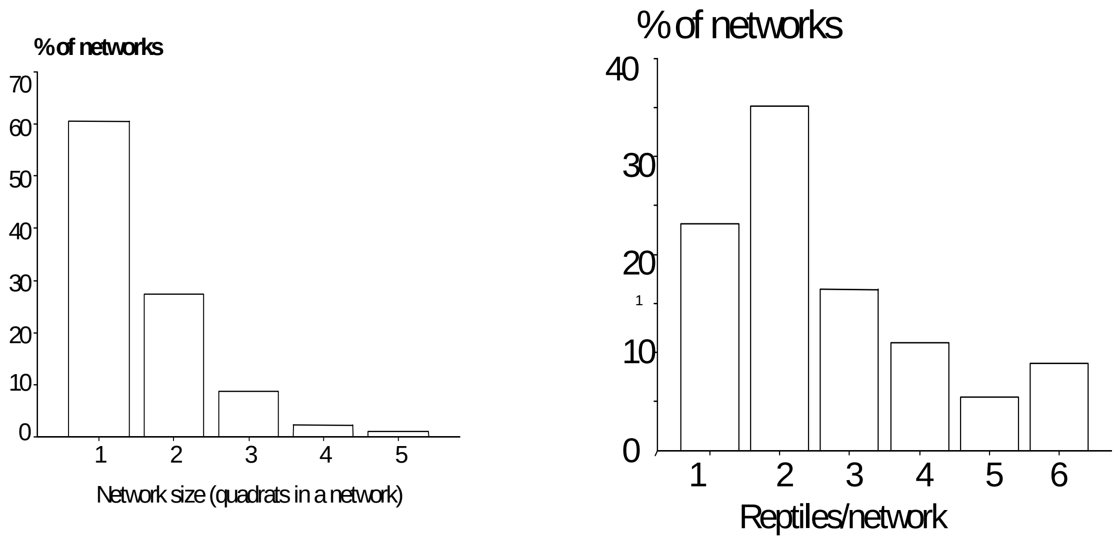


Figure 8.2. (a) The number of species in a network, and (b) the number of animals found in the same network, in four reptile taxa, in KMTR.

Geckos and skinks formed the major part of the community with almost 90% (N=243) of all sightings. Geckos of the genus *Cnemaspis* (the dwarf geckos) were the most abundant accounting for 117 individuals (48.1%). Skinks, mainly from two genera (*Mabuya* and *Scincella)*, were the second most common totaling 101 individuals (41.6%). Agamids, normally arboreal, were also recorded in the forest floor, accounting for 7% of the sightings. Snakes were represented by 5 species totaling only 8 individuals. At a species level *Cnemaspis indica* was the most abundant with 60 individuals (24.69%). *Mabuya beddomei* was the second most dominant (20.16%) followed by another skink endemic to the rainforest, *Scincella travancoricum* (19.34%). The Families Scincidae (skinks) and Geckonidae (geckos) dominated the forest floor reptile assemblage. Individuals of these taxa were also more likely to be in seen in pairs or in aggregations than snakes and agamids (Figure 8.2b). Skinks were recorded from 47 networks, 33 of which (70.2%) had 2 to 7 individuals. Of the 50 networks with geckos, 35 (70%) had 2 to 7 individuals. In contrast, snakes were always recorded as solitary individuals. Agamids were recorded from 12 networks of which only 4 (33%) had more than 2 individuals, with a maximum of 3.

The density varied among the three sites with Kakachi having the lowest density (mean=0.17 animals/quadrat, variance=0.001), while Kannikatti (mean=0.39 variance=0.006) and Sengaltheri (mean=0.32 variance=0.003) had much greater densities. The densities of individual taxon varied considerably among the sites (Table 8.2).

Table 8.2. Densities (animals/25 sq.m) of forest floor reptiles in three sites in Kalakkad-Mundanthurai Tiger Reserve (1997-98).

	Kannikatti	Sengaltheri	Kakachi
Geckos	0.22	0.14	0.05
Skinks	0.10	0.16	0.11
Agamids	0.08	0.01	0.00
Snakes	0.00	0.01	0.01
Total	0.39	0.32	0.17

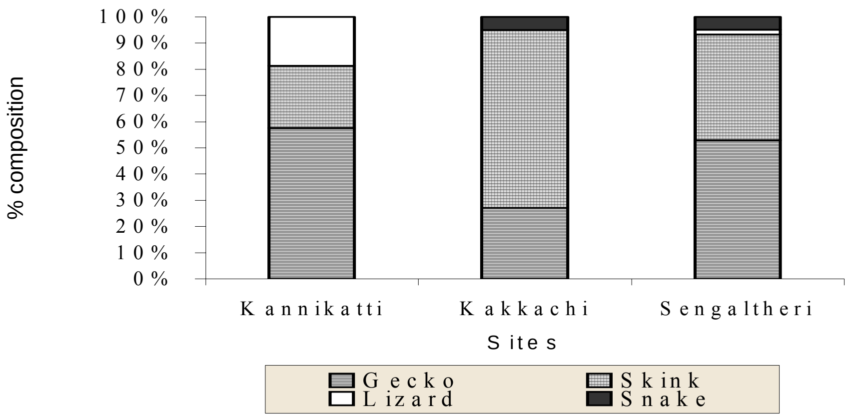


Figure 8.3. Percentage composition of four reptile taxa in three sites in KMTR.

The community composition varied considerably among the three sites. Sengaltheri (52.9%, N=104) and Kannikatti (57.5%, N=80) were dominated by geckos, while skinks dominated in Kakachi, (69.5%, N=59). Skinks were the second most abundant group in Kannikatti and Sengaltheri, however (Figure 8.3). While agamids were as abundant as skinks in Kannikatti, they were considerably less so in Sengaltheri, and absent in Kakachi. Snakes were not recorded in Kannikatti, and were more abundant in Kakachi than in Sengaltheri, although rare in both sites.

The forest floor reptile community in Kakachi was quite unique from the other two sites. *Cnemaspis indica* was the most abundant species in Kannikatti with 26 individuals (32.5%) and in Sengaltheri with 32 individuals (30.8%). Kakachi recorded only 16 individuals of *Cnemaspis* of which an unidentified species (provisionally called the red eye gecko) was the most abundant (62.5%). This species was primarily restricted to this site with only one record from Kannikatti. *Mabuya beddomei* was the most abundant skink in the drier areas of Kannikatti and Sengaltheri, while in Kakachi this species was totally absent, being replaced by an endemic skink *Scincella travancoricum* that was also the most dominant species. This species was recorded very few times at higher elevations in Sengaltheri. All agamid sightings (N=17), except for 2 from Sengaltheri, were from Kannikatti. Only 2 species of uropeltid snakes were recorded, both from Sengaltheri. No snakes were recorded from Kannikatti while pit vipers were more abundant in Kakachi.

Morisita-Horn measure of similarity (C_{MH}) was used to compare the similarity in relative abundance of different genera among sites. Kakachi was unique and had very little similarity with Kannikatti (C_{MH}=0.09) and Sengaltheri (C_{MH}=0.21), whereas the latter two sites were very similar (C_{MH}=0.93).

8.4.1.3 Microhabitat association

Bivariate analysis showed significant differences in the mean values of only two microhabitat variables (rock cover and woody climbers), between quadrats with and without reptile detection. A principal component analysis of habitat variables resulted in five components that together accounted for only 65.5% of the variance. Moreover, the components were not easily interpretable. Therefore, discriminant function analysis was used to identify differences among the reptilian taxa in their microhabitat associations. The groups that were used for the analysis were quadrats a) without reptiles, b) with only geckos, c) with only skinks, d) with only agamids, e) with only snakes, and f) quadrats with a combination of b to e, labelled as others.

The first discriminant function explained 85% of the variance amongst quadrats with the different taxa of reptiles and quadrats without reptiles. The second function accounted for 11%, the third function 3.7%, while the fourth function accounted for only 0.3% of the variance. As only the first discriminant function was significant (Wilk's λ= 0.860,χ^2 = 86.29, *df* = 20, *P* <0.001), only this function was used in further analysis. The Wilk's λ, log determinants and the structure matrix are given in Table 8.3. The number of tree buttresses and the number of burrows in a quadrat were the most important independent variables in the discriminant function (Table 8.3 a). The covariance of the groups agamids, snakes and others showed difference from the pooled within group covariance as shown by the difference in the log determinants (Table 8.3 b). The first discriminant function showed a positive relation with the number of tree buttresses, the number of burrows and the rock cover in the sites while it was negatively related to the herb layer (Table 8.3 c). The positive axis explained a gradient of greater complexity of habitat in the forest floor, *i.e* more micro habitats for litter dwelling reptiles, while the negative axis explained a gradient of dense understorey (herbs < 1 m) with a related decrease in the complexity of the forest floor habitat. The quadrats with the leaf litter reptiles differed significantly from the quadrats without reptiles (Mann_Whitney U test, MW U Z= -5.396, *P*<0.001), along function 1 (Figure 8.4 a). While the different taxa exhibited difference in the discrimination scores along function 1 (ANOVA F=5.672, *P*<0.001), the post hoc Tamhane's test showed no difference between geckos and skinks, the differences in the scores being significant only between geckos and others, and skinks and others. The discrimination was insignificant for quadrats with endemic species and those with non-endemic species along discriminant function 1 (MW U Z= -.589, *P* =0.556; Figure 8.4 b).

Table 8.3. The values for Wilk's λ, log determinants and the structure matrix for the discriminant function analysis of leaf litter reptiles in the contiguous rainforests, KMTR (1997-98).

a. Tests of Equality of Group Means

	Wilks' λ	F	DF1	DF2	Sig.
Herb layer	.993	.795	5	570	.553
Rock cover	.992	.953	5	570	.446
Burrows	.991	1.742	5	570	.056
Tree buttresses	.917	17.305	5	570	<.001

b. Log Determinants

Taxa	Rank	Log Determinant
No reptiles	4	6.186
Gecko	4	5.862
Skinks	4	5.648
Agamids	4	8.993
Snakes	4	-1.609
Others	4	8.072
Pooled within-groups	4	6.494

c. The Structure Matrix

	Functions			
	1	2	3	4
Tree buttresses	.959*	-.150	.239	-.021
Burrows	.139	.962*	-.016	-.236
Herb layer	-.146	.183	.749*	.620
Rock cover	.212	.070	-.562	.796*

* Largest absolute correlation between each variable and any discriminant function

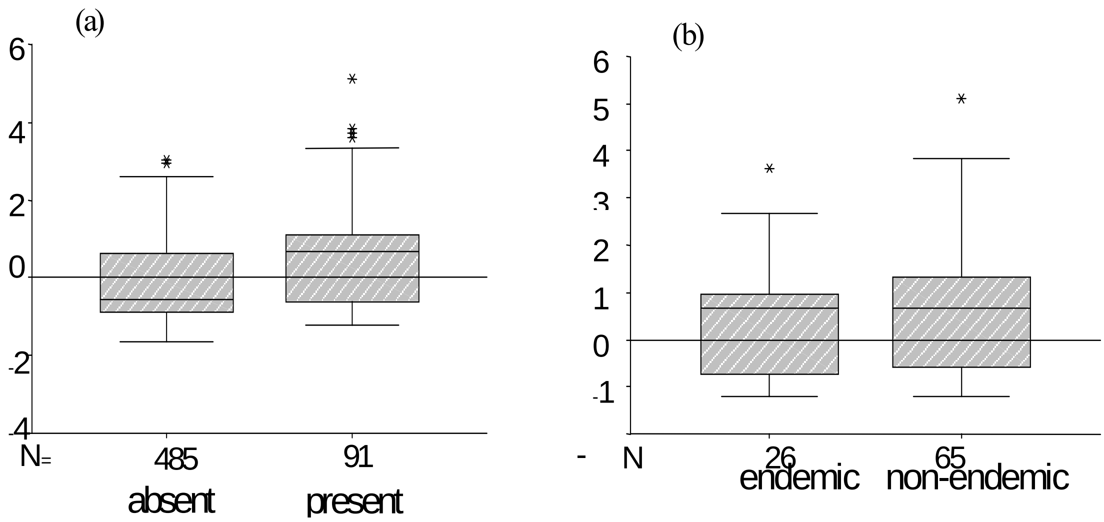


Figure 8.4. Box and whisker plot showing (a) the separation of quadrats with and without forest floor reptiles, and (b) quadrats with endemics and with non-endemics., along the first Function in DFA. The latter is not statistically significant. Data from KMTR, (1997-98).

8.4.2 Arboreal reptiles

8.4.2.1 Abundance and composition

A total of 314 arboreal reptiles belonging to 22 species were recorded from 18 transects in three sites. The overall encounter rates was 1.94 reptiles/transect (of 250 m), with agamids being the most abundant, (1.63 animals/transect), followed by geckos and skinks (0.17 and snakes (0.13). Species richness was highest among snakes belonging to the Families Colubridae and Viperidae totaling 8 species, but with only 38 individuals. The agamids equalled snakes in species richness (8 species), but were much more abundant accounting for 263 individuals (83.7%, N=314). Geckos and skinks were low both in species richness and abundance, with only 5 species and 12 individuals. The monitor lizard, *Varanus bengalensis*, was recorded only once.

Two agamids dominated the arboreal reptile community accounting for 78.57% of all the sightings. The flying lizard *Draco dussumieri* was the most abundant (50.63% of all sightings) followed by *Calotes ellioti* (27.94%). Out of the 22 species that was recorded by this method, 12 species (54.54%) were recorded ≤ 5 times, showing the low in abundance of most species. Snakes accounted for half of this group, with 6 of the total of 8 species being recorded ≤ 5 times. The most abundant snake was the common green vine snake *Ahaetulla nasutus*, forming 36.84% of the snakes sighted (N=38).

The numbers of species varied among individual transects (with replicates pooled) from 1 to 8 with a mean of 4 (S.E.=0.55). Species richness was lowest in transects in Kakachi with only 7 species totaling 16 individuals, and was greatest in Sengaltheri (15 species and 95 individuals). Kannikatti had only 12 species, but had a greater abundance with a total of 203 individuals.

Table 8.4. The species and number of individuals of arboreal reptiles recorded by forest transects in three sites in the contiguous rainforest of KMTR, (1997-98).

	Kannikatti	Kakachi	Sengaltheri	Total
Cnemaspis indica	0	0	3	3
C. ornatus	0	0	1	1
C. beddomei	2	0	0	2
Mabuya beddomii	3	0	2	5
Ristella spp	0	0	1	1
Calotes andamanensis	0	1	0	1
C. calotes	6	0	1	7
C. ellioti	53	0	16	69
C. grandisquamis	0	1	0	1
C. nemoricola	4	4	2	10
C. rouxii	3	0	9	12
Draco dussumieri	118	0	41	159
Psammophilus blanfordanus	0	0	4	4
Varanus bengalensis	0	0	1	1
Ahaetulla nasutus	5	4	5	14
Amphiesma beddomei	1	0	0	1
Boiga ceylonensis	0	1	3	4
Dendrelaphis grandoculis	3	1	1	5
Lycodon spp	0	0	1	1
Hypnale hypnale	0	0	1	1
Trimeresurus macrolepis	1	4	2	7
T. malabaricus	4	0	1	5
Total	203	16	95	314

Encounter rates of different taxa varied among the sites (Table 8.5). Kannikatti recorded the highest encounter rate followed by Sengaltheri, while Kakachi had a very low rate. Agamids dominated the arboreal reptile community in Kannikatti and in Sengaltheri, while the snakes were the dominant taxa in Kakachi. The encounter rate of geckos and skinks were similar in both Kannikatti and Sengaltheri, while it was conspicuous by its total absence in Kakachi. Snakes were in general low in abundance in all the three sites. Major differences among the sites were also evident in the relative abundance of different taxa (Figure 8.5). While agamids formed the major part of the arboreal reptile community in Kannikatti (90.7% of all sightings) and Sengaltheri (77.8%), snakes formed the major taxa in Kakachi (62.1%). The agamids recorded from Kakachi were rainforest endemic species, like *Calotes andamanensis, C. grandisquamis* and *C. nemoricola*, the first two being unique to this site. Two species of skinks were recorded from Sengaltheri, while only one species was recorded from Kannikatti. As in the forest floor reptiles, the arboreal reptile community in Kakachi had very little overlap in the composition of the four major taxa with Kannikatti (C_{MH}=0.05) and with Sengaltheri (C_{MH}=0.11), whereas the latter two sites had a very high overlap (C_{MH}=0.93).

Table 8.5. Encounter rates (animals/250 m) of arboreal reptiles in three sites in Kalakad-Mundanthurai Tiger Reserve, (1997-98).

	Kannikatti	Sengaltheri	Kakachi
Geckos & Skinks	0.2567	0.2567	0.0000
Agamids	3.4067	1.3717	0.1100
Snakes	0.0917	0.1283	0.1833
Total	3.7600	1.7583	0.2950

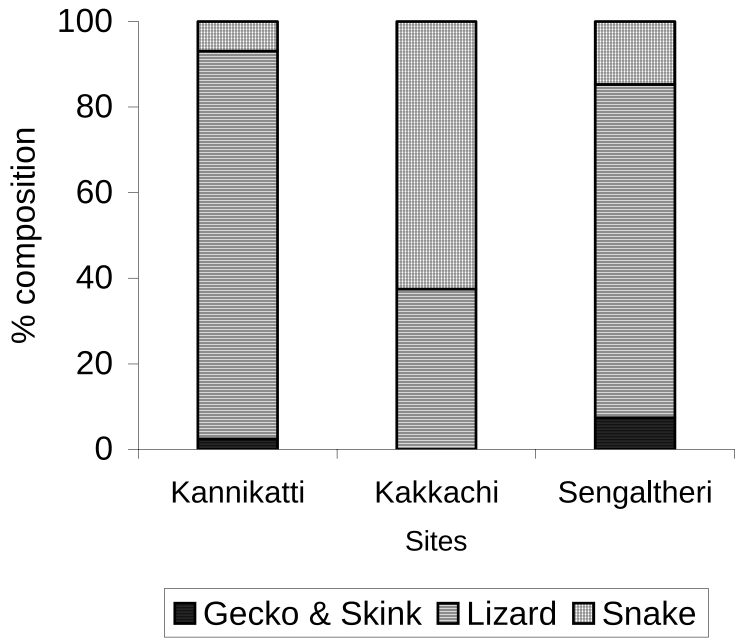


Figure 8.5. Percentage composition of arboreal reptiles in three sites in Kalakad-Mundanthurai Tiger Reserve.

