

**Reptilian species distribution in response to habitat fragmentation and  
microhabitats in the rainforests of southern Western Ghats, India**

A thesis submitted for award of the degree of

**Doctor of Philosophy**

in **WILDLIFE SCIENCE**

by

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to

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Wildlife Institute of India

## CERTIFICATE

This is to certify that the thesis, entitled “**Reptilian species distribution in response to habitat fragmentation and microhabitats in the rainforests of southern Western Ghats, India**” submitted for the award of Doctor of Philosophy in **WILDLIFE SCIENCE** to Forest Research Institute (Deemed University), Dehra Dun, is a record of original research work done by *Mr. N. M. Ishwar* in the division of Wildlife Biology, Wildlife Institute of India, under my guidance and supervision. I further certify that this research work has not previously formed the basis for the award of any other degree or diploma and it fulfils all the requirements laid down in the ordinance of Forest Research Institute (Deemed University).

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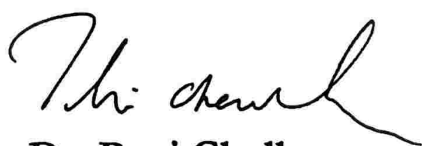
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## DECLARATION

I hereby declare that the thesis, entitled “**Reptilian species distribution in response to habitat fragmentation and microhabitats in the rainforests of southern Western Ghats, India**” submitted for the award Doctor of Philosophy in **WILDLIFE SCIENCE** to Forest Research Institute (Deemed University), Dehra Dun, is a record of original research work done by me under the supervision and guidance of Dr. Ravi Chellam, Scientist, Wildlife Institute of India, and it has not formed the basis for the award of any degree or diploma to any candidate of any university.



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**Place: Dehra Dun**  
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# CONTENTS

ACKNOWLEDGEMENTS	i-ii
SUMMARY	iii-vii
<b>1. INTRODUCTION</b>	<b>1-11</b>
1.1. HABITAT FRAGMENTATION	1
1.1.1. Fragmentation: Reduction in total area and edge effects	1
1.1.2. Changes to biodiversity due to fragmentation	3
1.2. WESTERN GHATS	4
1.3. REPTILES	5
1.3.1. Faunal affinities of Indian reptiles	6
1.3.2. Reptiles of the Western Ghats	6
1.3.3. Studies on Indian reptiles	7
1.3.4. Taxonomy	8
1.3.5. On geckos, skinks, agamids and snakes	8
1.4. OBJECTIVES OF THE STUDY	10
1.5. ORGANIZATION OF THE THESIS	11
<b>2. STUDY AREA</b>	<b>12-25</b>
2.1. THE SYSTEM: THE WESTERN GHATS	12
2.1.1. Introduction	12
2.1.2. Rationale in the selection of study areas	13
2.2. STUDY AREAS	14
2.2.1. Kalakad-Mundanthurai Tiger Reserve	14
2.2.1.1. <i>Geography and climate</i>	14
2.2.1.2. <i>Vegetation</i>	16
2.2.1.3. <i>Fauna</i>	16
2.2.1.4. <i>People</i>	17
2.2.1.5. <i>The study sites and their history</i>	17
2.2.2. Anamalai Hills	19
2.2.2.1. <i>Geography and climate</i>	19
2.2.2.2. <i>Vegetation</i>	22
2.2.2.3. <i>Fauna</i>	22
2.2.2.4. <i>People</i>	23
2.2.2.5. <i>History of the rainforest in Anamalai Hills</i>	23
2.2.2.6. <i>Rainforest fragments</i>	24
<b>3. SAMPLING METHODS AND DATA ANALYSIS</b>	<b>26-42</b>
3.1. SAMPLING METHODS	26
3.1.1. General considerations for sampling reptiles	26
3.1.2. Adaptive cluster sampling: A sampling protocol for rainforest leaf litter reptiles	26

3.1.3.	Forest transects: A sampling protocol for arboreal rainforest reptiles.....	32
3.1.4.	Stream surveys/Visual encounter surveys (VES).....	33
3.1.5.	Opportunistic sampling.....	33
3.2.	<b>HABITAT SAMPLING</b> .....	<b>34</b>
3.2.1.	Leaf litter reptiles: Adaptive cluster sampling.....	34
3.2.2.	Arboreal reptiles: Forest transects .....	34
3.3.	<b>SAMPLING SEASONS</b> .....	<b>34</b>
3.4.	<b>SAMPLING INTENSITY</b> .....	<b>35</b>
3.4.1.	Contiguous rainforests .....	35
3.4.2.	Forest fragments.....	35
3.5.	<b>DATA ANALYSIS</b> .....	<b>36</b>
3.5.1.	General considerations for statistical analysis.....	36
3.5.2.	Leaf litter reptiles.....	37
3.5.3.	Arboreal reptiles .....	37
3.5.4.	Overall community structure and endemism.....	37
3.5.5.	Similarity measures.....	37
3.5.6.	The effects of altitude and temperature on arboreal reptiles.....	38
3.5.7.	Microhabitat associations .....	38
3.5.8.	Nested subset analysis .....	40
3.5.9.	Species richness and habitat fragmentation.....	41
3.6.	<b>COLLECTIONS AND IDENTIFICATION OF SPECIES</b> .....	<b>41</b>
4.	<b>REPTILES IN THE CONTIGUOUS RAINFORESTS: DISTRIBUTION PATTERNS IN KALAKAD-MUNDANTHURAI TIGER RESERVE</b> .....	<b>43-75</b>
4.1.	<b>INTRODUCTION</b> .....	<b>43</b>
4.2.	<b>OBJECTIVES</b> .....	<b>45</b>
4.3.	<b>STUDY AREA</b> .....	<b>45</b>
4.4.	<b>METHODS AND ANALYSIS</b> .....	<b>45</b>
4.5.	<b>RESULTS</b> .....	<b>46</b>
4.5.1.	Leaf litter reptiles .....	46
4.5.1.1.	<i>Distribution patterns</i> .....	46
4.5.1.2.	<i>Abundance and community composition</i> .....	48
4.5.1.3.	<i>Density estimates</i> .....	51
4.5.1.4.	<i>Inter-site and seasonal variation</i> .....	51
4.5.2.	Arboreal reptiles .....	55
4.5.2.1.	<i>Abundance and community composition</i> .....	55
4.5.2.2.	<i>Encounter rates</i> .....	57
4.5.2.3.	<i>Inter-site and seasonal variation</i> .....	57
4.5.2.4.	<i>Altitudinal effects on arboreal reptile species richness and abundance</i> .....	61
4.5.2.5.	<i>Effects of temperature on arboreal reptile species richness and abundance</i> .....	64
4.5.3.	Reptile species richness and endemism .....	67

4.6. DISCUSSION.....	68
4.6.1. Community structure and composition .....	68
4.6.1.1. <i>Leaf litter reptiles</i> .....	68
4.6.1.2. <i>Arboreal reptiles</i> .....	69
4.6.2. Species richness and density .....	69
4.6.3. Altitudinal gradient causes turnover of species .....	71
4.6.4. Reptile species richness and endemism in the contiguous forests.....	72
4.6.5. Adaptive cluster sampling: An efficient sampling protocol.....	74
4.7. SUMMARY .....	75
5. REPTILES IN A FRAGMENTED LANDSCAPE: DISTRIBUTION PATTERNS IN THE ANAMALAI HILLS.....	76-108
5.1. INTRODUCTION .....	76
5.2. OBJECTIVES.....	77
5.3. STUDY AREA .....	78
5.4. METHODS AND DATA ANALYSIS .....	78
5.5. RESULTS .....	78
5.5.1. Leaf litter reptiles .....	78
5.5.1.1. <i>Distribution patterns</i> .....	78
5.5.1.2. <i>Abundance and community composition</i> .....	81
5.5.1.3. <i>Variation between forest fragments and seasons</i> .....	84
5.5.2. Arboreal reptiles .....	88
5.5.2.1. <i>Distribution patterns</i> .....	88
5.5.2.2. <i>Abundance and species composition</i> .....	90
5.5.2.3. <i>Variation between forest fragments and seasons</i> .....	91
5.5.2.4. <i>Effects of altitude</i> .....	96
5.5.3. Species richness and endemism .....	97
5.5.4. Comparison between contiguous and fragmented rainforest sites.....	99
5.5.5. Effects of fragmentation: Accumulation curves for the observed decline in species richness .....	100
5.6. DISCUSSION.....	102
5.6.1. Reptilian species richness and endemism in the rainforest fragments ..	102
5.6.2. Community structure and composition.....	103
5.6.3. Species richness declines with decreasing fragment size.....	105
5.6.4. Altitude relationships; insignificant .....	106
5.6.5. Species richness and abundance peaks in Medium and Large fragments .....	107
5.7. SUMMARY.....	108
6. MICROHABITAT ASSOCIATION.....	109-139
6.1. INTRODUCTION .....	109
6.2. OBJECTIVES.....	111
6.3. METHODS .....	111

6.3.1. Sampling animals.....	111
6.3.2. Measurement of microhabitat variables and data analysis .....	111
<b>6.4. RESULTS .....</b>	<b>112</b>
6.4.1. Leaf litter reptiles.....	112
6.4.1.1. <i>Microhabitat association in the contiguous rainforests</i> .....	112
6.4.1.2. <i>Microhabitat association in rainforest fragments</i> .....	116
6.4.2. Arboreal reptiles .....	120
6.4.2.1. <i>Microhabitat association in the contiguous forests</i> .....	120
6.4.2.2. <i>Microhabitat association in rainforest fragments</i> .....	125
6.4.2.3. <i>Partitioning of the vertical habitat by agamids</i> .....	131
<b>6.5. DISCUSSION.....</b>	<b>133</b>
6.5.1. Microhabitat associations in reptiles.....	133
6.5.1.1. <i>Leaf litter reptiles</i> .....	133
6.5.1.2. <i>Arboreal reptiles</i> .....	135
6.5.1.3. <i>Change in the reptilian assemblage due to forest fragmentation</i> .....	137
<b>6.6. SUMMARY .....</b>	<b>139</b>
<b>7. NESTEDNESS IN THE OCCURRENCE OF REPTILES IN THE RAINFOREST FRAGMENTS.....</b>	<b>140-150</b>
7.1. INTRODUCTION .....	140
7.2. OBJECTIVES.....	141
7.3. STUDY AREA .....	141
7.4. METHODS AND DATA ANALYSIS .....	141
7.5. RESULTS .....	141
7.5.1. Nested distribution .....	141
7.5.2. The influence of other causal factors on nestedness .....	146
7.6. DISCUSSION.....	147
7.6.1. Nestedness .....	147
7.6.2. Susceptibility of some reptile species to rainforest fragmentation.....	149
7.7. SUMMARY .....	150
<b>8. CONCLUSIONS AND RECOMMENDATIONS .....</b>	<b>151-156</b>
8.1. A COMPENDIUM OF FINDINGS AND RESEARCH NEEDS .....	151
8.2. RECOMMENDATIONS .....	154
8.2.1. Prioritization of rainforest fragments to conserve endemic reptilian species.....	154
8.2.2. Research needs .....	156
<b>REFERENCES .....</b>	<b>157-173</b>
<b>APPENDICES .....</b>	<b>174-183</b>

## LIST OF TABLES

Table 2.1. List of rainforest fragments (sampled between June 1998 to May 1999), and the description of the surrounding matrix in the Anamalai Hills.	25
Table 3.1. Sampling intensity in the contiguous rainforests of KMTR during 1997-1998.	35
Table 3.2. Sampling intensity in the rainforest fragments in Anamalai Hills during 1998-1999. Figures in parenthesis are the number of fragments in each of the size categories.	36
Table 4.1. Leaf litter reptile species and number of individuals recorded by adaptive cluster sampling in the contiguous rainforest of KMTR, (1997-98).	49
Table 4.2. Mann-Whitney U Test for 2 Independent samples (Z Statistic), to test for differences in the number of reptile species per network between sites and seasons, KMTR (1997-98). Figures in parenthesis give the mean and SE values of reptile species per network.	53
Table 4.3. Densities of leaf litter reptiles in KMTR, (1997-98). Densities expressed as animals/quadrat (5 m x 5 m).	55
Table 4.4. The species and number of individuals of arboreal reptiles recorded by forest transects in the contiguous rainforest of KMTR, (1997-98).	56
Table 4.5. Mann-Whitney U Test for 2 Independent samples (Z Statistic), to test for difference in arboreal reptile species richness between sampling sites and seasons, KMTR (1997-98). Figures in parenthesis give the mean and SE values of species richness.	58
Table 4.6. Mann-Whitney U Test for 2 Independent samples (Z Statistic) to test for difference in arboreal reptile abundance between sampling sites and seasons, KMTR (1997-98). Figures in parenthesis give the mean and SE values of species richness.	59
Table 4.7. Encounter rates (animals/250 m) of arboreal reptiles in KMTR, (1997-98).	61
Table 5.1. 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).	83
Table 5.2. Mean and SE values for network size, abundance and species per network in a) size classes of fragments and b) seasons.	86
Table 5.3. Density (number of animals/quadrat) of leaf litter reptiles in the different size classes of rainforest fragments, Anamalai Hills (1998-99).	87
Table 5.4. Morisita-Horn's measure of similarity for leaf litter reptiles in the different size classes of fragments, Anamalai Hills (1998-99).	88

Table 5.5. Arboreal reptile species and number of individuals recorded by Forest transects in the rainforest fragments of Anamalai Hills, (1998-99).	89
Table 5.6. Mann-Whitney U Test for 2 Independent samples (Z Statistic) to test for differences in species richness between different size classes of fragments and seasons, Anamalai Hills (1998-99).	92
Table 5.7. Mann-Whitney U Test for 2 Independent samples (Z Statistic) to test for differences in reptile abundance between different size classes of fragments and seasons, Anamalai Hills (1998-99).	93
Table 5.8. Encounter rates (animals/250 m) of arboreal reptiles in the different size classes of rainforest fragments, Anamalai Hills (1998-99). Figures in parenthesis give number of transects in each size category.	96
Table 5.9. Morisita-Horn's measure of similarity of arboreal reptile assemblage in the different size classes of rainforest fragments in Anamalai Hills (1998-99).	96
Table 5.10. R <sup>2</sup> values for the relationship of arboreal reptile species richness and abundance with altitude in the rainforests in Anamalai Hills, 1998-99. (L=linear model; Q=Quadratic Model). The figure in parenthesis give the altitudinal range sampled.	97
Table 5.11. Reptilian species richness and endemism in the remnant rainforest fragments, Anamalai Hills (1998-99). Figures in parenthesis give the number of fragments.	98
Table 5.12. Percentage composition of reptilian taxa in the contiguous rainforests (KMTR, 1997-98) and the fragments of Anamalai Hills, (1997-99).	99
Table 6.1. Mean and SE of microhabitat variables that were significantly different between quadrats with and without leaf litter reptiles using Oneway ANOVA, KMTR (1997-98). Figures in parenthesis give sample size.	112
Table 6.2. The values for Wilk's $\lambda$ , log determinants and the structure matrix for the discriminant function analysis of leaf litter reptiles in the contiguous rainforests, KMTR (1997-98).	114
Table 6.3. Mean and SE of microhabitat variables that were significantly different between quadrats with and without leaf litter reptiles using Oneway ANOVA, Anamalai Hills (1998-99). Figures in parenthesis give sample size.	116
Table 6.4. The values for Wilk's $\lambda$ , log determinants and the structure matrix for the discriminant function analysis for leaf litter reptiles in the fragmented landscape, Anamalai Hills (1998-99).	118
Table 6.5. Mean and standard errors of microhabitat variables that were significantly different between plots with and without arboreal reptiles using Oneway ANOVA, KMTR (1997-98). Figures in parenthesis give sample size	120

Table 6.6. The values for Wilk's $\lambda$ , log determinants and the structure matrix for the discriminant function analysis of arboreal reptiles in contiguous rainforests, KMTR (1997-98).	122
Table 6.7. Mean and standard errors of microhabitat variables that were significantly different between plots with and without arboreal reptiles using Oneway ANOVA, Anamalais (1998-99). Figures in parenthesis give sample size.	126
Table 6.8. The values for Wilk's $\lambda$ , log determinants and the structure matrix for the discriminant function analysis of arboreal reptiles in the rainforest fragments, Anamalai Hills (1998-99).	128
Table 7.1. The reorganization vector of the fragments in Anamalai Hills after maximal packing, using the nested temperature calculator.	144
Table. 7.2. The reorganization vector of the reptilian species in Anamalai Hills after maximal packing, using the nested temperature calculator.	145

## LIST OF FIGURES

Figure 2.1. Kalakad-Mundanthurai Tiger Reserve showing the extent of tropical rainforest and the location of the reservoirs and the intensive sampling sites.	15
Figure 2.2. The Indira Gandhi Wildlife Sanctuary showing the rainforest fragments in a matrix of plantations.	20
Figure 3.1. Placement rules and design for adaptive cluster sampling. The calculations for network size and density estimates are outlined in Figures a to c.	30
Figure 4.1. Network size of leaf litter reptiles, KMTR (1997-98).	47
Figure 4.2. Number of reptile species/network, KMTR (1997-98).	47
Figure 4.3. Number of reptiles per network in KMTR, (1997-98).	48
Figure 4.4. Aggregation of leaf litter reptiles/network, KMTR (1997-98).	50
Figure 4.5. Percentage of primary quadrats with reptiles across seasons, KMTR (1997-98) N=91.	51
Figure 4.6. The percentage composition of leaf litter reptiles in three sites, KMTR (1997-98).	54
Figure 4.7. The percentage composition of arboreal reptiles in three sites, KMTR (1997-98).	60
Figure 4.8. Arboreal reptile species richness along an altitudinal gradient, KMTR (1997-98).	62
Figure 4.9. Arboreal reptile abundance along an altitudinal gradient, KMTR (1997-98).	62
Figure 4.10. Encounter rates of arboreal reptile taxa along an altitudinal gradient, KMTR (1997-98).	63
Figure 4.11. Dendrogram showing arboreal reptile species similarities in transects, KMTR, (1997-98).	64
Figure 4.12. Arboreal reptile abundance along an atmospheric temperature gradient, KMTR (1997-98).	65
Figure 4.13. Arboreal reptile abundance along a substrate temperature gradient, KMTR (1997-98).	65
Figure 4.14. Taxa-wise response of arboreal reptiles to atmospheric temperature, KMTR (1997-98).	66

Figure 4.15. Taxa-wise response of arboreal reptiles to substrate temperature, KMTR (1997-98).	67
Figure 5.1. Network size of leaf litter reptiles, Anamalai Hills (1998-99). Figures in parenthesis gives sample size.	79
Figure 5.2. Number of reptile species/network, Anamalai Hills (1998-99). Figures in parenthesis gives sample size.	80
Figure 5.3. Number of reptiles/network, Anamalai Hills (1998-99). Figures in parenthesis gives sample size.	80
Figure 5.4. Percentage composition of leaf litter reptiles in rainforest fragments, Anamalai Hills (1998-99).	82
Figure 5.5. The proportion of endemic and non-endemic leaf litter reptile taxa in various size categories of fragments, Anamalai Hills (1998-99).	84
Figure 5.6. Percentage of primary quadrats with leaf litter reptiles in rainforest fragments across seasons, Anamalai Hills (1998-99).	85
Figure 5.7. The proportion of endemic and non-endemic arboreal reptile taxa in different size categories of fragments, Anamalai Hills (1998-99).	91
Figure 5.8. Variation in arboreal reptile species richness among (a) the different size categories of fragments, (b) seasons; and abundance between (c) the different size categories of fragments and (d) seasons, Anamalai Hills (1998-99).	94
Figure 5.9. The percentage composition of various taxa of arboreal reptiles in rainforest fragments, Anamalai Hills (1998-99).	95
Figure 5.10. Species accumulation of rainforest 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 in the Kalakad-Mundanthurai Tiger Reserve (expected values).	101
Figure 5.11. Species accumulation of rainforest 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.	102
Figure 6.1. Discrimination of quadrats with and without leaf litter reptiles along discriminant function 1, KMTR (1997-98).	115
Figure 6.2. Discrimination of quadrats with different reptilian taxa along discriminant function 1, KMTR (1997-98).	115
Figure 6.3. Discrimination of quadrats with endemic and non-endemic species along discriminant function 1, KMTR (1997-98).	115