8.4.2.2 Microhabitat association

Bivariate analysis detected significant difference in the mean values of nine microhabitat variables between plots with arboreal reptiles and those without them. These variables mainly represented the litter, vegetation characteristics and the altitude of the plots (Table 8.6).

Table 8.6. The microhabitat variables that were significantly different between plots with and without arboreal reptiles in KMTR (1997-98). Oneway ANOVA.

Habitat variable	Plots (3 m x 3 m)		F	Significance level
	with reptiles	without reptiles		
	Mean ± SE (N = 198)	Mean ± SE (N = 216)		
Substrate characteristics				
Litter depth	2.78 ± 0.04	3.36 ± 0.06	53.58	< 0.001
Rock cover	11.13 ± 1.27	15.91 ± 1.59	5.60	< 0.05
Litter cover	91.16 ± 0.96	84.85 ± 1.40	14.21	<0.001
Vegetation characteristics				
Herb layer	11.98 ± 0.33	4.74 ± 0.51	21.43	< 0.001
Shrub layer	9.67 ± 0.35	12.73 ± 0.52	24.76	< 0.001
Tree buttresses	0.37 ± 0.03	0.22 ± 0.03	10.70	< 0.001
Woody climber	0.81 ± 0.06	0.34 ± 0.04	35.65	<0.001
Basal area	1496.03 ± 162.07	767.46± 88.98	14.78	<0.001
Canopy height	23.81 ± 0.26	24.95 ± 0.37	6.49	<0.01
Canopy cover	89.62 ± 0.52	93.00 ± 0.33	29.29	<0.001

Discriminant function analysis was used to examine habitat association in arboreal reptiles**.** The groups used for the analysis were plots a) without reptiles, b) with only agamids, c) with only geckos and d) with only snakes. The first discriminant function explained 79.7% of the variance among plots with different taxa and those without reptiles. Second function accounted for 13.3%, and the third function for 6.9%. The first two functions were significant (Wilk's λ = 0.590, χ^2= 213.945, *df* = 33, *P* <0.001 and Wilk's λ = 0.884, χ^2 = 49.791, *df* = 20, *P* <0.001) and were used in further analysis. The Wilk's λ, log determinants and the structure matrix are given in Table 8.7. Microhabitat variables that quantified the vegetation characteristics were important in the discriminating ability of the two functions (Table 8.7 a). The different taxa differed in their covariance as shown by the log determinant values (Table 8.7 b). The first function showed a positive relationship with the variables that quantified the forest floor structure and the understory variables like litter depth and litter cover, herb and shrub layer. It was negatively related with variables related to standing vegetation like number of tree buttresses and basal area and the number of burrows. The second function was positively related to canopy height and cover, the number of burrows and rattan in plots (Table 8.7 c). Plots with arboreal reptiles differed significantly from those without arboreal reptiles along DF 1 (MW U Z= -11.753, *P*<0.001), while along DF 2 (MW U Z= -.183, *P* = .855) there was no difference (Figure 8.6 a,b). Even though the different taxa of arboreal reptiles showed differences in their associations along both the functions (ANOVA F=3.352 *P*<.05 and F=13.182 *P*<.001), the post hoc Tamhane's test identified maximum difference between agamids and snakes along both the functions (Figure 8.6 c,d). There was difference between plots with endemic and those with non-endemic species along both DF 1 and DF 2 (MW U Z= -.666, *P*=.506 and MW U Z= -.894, *P*=.371; (Figure 8.7 a,b).

Table 8.7. The values for Wilk's λ, log determinants and the structure matrix for the discriminant function analysis of arboreal reptiles in contiguous rainforests, KMTR (1997-98).

8.7a Tests of Equality of Group Means

	Wilks' λ	F	DF1	DF2	Sig.
Canopy height	.949	7.391	3	410	<.001
Canopy cover	.900	15.123	3	410	<.001
Litter depth	.881	18.456	3	410	<.001
Tree buttresses	.949	7.337	3	410	<.001
Herb layer	.943	8.247	3	410	<.001
Shrub layer	.938	9.030	3	410	<.001
Rock cover	.986	2.000	3	410	.113
Litter cover	.960	5.638	3	410	.001
Rattan	.967	4.656	3	410	.003
Burrows	.950	7.120	3	410	<.001
Basal area	.953	6.783	3	410	<.001

8.7b Log Determinants

Taxa	Rank	Log Determinant
Reptiles absent	11	34.598
Agamids	11	35.182
Geckos	*	*
Snakes	11	35.128
Pooled within-groups	11	36.214

* Too few cases for computation

8.7c The Structure Matrix

	Functions		
	1	2	3
Litter depth	.513*	-.179	-.145
Shrub layer	.356*	-.070	-.230
Herb layer	.332*	-.113	-.316
Litter cover	-.280*	-.121	.137
Rock cover	.171*	.029	-.027
Canopy height	.220	.595*	.103
Burrows	-.203	.574*	-.306
Rattan	-.156	.493*	-.190
Tree buttresses	-.262	-.106	.654*
Canopy cover	.404	.446	.540*
Basal area	-.285	.054	.454*

* Largest absolute correlation between each variable and any discriminant function

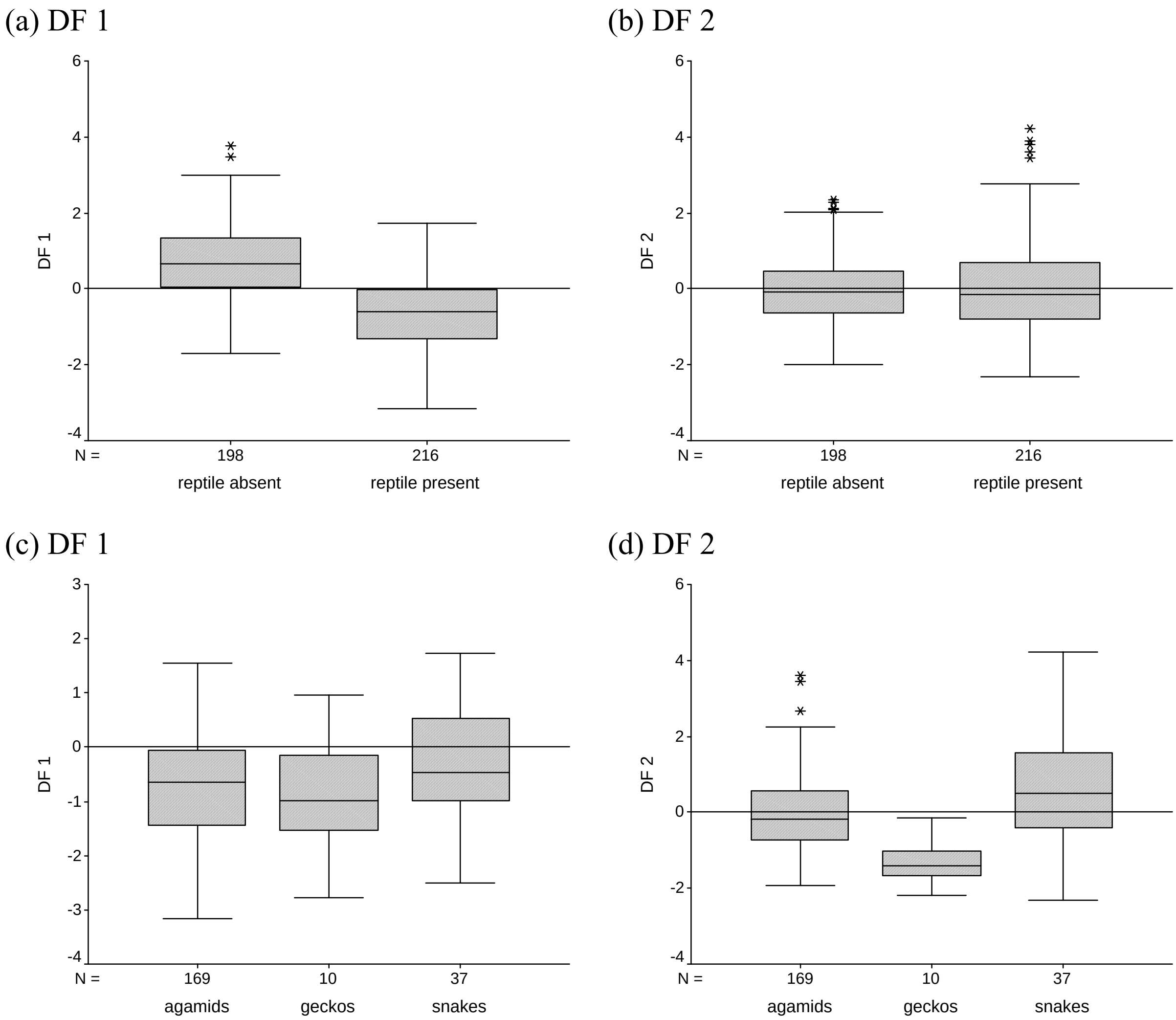


Figure 8.6. Discrimination of plots with and without arboreal reptiles along (a) DF 1, (b) DF 2 and the discrimination of plots with the different reptilian taxa along (c) DF 1 and (d) DF 2, KMTR (1997-98).

(a) DF 1 (b) DF 2

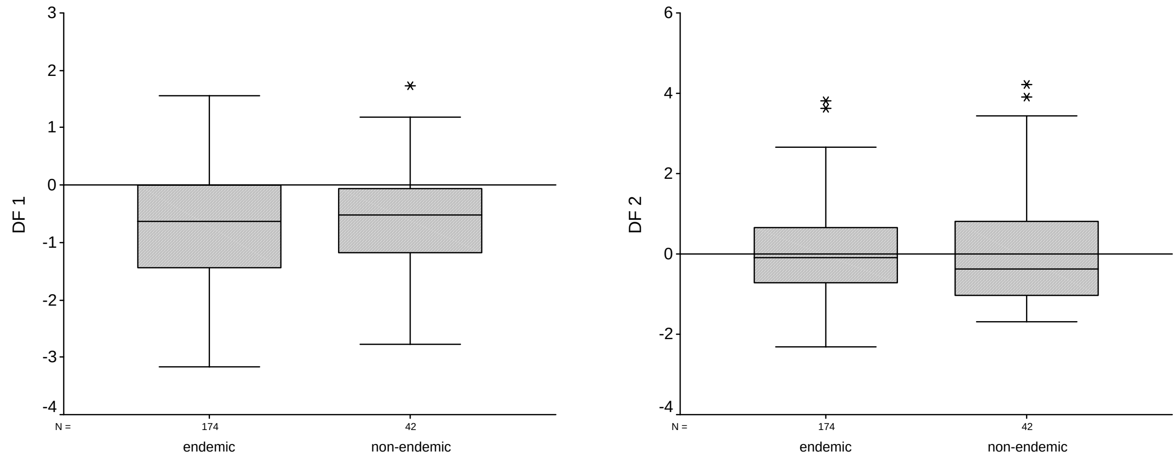


Figure 8.7. Discrimination of plots with endemic and non-endemic species of arboreal reptile along (a) DF 1 and (b) DF 2, KMTR (1997-98).

8.4.2.3 The effect of altitude

The mean number animals and the total number of species seen in a transect were used to examine the effect of altitude on abundance and species richness, respectively. Arboreal reptile species richness showed a quadratic relationship with altitude (R^2 = 0.487, P = 0.005, Figure 8.8). The number of species per transect showed an initial increase with altitude of the transect, reaching a maximum at mid elevations and then falling steeply at higher altitudes. This pattern in species richness along a altitudinal gradient is reflected in the fact that the species richness was greatest in transects of Sengaltheri (mean altitude 980 m), followed by Kannikatti (760 m) and then by Kakachi (1,200 m).

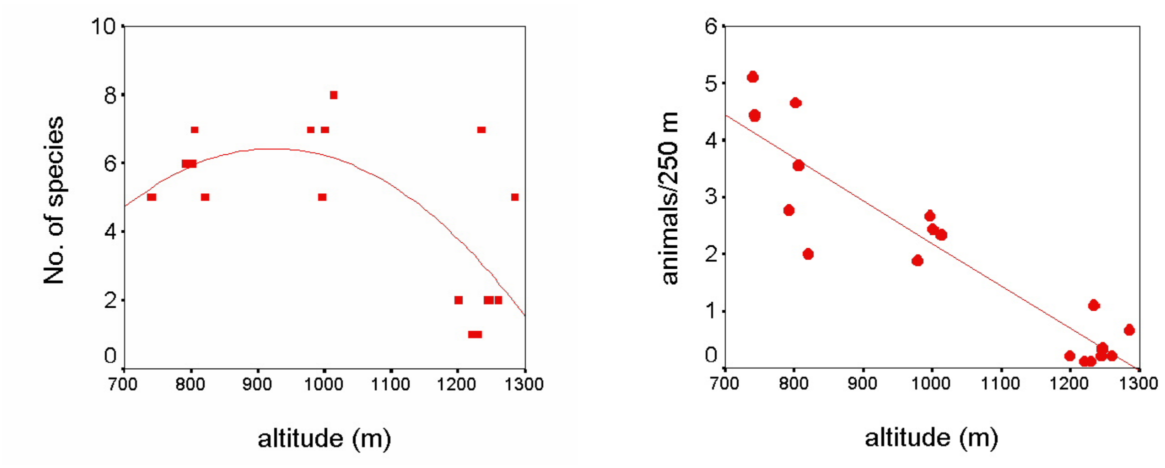


Figure 8.8. The effect of altitude on number of species (total for 9 replicates of 18 transects) and individuals (mean per transect) of arboreal reptiles see in rainforest in KMTR (1997-98).

On the other hand, abundance showed a linear, negative relationship with altitude (R^2 = 0.848, P = 0.000, Figure 8.8). Unlike species richness, abundance was greater in transects in Kannikatti, followed by Sengaltheri and Kakachi. Although a few other habitat variables were also related to both species richness and abundance (Table 8.8), partial correlations after controlling for the effect of altitude were not significant.

Table 8.8. R^2 values in the relationship of total reptile abundance and species richness in transects with habitat variables in the rainforest of Kalakkad-Mundanthurai Tiger Reserve. (L=linear model; Q=Quadratic Model)

Habitat variables	Abundance	Species richness
Altitude (m)	0.848 (L)***	0.487 (Q)**
Buttress trees (N)	0.107	0.359 (L)**
Canopy ht (m)	0.321 (Q)*	0.362 (Q)*
Canopy cover (%)	0.159	0.339 (Q)*
Herbs (no/plot)	0.310 (Q)*	0.333 (Q)*
Shrubs (no/plot)	0.352 (Q)*	0.141
Litter depth (cm)	0.380 (Q)*	0.248
Rock cover (%)	0.118	0.157
Root cover (%)	0.440 (Q)*	0.132

Although the overall arboreal reptile abundance showed a linear decline with altitude, individual taxa varied in their response to altitude (Figure 8.9). The encounter rates of agamids showed a sharp linear decline in abundance, with greater abundance at lower altitudes (700-900 m). Geckos and skinks showed a gentler decline in abundance with greater abundance at lower altitudes. Snakes showed a gradual increase in abundance from lower to mid-elevations, and declined at higher elevations. The encounter rates of snakes were greater than that of other taxa at higher elevations.

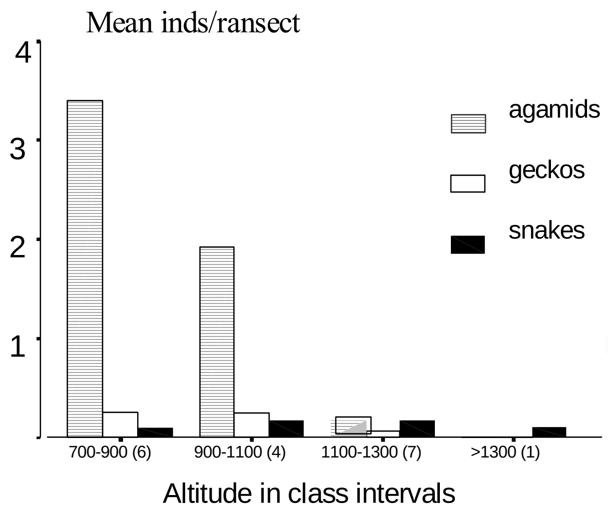


Figure 8.9. The abundance of agamids, geckos and snakes in transects (animals/250 m), in KMTR (1997-98). Number of transects in each altitudinal class is given in parenthesis.

8.4.2.4 Effects of temperature

Arboreal reptile, species richness did not show any relationship with either atmospheric temperature or substrate temperature. In contrast, abundance was influenced by both atmospheric and substrate temperature. The abundance of arboreal reptiles showed a linear relationship with atmospheric temperature (R^2 = 0.726, P<0.001), while with substrate temperature too a linear relationship was recorded (R^2 = 0.664, P< 0.001). The response of the different taxa to the atmospheric and substrate temperature also showed variation. While for agamids the peak in mean number of individuals per transects was at about 25°C, the occurrence of the other two taxa was restricted to the 19°C to 25°C temperature range. The response of the different taxa to the substrate temperature mirrored the pattern that was seen with atmospheric temperature. The number of individuals per transect of agamids increased with a gradual increase in the substrate temperature while that of the other two taxa were restricted to the 17°C to 23°C temperature range.

8.4.3 Species richness and endemism

A total of 54 species of reptiles from 9 families and 26 genera were recorded from the rainforests of KMTR using all methods (Appendix II). Sauria was represented by 22 species (40.74%), while Serpents was represented by 31 species (57.41%). Only one species of testudine, *Melanochelys trijuga,* was recorded. Family Gekkonidae was dominated by the genus *Cnemaspis* (6 species), majority of which are endemic to the rainforest of Western Ghats. One species of another genus of gecko recorded *Hemidactylus* (=*Dravidogecko*) *anamallensis* is known only from the rainforests of the Western Ghats. Family Agamidae was dominated by the genus *Calotes* with 6 species. The rare and endemic *Otocryptis beddomei* was recorded from the higher reaches of KMTR bordering Kerala. *Psammophilus* genus was represented by two species. These species are not typical rainforest species but occur in rocky areas along rainforest edges. Genus *Mabuya* species) dominated the Family Scincidae, while two other genra of fossorial skinks *Scincella* and *Ristella*, the latter being endemic were also recorded. The fossorial Family of Uropeltidae was represented by 3 genera of which *Uropeltis* had greater species. Among other snakes, Family Colubridae was the most speciose with 8 genera and 18 species. Elapidae was represented by 2 genera with one species each. In Viperidae 2 genera and 5 species were recorded.