Figure 6.4. Discrimination of quadrats with and without leaf litter reptiles along discriminant function 1, Anamalai Hills (1998-99).	119
Figure 6.5. Discrimination of quadrats with different reptilian taxa along discriminant function 1, Anamalai Hills (1998-99).	119
Figure 6.6. Discrimination of quadrats with endemic and non-endemic species along discriminant function 1, Anamalai Hills (1998-99).	119
Figure 6.7. 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).	124
Figure 6.8. Discrimination of plots with endemic and non-endemic species of arboreal reptile along (a) DF 1 and (b) DF 2, KMTR (1997-98).	125
Figure 6.9. 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, Anamalai Hills (1998-99).	130
Figure 6.10. The discrimination of plots with arboreal reptile endemic and non-endemic along (a) DF 1 and (b) DF 2, Anamalai Hills (1998-99).	131
Figure 6.11. The partitioning of the vertical stratum by the agamids in (a) KMTR (1997-98) and (b) Anamalai Hills, (1998-99). Only species with >5 sightings are included.	132
Figure 7.1. The maximally packed species incidence matrix with idiosyncratic sites and species and the probability estimation function, for reptiles in the rainforest fragments of Anamalai Hills. The identity of species (horizontal) and fragment (vertical) are as in Table 7.4 and 7.5 respectively.	143
Figure 7.2. The relationship between species richness of a fragment and the time elapsed since its isolation in Anamalai Hills (1998-99).	146

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*Finally, my mother, father, brother and my relatives for keeping me focused and for putting up with all the long absence from home. Thanks to for everything. My friend Anand at Madras for keeping tabs and informing me of the happening in Madras.*

**N.M.ISHWAR**

## SUMMARY

Habitat fragmentation has long been recognized as a threat to biological diversity and a major cause in the sudden increase in the extinction rates of species. Demographic and environmental stochasticity, habitat degeneration, the decrease in genetic variability and the influx of secondary forest species all lead to the extinction of forest species in the forest fragments. The forests in the various hill ranges in the Western Ghats are under anthropogenic pressure, mainly due to commercial plantations like tea, coffee, cardamom and spices and timber. The construction of dams for irrigation and hydroelectric power projects and roads and rapid urbanization are other ways by which the once contiguous middle elevation rainforests of the Western Ghats have been dismembered into scattered fragments. The rainforests of the Western Ghats is one of the richest biogeographic zones in the country with more than 50% of the reptiles reported from the area being endemic to these forests.

The most serious problem that is faced by the wildlife managers in the Western Ghats is that the remaining forests, especially the rainforests, occur in a highly fragmented state. The effect of rainforest fragmentation has taken its toll on the overall biological diversity with declines in reptile species contributing to this loss. Addressing this conservation problem becomes difficult in any forum, as studies on reptiles are few and poorly represented in literature. In this background, the objectives of the present study broadly defined here were to understand 1) the factors that govern the distribution of reptiles in the rainforests. The factors include both macro and microhabitat variables that the reptiles are known to respond to; and 2) to see if the process of rainforest fragmentation has affected the reptilian distribution and community structure, and to understand the direction of this impact. To a varying degree, the chapters in this thesis explore in detail the two major points expressed above, and detailed assessment of what is needed to promote reptile conservation is provided at the end.

The study was divided into two phases, the first phase was devoted to understanding the factors that were likely to influence the distribution of rainforest reptiles, while the second phase looked into the effects of rainforest fragmentation on reptiles. A

combination of sampling techniques that included the adaptive cluster sampling (for leaf litter reptiles), the forest transects (for arboreal reptiles), stream surveys (for nocturnal stream dwelling reptiles) and opportunistic sampling was used to sample rainforest reptiles. Three sites in the contiguous rainforests of Kalakad-Mundanthurai Tiger Reserve (KMTR), that broadly represented the altitude range and the different drainages, formed the site for the first phase of the fieldwork. The fourteen rainforest fragments in the Anamalai Hills were the study sites for the second phase of fieldwork where the effects of rainforest fragmentation were enumerated. The rainforest fragments varied in size, ownership, surrounding matrix, and altitude and were in a landscape that was dominated by tea. Sampling was restricted to an altitudinal range of 700 to 1,450 m in altitude.

It is difficult to place the results of this study in the context of previous work as there are very few studies have tried to assess the impact of rainforest fragmentation on reptilian communities, and none have been carried out in the tropical rainforests of the Indian subcontinent. The lack of density estimates and encounter rates for the different reptilian taxa or for individual species from other studies, and the almost nonexistent information on microhabitat requirements of rainforest reptiles, makes the comparison even more difficult.

In total, 66 species of reptiles were recorded from the both the study sites in the state of Tamil Nadu. The contiguous rainforests of KMTR (54 species) had 26 (39.39%) unique reptilian species, while the rainforest fragments of the Anamalai Hills (40 species) had only 12 (18.18%) unique species, with both the sites sharing 42.42% (28 species) of reptiles.

In the contiguous rainforests of KMTR, geckos and skinks dominated the leaf litter assemblage. Reptiles did not form multi-species assemblage, nor were they seen in aggregation of > 2 individuals. The study revealed that the density of leaf litter reptiles in the contiguous rainforests was 0.28 animals/25 m<sup>2</sup>. It is hypothesized that the reason for the low densities in these rainforests when compared with other tropical

sites is due to the difference in the structural complexity and litterfall rates in these forests. Leaf litter reptile abundance was greater in Sengaltheri while the high altitude site of Kakachi had very low abundance. There was no significant difference in the abundance and species richness of the leaf litter across sites and seasons within KMTR. The arboreal assemblage was dominated by agamid species (e.g. *Draco dussumieri* and *Calotes ellioti*) with an overall encounter rate of 1.94 animals/250 m. Sengaltheri had greater species richness while Kannikatti had greater abundance in the arboreal assemblage. In both the leaf litter and arboreal assemblages, the high altitude site of Kakachi supported a unique assemblage in terms of species richness and abundance.

Arboreal reptile species richness showed a quadratic relation with altitude ( $R^2 = 0.473$ ,  $P = 0.008$ ), while the arboreal reptile abundance showed a linear decline with the increase in altitude ( $R^2 = 0.85$ ,  $P < 0.001$ ), although individual taxa varied in their response to altitude. Temperature (atmospheric and substrate temperature) also influenced arboreal reptile abundance, while its influence on species richness was insignificant.

The leaf litter assemblage in the rainforest fragments was dominated by skinks and geckos, while the arboreal assemblage was dominated by agamids. The smaller sized fragments in the Anamalai Hills, apart from having fewer species, had greater densities of both leaf litter and arboreal reptiles than the larger fragments. The overall densities (0.37 animals/25 m<sup>2</sup>) and encounter rates (1.84 animals/250 m) in the rainforest fragments was greater than the contiguous rainforests. The greater abundance in the fragments of Anamalai Hills was mainly caused by an increase in the abundance of non-endemic and habitat generalist species in the Medium and Small sized fragments. Fragments planted with cardamom supported a unique reptile assemblage.

The effect of altitude on arboreal reptile species richness and abundance was insignificant in the forest fragments, largely due to the presence of non endemic and habitat generalist species in these assemblages. Fragmentation was related to a decline in the number of reptile species and endemic species in the rainforest fragments, even when other factors like area and altitude were controlled for.

No major difference was observed in the microhabitat association between geckos and skinks. However, there was a tendency for skinks to be associated with areas with greater leaf litter and understorey, while rocks seemed to be important for geckos. Among the arboreal reptiles, agamids were associated with areas with greater basal area and lower canopy while the converse was true for snakes. The endemic and typical rainforest species were most often found in areas with minimal disturbance, while the secondary forest species were associated with disturbed areas. The changes in habitat quality largely due to habitat fragmentation have had a greater effect on the arboreal assemblage than the leaf litter assemblage.

The occurrence of reptiles in the rainforest fragments showed nestedness, with the majority of the species found in the smaller fragments being recorded from the Very Large fragment. The extinction prone species identified were largely habitat specialists that include a majority of snakes (eg. *Melanophidium punctatum*, *Coluber* spp. *Uropeltis nitida*, *Lycodon* spp.), the high altitude lizard *Salea anamallayana* and the members of the genus *Scincella*. It is predicted that the recolonization ability and the differential extinction rates may influence the persistence of species in the rainforest fragments. Species richness of a fragment showed a quadratic relationship with years since isolation of the fragment. This is a significant finding, as it suggests a lag period of 70 years after which the species richness in the fragment declines.

The observed pattern of turnover of reptile species along an altitudinal range, the order of the extinction prone species and the prioritisation of remnant rainforest fragments can be used in the planning and design of protected areas, with emphasis on the conservation of the rare and endangered reptiles in the Western Ghats.

The two major methods that were used to sample the leaf litter and arboreal assemblage proved to be very successful. Adaptive cluster sampling served as a better technique in sampling rainforest leaf litter reptiles, and provided an unbiased estimator of mean density and the variance. It also provided new descriptors of the reptilian community like network size, mean number of species per network and mean number of individuals per network.

# CHAPTER 1

## INTRODUCTION

### 1.1 HABITAT FRAGMENTATION

Human settlement and related activities such as forestry, plantations and agriculture have altered the natural landscape and pose the single greatest threat to the planet's biological diversity (Wilcox and Murphy 1985; Simberloff 1986). The effects of habitat fragmentation can be broadly categorised into two components a) a reduction in the total area of the original habitat, b) changes in the macro and microhabitat conditions and the creation of an edge between the original habitat and the human altered landscape, collectively referred to as "edge effects". In forested areas, the combined effects of these factors lead to an increase in tree mortality and penetration of non-forest (exotic), species into forested habitats displacing rare, endemic and forest species. Fragmentation may also have a negative effect on the population size and the dispersal capabilities of the native species, thereby elevating their extinction rates (Janzen 1986; Lovejoy et al. 1986; Wilcove et al. 1986; Laurance and Yensen 1991; Saunders et al. 1991; Terborgh 1992; Burkey 1995; Murcia 1995).