Out of the 54 species recorded from the rainforests of KMTR, 61.1% (34 species), were endemic to the Western Ghats, while 40.7% (22 species), were endemic to the rainforests of the Western Ghats. The rediscovery of *Calotes andamanensis* (green crestless forest lizard), from the rainforest of Kakachi, sightings of *Otocryptis beddomii* (Indian kangaroo lizard), *Ophiophagus hannah* (King cobra), and possible new species in the genus *Lycodon* (wolf snake) and *Cnemaspis* (dwarf or day geckos), the rainforest endemic genera of skinks *Ristella* and *Scincella*, along with the presence of six species of uropeltids, *Dendrelaphis grandoculis, Calliophis melanurus nigrescens* and *Trimeresurus gramineus* were the highlights of this study.

8.5 DISCUSSION

8.5.1 Forest floor reptiles

The local distribution of forest floor reptiles was drastically different from that of the amphibians in the same area. The occurrence (%age of primary quadrats with animals), clumping (number of animals/quadrat), and multispecies assemblages were far lower than in the case of amphibians, and as a result the forest floor reptiles occurred at a far lower densities (see Chapter 5 for amphibians). There were some differences among the major taxa, with skinks and geckos being more abundant than agamids and snakes. The former two taxa also showed a greater degree of clumped distribution, and were more likely to form multispecies assemblages. Agamids and snakes formed a small part of the forest floor assemblage in the contiguous forests, which has also been reported by Inger *et al.* (1987) and Pawar (1999). The low abundance of snakes is surprising since many of the species are terrestrial and semi-fossorial in habit. This is partly because many of the snakes are highly mobile and thus escape detection during sampling. In addition, the sampling method did not cover the fossorial uropeltid snakes which are a very speciose group with 33 species recorded from the Western Ghats.

In the leaf litter assemblage, dominated by geckos and skinks, there was a preference for areas where the forest floor had more burrows and rocks. There was also a preference for areas with greater structural diversity in the above ground vegetation, mainly the presence of tree buttresses. This association of geckos and skinks to specific microhabitat features has also been shown in other studies (Heatwole 1977; Sarre *et al.* 1996; Howard & Hailey 1999). These specific habitat features are essential for leaf litter reptiles as they can meet the conflicting demands of thermoregulation, predator avoidance and participating in other activities, as has been reported elsewhere (Lima & Dill 1990; Sarre *et al.* 1996). It is also very likely that the microclimatic conditions under rocks are cool and humid, an ideal environment for the presence of small arthropods, which form the major prey base for these leaf litter reptiles. As the assemblage in the contiguous rainforests did not have many non-endemic species, there was no significant difference in the microhabitat attributes between areas that were used by endemic and the non-endemic reptiles.

8.5.2 Arboreal reptiles

Agamids dominated the assemblage in the contiguous rainforest, and they exhibited strong associations with locations supporting greater basal area with medium levels of understorey and canopy cover. The association of arboreal reptiles to such structural features of the habitat has also been recorded in other studies (Vitt 1995; Vitt & Zani 1996). The agamids in this assemblage were dominated by *Calotes*, represented by 6 of a total of 8 species. Among the four species of *Calotes* recorded >5 times, the smaller species, *Calotes rouxii* and *C. elliot*i, were associated with areas with dense understorey and vegetation at lower heights, while the larger and endemic members of *Calotes* (*C. grandisquamis* and *C. nemoricola)* were restricted to areas with larger trees and greater canopy heights and were recorded at greater heights in the vegetation.

Data pertaining to the habitat of partitioning in snakes are quite rare due to the secretive nature and the difficulty in observing them in their natural habitat (Reinert 1993). Many of the snakes are predatory, and the location and distribution of their prey undoubtedly plays an important role in their habitat associations. Snakes probably assess the distribution and abundance of prey from chemical cues and actively select locations based on this information (Madison 1978; Ford & Burghardt 1993). The snakes recorded from KMTR were mainly from the family Colubridae and Viperidae. Many of the colubrids are large in size, mainly species of the midstorey and capable of rapid movement in the canopy. In comparison, the pit vipers are small, understorey species and only capable of slow movements. It is probable that colubrids are active foragers covering a larger area in search of prey and for possible basking sites and hence are not particular in their preference of any structural features of the habitat. This is not true for the viperids as they are not capable of large scale movements, and hence employ a sit and wait foraging tactic. They also need to actively select locations that are suitable for thermoregulation that are quite close to feeding sites. Hence, they are associated with the understorey, which provide greater microhabitats that are suitable for basking. A majority of these is also closely associated with streams, which is used nocturnally by these species as their feeding grounds. The complete absence of pit vipers in the disturbed and smaller fragments is largely due to the absence of streams and the presence of dense understorey, which results in minimal opportunities for basking. Similar patterns have been reported in other tropical reptile communities (Vitt 1991; Vitt & de Carvalho 1995).

8.5.3 Density

Comparison of species richness and density estimates between studies is handicapped due to the lack of common sampling techniques, sampling effort, area sampled, and coverage of taxa.. In many studies combined density values for amphibians and reptiles are given, while in some density estimates are not provided.

The densities of lizards (all saurians), reported from six sites of lowland tropical rainforests of Southeast Asia and central America (Inger 1980a), range from 0.25 individuals per 100 m^2 in Nanga Tekalit, Borneo to 15.4 individuals per 100 m^2 in Panama. In comparison, the densities of lizards (geckos, skinks and agamids included), for the rainforest in KMTR as a whole was 1.08 individuals per 100 m^2. The densities in Kannikatti (700 m) and Sengaltheri (1000 m), the two sites in relatively low altitudes, were considerably higher (1.56 and 1.24 animals per 100 sq.m, respectively) than in Kakachi (0.64 animals per 100 sq.m) at a higher altitude (1300 m). It should be noted, however, that the above density estimates of forest floor reptiles exclude some species of agamids which are primarily arboreal or understorey animals. For example, *Draco dussumieri*, which occurred at a high density in low altitudes, and *Calotes ellioti* and *C.nemoricola* at medium altitudes were all primarily arboreal. The low density of forest floor lizards in KMTR concur with the low densities in Southeast Asian rainforests (Inger 1980a) compared with New World tropics (Scott 1976; Inger 1980a, 1980b; Duellman & Trueb 1985; Lieberman 1986). This difference in densities has been attributed to the structure of the Indo-Malayan rainforests, especially low litterfall and the related decline in seed-eating and forest floor arthropods, which are the primary food source for the reptiles (Inger 1980a). Nevertheless, the densities in KMTR are higher than that reported from Southeast Asian rainforests sites (Inger 1980a).

8.5.4 Species richness and endemism

Reliable estimates of the overall reptile species richness are available for many sites in Southeast Asian rainforests and New World tropics. The area coverage is a major constraint while comparing species richness, however. This information has been compiled only for lizards (Inger 1980a, b) and ranges in Southeast Asia from 8 species in the Ulu Gombak primary rainforests in Malayasia, to 21 species in Nanga Tekalit, Borneo. Studies in the rainforests of north-east India reported 18 species of lizards (Pawar 1999), while 18 species have been reported from the Ponmudi Hills in the southern Western Ghats, west of KMTR (Inger *et al.* 1984). In the present study, 23 species of lizards were recorded. Although quite low, compared to 40 species of lizards recorded from the deserts of Australia (Pianka 1969), KMTR has higher species richness in lizards than most other tropical forests.

The pattern does not change when one includes all reptilian species recorded from any locality within the Indian subcontinent. The reptile species richness in the rainforests of KMTR (54 species) ranks the highest compared to other reports from India; 33 species from the Ponmudi Hills (Inger *et al.* 1984), and ca. 24 to a maximum of 44 species reported in four reserves from the Western Ghats (Bhupathy & Kannan 1997). It is thus clear that the contiguous rainforests of KMTR support one of the richest assemblages of reptiles that have been reported from any single habitat, at least within the Indian subcontinent. It should be noted, however, that this estimate does not cover other vegetation types that occur in the Reserve, some of which have their exclusive reptilian fauna.

The 54 species recorded from rainforests in KMTR accounts for about 42% of the reptiles that are known from the rainforests of the Western Ghats. This includes a new record of *Calotes andamanensis,* re-discovered after almost 100 years (Ishwar & Das 1998), and three unidentified including two new species of *Cnemaspis*. The present list of 54 species might be quite close to the true number that is likely to occur in this rainforest, with additions expected only from the lesser known taxa of fossorial snakes. Inger *et al.* (1987), hypothesized that geographical isolation of the hill ranges in the Western Ghats is likely to be the reason for the high levels of diversity and regional endemism. In support of this, he found that each of the mountain ranges in the Western Ghats had approximately the same number of endemic forms (12 species) of herpetofauna. This receives further support from the present study, with at least seven species likely to be endemic to this mountain range/rainforests alone.

Among the taxa underrepresented in the sampling were mainly the fossorial forms of the family Uropeltidae (shield tailed snakes), and Typhlopidae (blind worm snakes). There are about 35 species of uropeltids and 15 species of blind worm snakes in India. Most of the uropeltids are restricted to the high elevation mountainous forests in the Western Ghats. In the present study, only five species of uropeltids belonging to three genera have been recorded. There are records of four more genera from the Western Ghats, which were not seen during this study. This may be because most of these fossorial reptiles are highly localized in their distribution and may not be sympatric. It might also be that the sampling procedure was not efficient in sampling fossorial reptiles. In fact there are no standard protocol for sampling these reptiles, apart from the pitfall traps, which are not viable in the rainforest (Karthik Shankar per. comm.). However, the scarcity of many other species of rainforest reptiles like the endemic genus of *Ristella* and *Scincella* and many snakes from accessible habitats like litter and the understorey may not be a sampling bias, and appears to represent their rarity in the rainforests.

8.5.5 Spatial variation in community structure

The forest floor and arboreal reptiles showed considerable, but similar, variation among the three sampling sites in absolute abundance (densities and encounter rates, respectively), as well as relative abundance (percentage composition). Thus, agamids were the dominant taxon in Kannikatti, geckos and skinks in Sengaltheri and snakes in Kakachi. An altitudinal gradient was clearly discernible in the case of arboreal reptiles. Reptilian species richness and abundance have been documented to change along altitudinal gradients (*e.g.* Brown & Alcala 1961; Porter 1972; Scott 1976; Heatwole 1982; Duellman & Trueb 1985; Inger *et al.* 1987; Fauth *et al.* 1989; Woinarski & Gambold 1992; Bhupathy & Kannan 1997), and this may be primarily due to temperature (Porter 1972). This relationship is often unimodal, with a greater abundance and species richness in the mid-altitude. In the present study, arboreal reptile abundance declined linearly with altitude, while species richness showed a unimodal distribution. The former relationship is primarily due to the linear decline with altitude in the abundance of agamids, especially *Draco dussumeri*, which formed >50% of the sightings. When agamids, geckos, and snakes were examined separately, it was seen that the latter two groups in fact reached higher abundance in mid altitudes. These three taxa have been reported to respond differently to altitude elsewhere also (Fauth *et al.* 1989; Woinarski & Gambold 1992). Individual species within taxa, might also vary in their response to altitude (Bhupathy & Kannan 1997). Although the unimodal relationship between species richness and altitude was weaker than the relationship between abundance and altitude, it is similar to the relationship reported by Brown (1964), Scott (1976), Heatwole (1982) and Fauth *et al.* (1989).

Several hypotheses, often not mutually exclusive, have been put forth to explain the relationship between altitude and species richness in many taxonomic groups. Especially important for reptiles are the altitudinal gradient in temperature to which reptiles are sensitive (Porter 1972). Several habitat features such as canopy height, leaf litter fall, and tree densities vary along an altitudinal gradient (*e.g.* Patterson *et al.* 1990). This variation might in fact reflect overall productivity of the habitat, which has been reported to reach a peak at mid-altitudes. The unimodal distribution of reptiles along the altitudinal gradient might reflect this (Scott 1976). In this study, however, the correlation of reptile abundance and richness with macrohabitat variables like temperature was considerably lower than that with altitude.

8.6 SUMMARY

The continuous rainforests of KMTR support a rich and diverse assemblage reptile. Geckos and skinks dominated the litter assemblage, while agamid lizards dominated the arboreal assemblage. The densities of reptiles were relatively low when compared with other tropical sites. Geckos and skinks did not form conspecific or multi-species aggregations. While geckos and skinks showed a preference for areas with greater rock cover and burrows, agamid lizards were associated with areas with greater tree basal area and medium levels of understorey and canopy cover. Although there were inter-site differences in species composition and richness in both the litter and arboreal assemblages, there was no significant seasonal variation. Species richness peaked at mid elevations while abundance declined along an elevation gradient.

9 REPTILES IN RAINFOREST FRAGMENTS

9.1 INTRODUCTION

Reptiles are an interesting group of animals to examine the effects of habitat fragmentation because they form a diverse morphological assemblage in a forested ecosystem. They also differ considerably in their sensitivity to changes in microclimates and other microhabitat features which are expected in forest fragments. Unlike amphibians of the Western Ghats most of which occur in the rainforest, a large number of reptiles occur also other forest types such as deciduous forests. This also offers us an opportunity to examine the intrusion by generalist species due to habitat fragmentation.

The study on reptiles in rainforest fragments in the Anamalai Hills was carried out in 1998-99, after the studies in Kalakad-Mundanthurai Tiger Reserve.

9.2 OBJECTIVES

The objectives in this chapter are to:

- To determine the distribution patterns of reptiles in the rainforest fragments.
- To examine the changes in the leaf litter and arboreal reptile assemblages due to forest fragmentation.
- Compare the microhabitat associations of rainforest reptiles in a contiguous forest with that in forest fragments; and
- Determine the changes in the reptilian community composition due to the changes in the microhabitats, resulting from rainforest fragmentation.

9.3 METHODS

The leaf litter and the arboreal reptiles were sampled using the adaptive cluster sampling and forest transects, respectively. Details on sampling design and intensity in each of the size category of fragments and the framework for data analysis are given in Section 8.2. In total, 14 rainforest fragments (see Chapter 2) were sampled in all the three seasons (south-west monsoon, north-east monsoon and summer). However, due to small sample sizes data from different seasons have been pooled. Small sample sizes did not also allow an examination of network characteristics in relation to fragment area. Therefore, all dependent variables are examined primarily with reference to four fragment size classes; Very Large (<200 ha, n=1), Large (50-200 ha, n=3), Medium (10-49 ha, n=5), and Small (<10 ha, n=5). Sampling of reptiles in rainforest fragments was carried out in 1998-99.

9.4 RESULTS

9.4.1 Forest floor reptiles

9.4.1.1 Network characteristics

A total of 460 primary quadrats and 54 secondary quadrats were laid in the 14 fragments. In all 260 leaf litter reptiles from 20 species were recorded (Table 9.2). Only 105 of the primary quadrats (22.8 %) recorded reptiles, indicating their sparse distribution. Network size varied from one to a maximum of four quadrats, with a mean of 1.51 (SE=0.07).

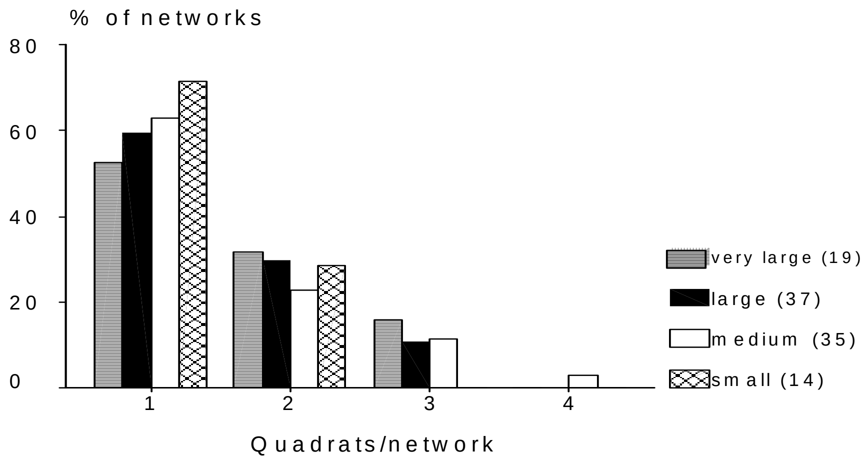


Figure 9.1. Network size (number of 5 x 5 m quadrats with reptiles in a network) in four fragment size classes in the Anamalai Hills (1998-99). The number of networks in each fragment size class is given in parenthesis.

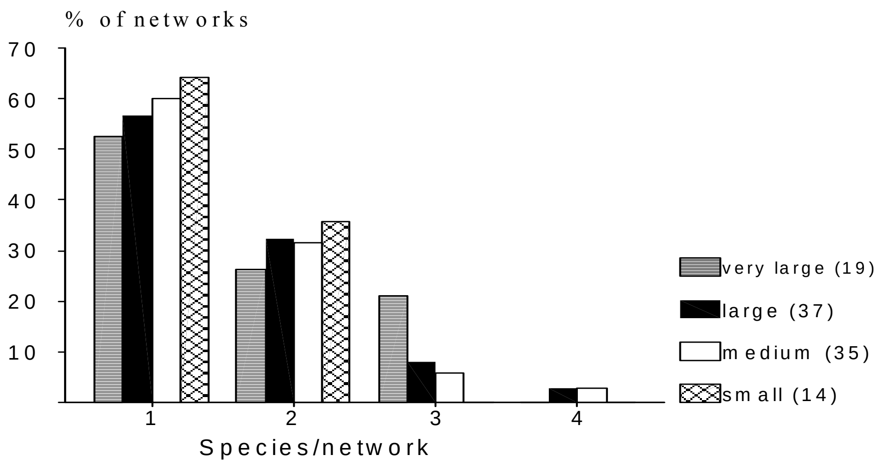


Figure 9.2. The number of reptile species per network in four fragment size classes in the Anamalai Hills (1998-99). The number of networks in each fragment size class is given in parenthesis.