#### 1.1.1 Fragmentation: Reduction in total area and edge effects

Fragmenting a habitat, by its very nature, reduces the total area of the original habitat and is associated with a reduction in the density of resources. This can potentially impact the biota more than any other factor (Keller and Anderson 1992). Habitat fragmentation affects the flora and fauna of a given ecosystem by replacing a naturally occurring ecosystem with a human-dominated landscape. These landscapes may be inhospitable to a certain number of the original species and may directly contribute to the extinction of species within habitat islands by shifting community composition in favour of species that are highly adaptable to changing conditions (Lovejoy et al. 1986). In addition to favouring species that are highly adaptable, the loss of habitat associated with habitat fragmentation may cause populations of interior species and their distribution ranges to decline (Soule 1986; Saunders 1989). Habitat islands that result from fragmentation often experience a decline in species richness

(MacArthur and Wilson 1967), and the fragments may eventually sustain only a subset of the species found in the parent patch (Patterson 1987; Cutler 1991). Studies have demonstrated the loss of habitat specialists from fragments consistently across taxa, many of which are endemic species (Laurance 1991; Newmark 1991). Consequently, species that benefit from human activities are not the ones at risk of extinction or range reduction. Instead, we need to protect those species that are best adapted for survival in the rapidly disappearing unfragmented habitat (Harris 1984).

Size and shape of a fragment and the area of associated edge are inextricably linked. Abrupt edges often result from fragmenting an ecosystem, in contrast to the more gradual natural ecotones. It has also been documented that the remnant patches show progressive degradation over time resulting in micro environmental changes (Kapos 1989). Habitat edge positively impacts many species of plants and animals, but as mentioned previously, the species which benefit typically are those which do not require human protection and management because they can easily meet their resource needs outside of the intact ecosystem (Lovejoy et al. 1986). Although edge has been typically associated with an increase in species richness, researchers have documented the negative impacts of edge habitat on the native biota (Harris 1984). Another potentially adverse effect of human created habitat edges is that it inherently reduces the size of the interior habitat because of the many physical changes, which occur where an edge is juxtaposed upon a matrix of secondary vegetation. The presence of the edge habitat may lead to increased exposure to wind which results in higher tree-fall rates and increased tree mortality, while temperature and humidity are also quite different at the edge than in the forest interior (Lovejoy et al. 1986). Studies have demonstrated that, while changes in the natural vegetation may extend from 10 to 30 m into a forest, the effects on fauna may extend up to 300-600 m into a fragment from the edge (Wilcove et al. 1986). Therefore, the smaller the fragment, the less likely "interior habitat" will be present, and thus the entire patch may become "edge habitat". Moreover, as fragments are often embedded in a human dominated landscape, the distances between fragments vary, and there is often no functional

habitat connectivity between fragments thus leading to their isolation. This is a cause for concern as individuals of a given species are unable to disperse between two fragments that are widely separated thus essentially dividing the population, with a possible increase in rates of inbreeding. Inbreeding leads to loss of heterozygosity and allele diversity. The resultant homozygosity in certain genes can lead to an evolutionary dead end for a species (Allendorf 1986; Burkey 1989). Isolation also leads to a decline in species richness because extinction is no longer balanced by recolonization.

### **1.1.2 Changes to biodiversity due to fragmentation**

Besides physically changing the original habitat, decreasing the size of the original habitat can reduce the biological diversity of an area in several ways. Reduction in the biodiversity of an area may occur if habitat fragments are smaller than the home range of animals that existed within the intact ecosystem. If a habitat fragment exists that is smaller than the minimum area required by a given species, individuals of that species are not likely to be found within that habitat fragment (Robbins 1980; Wilcove et al. 1986). Loss of any species from a community may have secondary effects that reverberate throughout the ecosystem. Therefore the effects of isolation, area size and habitat quality on the survival of fauna and flora, has been a major focus of research leading to at least two integrated, long term studies on forest fragmentation, namely the Biological Dynamics of Forest Fragments Project (BDEFPP), in the Amazonian forests of Brazil and the Forschungsverbund, Isolation, FlachengroBe and Biotopqualität (FIFB), project in Europe. This has resulted in two books on the topic focusing on a variety of taxa (Settele et al. 1996; Laurance and Bierregaard 1997). Results from these studies, and approximately twenty other fragmentation studies show an increase in the number of light-loving edge species in the remnant fragments after isolation (Didham 1997; Kapos et al. 1997; Malcolm 1997; Tocher 1997; Debinski and Holt 2000), resulting in a shift in the species composition in an assemblage. However, literature addressing the effects of anthropogenic habitat fragmentation on reptilian communities is limited in its geographical coverage (Kitchener et al. 1980; Bowman et al.

1990; Bender et al. 1996; Heang et al. 1996; Henle 1996; Martens et al. 1996; Sarre et al. 1996; Lenart et al. 1997), with many studies restricted to a single species.

Deforestation, forest degradation and habitat fragmentation are ubiquitous in the tropics and have grave consequences for the fate of biodiversity (Ramesh et al. 1997). Tropical communities are often more susceptible to loss of biological diversity than temperate communities because tropical species typically are found in lower densities and often have weaker dispersal capabilities (Gentry 1986). Besides being home to extinction-prone species, tropical communities are prone to destruction and fragmentation because a majority of the biome is found in the developing countries that support large and growing human populations. In these nations, citizens often rely on the revenue from rainforest timber or livestock raised on cleared rainforest land for survival. This constant pressure on rainforest communities has led to excessive habitat fragmentation resulting in small isolated fragments, which often leads to a significant reduction in biological diversity (Myers 1986).

## 1.2 WESTERN GHATS

The Western Ghats are a chain of ancient mountains, running parallel to the west coast of the Indian Peninsula. These mountains have long been recognised as a distinct phytogeographic zone in the subcontinent. The Western Ghats mountains extends over a distance of ca. 1,500 km, between 22°N and 8° N latitudes. The Western Ghats have a 30 km wide break in their continuity called the Palghat Gap and another narrower pass at an elevation of 200 m called the Shencottah Gap. The Western Ghats spreads over an area of ca. 160,000 km<sup>2</sup> encompassing a considerable gradient of temperature, rainfall and habitats. The tropical rainforests in these mountains has been variously classified as Indo-Malayan, south-east tropical rainforest (Whitmore 1989; Richards 1996). The annual rainfall varies from over 8,000 mm with far more rainy days in the windward western areas to less than 600 mm in the rain-shadow eastern areas (Pascal 1988, 1991). The Western Ghats south of 11°N receives rain almost throughout the year (dry only for 2-3 months in a year), and it is to this region of the Ghats that the rainforests are largely restricted. Because of its geographic isolation during the late

Tertiary and subsequent evolution, the Western Ghat Mountains are one of the richest centres of endemism in India. Nearly 63% of India's arborescent evergreen taxa are endemic to the Western Ghats (Ramesh and Pascal 1991). The number of endemic plant species in the Western Ghats is estimated to be 1,500. The region south of the Palghat Gap is very rich in plants with 87% of the total endemic species of the Western Ghats and 37 % of this total are endemic to this region alone (Ramesh and Pascal 1991). The rainforests in the Western Ghats support a very rich and varied fauna and flora, the majority of which are endemic (Mani 1974; Inger and Dutta 1986; Nair and Daniel 1986; Kumar 1989; Daniels 1993, 1995). High floral and faunal uniqueness has led to the recognition of the Western Ghats as a global hotspot of biodiversity in the world (Myers et al. 2000). The Western Ghats nevertheless is under threat of losing its much-acclaimed vertebrate diversity due to habitat fragmentation.

The last hundred years has witnessed the extensive deforestation in the Western Ghats especially in the rainforests mainly due to the conversion of rainforest areas into plantation of coffee, tea, cinchona and teak. The consequence has been a large-scale loss of forest cover, and the fragmentation of the remaining habitat into numerous isolated patches (Chattopadhyay 1985). Deforestation coupled with the creation of hydel reservoirs within forested areas has severely fragmented these forests (Nair 1991). Extensive removal of native vegetation (ca. 60%) for the establishment of plantations, reservoirs and other developmental projects, has resulted in the remaining natural vegetation being reduced to fragmented patches across the landscape, varying in size (from a few hectares to over 20 km<sup>2</sup>), shape, isolation and type of ownership (Ramesh et al. 1997).

### **1.3 REPTILES**

Reptiles are traditionally labelled poikilotherms, or animals whose body temperature closely follows that of the external environment. Our present knowledge on the ecology of many reptiles have shown that this term is misleading and the most appropriate term is ectotherms, or animals that primarily rely on the external (environmental), sources for body heat (Heatwole and Taylor 1987). Reptiles along with amphibians are important

components of the energy flow of many forest ecosystems, where they are commonly upper level consumers of prey too small to be utilised by birds and small mammals, thus forming an important component in the food web of an ecosystem (Pough 1983). An understanding of the structuring of these communities is thus vital, particularly since most of the theories on the structure of vertebrate communities are based on birds and mammals (but see Pianka 1986; Toft 1985). The latest comprehensive compilation of reptiles of the world lists ca. 7,870 species, with the most species rich region being the Asian region. Squamates (lizards), dominate the reptile fauna with ca. 4,557 (57.90%), followed by the Serpentes (snakes), with ca. 2,935 (37.29%) (Uetz 2000 a, b). The reptilian fauna of India is rich, varied and unique in its composition, and forms a major component of the Indian vertebrate fauna (Murthy 1991). About 484 species of reptiles belonging to 25 families occur in India (Das 1997). The snakes dominate the list with 278 species, followed by lizards with 161 species, and turtles and tortoises (Testudines), with 38 species. Crocodiles (Crocodylia), are represented by only 3 species in the Indian subcontinent (Das 1997).

### **1.3.1 Faunal affinities of Indian reptiles**

India and its neighbouring countries which form South Asia is at the crossroads of two distinct bio-geographic realms, the Palearctic and the Oriental Indian region and this is the main reason for their high species diversity and distinct reptilian fauna (Das 1996). The Indian reptilian fauna is dominated by the presence of Indo-Malayan, Afro-Mediterranean and Indian radiations (Das 1996).