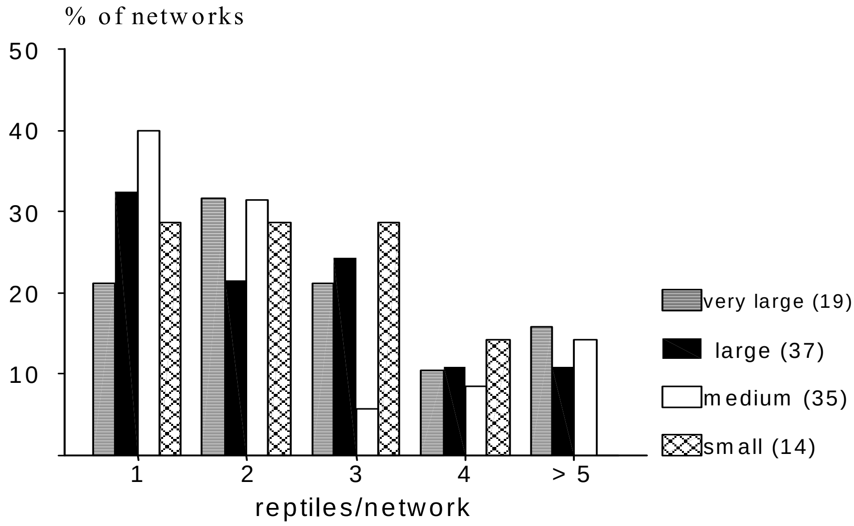


Figure 9.3. The number of reptiles per network in four fragment size classes in the Anamalai Hills (1998-99). The number of networks in each fragment size class is given in parenthesis.

Species richness per network varied from one to four, with a mean of 1.54 (SE= 0.07). Only the Large and Medium sized fragments had networks with four species, while up to three species were commonly recorded in the Very Large fragment (Figure 9.2). Small fragments did not have networks with more than two species. The number of reptiles in a network varied from one to eight with a mean of 2.41 (SE=0.13). Up to four reptiles per network were commonly recorded in all size classes of fragments, while the Small fragments did not have networks with ≥ five reptiles (Figure 9.3).

The percentage of primary quadrats with reptiles was greater in the Large and Medium sized fragments while it was lowest in the Small fragments, this difference was significant (Krushkal_Wallis Oneway, KW χ^2 =40.28, *df*=3, *P*<0.001). There was also no difference in network size among the four fragment size classes (KW χ^2 =1.66, *df*=3, *P*=0.65). Network size did not differ even when data was pooled for fragments into two size classes (Large <50 ha and Small >50 ha) (KW χ^2 =0.64, *df*=1, *P*=0.42). Similarly, the abundance of litter reptiles also did not differ between fragment size classes (KW χ^2 =1.94, *df*=3, *P*=0.58). Species richness per network showed no variation among the four fragment size classes (KW χ^2 =1.23, *df*=3, *P*=0.75). The network characteristics in four fragment size classes are summarised in Table 9.1.

Table 9.1. Mean and SE values for network size, abundance and species per network in a) size classes of fragments and b) seasons.

	Network size Mean ± SE	Reptiles per network Mean ± SE	Species per network Mean ± SE
Very Large	1.63 ± 0.17	2.79 ± 0.36	1.68 ± 0.19
Large	1.51 ± 0.11	2.54 ± 0.26	1.57 ± 0.13
Medium	1.54 ± 0.14	2.31 ± 0.26	1.51 ± 0.13
Small	1.29 ± 0.13	2.29 ± 0.29	1.36 ± 0.13

9.4.1.2 Community composition

A total of 20 species were recorded by adaptive cluster sampling in the rainforest fragments. The leaf litter assemblage in the fragments was highly uneven, with eight of the 20 species being represented by ≤ five individuals (Table 9.2), four of which were snakes. Consequently, most of the analysis on community composition was done at higher taxa levels, at the level of Families for geckos, skinks, and agamids, while for snakes it was at the Order level.

Skinks were the dominant taxon in the leaf litter assemblage, accounting for 138 individuals (53.10%, n=260), but represented by only four species of which two (*Scincella travancoricum* and *Ristella guntheri*) were rainforest endemics. Geckos, represented by the genus *Cnemaspis*, were the most species rich (eight), and accounted for 95 individuals (36.50%), followed by the snakes (six species) accounting for only 18 individuals (6.92%). Agamids were very few in the leaf litter assemblage with only 2 species and 9 individuals (3.46%).

Skinks were the most dominant taxon in all the fragments. Geckos showed a decline in their contribution to the assemblage with a decrease in fragment area, and this decrease was accompanied by an increase in the proportion of agamids (Figure 9.4). The abundance of snakes was greater in the Large and Medium fragments (8 and 7 individuals respectively), while in the small sized fragments the abundance of snakes (one individual), was minimal.

The reptilian leaf litter assemblages in two rainforest fragments planted with cardamom were very different from that found in the other fragments. The Large fragment of Sankarankudi, though dominated by skinks (80%), had very few geckos (5%), while in the Medium fragment of Korangumudi, though dominated by the skinks (55.55%), and geckos (33.33%), completely lacked snakes (Table 9.2).

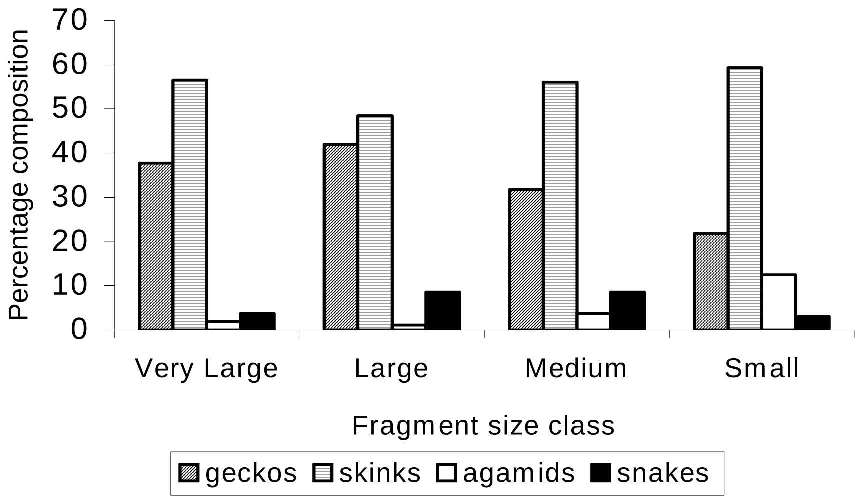


Figure 9.4. The percentage composition of forest floor reptiles in four fragment size classes in the Anamalai Hills (1998-99).

In general, the abundance of non-endemic litter reptiles was greater in the Medium and Small sized fragments when compared with the Very Large fragment. Geckos that were recorded in the leaf litter assemblage in all the rainforest fragments were endemic species. Though skinks dominated the assemblage in all size categories of fragments, non-endemic skinks increased in abundance as the size of the fragment decreased. The non-endemic species were very few in the Very Large (Akkamalai) fragment, while in the Small fragments skinks were only represented by the non-endemic species (Figure 9.5).

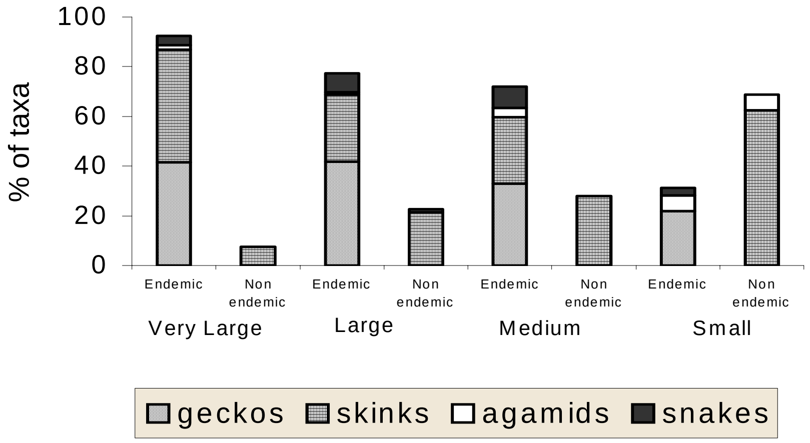


Figure 9.5. The proportion of endemic and non-endemic leaf litter reptile taxa in various size categories of fragments, Anamalai Hills (1998-99).

Table 9.2. The species and number of individuals of leaf litter reptiles recorded from adaptive cluster sampling in the 14 rainforest fragments of Anamalai Hills, (1998-99).

SPECIES	FOREST FRAGMENTS*														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total
Cnemaspis indica	0	0	4	0	0	0	0	0	0	0	0	1	1	0	6
C. mysoriensis	2	8	5	1	0	0	0	0	1	0	0	1	0	0	18
C. ornatus	4	1	0	0	0	0	0	0	1	0	0	0	0	2	8
C. spp 1 (white belly)	1	3	3	0	0	8	0	0	0	0	0	0	0	0	15
C. spp 2 (yellow throat)	1	0	7	0	8	2	1	3	0	0	1	0	0	0	23
C. spp 3 (red eye)	5	0	0	0	0	0	0	0	0	0	0	0	0	0	5
C. spp 4 (total black)	6	2	3	0	0	0	1	0	1	0	1	0	0	0	14
C. spp 5 (black throat)	3	0	2	0	0	0	1	0	0	0	0	0	0	0	6
Calotes ellioti	1	0	0	1	0	0	0	2	1	0	0	1	0	1	7
C. rouxii	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2
Mabuya beddomii	4	5	6	6	1	0	14	4	3	3	4	9	4	0	63
M. carinata	0	0	0	3	1	0	0	0	0	0	0	0	0	0	4
Scincella travancoricum	23	17	0	0	1	4	0	0	1	0	0	0	0	0	46
Ristella guntheri	1	0	1	7	4	7	0	4	1	0	0	0	0	0	25
Uropeltis ocellata	0	1	0	0	0	0	1	0	0	0	0	0	0	0	2
Amphiesma beddomei	2	0	1	2	2	0	0	0	0	0	0	0	0	0	7
Calliophis melanurus nigrescens	0	1	2	0	0	0	0	0	0	0	1	0	0	0	4
Hypnale hypnale	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
Trimeresurus macrolepis	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
T. malabaricus	0	0	0	0	0	0	3	0	0	0	0	0	0	0	3
Total	53	38	35	20	18	21	21	13	9	3	7	12	7	3	260

***** for identity of the rainforest fragments refer Table 2.1 in Chapter 2.

9.4.1.3 Density

When data were pooled across all the fragments, the overall density of forest floor reptiles was 0.37 animals/quadrat, the variance being 0.001. Skinks dominated the assemblage with 0.21 animals/quadrat, followed by geckos (0.12). The other two taxa namely, snakes (0.03), and agamids (0.01), had much lower densities. The Large and Medium fragments had the highest density, while the Very Large fragment and the Small fragments had the lowest densities (Table 9.3). While the densities of agamids increased with decreasing fragment size, geckos and skinks had higher densities in the Medium fragments. The densities of snakes were also higher in the Large and Medium fragments (Table 9.3).

Table 9.3. Density (number of animals/ 5 m x 5 m quadrat) of forest floor reptiles in the different size classes of rainforest fragments, Anamalai Hills (1998-99).

	Geckos	Skinks	Agamids	Snakes	Total
Very Large	0.1024	0.1667	0.0092	0.0183	0.2966
Large	0.1273	0.2683	0.0133	0.0387	0.4478
Medium	0.1591	0.2837	0.0177	0.0213	0.4823
Small	0.0914	0.1991	0.0365	0.0062	0.3332

The Very Large fragment showed the highest similarity with the Large fragments, while the Large fragments had the highest similarity with the Medium sized fragments which in turn showed the highest similarity with the Small fragments. Thus, similarity in the species composition decreased between fragments as the difference in their area (Table 9.4).

Table 9.4. Morisita-Horn's measure of similarity for leaf litter reptiles in the different size classes of fragments, Anamalai Hills (1998-99).

	Large	Medium	Small
Very Large	0.654	0.346	0.183
Large		0.755	0.487
Medium			0.623

9.4.2 Arboreal reptiles

9.4.2.1 Abundance and composition

Sampling for arboreal reptiles in 14 forest fragments yielded 549 individuals belonging to 19 species. Data pooled for all replicates (9) in each transect showed the species richness per transect varying from two to nine, with a mean of 5.27 (SE= 0.31), and a median of five species per transect (250 m). Species richness was greatest in a Large fragment (Manamboli), and lowest in a Small fragment (Varattuparai IV) (Table 5.5). Reptile abundance per transect (including replicates), varied from 6 to 39 individuals, with a mean of 16.64 (SE=1.17). The abundance was highest in the Very Large fragment of Akkamalai while it was lowest in the Small fragments of Varattuparai I and Tata II (Table 9.5).

Table 9.5. Arboreal reptile species and number of individuals recorded by forest transects in 14 rainforest fragments of Anamalai Hills, (1998-99).

SPECIES	Forest fragments														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total
Cnemaspis indica	0	0	0	1	0	2	0	0	0	0	0	0	0	0	**3**
C. mysoriensis	0	0	1	0	0	0	0	0	0	0	0	0	0	0	**1**
C. spp 1 (white belly)	1	1	0	0	0	0	0	0	0	0	0	0	0	0	**2**
C. spp 2 (yellow throat)	1	1	1	0	0	0	0	0	0	0	0	0	0	0	**3**
C. spp 6	5	1	0	4	1	0	0	1	1	0	0	0	0	1	**14**
Calotes ellioti	47	39	26	24	16	19	2	10	26	3	3	9	6	3	**233**
C. grandisquamis	15	8	6	3	4	2	1	0	0	0	1	2	0	0	**42**
C. nemoricola	10	4	4	2	2	0	0	0	1	0	1	0	0	0	**24**
C. rouxii	0	0	4	0	0	0	0	0	0	2	5	3	0	2	**16**
Draco drussumieri	2	5	26	27	4	4	16	5	31	1	1	1	5	0	**128**
Varanus bengalensis	7	1	3	0	0	0	0	0	1	0	0	1	0	0	**13**
Ahaetulla nasutus	8	2	1	0	1	1	0	0	0	0	0	1	0	0	**14**
Amphiesma beddomei	0	0	0	2	0	0	0	0	0	0	0	0	0	0	**2**
Coluber mucosus	1	1	1	2	0	0	0	0	0	0	0	0	0	0	**5**
Dendrelapis tristis	0	0	1	1	0	0	0	0	0	0	0	0	0	0	**2**
Calliophis melanurus nigrescens	0	0	0	1	0	0	0	0	0	0	0	0	0	0	**1**
Hypnale hypnale	0	0	1	0	0	0	0	0	0	0	0	0	0	0	**1**
Trimeresurus macrolepis	17	11	0	0	0	0	0	0	0	0	1	0	0	0	**29**
T. malabaricus	0	0	5	1	0	0	0	0	9	0	0	1	0	0	**16**
Total	**114**	**74**	**80**	**68**	**28**	**28**	**19**	**16**	**69**	**6**	**12**	**18**	**11**	**6**	**549**

The overall encounter rates of arboreal reptiles was 1.84 animals/250 m. Agamids was the dominant taxon (1.53 animals/250 m), followed by snakes (0.23 animals/250 m), and geckos (0.08 animals/250 m). The agamids were represented by six species accounting for 83.61% of all sightings (Table 9.5). Species richness was greatest in snakes, with 8 species, but accounted for only 12.2% of all sightings. Geckos were represented by five species, and accounted for only 4.2% of the sightings. Many arboreal reptiles were low in abundance, with nine of the 19 species being recorded ≤ 5 times, indicating a highly uneven arboreal assemblage.At a species level, two agamids (*Calotes ellioti* 42.44% and *Draco dussumieri* 23.31%), accounted for 65.75% of all sightings in the assemblage. The contribution to the arboreal assemblage by any of the other species did not exceed 10%. Among snakes the most abundant species was the large scaled pit viper (*Trimeresurus macrolepis*), while among geckos it was an unidentified *Cnemaspis* species, contributing 5.29% and 2.55% of the overall sightings, respectively.

Arboreal reptile species richness per transect showed a significant difference between fragment size classes (KW χ^2 = 16.97, *df*=3, *P*= 0.001). The difference in species richness was greatest between the Large and Medium, and Large and Small sized fragments (Figure 9.6). The encounter rates of arboreal reptiles also showed difference among the different size class of fragments. It was greatest in the Medium sized fragments and lowest in the Small sized fragments. The encounter rates of individual taxa also showed difference among the size categories of fragments. While the encounter rates of agamids peaked in the Medium fragments, geckos and snakes decreased along a size gradient (Table 9.6).

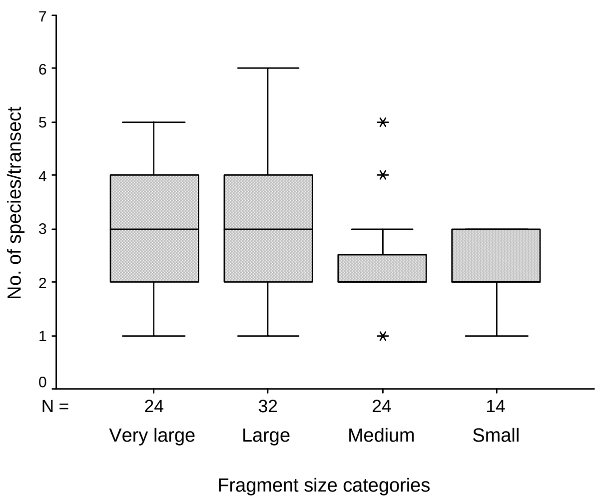


Figure 9.6. Species richness in arboreal reptiles in four rainforest fragment size classes in the Anamalai Hills (1998-99).

Table 9.6. Encounter rates (animals/250 m) of arboreal reptiles in the different size classes of rainforest fragments, Anamalai Hills (1998-99). Figures in parenthesis give the number of transects in each size category.