### **1.3.2 Reptiles of the Western Ghats**

The Western Ghats supports a rich assemblage of reptiles many of which are endemic to this region. Out of ca. 480 reptile species reported from India, 197 species are reported from the Western Ghats (Kumar et al. 1998), of which about 130 are found in the rainforests. Fifty per cent (ca. 98 species), of the reptiles found in the Western Ghats are endemic to the region. Consequently, the Western Ghats along with north-east India are considered the richest biogeographic regions in the country (Kumar et al. 1998). Certain

groups of reptiles have a very high proportion of endemic species. Out of the 47 uropeltid species (shield tailed snakes) described from southern India and Ceylon, 33 species are endemic to the Western Ghats (Gans 1966; Murthy 1992a). Endemism is also high among lizards with 40 endemics out of the 62 species recorded from the Western Ghats. Many of these diverse and endemic reptiles are known from single locality records and habitat fragmentation may have already caused the extinction of some of them. It has been documented that loss of habitat, habitat fragmentation and human interference are the major threats to the reptilian fauna in the country (Kumar et al. 1998). Despite high levels of endemism among reptiles in the Western Ghats, detailed studies on their distribution, community structure, conservation and ecology are few.

### 1.3.3 Studies on Indian reptiles

Studies on the reptilian fauna of India date back to the 19th century (Gunther 1864), and the three volumes by Smith (1933, 1935, 1943), remain till date the basic and the most authentic sources of information on the taxonomy and distribution of reptiles in India. Apart from these compilations, field guides on different groups of reptiles have been published to help in their identification. Example publications include Daniel (1983), for common reptiles, Murthy (1985), for lizards, Das (1985, 1995), for turtles and tortoises, Whitaker (1978), for snakes and Rajendran (1985), for Uropeltids. Apart from these there have been numerous surveys restricted to specific areas in India (*e.g.* Chari 1955; Murthy 1982, 1986, 1990, 1994; Ghate and Yazdani 1990; Groombridge 1990; Karthikeyan 1991). Mahendra (1939), Jayaram (1974), and more recently Das (1996), have attempted to document the biogeographic affinities of the reptilian fauna of India. These studies reveal not only the high diversity of reptilian fauna in India but also the high levels of endemism that are found within the country. Detailed studies on individual species or taxa, reptilian distribution patterns, the factors that control these patterns and more importantly studies on Indian reptile systematics and evolution are lacking. Hence, the database on Indian reptile distribution and abundance is incomplete.

There are only a few detailed community level studies on Indian reptiles (Inger et al. 1984, 1987; Bhupathy and Kannan 1997; Pawar 1999). Apart from a single study in north-east India (Pawar 1999), a majority of the studies are limited to the Western Ghats. The necessity for studies related to the ecology, the community structure and the effect of macro and microhabitats on the rich and diverse Indian reptilian fauna cannot be over-emphasized. The present study aims to fill this lacuna in our understanding of the reptilian fauna of the Western Ghats and the possible consequence of continuing habitat loss and fragmentation.

Studies on reptiles in the two study areas of Kalakad-Mundanthurai Tiger Reserve and Anamalai Hills have been restricted to surveys primarily by Zoological Survey of India (Murthy 1971, 1990, 1992b; Aengals 1995). This is the first detailed and systematic study on the rainforest reptiles in these two study areas.

#### **1.3.4 Taxonomy**

The systematic classification of reptiles of the Indian subcontinent was pioneered by Gunther (1864), Boulenger (1890), and later by Smith which resulted in the publication of three volumes in the Fauna of British India series; Smith (1933, 1935, 1943). Smith's work apart from dealing with taxonomy also gives details on the ecology and behaviour of reptiles. Despite its vintage, this continues to be the only reliable and authoritative source for the identification of the reptilian fauna in the country. The major hindrance in the development of reptilian taxonomy in India as a science is the lack of easy to use field guides.

#### **1.3.5 On geckos, skinks, agamids and snakes**

As a group, the reptiles are highly diverse in their external morphology and their ecology. It is likely that the reptilian evolution has been along several lines leading to its present day diversity. Many of these species are endemic and rare, and consequently, the study of reptiles has always been difficult for field biologist and ecologists. Added to this is the lack of a good field guide and the difficulties of

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acquiring adequate sample size, for statistical analysis. In trying to tease out the patterns of reptilian communities and to explain these in the light of modern ecological theories, it has been necessary for me to group certain similar forms of reptiles. In the present study, the Order Squamata has been arranged into three taxa; geckos (all the species under the family: Gekkonidae, Genera: *Cnemaspis* and *Hemidactylus*), skinks (all the species under the Family: Scincidae, Genera: *Mabuya*, *Ristella* and *Scincella*), and agamids (all the species under the Family: Agamidae, Genera: *Calotes*, *Draco*, *Otocryptis*, *Psammophilus* and *Salea*). I believe this arrangement of species into taxon groups is valid as the species within each group are quite similar in their morphology, ecology and habitat requirements. This organisation has also helped in the selection of the appropriate sampling protocol for these diverse groups of reptiles.

The other Order Serpentes has not been arranged into any finer taxa and has been retained as a single unit. Though members in this order do differ in their ecology and morphology, it was necessary to group them together due to very low detections of individual genera. The study of snakes has always been a problem due to inherent differences in their ecology and behaviour (Stamps 1977; Lloyd et al. 1968; Toft 1985; Pianka 1986; Seigel and Collins 1993). Snakes are wide ranging, occur in apparently low densities and are difficult to observe in the field. The cumulative effect has been that snakes have seldom been the focus of community studies (Seigel and Collins, 1993). Although the present study tried to address the problem of sampling this diverse group of reptiles by using two new sampling methods, the sampling success of some forms of snakes was limited.

The leaf litter and arboreal assemblages addressed in this study are primarily diurnal. There were only a few nocturnal species of *Cnemaspis* and snakes encountered. Due to logistical constraints, the present study does not address the habitat requirements or distribution patterns of these nocturnal species, but their sighting records were used to explore the patterns of species richness.

## 1.4 OBJECTIVES OF THE STUDY

Given the lack of information on reptiles in the Indian subcontinent and in particular to the reptiles that inhabit the rainforests, the study had rather broad objectives. The research was executed in two phases, in the initial phase of the study it was essential to examine the distribution patterns and the factors that govern these patterns in a contiguous rainforest before the impacts of rainforest fragmentation on the reptilian assemblage were determined. Therefore, the study was designed to include two study areas. The study methods and the basic patterns of reptile distribution were identified in the contiguous rainforest of Kalakad-Mundanthurai Tiger Reserve. The rainforest fragments of Anamalai Hills served as the ideal system to study the impact of rainforest fragmentation on reptiles and the associated changes in the community structure and distribution patterns of reptiles. Consequently, the objectives can be broadly stated as follows

- To determine the diversity and the distribution patterns of rainforest reptile communities.

Given the need to document the diversity of reptiles in various habitat types and the lack of information on the diversity of reptiles in the rainforests, the first objective was to document the species richness, the relative abundance and the distribution patterns of rainforest reptiles in the contiguous rainforests.

- To examine the relationship between habitat variables and the distribution of leaf litter and arboreal reptiles.

The habitat associations of rainforest reptiles were examined at both the macro and microhabitat levels. The initial sampling was done in the contiguous rainforest to gain an understanding of the variables that are associated with the distribution of rainforest reptiles. The sampling in the remnant fragments was to validate these findings, and to explore differences in the habitat associations of species due to rainforest fragmentation.

- To determine the impact of rainforest fragmentation on the reptilian community structure.

The impact of rainforest fragmentation on reptiles was examined in different size categories of rainforest fragments in terms of a) the species richness, abundance and endemism, b) the changes in the reptilian assemblage due to the presence of non-rainforest species and the difference in habitat quality in different fragments, and c) the degree of nested distribution of reptiles in the rainforest fragments and the likely causes for this pattern.

## **1.5 ORGANIZATION OF THE THESIS**

Detailed description of both the study areas is given in Chapter 2, while details of the sampling methods, the intensity of sampling and the framework for data analysis are dealt with in Chapter 3. Chapter 4 addresses the distribution of reptiles in the contiguous rainforest of Kalakad-Mundanthurai Tiger Reserve, while Chapter 5 reports on the distribution of reptiles in the rainforest fragments of Anamalai Hills. The microhabitat associations of rainforest reptiles in both the contiguous and the rainforest fragments are explained in Chapter 6. The nested distribution of reptiles in the rainforest fragments of Anamalai Hills is given in Chapter 7, while the major findings of the study are summed up in the last chapter. Management recommendations for the rainforest fragments and the reptilian communities found there are made in this chapter.

## CHAPTER 2 STUDY AREA

### 2.1 THE SYSTEM: THE WESTERN GHATS

#### 2.1.1 Introduction

The mountain ranges of the Western Ghats, also known as the Sahyadris in Indian languages, run almost parallel to the west coast, for most parts 30-50 km inland. These hills traverse through the states of Tamil Nadu, Kerala, Karnataka, Goa, Maharashtra and Gujarat covering an area of about 160,000 km<sup>2</sup>. With more than 60 west flowing and all the three major east flowing rivers (Cauvery, Krishna and Godavari) originating from it, the Western Ghats is the major source of hydel power, drinking water, and irrigation for peninsular India as a whole. Until recently, these hills were also the major source of timber and industrial wood for southern India, which has led to large-scale conversion of forested areas into plantations of cash crops like coffee, tea, cardamom, rubber and pepper.

The Western Ghats are geologically complex, not conforming to any particular geological formation. In the extreme south (south of Shencottah Pass at 9°N), is Khondolites, consisting of gneiss and schists with silimanite and garnet. Between 9° and 13°N (Kodagu), Charnokites dominate, consisting of granitoid gneiss with pyroxene and hypersthene, which are ferro-magnesian minerals (Pascal 1988).

Altitude governs the temperature in these areas, with the mean annual temperature varying from 28°C at sea level to about 15°C degree at 2,000 m, with the mean minimum temperature being ca. 5°C at 2000 m (Pascal 1988). The wide variation in rainfall, temperature and altitude is reflected in the variety of vegetation types in the area, consisting of evergreen, semi-evergreen, moist-deciduous, dry-deciduous, montane, sub-tropical and temperate forest (Pascal 1988), with evergreen, semi evergreen and moist deciduous forests accounting for 84% of the total vegetation cover (Gaussen et al. 1986). The rainforests of the Western Ghats are comparable with those found in Africa, South America, Malaysia and Indonesia in terms of their plant biomass and

density (Pascal 1996). The forests of Western Ghats are well known for their species richness and endemism among plants (Ahmedullah and Nayar 1987), and sustain 5.2% of known plant species and 4.3% of known animal species of the world (Nair 1991).