	Geckos	Agamids	Snakes	Total
Very Large (8) >200 ha	0.1	1.12	0.36	1.58
Large (12) 50-200 ha	0.09	1.68	0.27	2.05
Medium (8) 10-50 ha	0.07	2.00	0.15	2.22
Small (5) <10 ha	0.02	1.11	0.07	1.18

The percentage composition of the three arboreal taxa was also estimated for the different size categories of fragments. The agamids remained the dominant taxon in all the fragment size classes, reaching its highest relative abundance in the Medium sized fragments (Figure 9.7). Snakes and geckos showed a decline in their contribution to the assemblage from the Very Large to the Small fragments. Thus, geckos and skinks showed a linear decline with a decline in the area of the fragment while the abundance of agamids peaked in the Medium sized fragments.

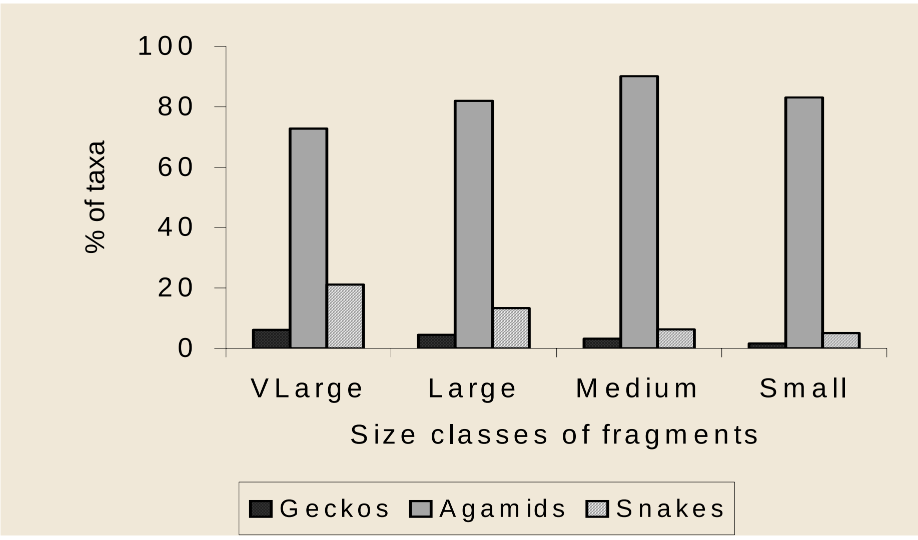


Figure 9.7.The percentage composition of various taxa of arboreal reptiles in four area classes of rainforest fragments, Anamalai Hills (1998-99).

Among the agamids, there was an increase in the proportion of the non-endemic species in the Medium and Small rainforest fragments when compared to the Very Large and Large fragments. Among snakes, there was a decrease in the proportion as the size of the fragment decreased, and this pattern was also exhibited by the non-endemic species of snakes (Figure 9.8).

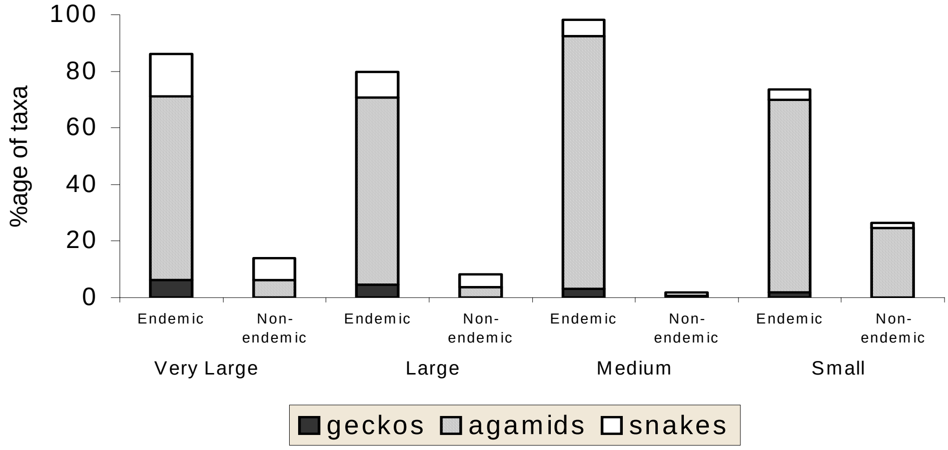


Figure 9.8. The percentage of endemic and non-endemic arboreal reptile taxa in the different size categories of fragments, Anamalai Hills (1998-99).

The arboreal reptile assemblages in the two fragments planted with cardamom were very different from the other forest fragments. Although, agamids was still the most dominant taxon, the most dominant species in these two fragments was the flying lizard, *Darco dussumieri* accounting for 39.70% in Sankarankudi and 44.93% in Korangumudi, while in most other fragments, *Calotes ellioti* was the dominant species. Geckos were very few in these two fragments accounting for only 7.35% and 1.45% of the sightings, respectively.

Altitude was not a significant factor in determining arboreal reptile species richness (R^2=0.09, P>0.05) abundance (R^2 =0.03, P>0.05) in the rainforest fragments.

9.4.3 Species richness and endemism

In total, the 14 rainforest fragments which were sampled had 40 species in 9 families and 23 genera (Appendix II). Order Sauria was represented by 21 species (52.5%), while Serpentes were represented by 19 species (47.5%). No species of the Order Testudine were recorded. Family Gekkonidae was represented by a single genus *Cnemaspis* (9 species), many of which are endemic to the rainforest of Western Ghats. Family Agamidae was represented by six species, four of the genus *Calotes*, and one each from *Draco* and the endemic, high altitude genus *Salea*. Scincidae (skinks), were represented by the genus *Mabuya* (2 species), and the rainforest endemics *Scincella* (2 species) and one species of *Ristella*. The fossorial Family of Uropeltidae was represented by two genera, of which genus *Uropeltis* has more species. Colubridae, was the most species rich family with 9 genera and 10 species. Elapidae was represented by a single species, while Viperidae was represented by two genera and three species.

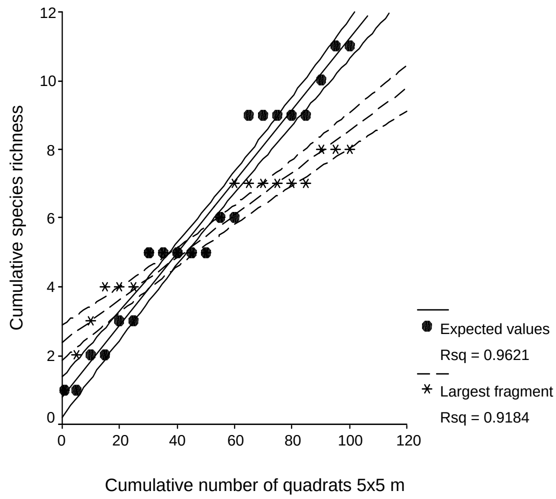
Of the 40 species recorded, 72.5% (29 species) were endemic to the Western Ghats, while 45% (18 species) were endemic to the rainforests (Table 9.7). The Very Large fragment had a greater number of species that were endemic to both the Western Ghats and to the rainforests. The Very Large fragment had 17 rainforest endemic species compared to 16 such species for all other fragments together. Thus, within the Anamalai Hills, there was a decline in species richness as well as endemic species in the fragments as the size of the fragment decreased (Table 9.7). This trend holds good when compared with the contiguous and relatively undisturbed site in KMTR.

Table 9.7. Reptilian species richness and endemism in the rainforest fragments in Anamalai Hills (1998-99), and KMTR. Figures in parenthesis give the number of fragments.

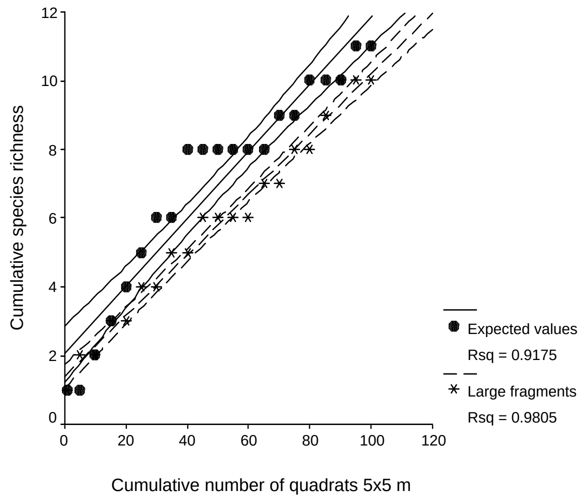
	Total species richness	Endemic species	
		Western Ghats	Rainforest of Western Ghats
Anamalai Hills (14)	**40**	**29**	**18**
Very large (1)	30	25	17
Large (3)	31	21	12
Medium (5)	32	23	14
Small (5)	19	15	6
Large,Medium and Small fragments (13)	36	26	16
KMTR	**54**	**34**	**22**

The decrease in species richness in fragments was further revealed by the comparison of species accumulation in 100 randomly selected quadrats in both the study sites. The effect of altitude was controlled for by restricting the choice of quadrats to comparable altitudinal classes. The accumulation of species in the Very Large fragment was similar to that of contiguous rainforests till about 60 quadrats, but with an increase in area the species richness was higher in the contiguous rainforests (Figure 9.9 a). The rate of species accumulation in Large fragments was lower than that in the contiguous rainforests (Figure 9.9 b) and that of Medium and Small fragments even lesser (Figure 9.9 c and d). This further establishes that the species decline in the fragments is more due to the process of rainforest fragmentation than other factors like altitude and area.

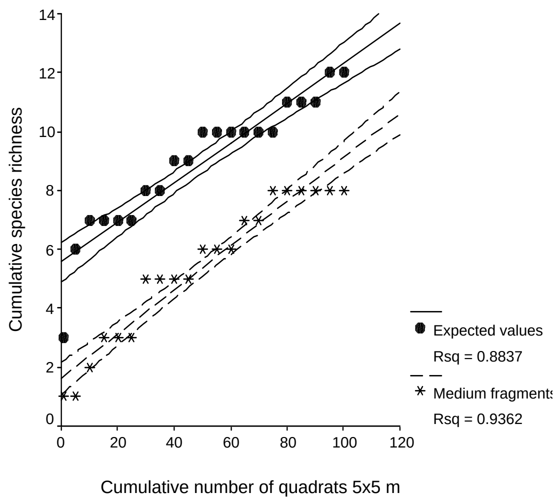
(a) Very Large fragment



(b) Large fragments



(c) Medium fragments



(d) Small fragments

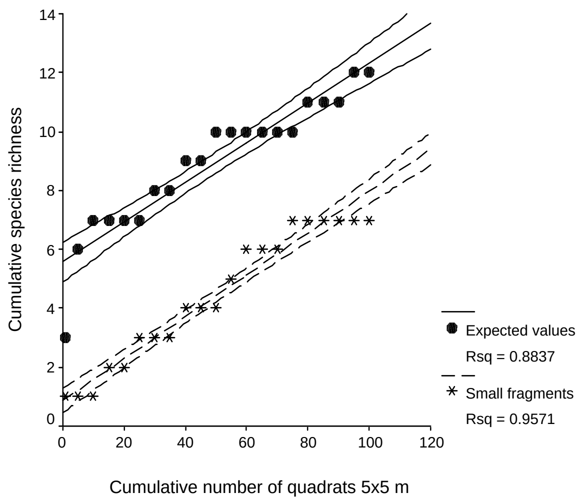
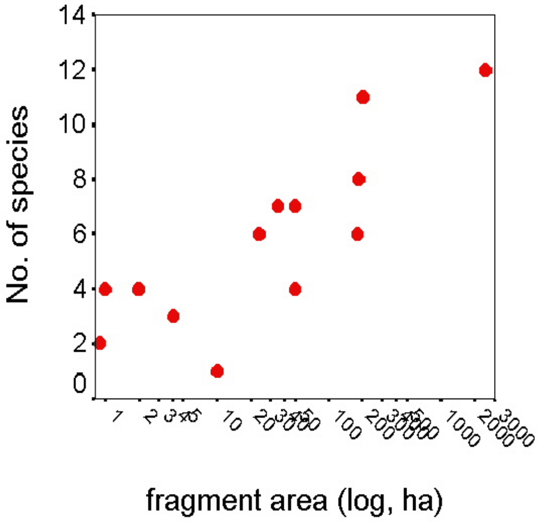


Figure 9.9. Species accumulation of rainforest floor reptiles in 100 random quadrats in a) Very Large fragment (>200 ha), b) Large fragments (50-200 ha), c) Medium fragments (10-50 ha) d) Small fragments (<10 ha) in the Anamalai Hills, compared to 100 random quadrats from the Kalakad-Mundanthurai Tiger Reserve (expected values).

9.4.4 Habitat correlates of species richness and density

The overall species richness (all reptile taxa and sampling methods together) in the 14 rainforest fragments was highly correlated with fragment area (Figure 9.10). However, the density of all species together, or that of 4 different taxa was not correlated with fragment area (Table 9.9). Instead, the total density was correlated positively with the number of cut saplings in the plot, a sign of human disturbance. The density of geckos was positively correlated with cut sapling as well as with the number of buttressed trees. The densities of skinks and lizards were not correlated with any of the habitat variables, while that of snakes was correlated positively with canopy height, an indicator of undisturbed forest.



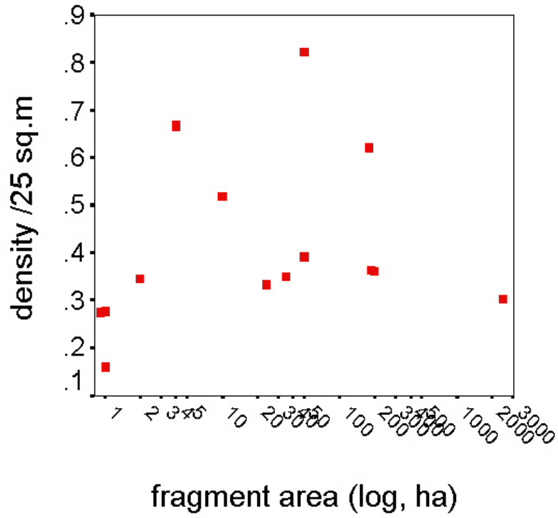


Figure 9.10. The influence of fragment area on (left) species richness of reptiles, and (right) the density of forest floor reptiles in 14 rainforest fragments in the Anamalai Hills (1998-99).

Table 9.9. Pearson correlation (r) between densities of forest floor reptiles (total and 4 different taxa) and several habitat variables, in 14 rainforest fragments in the Anamalai Hills (1998-99).

	Total	Gecko	Skink	Agamids	Snakes
Area	.2263	.2279	.1669	-.2078	.4213
Altitude	-.0516	-.0039	.0121	-.1649	-.1716
Canopy cover	-.3254	.0616	-.4518	-.2060	.3918
Rock cover	-.1135	.0655	-.1858	-.3676	.4521
Root cover	.0722	-.1657	.1493	-.2083	.4497
Canopy ht	.1060	-.1343	. 1288	-.1347	. 6250*
Cut sapling	.6396*	.6924**	.4336	-.3121	-.1590
Cut trees	.1727	.2843	.1494	-.2081	-.4819
Tree density	-.5196	-.2102	-.4831	-.2159	-.0426
Soil temp	.1912	-.2561	.4062	-.1141	-.0227
Soil moisture	.0160	-.2953	.1435	.2149	.1945
Buttress trees	.3505	.5980*	-.0096	.3901	-.0547

9.5 DISCUSSION

9.5.1 Species richness, endemism and density

Habitat fragmentation replaces a naturally ecosystem with a human-dominated landscape inhospitable to several original species, but favourable to species that are highly adaptable. Most of the latter are, however, species that infiltrate from elsewhere. This has been amply demonstrated in the case of reptiles in the Anamalai Hills. Typical examples are occurrence of secondary forest species like *Calotes rouxii*, *Mabuya carinata* and *M. beddomii* in the leaf litter assemblage in most of the fragments, and their increased abundance in the smaller fragments. Typical rainforest species of the genus *Cnemaspis*, *Ristella* and *Scincella* and many snakes were not recorded in the Small and more disturbed fragments. The arboreal assemblage showed a similar pattern, with the complete dominance by *Calotes ellioti* and *Draco dussumieri* in all the rainforest fragments, and a decrease in the abundance of typical rainforest species like *C. grandisquamis* and *C. nemoricola.*

The overall species richness in rainforest fragments was considerably lower (40 species) than in the contiguous rainforest in KMTR (54 species), unlike in the case of amphibians in which more species was recorded from the rainforest fragments (40 species) than KMTR (32 species). The latter is attributed to the patchy distribution of amphibians and turn over species with drainage (see Chapters 6 and 7). Despite an overall increase in species richness with fragment area, however, the Large and Medium sized fragments had more species than the Very Large fragment, primarily due to the influx of generalist species. The number of endemic species was greater in the Very Large fragment, than the Large and Medium fragments together. Thus, the fragment area effect seems to be greater in reptiles than in the amphibians, especially in the case of endemics. This is perhaps because the reptiles, especially snakes, require relatively large home ranges, and also are active predators, compared to amphibians which are passive predators.

Interestingly the overall density of forest floor reptiles and the densities of different taxa were not significantly correlated with fragment area. This might reflect differences among the species in their response to fragment area, with some responding positively and others negatively. Due to the low abundance of most species, this could not be examined. Another factor is density compensation (Case 1975; Malcom 1997) *i.e.* the loss of some species in an assemblage is compensated by the colonization of other species. It is noteworthy that the density of geckos was positively correlated with disturbance (cut sapling), while that of snakes was positively correlated with canopy height (an indicator of lack of disturbance). The density of snakes also showed the highest correlation with fragment area, showing their large area requirements. Species in each taxon would respond differently to changes in habitat features, an examination of which was not possible due to small sample sizes.

The species-area relationship is epiphenomeral as area is confounded by other variables such as vegetation diversity, microhabitat diversity and associated human disturbance (Abensperg-Traun *et al.* 1996; Smith *et al.* 1996). It is likely that these factors are more important for the immediate survival of the species in that area. Recent studies have demonstrated that the persistence of species in a fragmented habitat is related more to the habitat quality within and surrounding the fragments (Bierregaard *et al.* 1992) and the presence of microhabitats (Bright & Morris 1996), than to the actual area of the fragment, whose influence seems to have been over-emphasized.

9.5.2 Community structure and composition

In the arboreal assemblage, as in the contiguous rainforests of KMTR, agamids dominated the assemblage in the fragments. However, species that were numerically dominant in the fragments were non-endemic species, being also recorded from disturbed areas adjoining the rainforests. These species have gained entry into the previously inhospitable rainforest fragments, and displaced the typical rainforest species from the habitat. Arboreal geckos were numerous (9 species) in the rainforest fragments when compared with the contiguous rainforest of KMTR (6 species), while the number of snakes, excluding fossorial species, was low in the fragments (14), when compared with the contiguous rainforests of (24 species). The snakes in the forest fragments were largely dominated by the pit vipers, which were again largely restricted to the Large and Medium disturbed remnants. Many of the more abundant and common arboreal species like vine snakes and tree snakes were relatively few and rare in the rainforest, being more abundant in the Very Large fragment. These species were more commonly recorded from the contiguous rainforests of KMTR and their absence in the fragments is significant but difficult to explain. Of the rainforest reptiles that were studied, snakes showed the largest difference in occurrence in the fragments, being completely absent in the Small fragments. Species richness and abundance peaks in Medium and Large fragments. It is known that among reptiles, snakes are more restricted in their distribution and abundance by their food preference than by habitat complexity and disturbance (Reinert 1993).

Forest fragmentation leads to increased population densities of some species (Laurance 1994; Terborgh *et al.* 1997). It is unclear if this is a temporary or permanent effect (Bierregaard & Lovejoy 1989; Malcolm 1997). In the present study the overall densities of leaf litter reptiles and the encounter rates of arboreal reptiles in the Medium and Large fragments were higher than that recorded in the Very Large fragment and the Small fragments. It is likely that larger fragments hypothetically will support increased topographical relief and habitat diversity. If the altitude and the climatic conditions are controlled for then, there is unlikely to be an increase in the new niches beyond a certain optimum area, mainly due to the saturation of the habitat diversity. Another reason for the greater species richness and abundance in the Large and Medium sized fragments is that the Very Large fragment, by virtue of being greater in area could have reached a state of equilibrium, while this state of equilibrium has not yet reached in the Large and Medium fragments. Apart from this, it is also interesting to note that the Large and Medium fragments have moderate levels of disturbance. This finding also lends credibility to the intermediate disturbance hypothesis (Levin & Paine 1974; Connel 1978). It is also probable that the fragments in the Anamalai Hills are in different successional stages with disturbance affecting the structural diversity as well as the overall species diversity.

The increase in species richness and abundance in the Large and Medium fragments could also be due to the availability of two kinds of habitats, namely the habitat edge and a distinct undisturbed forest interior. The habitat specialists are restricted to the forest interiors and the edge habitat is mainly occupied by the habitat generalist species. Consequently, these fragments tend to be super saturated with species and individuals, referred to as the ‘crowding effect’ (Case & Bolger 1991).

9.6 SUMMARY

The fragmentation of contiguous rainforest into smaller isolated fragments has led to changes in the distribution and structure of both the litter and arboreal reptile assemblages. The Medium and Large sized fragments, which also showed moderate levels of disturbance, exhibited a peak in species richness and abundance both in the leaf litter and arboreal assemblages. This was primarily due to the influx of generalist species. There was a noticeable decrease in the species richness and abundance of snakes and geckos in the smaller fragments with an increase in agamids. Many of the species recorded from the Smaller and disturbed remnants were non-endemic species. The number of endemic species was greater in the Very large fragment than other fragments. The influence of altitude on the reptilian species richness and abundance was weak mainly due to the presence of non-endemic species in the assemblage. The arboreal assemblage seems to be more adversely affected by rainforest fragmentation and the resulting disturbance than the leaf litter assemblage. The changes in the species composition in the both the assemblages, caused by the extinction of some species and the greater abundance of non-endemic species indicate that reptiles vary widely in their response to habitat fragmentation.

10 NESTEDNESS IN RAINFOREST FRAGMENTS

10.1 INTRODUCTION

Habitat fragments are expected to contain fewer species than similar sized areas in the contiguous habitat due to extinction after isolation, caused by a variety of processes that together comprise ‘faunal relaxation’ (Brown 1971; Newmark 1987). Such systems exhibit distinctive patterns of species richness and composition termed as ‘nested subsets’. In this system, species found in smaller fragments represent a subset of species found in the larger fragments, rather than a random draw of species that are found in the entire species pool (Patterson & Atmar 2000). Independent of faunal relaxation, colonization, disturbance, hierarchical niche relationship and passive sampling are some of the other factors that can explain nestedness (Patterson & Atmar 2000).

A highly predictable extinction sequence is implied by these nested species distribution patterns, and this sequence is important to both the philosophy and practice of conservation biology (Atmar & Patterson 1993). The ‘Temperature Calculator’ (Atmar & Patterson 1995) is a very useful tool in examining the extent of nestedness among a set of faunal assemblages. This is also useful in testing the hypothesis whether such a set is significantly nested in relation to the random pattern of species distribution. This also aids in the identification of species that are at the threshold of extinction and in the identification of the level of hospitality of the fragments (Atmar & Patterson 1993, 1995; Patterson & Atmar 2000).

10.2 OBJECTIVES

The specific objectives of this chapter are to:

- Examine the degree of nestedness of species distribution in the sampled forest fragments and to identify the causes for this pattern.
- Identify species that are likely to move towards extinction and also to identify the order of extinction. and
- To examine the hospitality or suitability of the fragments to support rainforest reptiles.

10.3 METHODS

The data set used to test for nestedness in reptile distribution was the list of species from the 14 forest fragments, which incorporated information from all the sampling methods including the opportunistic sampling (Chapter 9).

10.4 RESULTS

10.4.1 Nested distribution

The incidence matrix used in the temperature calculator had 40 species in 14 fragments. The species occurrence in the fragments showed nestedness, the temperature of the system being T = 16.15°. (P<0.001, Figure 10.1). The graph below the matrix portrays the species and also identifies the idiosyncratic species, while the graph on the right of the matrix represents the fragments and also distinguishes the idiosyncratic fragments. Idiosyncratic sites and species are those that have temperature values higher than that of the system temperature. Akkamalai, Manamboli, Puthuthottam, Tata II and Varattuparai I were the idiosyncratic sites, as one moves from top to bottom of the graph, while the idiosyncratic species were *Draco dussumieri*, *Mabuya beddomii*, *Calotes rouxii*, *M. carinata*, *Varanus bengalensis*, *Trimeresurus malabaricus*, *Cnemaspis indica*, *C. ornata*, *Uropeltis rubromaculatus*, *Cnemaspis* spp. 3 (red eye), *Uropeltis nitida* and *Coluber* species, as one moves from left to right (Figure 10.1). The matrix reorganization vectors for fragments (Table 10.1) and species (Table 10.2) give the reordered sites and species after maximally packing the matrix. The very large fragment (Akkamalai), was the most hospitable site supporting a majority of the species from the total pool, while the small fragment (Varattuparai I) was the least hospitable supporting very few species, many of which were non-rainforest species. The probability calculations are also shown at the bottom of Figure 10.1.

Table 10.1. The reorganization vector of the fragments in Anamalai Hills after maximal packing, using the nested temperature calculator.

Current Row Position	Original Row Position	Fragment name
1	1	Akkamalai
2	3	Manamboli
3	4	Sankarankudi
4	5	Iyerpadi Church
5	2	Andiparai
6	6	Pudhuthottam
7	8	Pannimedu
8	9	Korangumudi
9	7	Tata Finley
10	10	Varattuparai II
11	11	Varattuparai III
12	13	Tata II
13	12	Varattuparai IV
14	14	Varattuparai I

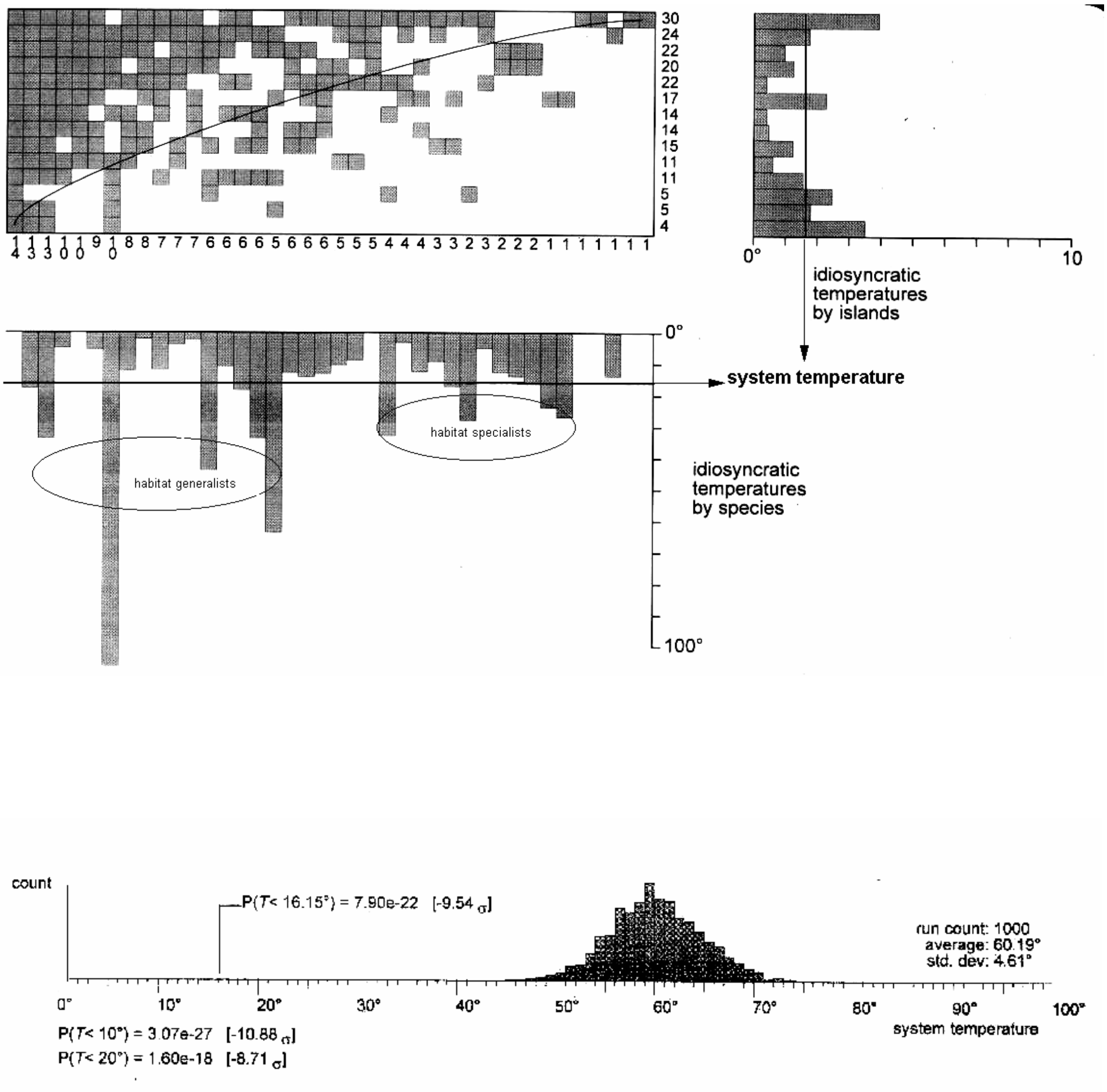


Figure 10.1. The maximally packed species incidence matrix with idiosyncratic sites and species and the probabilty estimation function, for reptiles in the rainforest fragments of Anamalai Hills. The identity of species (horizontal), and fragment (vertical) are as in Table 10.1 and 10.2, respectively.

Table. 10.2. The reorganization vector of the reptilian species in 14 rainforest fragments in the Anamalai Hills after maximal packing, using the nested temperature calculator.

Current Column Position	Original Column Position	Species
1	1	*Calotes ellioti*
2	2	*Draco dussumieri*
3	3	*Mabuya beddomii*
4	4	*Calotes grandisquamis*
5	5	*Amphiesma beddomei*
6	7	*Cnemaspis spp 2 (yellow throat)*
7	6	*Calotes rouxii*
8	8	*Cnemaspis spp 4 (total black)*
9	9	*Coluber mucosus*
10	12	*Ahaetulla nasutus*
11	10	*Calotes nemoricola*
12	11	*Ristella guntheri*
13	13	*Mabuya carinata*
14	16	*Cnemaspis mysorensis*
15	17	*Varanus bengalensis*
16	14	*Trimeresurus malabaricus*
17	20	*Cnemaspis indica*
18	15	*Cnemaspis spp 6*
19	19	*Uropeltis ocellata*
20	18	*Scincella travancoricum*
21	22	*Trimeresurus macrolepis*
22	21	*Calliophis melanurus nigrescens*
23	26	*Boiga ceylonensis*
24	23	*Cnemaspis ornatus*
25	25	*Cnemaspis spp 1 (white belly)*
26	24	*Typhlops spp*
27	27	*Cnemaspis spp 5 (black throat)*
28	28	*Uropeltis rubromaculatus*
29	30	*Cnemaspis spp 3 (red eye)*
30	29	*Lycodon spp*
31	34	*Oliogodon arnensis*
32	36	*Dendrelapis tristis*
33	35	*Elaphae helena*
34	33	*Uropeltis nitida*
35	32	*Coluber spp*
36	37	*Xenochrophis piscator*
37	38	*Salea anamallayanan*
38	31	*Hypnale hypnale*
39	39	*Scincella spp 1*
40	40	*Melanophidium punctatum*

10.4.2 The influence of other factors on nestedness

Years elapsed since the isolation of a forest fragment showed a positive correlation with the fragment's position in the nested hierarchy (Spearman's rho 0.839 P<0.001), while a negative relation was seen between years since isolation and the species richness of the fragment (Spearman's rho -0.771 P<0.001), implying that the more isolated fragments have fewer species. A quadratic relationship between species richness of a fragment and time elapsed since its isolation (R^2 0.726, P<0.001; Figure 10.2), was established. A pronounced decline in species richness occurs after ca. 70 years of a fragment's isolation. The non-nestedness of microhabitat distribution in fragments was evident by a negative relation between the area of a fragment with the fragments position in the nested hierarchy (Spearman's rho -0.958 P<0.001).

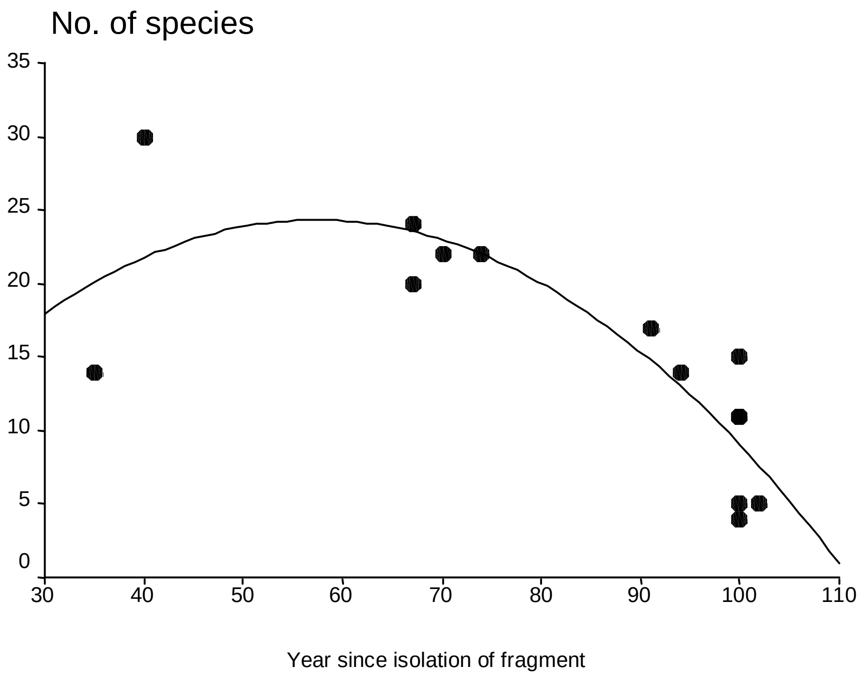


Figure 10.2. The influence of time since isolation on reptile species richness in 14 rainforest fragments in the Anamalai Hills (1998-99).

10.5 DISCUSSION

10.5.1 Nestedness

In the case of perfect nestedness, all species recorded in smaller islands or fragments also occur in the largest island or fragment, and this appears to be a common property of species distribution both in true islands (Patterson 1987; Simberloff & Martin 1991; Beckon 1993; Atmar & Patterson 1993), and in habitat islands (Blake 1991; Bolger *et al.* 1991; Cutler 1991; Patterson & Brown 1986; Wright & Reeves 1992; Wright *et al.* 1998).

However, few other biotas exhibit perfect nestedness. The mechanisms that have been proposed to account for the nestedness in species distribution include differential extinction rates (Patterson & Atmar 1986; Cutler 1991; McDonald & Brown 1992; Yiming *et al.* 1998), nested distribution of habitats (Schoener & Schoener 1983; Simberloff & Martin 1991), and differential colonization of the habitat by the species (Kadmon 1995). These mechanisms are not mutually exclusive, and a combination of these can potentially result in nestedness (Patterson 1987; Simberloff & Martin 1991; Patterson & Atmar 2000).

The reptiles found in the rainforest fragments of Anamalai Hills share a common biogeographic history, as they were once contiguous with each other (Congreve 1940). Due to this common biogeographic history other causal factors for the nestedness in the distribution of rainforest reptiles need to be examined.