### **2.1.2 Rationale in the selection of study areas**

One of the major challenges for forest managers in the Western Ghats is the protection of the remaining forests, especially the rainforests that occur in a highly fragmented state. Very few of the areas have rainforests of more than 200 km<sup>2</sup> in extent, namely the Agasthyamalai Hills, Cardamom Hills, Silent Valley-New Amarambalam Forests, and the southern parts of Karnataka. Fragmentation and degradation of the forests north of the Sharavati River (in northern Karnataka, Goa, Maharashtra and Gujarat), has been so extensive that the vegetation can no longer be classified as rainforests. Many of the small rainforest fragments (which together might cover nearly 60% of the remaining rainforests), are privately owned, with cardamom and coffee plantations under a canopy of rainforest trees or are otherwise under considerable human pressure for fuel wood and timber. Intensive use of pesticides and fertilizers by the estates upstream of forest fragments are a major source of pollution, and coupled with other pressures might lead to the long term changes in the microhabitats. The pressure on these forests has increased with the growth of human population in the fringe areas of the forest and this has led to the degradation of the remaining forested areas. A survey of the Chikmagalur district in the Western Ghats estimated an area equivalent to 13,064 ha of forest being cleared for fuel wood requirements by the local population every year (FSI 1996; 252 p). Therefore, the long-term survival of most of the endemic species depends on our ability to manage these rainforests in a fragmented state.

Given the lack of information on the impacts of rainforest fragmentation on the reptiles of the Western Ghats, the study was carried in two phases. In the first phase, factors that influence the distribution of reptiles in a relatively contiguous rainforest were examined. The study area for this component of the study was the Kalakad-

Mundanthurai Tiger Reserve (KMTR), in the Agasthyamalai Hills. During the second phase rainforest fragments in the Anamalai Hills, were studied.

## **2.2 STUDY AREAS**

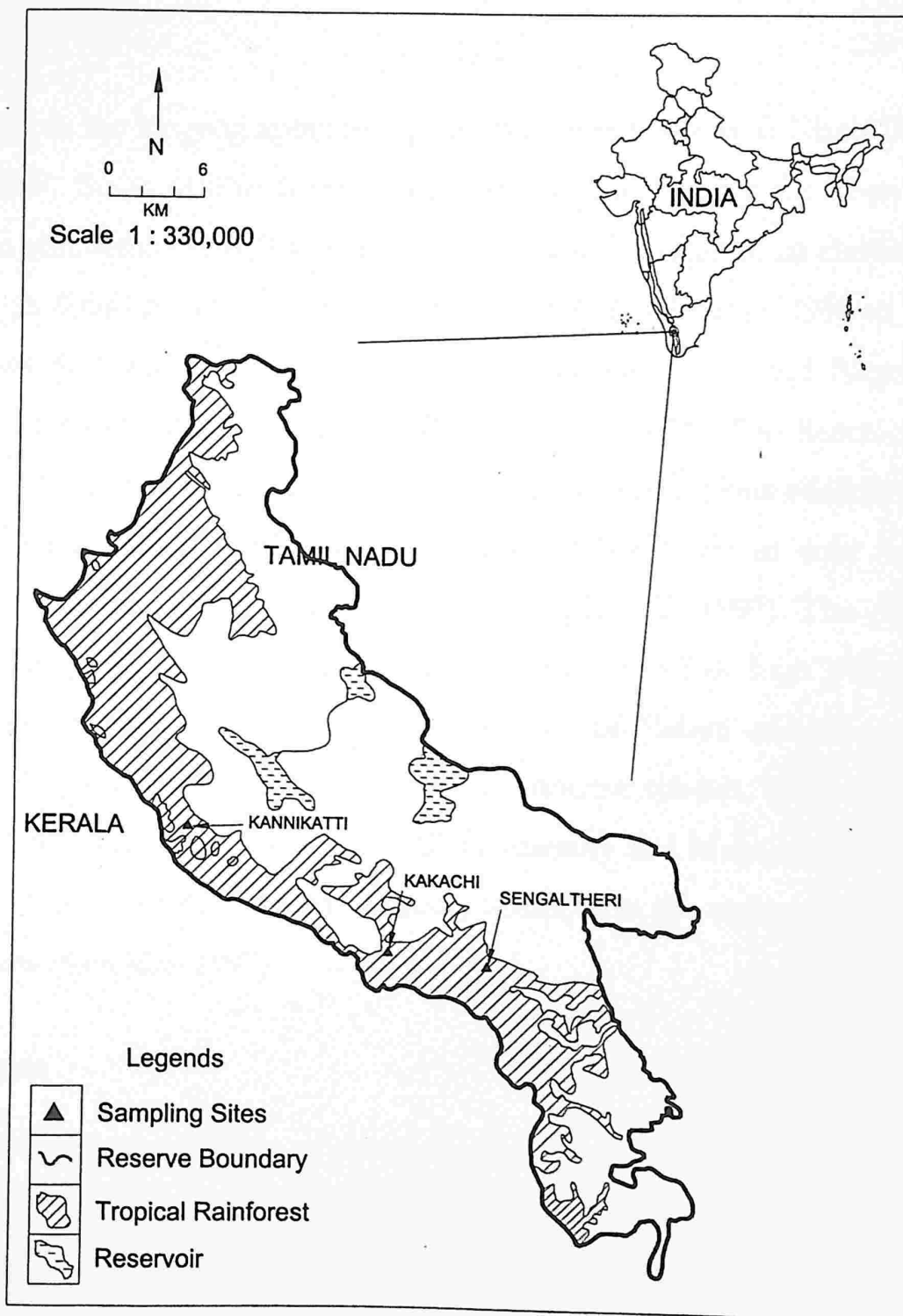
### **2.2.1 Kalakad-Mundanthurai Tiger Reserve**

#### **2.2.1.1 *Geography and climate***

The Kalakad-Mundanthurai Tiger Reserve ( $8^{\circ} 25' - 8^{\circ} 53' N$  and  $77^{\circ} 10' - 77^{\circ} 35' E$ ), is the southern-most Tiger Reserve in India, situated at the southern tip of the Western Ghats mountains (Figure 2.1). The Reserve was notified in the year 1988 with an initial area of 812 km<sup>2</sup>, 83 km<sup>2</sup> of reserved forest has recently been added and presently the total area of the Reserve is 895 km<sup>2</sup>. KMTR forms a major portion of the Agasthyamalai hills along with the Peppara and Neyyar Wildlife Sanctuaries on the western slopes in Kerala state. Ambasamudram and Tenkasi taluks (Tirunelveli district), in the North, Ambasamudram and Nanguneri taluks (Tirunelveli district), in the east, Kanyakumari district in the south in the state of Tamil Nadu, and the state of Kerala in the west bound the Tiger Reserve.

The altitude of the Reserve ranges from about 50 m to ca. 1,867 m. The highest peak in the Reserve is the Agasthyamalai peak (1,867 m), which forms the western limit of the Reserve. The topography is quite variable with steep rocky slopes in the northern and southern boundaries to gentle undulating areas in the plateau. The soil is yellow to reddish yellow, ferruginous sandy loam on the hill slopes and elevated grounds. The ground is rocky and the soil is hard due to excessive leaching at many areas, and small alluvial deposits being found along most of the riverbanks. The soil depth is up to 5 m along the gentle slopes and broad valleys. Humus content is high in the evergreen forests, moderate in the deciduous forests with deeper soil where sporadic clay and swampy conditions can be met with and low amount in the outer fringes. Soil pH ranges from 5.8 to 7 in the evergreen forests and from 5.1 to 6.8 in the semi-evergreen forests. Moisture content of the soil varies in the scrub jungles, low altitudinal grasslands, semi-evergreen and evergreen forests from 56.1% to 84.6% (Pascal 1988).

Figure 2.1. Kalakad-Mundanthurai Tiger Reserve showing the extent of tropical rainforest and the location of the reservoirs and the intensive sampling sites.



Being at the southern tip of the Western Ghats, some parts of the Reserve receive rainfall for almost 10 months in a year. The area receives annual rainfall from both the south-west monsoon (June to September) and the north-east monsoon (October to January), the annual rainfall ranging from 750 mm in the rain shadow eastern slopes to over 3,000 mm in the western slopes (Rawat et al. 1999).

#### 2.2.1.2 *Vegetation*

KMTR falls in the biogeographic province 5B Southern Western Ghats (Rodgers and Panwar 1988). Seven distinct forest types have been identified in the Reserve based on Champion and Seth (1968). The rainforests are mainly limited to an elevation range of 900 m to ca. 1,600 m. The major vegetation in the mid-elevation (900 to 1,200 m), is of the *Cullenia exarillata-Mesua ferrea-Palaquium ellipticum* series and *Nageia wallichiana* facies of the same series (Pascal 1988; Ramesh et al. 1997). The Reserve has one of the largest contiguous tracts of relatively undisturbed contiguous rainforest remaining in the Western Ghats, probably about 400 km<sup>2</sup> or more in area including the rainforests in the adjoining state of Kerala (Ramesh et al. 1997). The Agasthyamalai hill range has been recognized as one of the five centres of high plant diversity in India by the International Union for Conservation of Nature and Natural Resources and is well known for its species richness and endemic species. The area harbours no less than 1,500 flowering plant species (Parthasarathy and Mahadevan 1987), and has been identified as one of the plant diversity hotspots in the country for its high levels of endemism (Gopalan 1997).

#### 2.2.1.3 *Fauna*

One of the largest populations of the critically endangered lion-tailed macaque (*Macaca silenus*) is found in these rainforests. Other mammals which occur in KMTR are tiger (*Panthera tigris*), leopard (*Panthera pardus*), dhole or the Asiatic wild dog (*Cuon alpinus*), sloth bear (*Melursus ursinus*), Nilgiri tahr (*Hemitragus hylocrius*), sambar (*Cervus unicolor*), chital (*Axis axis*), slender loris (*Loris tardigradus*), elephant (*Elephas maximus*) and gaur (*Bos gaurus*). Other endemic non-volant mammals, include the Nilgiri marten (*Martes*

*gwatkinsi*), the brown palm civet (*Paradoxurus jerdoni*), the stripe-necked mongoose (*Herpestes vitticollis vitticollis*), the brown mongoose (*H. fuscus fuscus*), and the Malabar spiny dormouse (*Platacanthomys lasiurus*). Over 200 species of birds have been reported from these forests, that include the Great pied hornbill (*Buceros bicornis*), the Ceylon frogmouth (*Batrachostomatrus monileger*), the Great black woodpecker (*Dryocopus javensis*), the Oriental bay owl (*Phodilus badius*) and the Broadtailed grass warbler (*Schoenicola platyrus*). Detailed studies on amphibian and reptiles have just started and among amphibians, many rare and endemic species have been reported (Vasudevan 1997), that includes the rare microhylid (*Melanobatrachus indicus*), while there has been no systematic effort to document the rich invertebrate fauna in these forests.

#### 2.2.1.4 People

Local tribes in the Reserve are represented by the Kanis, found in five small settlements within the Reserve, and they number approximately four hundred. They are god fearing and mainly depend on agriculture, fishing and honey collection for their living. The presence of the hydel projects of the Tamil Nadu Electricity Board, mainly in the Mundanthurai plateau is the reason for ca. 1,500 people living in the Tiger Reserve. These human settlements depend on the surrounding forests for fuel wood. Apart from these there are also ca. 7,000 people employed by the Bombay Burmah Trading Corporation (BBTC), who also depend on the forests for fuel wood (Ali 1999).

#### 2.2.1.5 The study sites and their history

There are three major watersheds within the Tiger Reserve; the upper Kodayar, Manimuthar and Tambaraparani. Three sites namely Kakachi (1,200 m), Sengaltheri (900 m), and Kannikatti (740 m), were selected for intensive sampling. These sites, located on the north-eastern ridge of the mountains, broadly represent the altitudinal range in the Reserve and are located in different drainages.

### *Kannikatti*

The driest of the three sites, the forest here ranges from < 700 m to > 1,800 m and is contiguous with the Neyyar Wildlife Sanctuary in Kerala at higher reaches and the dry deciduous forests and the plantations of coconut and eucalyptus (Kattalamalai Estate), at lower reaches. The canopy height ranges from about 20 to 28 m and is characterized by the presence of *Cullenia exarillata*, *Pallaquium ellipticum* and *Gluta travancorica*, an endemic to the Agastyamalai region (Ramesh and Guero 2000). Some species are either exclusive to this type of forest or rarely found further north of the Agastyamalai region (Ramesh and Guero 2000). They are represented by *Callophyllum austroindicum*, *Garcinia rubro-echidnata*, *Garcinia travancorica*, *Diospyros barberi* and *Atuna travancorica*.

### *Sengaltheri*

The rainforests here adjoin the dry deciduous forests and cover an altitudinal range from <700 m to >1,500 m. Nearly a century ago about three 5 ha. patches of evergreen forests were converted to cardamom plantations and other cash crops, with the cultivation continuing till early 1993 (Ali 1999). The forests here are represented by *Filicium decipiens*, *Actinodaphne tadulingami*, *Elaeocarpus tuberculatusi*, *Pallaquium ellipticum*, *Artocarpus heterophyllus*, *Myristica dactyloides*, *Canarium strictum*, *Cullenia exarillata* and *Mesua ferrea* (Prathasarathy and Mahadevan 1987). Sampling in this site was limited only to the rainforests and not the plantations.

### *Kakachi*

The wet evergreen forests of Kakachi are mostly in an elevation range of 1,200 to 1,300 m. The canopy height here ranges from 30 m to 40 m (Ramesh and Guero 2000), and it is the wettest of the three sites. The rainforest in this site forms a critical connection between the upper portions of Kalakad Range Forest (Sengaltheri), and Singampatti ex-Zamin Forest (the lower portions of Kannikatti area), and is a corridor for the critically endangered Lion-tailed macaque. Tea, coffee and cardamom plantations of BBTC, totalling 3390.11 ha surround this site (Ali 1999). Although some amount of forest destruction does take place in areas adjoining the estates, the

area supports both virgin forests and various stages of secondary disturbed forests mainly due to human impacts (Ganesh et al. 1996). Sampling was restricted to the relatively undisturbed rainforests about 2 km from the plantations.

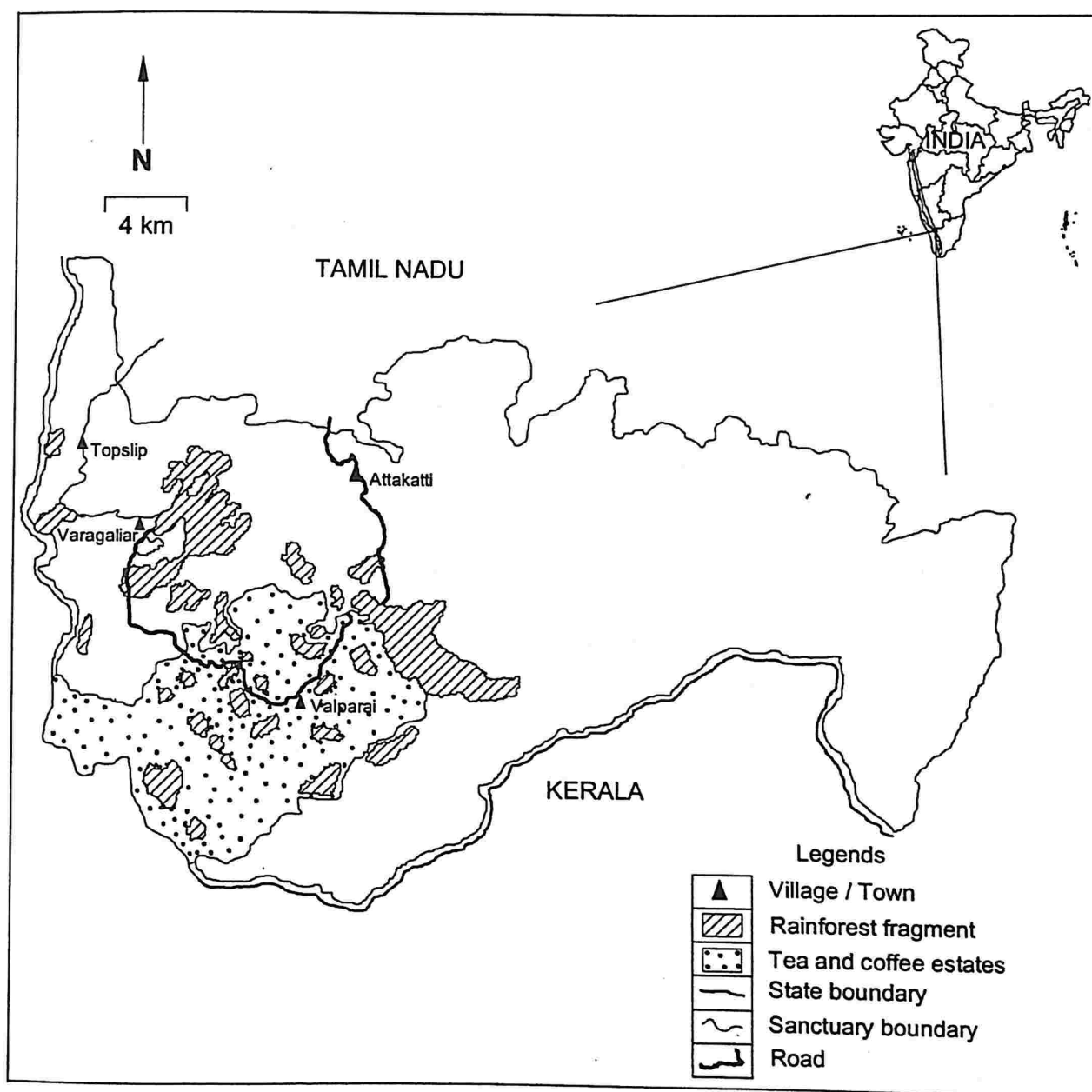
## 2.2.2 Anamalai Hills

### 2.2.2.1 *Geography and climate*

The Indira Gandhi Wildlife Sanctuary (10° 12' and 10° 54' N and 76° 44' and 77° 48' E), in the state of Tamil Nadu is one of the largest sanctuaries in south India (Figure 2.2). This Sanctuary is part of the larger mountain range of Anamalai Hills and was established in 1976. The Sanctuary covers an area of 987 km<sup>2</sup>. Located mainly in the Valparai taluk, it extends into Pollachi and Udumalpet taluks (Coimbatore district), and the Kodaikanal taluk (Dindigul district). It extends 45 km north-south, and 25 km east-west and is about 90 km from Coimbatore city. Three major public roads from Pollachi town pass through the Sanctuary - the Pollachi-Chalakudi road through Valparai, the Pollachi-Parambikulam road through Topslip and the Pollachi-Munnar road through Udumalpet range. There is a good network of roads connecting the Valparai town to various estate settlements.

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

Figure 2.2. The Indira Gandhi Wildlife Sanctuary showing the rainforest fragments in a matrix of plantations.



The altitude of the Sanctuary ranges from 220 m in the foothills east of the Sanctuary 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. In the north, hills descend precipitously to the cultivated plains. The central portion around the Valparai town, at an elevation of 900 m to 1,500 m, has been converted to tea and coffee plantations. In the south and south-east parts in the Udumalpet and Amaravathi ranges, the hills are elevated, steep and abruptly descend down to the plains. The soil found in the Anamalai Hills is classified as lateritic soil (Krishnan 1982). It is a porous, pitted, clay-like rock with red, brown, grey and mottled colours depending on the composition. The rocks found here are classified into metamorphic and igneous types, and are estimated to be from the Pre-Cambrian period. Rainfall varies considerably, ranging from 500 mm in the eastern slopes of the Sanctuary to 5,000 mm in the western slopes. The Sanctuary receives both south-west (June to September) and north-east (October and November) monsoons, with about 80% of the rainfall being during the former. The temperature ranges from  $<5^{\circ}\text{C}$  in the winter at elevations above 2,000 m to nearly  $40^{\circ}\text{C}$  in the eastern plains in summer (Umapathy and Kumar 2000).