Faunal collapse and relaxation models predict species loss as refuges change in status from being continuous with each other to being totally isolated (Boecklen & Simberloff 1986). In the present study, time since isolation of the fragment has a definite influence on the species richness in a fragment. The remnant fragments in Anamalai Hills exhibited a distinct decrease in their species richness after about 70 years of its isolation. The reason for this pause of 70 years after which a distinct drop in the species richness is seen is not clear. It is also of interest that these fragments that have greater species richness at present and are within the 70 year pause period, and are all fragments in the Very Large, Large and Medium size categories. These fragments also have greater densities of reptiles than the other fragments, possibly due to the crowding effect. Therefore, the present pattern of nestedness apart from being influenced by the above mentioned causal factors is mainly due to the differential extinction rates of species in the fragments, primarily caused by the invasion of non-endemic species and the presence of certain microhabitats in totally disturbed areas. Nestedness is influenced by the presence of non-endemic species that are capable of dispersing through the surrounding matrix of secondary vegetation (eg. *Mabuya beddomii*, *M. carinata, Calotes rouxii*, *Cnemaspis ornata)*. The persistence of endemic species (eg. *Trimeresurus malabaricus*, *Cnemaspis indica*, *Cnemaspis* spp. 3 (red eye), *Uropeltis nitidus* and *Coluber* species) could be due to the presence of their specific microhabitat in these fragments. Except for *Trimeresurus malabaricus* and *Cnemaspis indica* <5 individuals represented the other endemic species. It is probable that with greater sampling intensity, the occurrence of these species in other fragments might also be documented, consequently demonstrating greater nestedness. Among the idiosyncratic sites that increased the system temperature was the Medium fragment (Puthuthottam), and the two small fragments (Tata II and Varattuparai I). These fragments recorded greater levels of disturbance and many of the secondary forest species were recorded in these sites. The other idiosyncratic site was the Very Large fragment (Akkamalai), mainly due to the absence of many of the secondary forest species, while supporting a majority of rainforest endemics. It should also be noted that Puthuthottam also recorded a species of unidentified snake (*Coluber* spp.), and also supports members of the endemic genus *Ristella*. The persistence of these species in this disturbed fragment is possibly due to the presence of specific microhabitats, though the effect of passive sampling cannot be ruled out.

The extinction sequence of species in a nested system is of vital importance in the conservation and protection of biological diversity. This is derived from the extinction curve, wherein the species that are found to the top right of the matrix are considered to be on the threshold of extinction (Atmar & Patterson 1993, 1995; Patterson & Atmar 2000). In the present study, the extinction prone species include a majority of snakes (eg. *Melanophidium punctatum, Coluber* spp. *Uropeltis nitida, Lycodon* spp. to name a few), the high altitude lizard *Salea anamallayana* and the members of the genus *Scincella*. These are all typical forest species and endemic to the rainforest, incapable of movement across the surrounding matrix of secondary vegetation. Their persistence in the fragments can only be explained in terms of an alteration in their habitat requirements after fragmentation, or that it might be too early to decide on the extinction probabilities of these species due to fragmentation, in the larger fragments in which they occur.

10.5.2 Susceptibility of reptile species to fragmentation

Habitat fragmentation results in the extinction of some reptile species, while there seems to be no noticeable influence on others. This is explained by a) larger reptiles are more susceptible than smaller reptiles, and b) habitat specialists, which are not only rare, but are also more susceptible to extinction than habitat generalists, which occur in greater abundance. Alternately, if one considers the number of fragments that the species is found in, without considering its abundance, then species that were found in a few islands were those that were rare and tend to be habitat specialists (Case 1975). In the present study, habitat specialists were recorded in relatively fewer islands than the generalists and were more prone to extinction. This is further established by the fact that the species on the threshold of extinction (*i.e.* species that were found towards the latter half of the extinction curve) were habitat specialists and endemic to the rainforests.

Snakes were conspicuous by their complete absence in the smaller fragments. Also, these species were numerically greater than the members of other taxa on the list of species that are in the threshold of extinction (8 of the last 10 species in the matrix). This is largely because snakes in general require large areas of continuous habitat (greater home range) and the greater specificity of their diet. It is unlikely that Small fragments can support higher abundance of prey (mainly rodents and frogs). This is compounded by the fact that these Small fragments are completely isolated from each other and embedded in a sea of secondary vegetation, primarily tea, which makes migration to other fragments almost impractical for these species. Also, except for the shield-tail snakes, which are smaller, the other snakes are bigger in size compared to other species of reptiles. Among agamids that are on the extinction curve was the endemic and larger bodied species like *Calotes nemoricola* and *C. grandisquamis*. These species occur in low population densities and were generally low in abundance in the smaller and more disturbed fragments. This predisposition of habitat specialists to be absent from smaller and highly disturbed areas has also been documented in a study of reptiles in the Gulf of California Islands (Case 1975).

10.6 SUMMARY

The reptiles in the smaller fragments are largely a nested subset of those species recorded from the larger fragment. However, nestedness was not complete with unexpected absence and presence of species in the matrix. This pattern of reptile occurrence in the rainforest fragments is primarily due to the differential extinction sequence and the differences in the colonization ability of species. This corresponds to the ability of non-endemic species to invade previously inaccessible areas but now disturbed small fragments and to a lesser extent by the persistence of some endemic species in disturbed areas. Some of the species headed towards extinction, and in need of increased protection, and fragments that need to be conserved for their species diversity are identified.

11 A RAPID SURVEY IN KERALA

11.1 INTRODUCTION

The third phase of the project was a rapid survey in the State of Kerala to examine the extent to which the major findings on impacts of rainforest fragmentation on herpetofauna are applicable elsewhere in the Western Ghats. Kerala was chosen for the survey because it has the largest extent of rainforest in the Western Ghats, with extensive fragmentation. The survey was carried out after the analysis of data from the first two phases was completed and major conclusions had been made. A major conclusion was that rainforest fragments together still retain a considerable number of endemics, even though species richness in individual fragments was significantly lower. This chapter summarizes the results of the rapid survey carried out primarily to validate this conclusion. Several other significant conclusions on abundance, species composition, and habitat correlates, to name a few, could not be validated due to severe constraints of time.

11.2 OBJECTIVES

Although it was initially planned that several forest fragments in Kerala would be surveyed, due constraints of time only 11 fragments could be surveyed. Therefore, the objective of the survey to examine the extent to which the overall species richness, species richness of endemics and the proportion of the latter were comparable to that in the contiguous rainforest in the Kalakad-Mundanthurai Tiger Reserve (KMTR) and the forest fragments in the Anamalai Hills.

11.3 STUDY AREAS

The survey was conducted between February and May 2001 in Nemmara (Nelliampathy forests) Munnar and Thenmalai Forest Divisions of Kerala, representing three hill ranges (Figure 11.1). The landscape in Nelliampathy, northwest of Anamalai Hills, was dominated by coffee, tea, and cardamom plantations, in which were embedded rainforest fragments. The rainforest fragments occurred here in an altitudinal range of 900 m to 1300 m. The rainforest forest in this area was of the same type as in the Valparai valley (see Section 2.2.2.2). Due to the predominance of coffee plantations, human presence in the landscape has been considerably less than in the Valparai valley dominated by tea. The landscape still supported an array of wildlife very similar to that in the Anamalai Hills (see Section 2.2.2.3), with which it had habitat contiguity. Many rainforest fragments had resident populations of the lion-tailed macaque, Nilgiri langur, giant squirrel, and other species of small mammals.

The Munnar landscape occurred in a higher altitude (1700 m to 2000 m ??), and was completely dominated by tea. Due to the higher altitude, the rainforest vegetation was of the *Mesua ferrea-Palaquium ellipticum* type (Pascal 1988). The rainforest fragments here were completely surrounded by tea plantations, and no lion-tailed macaques, although Nilgiri langur and giant squirrel were common.

The Thenmala hills form the northern most part of the Ashambu Hills, just south of the Shenkotta pass (Figure 11.1). The rainforest fragments here occurred in an altitudinal range of 500 m to 700 m. The landscape was dominated by tea and rubber plantations, and other agricultural lands (*e.g.* coconut and arecanut). Accordingly, the rainforest fragments were surrounded by a variety of man made vegetation.

Being south of the Palakkad gap, all three hill ranges had rainfall pattern that was comparable to that in KMTR and Anamalai Hills, the annual rainfall being about 300 cm. (Pascal 1988). However, being at a higher altitude Munnar had a much lower maximum and minimum temperature.

11.4 METHODS

The number of rainforest fragments that could be sampled was severely constrained by the time that was available (February to May 2001). Only 11 fragments were sampled in all three forest divisions together; N in Nelliampathy, N2 in Munnar and N3 in Thenmala. Of these N1 were medium sized (11-150 ha). The area of the fragments was visually estimated. Due to the small number of fragments sampled, influence of fragment area on community structure is examined only with reference to the two fragment size classes. Moreover, no attempt was made to estimate abundance or to examine the effect of habitat features other than area. Only two characteristics of the herpetofaunal community were examined: overall species richness and that of endemics. These two are compared with results obtained from the contiguous rainforest in KMTR.

Although the survey employed quadrat search for forest floor amphibians and reptiles (see Section 5.2.1.1 for details) and transects for arboreal reptiles (Section 8.2.2.2), only the data on species occurrence have been used in the analysis presented below. This data also included opportunistic sightings.

11.5 RESULTS AND DISCUSSION

11.5.1 Amphibians

The survey documented 31 species of amphibians of which 24 are endemic to the Western Ghats (Appendix I). Among these species, six have not been identified. At least one “new species” of *Bufo* has been recorded. The percentage of endemic species in the 11 rainforest fragments of Kerala (77%) was comparable to that of Anamalai Hills (76%, N = 40) and the contiguous rainforest in Kalakad-Mundanthurai Tiger Reserve (79%, N = 32) (Figure 11. 2). Among the three divisions in Kerala, Munnar had the highest percentage of endemic species (88%, N = 18) followed by Thenmalai (64% N = 9), and Nemmara (60%, N = 15) (Figure 11.3). The variation in the percentage of endemic species among the three divisions could be due to altitude, since Nemmara and Thenmalai forest fragments were in lower elevation while Munnar was in a higher elevation. There is a tendency for endemism in amphibians to be highest between 800 m and 1400 m msl (Daniels, 1992).

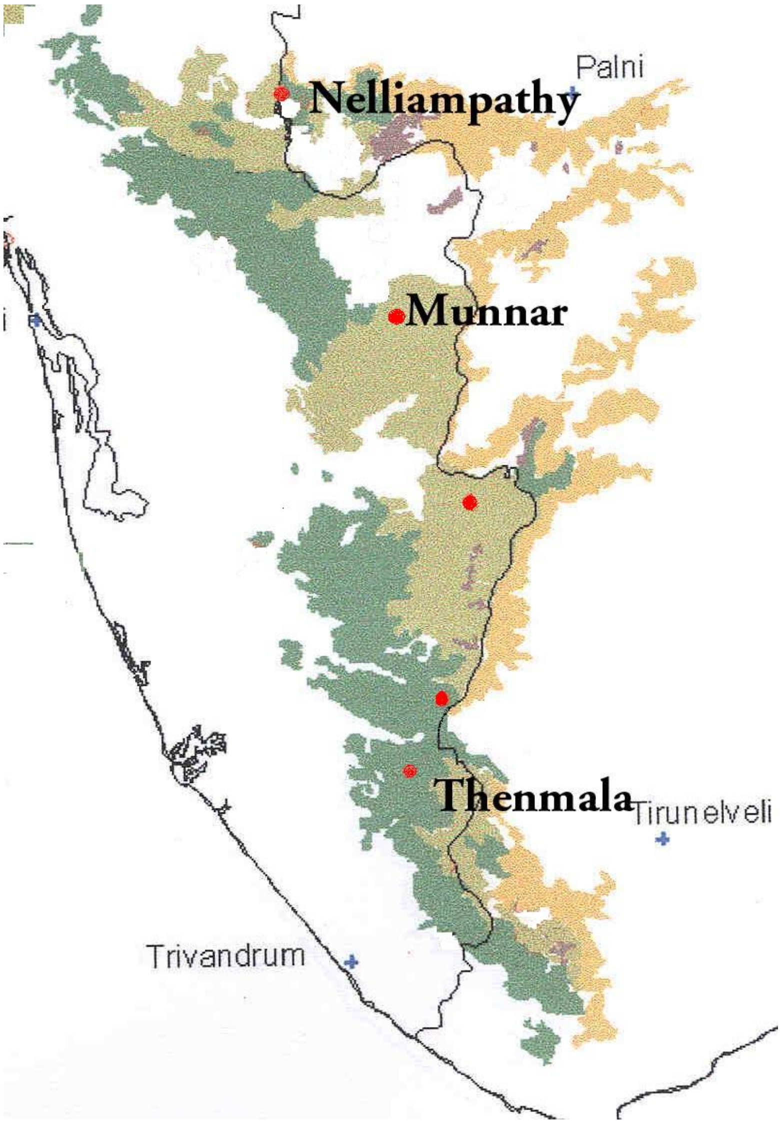


Figure 11.1. The location of sampling sites (Nelliampathy, Munnar and Thenmala) for the rapid survey of amphibians and reptiles in Kerala during February-May, 2001.

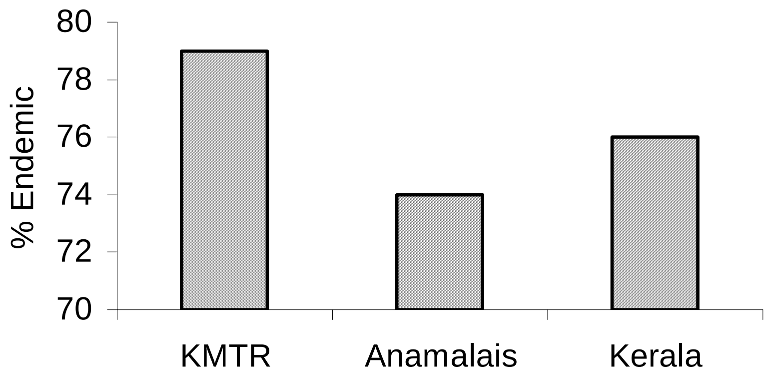


Figure 11.2. Percentage of endemic amphibian species recorded in different study areas.

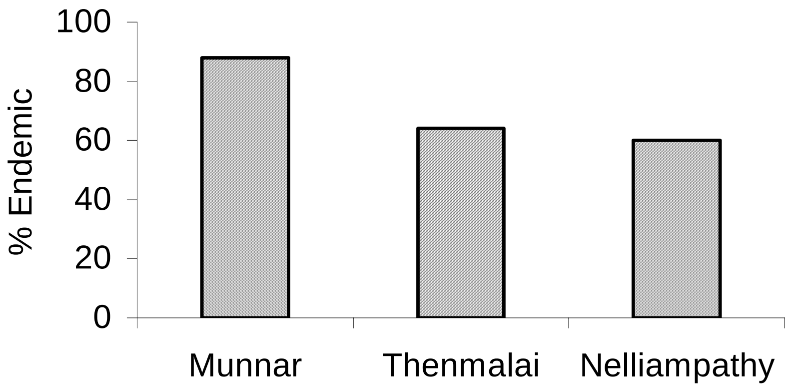


Figure 11.3. Percentage of endemic amphibian species recorded in rainforest fragments in three divisions in Kerala between February and May 2001.

A comparison of the data from fragments of different size classes indicates that there is a decline in the proportion of endemic species with decreasing fragment area. in the fragments that were sampled in Kerala, as in the case of fragments in the Anamalai Hills (Figure 11.4). The large fragments had proportion of endemic species comparable to that of the contiguous rainforests of KMTR. Although there was a tendency for the proportion of endemic species in small fragments to decrease significantly from the values obtained for the large and contiguous rainforest samples, the range of values obtained indicates that size of the fragment alone did not contribute to the decline in diversity of amphibians. Some medium sized and small fragments that were less disturbed and were relatively intact had greater proportion of endemic amphibian species.

The fragments in Munnar are geographically located closest to those in Anamalai Hills than the fragments in other divisions. The elevation range of the forest fragments in the large size category was also comparable for the Anamalai Hills and Munnar. This is reflected in the similarity in the amphibian species between these two areas.

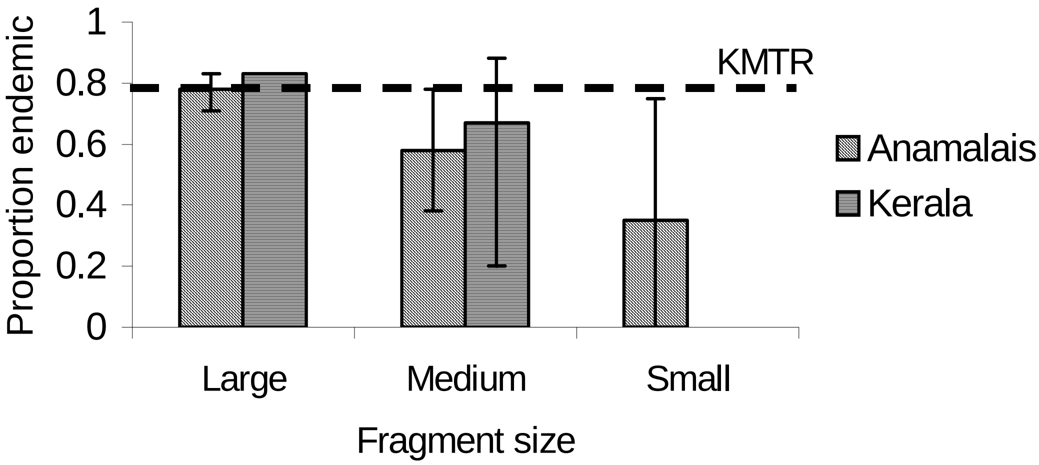


Figure 11.4. The proportion of endemic amphibian species in contiguous rainforest of KMTR, rainforest fragments in the Anamalai Hills and Kerala. Bars indicate the maximum and minimum value wherever available.

11.5.2 Reptiles

A total of 40 reptile species was documented during the survey (Appendix II) of which 10 species were endemic to the Western Ghats, while 18 species were endemic to the rainforests of the Western Ghats. However, 14 species have not yet been identified. Thenmala had 28 species, while Munnar and Nemmara had 15 species each (Figure 11.5). However, rainforest endemics were greater in Munnar than in the other two divisions (Figure 11.6). This variation in the species richness and endemism among the three divisions is explained from our earlier study in Tamil Nadu, which has documented an altitudinal gradient in species richness as well as endemism (Chapter 8). It is important to note that Nemmara (800 m) and Thenmalai (600 m) were in lower elevations while Munnar (1600 m) was in a higher elevation.

The contiguous rainforests of KMTR was highest in terms of species richness and rainforest endemic species (54, 22 respectively), while the overall species richness and rainforest endemic species was similar in both the fragmented areas of Anamalai Hills and in the three divisions in Kerala (40; 18 respectively). However, many of the smaller rainforest fragments in the Anamalai Hills and the rainforest fragments in the three divisions surveyed in Kerala supported endangered and endemic species like *Otocryptis beddomii*, *Melanochelys trijuga coronata* and unidentified species of *Cnemaspis*. Moreover, some species which occur only in the higher or lower elevations may be now restricted only to rainforest fragments. Three examples are given here.

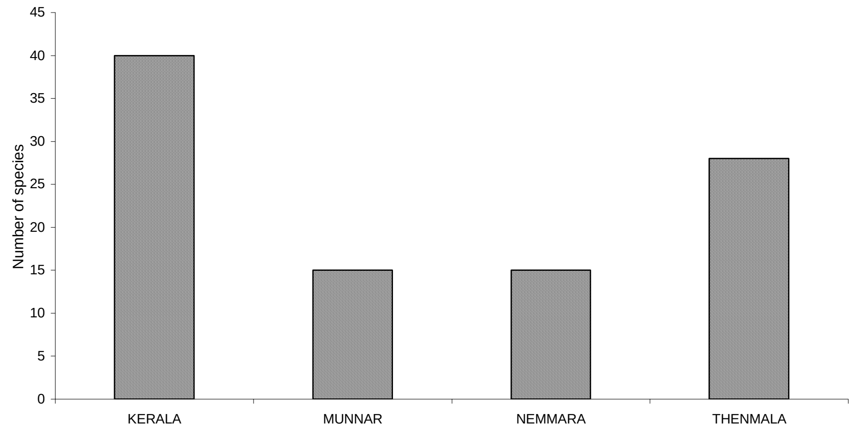


Figure 11.4. The number of reptile species recorded from 11 rainforest fragments that were surveyed in 3 forest divisions in Kerala, as well as in each of the 3 forest divisions.

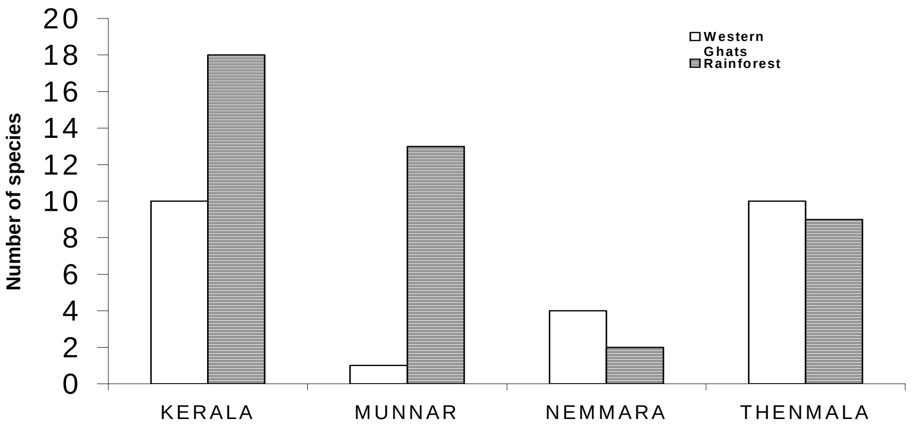


Figure 11.5. The number of endemics that are exclusive to rainforest and other endemics of the Western Ghats in all three forest divisions that were surveyed in Kerala, together as well as in each division.

Salea anamallayana

This species probably occurs only in the altitudinal range of 1,500 m to 2,200 m, where it is the most common, if not the only, agamid lizard. During the survey it was sighted only in Munnar (but quite abundantly at 5.16 animals/250 m), since the other divisions were surveyed below its altitudinal range. In comparison, the overall encounter rates of agamids (all species together) were much lower in both the contiguous rainforest of KMTR (1.94 animals/250 m) and in the rainforest fragments the Anamalai Hills (1.84 animals/250 m). It is important to note that this species was recorded very few times in the high elevation rainforest of Anamalai Hills, while it was the most abundant species in the arboreal assemblage in Munnar. The rainforest fragments in Munnar is therefore of particular importance to the conservation of this species.

Otocryptis beddomii

This has been an elusive species to reptile biologists for many decades. After its description in 1885 from the Sivagiri Hills in Tamil Nadu, there has not been many sightings on this species or any studies on its habitat requirements and ecology. A species that has the reputation of running on its hind limbs when chased, (hence the name the Kangaroo lizard), it is mainly restricted to low elevation rainforest in the Western Ghats, its preferred micro-habitat being leaf litter. This species was recorded from the Palaruvi, and Rosemala forests in Thenmala Division. A monotypic species in India, its nearest relative being in Sri Lanka, it has not been recorded from Tamil Nadu in recent times. One of the likely reasons for this is the complete loss of low elevation rainforest. The restricted distribution of this species makes the low elevation rainforest fragments in the Thenmala Forest Division a very important area for its continued survival.

Melanochelys trijuga coronata

Of the three subspecies of *Melanochelys trijuga* reported from India, *M. trijuga coronata* is probably the most distinct, with a striking head pattern. It has a broad black diamond shaped mark on the crown of the head, bright yellow or white coloured temporal region, the other head regions being olivaceous in colour. The shell as a whole is uniformly black. In contrast, the head pattern in the other subspecies consists of mainly small, yellow to pink spots that disappear with age and the plastron is lighter in colour (Das and Pritchard, 1990). The distribution of *M. trijuga coronata* is also interesting in that it is restricted to the Kerala State, hence the common name Cochin black turtle.

A juvenile of *M. trijuga coronata* (length: 8.5 cm and width: 7 cm) was recorded from the Thenmala Forest Division, in a pond (Amaikulam), near the town of Kulathuphuza. Local people reportedly collect this subspecies and the endemic Travancore tortoise (*Indotestudo forstenii*) for pet trade and as a source of protein. This is reportedly a very common and widely occurring species in this area.

The habitats of this turtle are the ponds and rivers largely in the low elevation forests and adjoining areas in Kerala. This habitat has been under tremendous anthropogenic pressure, highly fragmented, and surrounded by plantations, mainly cardamom and rubber. The continued survival of this subspecies would rest on the protection of these highly fragmented and vulnerable areas from hunting and also limiting the run off of pesticides into the ponds and streams.

11.6 SUMMARY

Many of the rainforest fragments such as those in Munnar hold several endemic species of amphibians and have important conservation value. Size of the fragments alone does not contribute to the reduction in the endemic amphibians, the quality of the fragment plays an important role in regulating the diversity of amphibians in the fragmented landscape. The general pattern of loss of endemic species with increasing intensity of fragmentation of the rainforest habitat may hold true for the southern Western Ghats. Although individual fragments have low species richness and percentage of endemics, fragments together have species richness and percentage of endemics that are comparable to the contiguous rainforest. This is despite the fact that the fragments together form only a small percentage of the contiguous forest in area. This highlights the importance of retaining rainforest fragments in the Western Ghats.,In view of extent of rainforest fragmentation of the Western Ghats, it should be considered a priority to inventory the amphibian taxa and document the so far undescribed species surviving in the remnant rainforest fragments.

The forest divisions that we surveyed in Kerala have the only few patches of low elevation (Thenmala) and the high elevation (Munnar) rainforest that remain in the southern Western Ghats. These fragments are home to some very unique species like the *Melanochelys trijuga coronata* and *Otocryptis beddomii* (Thenmala), and *Salea anamallyana* (Munnar) Substantial populations of many other endemic species also occur in these fragments which, therefore have very important conservation values. There is a general loss of endemic species with increasing intensity of fragmentation of rainforests as clearly documented by our study in Tamil Nadu. This pattern may hold true for other areas in southern Western Ghats. However, apart from fragment area human disturbance is also a major factor governing the occurrence and abundance of many species. A turnover of species and abundance along an elevation gradient is clearly evident, with some species restricted to lower elevations and some others to higher elevations. Hence, it is essential that the protected area network covers different altitudinal zones, if we are to conserve the entire reptile diversity. There is also an urgent need to systematically inventory the remaining rainforest fragments in order to identify their conservation values.

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APPENDIX I. Amphibians recorded during the study

Kalakad-Mundanthurai Tiger Reserve (1996-97)

Family: Ichthyophidae

1. *Ichthyophis* species 1
2. *Ichthyophis* species 2

Family: Uraeothyphlidae

3. *Uraeotyphlus malabaricus*

Family: Bufonidae

4. *Bufo melanostictus*
5. *B. beddomi*
6. *B. microtympanum*

Family: Microhylidae

7. *Melanobatrachus indicus*
8. *Ramanella triangularis*

Family: Rhacophoridae

9. *Philautus temporalis*
10. *P. variabilis*
11. *P. pulcherrimus*
12. *P. charius*
13. *P. glandulosus*
14. *P.* species1
15. *Polypedates maculatus*
16. *Rhacophorus calcadensis*

Family: Ranidae

17. *Euphlyctis cyanophlyctis*
18. *Indirana beddomi*
19. *I. brachytarsus*
20. *I. leptodactyla*
21. *I. diplostictus*
22. *Limnonectes keralensis*
23. *Micrixalus fuscus*
24. *M. saxicola*
25. *M.* species
26. *Nyctibatrachus aliceae*
27. *N. major*
28. *N. vasanthi*
29. *N. beddomi*
30. *Rana aurantiaca*
31. *R. curtipes*
32. *R. temporalis*

Anamalai Hills (1997-99)

Family: Ichthyophidae

1. *Ichthyophis* species 1

Family: Uraeothyphlidae

2. *Uraeotyphlus menoni*
3. *Uraeotyphlus narayani*
4. *Uraeotyphlus malabaricus*

Family: Bufonidae

5. *Bufo melanostictus*
6. *B. beddomi*
7. *B.* species
8. *B. parietalis*
9. *Pedostibes tuberculosus*

Family: Microhylidae

10. *Melanobatrachus indicus*
11. *Ramanella triangularis*

Family: Rhacophoridae

12. *Philautus variabilis*
13. *P. temporalis*
14. *P. pulcherrimus*
15. *P. charius*
16. *P. signatus*
17. *P.* species 1
18. *P.* species 2
19. *P.* species 3
20. *Polypedates maculatus*
21. *Rhacophorus calcadensis*
22. *R. pseudomalabaricus*
23. *R.* species

Family: Ranidae

24. *Euphlyctis cyanophlyctis*
25. *Indirana beddomi*
26. *I. brachytarsus*
27. *I. leptodactyla*
28. *Limnonectes keralensis*
29. *L. limnocharis*
30. *Micrixalus fuscus*
31. *M. silvaticus*
32. *M. gadgili*
33. *M.* species
34. *Nyctibatrachus beddomi*
35. *N. deccanensis*
36. *N.* species 1
37. *N.* species 2
38. *Rana aurantiaca*
39. R. temporalis
40. Unidentified Ranid

List of amphibian species recorded during the rapid survey in three forest divisions in Kerala (2001).

Species	All divisions together	Munnar	Nemmara	Thenmala
Family: Bufonidae				
Bufo species	1	1		
Bufo melanostictus	1		1	1
Family: Rhacophoridae				
Polypedates pleurostictus	1	1		
P. species	1	1		
Philautus leucorhinus	1	1	1	1
P. species1	1	1		
P. species2	1	1		
P. pulcherrimus	1	1	1	1
P. charius	1	1		
P. temporalis	1		1	1
Rhocophorus species	1	1		
Rhacophorus malabaricus	1		1	1
Family: Ranidae				
Euphlytis cyanophlictis	1		1	1
Limnonectes nilagirica	1	1		
L. brevipalmata	1		1	1
Indirana leptodactyla	1	1		
I. beddomi	1	1	1	1
I. brachytarsus	1		1	
I. phrynoderma	1	1		
I. semipalmata	1			1
Micrixalus fuscus	1		1	1
M. gadgili	1		1	
M. nudis	1			1
M. silvaticus	1	1		
M. species	1	1		
Nyctibatrachus species	1		1	
Rana aurantiaca	1		1	
R. temporalis	1		1	
Total no. of species	**28**	**15**	**14**	**11**

APPENDIX II. Reptiles recorded during the study

Kalakad-Mundanthurai Tiger Reserve (1996-1999)

Family: Bataguridae

1. *Melanochelys trijuga*

Family: Gekkonidae

2. *Cnemaspis indica* **
3. *C.ornatus* *
4. *C.beddomei***
5. *Cnemaspis* spp.1**
6. *Cnemaspis* spp.2 (yellow throat)**
7. *Cnemaspis* spp.3 (Red eyed gecko)**
8. *Hemidactylus anamallensis = (Dravidogecko anamallensis)***

Family: Agamidae

9. *Calotes andamanensis* **
10. *C. calotes*
11. *C. ellioti* *
12. *C. grandisquamis* *
13. *C. nemoricola* *
14. *C. rouxii*
15. *Draco dussumieri* *
16. *Otocryptis beddomii* **
17. *Psammophilus blanfordanus*
18. *P. dorsalis*

Family: Scincidae

19. *Mabuya beddomii*
20. *M. carinata*
21. *M. macularius*
22. *Scincella travancoricum* (= *Liolopisma travancoricum)***
23. *Ristella* spp.**

Family: Varanidae

24. *Varanus bengalensis*

Family: Uropeltidae

25. *Brachyophidium rhodogaster* *
26. *Melanophidium punctatum* **
27. *Uropeltis arcticeps**
28. *U. ellioti**
29. *U. ocellata* *
30. *Uropeltis* spp.**

Family: Colubridae

31. *Ahaetulla dispar**
32. *Ahaetulla nasutus*
33. *Ahaetulla perroteti* **
34. *Ahaetulla pulverulentus*
35. *Amphiesma beddomei* *
36. *Boiga ceylonensis* **
37. *B. forsteni*

38. *Coluber mucosus*
39. *Dendrelaphis grandoculis* *****
40. *D. tristis*
41. *Lycodon aulicus*
42. *L. travancoricus* ******
43. *Lycodon spp.* *****
44. *Macropisthodon plumbicolor*
45. *Oliogodon arnensis*
46. *O. brevicaudus* *****
47. *Xenochropis piscator*

Family: Elapidae

48. *Calliophis melanurus nigrescens* *****
49. *Ophiophagus hannah*

Family: Viperidae

50. *Hypnale hypnale*
51. *Trimeresurus gramineus*
52. *T. macrolepis* ******
53. *T. malabaricus* *****
54. *T. strigatus*

Anamalai Hills (1999-2000)

Family: Geckonidae

*1 Cnemaspis indica***
*2 C.mysoriensis***
*3 C.ornatus**
*4 C. spp 1 (white belly)***
*5 C. spp 2 (yellow throat)***
*6 C. spp 3 (red eye)***
*7 C. spp 4 (total black)***
*8 C. spp 5 (black throat)***
*9 C. spp 6 (?)***

Family: Agamidae

*10 Calotes ellioti**
*11 C.grandisquamis**
*12 C.nemoricola**
13 C.rouxii
*14 Draco drussumeri**
*15 Salea anamallayana***

Family: Scincidae

16 Mabuya beddomii
17 M.carinata
*18 Ristella guntheri***
*19 Scincella travancoricum***
*20 Scincella spp***

Family: Varanidae
21 *Varanus bengalensis*

Family: Typhlopidae
22 *Typhlops spp.***

Family: Uropeltidae
23 *Melanophidium punctatum***
24 *Uropeltis nitida***
25 *U.ocellata***
26 *U.rubromaculatus***

Family: Colubridae
27 *Ahaetulla nasutus*
28 *Amphiesma beddomei**
29 *Boiga ceylonensis***
30 *Coluber mucosus*
31 *Coluber spp.**
32 *Dendrelapis tristis*
33 *Elaphae helena*
34 *Lycodon spp.***
35 *Oligodon arnensis*
36 *Xenochrophis piscator*

Family: Elapidae
37 *Calliophis melanurus nigrescens**

Family: Viperidae
38 *Hypnale hypnale*
39 *Trimeresurus macrolepis**
40 *T. malabaricus**

List of reptile species recorded during the rapid survey in three forest divisions in Kerala (2001).

Species	All divisions together	Munnar	Nemmara	Thenmala
Family: Bataguridae				
Melanochelys trijuga coronata	1			1
Indotestudo forstenii	1			1
Family: Gekkonidae				
Cnemaspis sp. 1	1	1		
Cnemaspis sp. 2	1		1	
Cnemaspis sp. 3	1		1	1
Cnemaspis sp.4	1			1
Cnemaspis sp.5	1	1		1
Hemidactylus anamallensis	1	1		
Hemidactylus sp.1	1			1
Hemidactylus sp. 2	1			1
Hemidactylus frenatus	1			1
Family: Agamidae				
Calotes calotes	1		1	1
C. ellioti	1		1	1
C. grandisquamis	1	1	1	1
C. nemoricola	1			1
C. rouxii	1	1	1	1
Draco dussumieri	1		1	1
Otocryptis beddomii	1			1
Salea anamallayana	1	1		
Family: Scincidae				
Mabuya beddomii	1		1	1
M. carinata	1		1	
Scincella travancoricum	1	1		1
Scincella sp. 1 (orange belly)	1	1		
Scincella sp. 2 (white belly)	1	1		1
Scincella sp. 3 (Themala)	1			
Ristella (Munnar)	1	1		
Family: Uropeltidae				
Uropeltis sp.	1	1		1
Family: Colubridae				
Ahaetulla nasutus	1	1	1	1
Amphiesma beddomei	1			1
Boiga ceylonensis	1			1
Coluber mucosus	1		1	1

Species	All divisions together	Munnar	Nemmara	Thenmala
Dendrelaphis grandoculis	1			1
D. tristis	1		1	
L. travancoricus	1	1	1	1
Lycodon sp. 1	1		1	
Coluber sp. 1	1			1
Family: Elapidae				
Ophiophagus hannah	1	1		
Family: Viperidae				
T. macrolepis	1	1		
T. malabaricus	1		1	1
Hypnale hypnale	1			1
Total no. of species	**40**	**15**	**15**	**28**