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

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### 2.2.2.2 Vegetation

The natural vegetation in this area includes wet evergreen forest, montane shola-grassland, moist deciduous, dry deciduous and thorn forests. Tropical wet evergreen forest is found at an altitude of 600 m to 1,600 m, where the *Cullenia-Mesua-Palaquium*, *Hopea-Mesua-Artocarpus*, and *Dipterocarpus-Anacolosa* associations are found (Pascal 1988). Here, 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 japonica*, and *Eugenia* species. Typically, these forests are interspersed with montane grasslands, forming the shola-grassland complex. The lower elevations of the eastern slopes have mixed dry and moist deciduous forests, where *Tectona grandis*, *Terminalia bellerica*, *T. tomentosa*, *T. paniculata*, *Dillenia pentagyna* and *Lagerstroemia lanceolata* are the dominant tree species. The thorn forests occur mainly in the plains, east of the Sanctuary. The major tree species are *Acacia latronum*, *A. nilotica*, *A. ferruginea*, *A. leucophloea*, *Zizyphus mauritiana* and *Albizzia amara*. An extensive area has been planted with teak, mostly between 600 m and 1,000 m altitude. Although, accurate estimates of area under major vegetation types are not available, the Tamil Nadu Forest Department statistics of 1980s indicates that the rainforest covered about 80 km<sup>2</sup>.

### 2.2.2.3 Fauna

Although no comprehensive assessments have been made, faunal species richness and endemism are likely to be very high, as typical of Western Ghats. The Sanctuary has substantial populations of large mammals that include tiger, leopard, dhole, sambar, chital, elephant, gaur and sloth bear. The shola-grassland system in the Grass Hills and the adjoining Eravikulam National Park support the single largest population of the endemic mountain goat Nilgiri tahr, consisting of about 1,100 animals (Swengel 1991). Other endemic non-volant mammals, known from the Sanctuary include the lion-tailed macaque, the Nilgiri langur (*Trachypithecus johnii*), Nilgiri marten, the brown palm civet, the stripe-necked mongoose, the brown mongoose, the Malabar spiny

dormouse and the dusky-striped squirrel (*Funambulus sublineatus*). The herpetofauna, fishes and invertebrates have not been adequately surveyed.

#### 2.2.2.4 *People*

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

#### 2.2.2.5 *History of the rainforest in Anamalai Hills*

The Anamalai Hills are called so, after the elephants, which were once found in abundance here. It is a continuation of the Western Ghats immediately south of the Palghat Gap. In the early days of the British rule, the forests in this area did not have any specific management nor was any of the forest properly surveyed. The deforestation of the Anamalai Hills can be traced back to the construction of vessels of war in the Bombay dockyard (Sundararaju 1987). British surveyors reported good quantity and quality of teak trees in early 1820s, after which the Bombay Marine Company started extraction of timber from these forests. The extraction declined considerably in 1862-63 when the construction of vessels of war in Bombay was given up. After the enactment of Madras Forest Act in 1882, the Government set apart an area of ca. 19,114 ha of virgin evergreen forestland in the Valparai area for raising tea, coffee, and cardamom plantations, which was leased to private companies for cultivation. The Waterfall Estate (1890) was the first one to clear the forests, and was followed by other estates until 1930 (Congreve 1940). The Forest Department continued logging in the northern side of the Sanctuary until 1976. At present 18,032 ha of tea, coffee, and cardamom estates and 3,717 ha of cinchona plantation (half of which have been converted into tea plantation), are situated within the Sanctuary (Sundararaju 1987).

### 2.2.2.6 Rainforest fragments

The forest in the Anamalai Hills exemplifies the progressive decay of the rainforests where until as late as 1900 the entire landscape was carpeted with contiguous evergreen forests (Congreve 1940). Being at the "T" junction of the northern end of the southern Western Ghats, the Anamalai Hills once had extensive wet evergreen forests. Between 1860 and 1930, extensive areas of rainforests were clear felled for planting tea, coffee and teak. Some areas were also lost to reservoirs, roads and human settlements. Presently, privately owned tea and coffee estates cover more than 180 km<sup>2</sup> in the centre of the Sanctuary (Sundararaju 1987). Most of the rainforest fragments occur as islands in this landscape dominated by tea plantations, and are privately owned. Those that come under the administrative control of the Sanctuary are also surrounded by these plantations and some times by teak plantations.

More than 60% of the remaining rainforests of the Western Ghats are in the form of fragments ranging in area from < 10 ha to 2,000 ha (Umapathy and Kumar 2000). There are about 30 such rainforest fragments in the Anamalai Hills. These fragments were formed mostly between 1890 and 1970.

The wet evergreen forests in these mountain ranges and the fragmented landscape are well known for their diverse flora (Annaselvam and Parthasarathy 1999). The forests have rare and endemic forms such as the shrub *Utleria salicifolia* (Nayar 1980). The forests here are characterized by tree species such as *Dipterocarpus indicus*, *Vateria indica* and *Callophyllum polyanthum*. *Hopea parviflora*, *Dysoxylum malabaricum*, *Artocarpus hirsuta*, *Cullenia exarillata* and *Humboldtia* spp. were some of the other trees found. The understorey plants are known to be equally diverse as the tree species in the Anamalai Hills (Annaselvam and Parthasarathy, 1999). The ownership and the matrix adjoining the rainforest fragments that were selected for intensive sampling varied and are given in (Table 2.1).

**Table 2.1. List of rainforest fragments (sampled between June 1998 to May 1999), and the description of the surrounding matrix in the Anamalai Hills.**

(The identity of the rainforest fragments in the remaining part of the thesis is based on the serial number in this table).

S. No.	Fragment Name	Area (ha)	Altitude range (m)	Ownership*	Habitat matrix**
1	Akkamalai	2500	1240-1400	F	SE, DE, R, Ca
2	Andiparai	185	1200-1280	F	S, T
3	Manamboli	200	700-1000	F	DE, C, T
4	Sankarankudi	180	990-1150	F	T, DE
5	Iyerpadi Church	50	1000-1150	P	C, SE
6	Puduthottam	50	990-1120	P	T, C
7	Tata Finlay	24	900-980	P	T, C, R, E
8	Pannimedu	10	950-1200	P	T, R, S
9	Korangumudi	35	990-1100	P	R, C, T
10	Varattuparai I	1	900	P	T, C
11	Varattuparai II	2	920-940	P	T, C
12	Varattuparai III	4	940	P	T, C
13	Varattuparai IV	1	940	P	T, C
14	Tata II	0.5	910	P	T, E

\* F – Forest department; P – Privately owned.

\*\* The vegetation type surrounding the fragment. The rainforest fragments are arranged in descending order of perimeter contact of these habitat types with each. C – Coffee; Ca – Cardamom; DE – Dry evergreen; E – Eucalyptus; R – Reservoir; S – Secondary forest; SE – Stunted high elevation evergreen forest; T – Tea.

## CHAPTER 3 SAMPLING METHODS AND DATA ANALYSIS

### 3.1 SAMPLING METHODS

#### 3.1.1 General considerations for sampling reptiles

Reptiles are a highly diverse group with a variety of life history modes and occupy a variety of microhabitats. Given this diversity, it is not possible to sample all taxa of reptiles using any single survey method. This study employed three different methods that targeted particular groups of reptiles. The three major sampling techniques used were adaptive cluster sampling (a modification of quadrat search for ground dwelling leaf litter reptiles), forest transects (for arboreal reptiles up to 8 m height in the forest), and stream surveys/visual encounter surveys (for nocturnal stream dwelling reptiles) (Heyer 1967; Corn and Bury 1990; Welsh and Lind 1991; Heyer et al. 1994). Detailed records of opportunistic sightings of reptiles were also maintained. In general, reptiles were searched for under stones, fallen logs, tree buttresses, tree holes, burrows, in leaf litter, on herbs and shrubs, tree bark and other sun lit areas on the trees and other known microhabitats of reptiles. The sampling procedures were the same for both the contiguous forests of KMTR and the rainforest fragments in Anamalai Hills.

#### 3.1.2 Adaptive cluster sampling: A sampling protocol for rainforest leaf litter reptiles

Traditional quadrat sampling was used initially in an attempt to sample the rainforest leaf litter reptiles. This method of sampling forest litter herpetofauna was formalized by Lloyd et al. (1968), and has been improved upon by later researchers. To standardize the size of the quadrat, varying dimensions (10 m x 10 m, 8 m x 8 m and 5 m x 5 m), of quadrat were evaluated for their suitability and efficiency. In the selection of the quadrat size for intensive sampling, importance was given to the requirements of sample size and the efficiency of detecting reptiles. The 10 m x 10 m and 8 m x 8 m quadrats were found to be too large in a rainforest for effective sampling.

The quadrat area was demarcated using a nylon rope on the forest floor, and two observers searched the various microhabitats. Fallen logs and rocks were moved around and whenever possible they were overturned to search for reptiles. The two observers moved from two diagonally opposite corners of the quadrat, towards the centre, in a circular fashion. As they moved towards the centre of the quadrat, leaf litter and other materials on the forest floor were moved towards the outside of the quadrat, with the help of a 'search stick'. This helped in disturbing reptiles that lay hidden in the litter and under rocks, moving them towards the centre of the quadrat and thereby helping in their detection and capture. Sampling by this method was limited to a vertical height of two metres. This constraint was essential, as it was not feasible to search both the litter and the understorey for reptiles with the same efficiency. Since this method was very intensive and caused disturbance to the area sampled, fresh quadrats were laid during each sampling season.

In total 330 random quadrats were laid, of which 172 quadrats had no reptile detections. The large proportion of quadrats without any reptiles (>50%), and their low abundance whenever they were present in quadrats proved to be a major constraint in data analysis. This led to the hypothesis that reptiles may be aggregated (clustered), in their distribution. Therefore, a modification of the traditional quadrat sampling, the adaptive cluster sampling (Thompson 1991; Thompson and Seber 1994), was adopted to sample the leaf litter reptiles.

The sampling units were 5 m x 5 m quadrats and the search method followed Inger (1994), and as described earlier. If a reptile was sighted in one of the random quadrats (henceforth referred to as **Primary Quadrats**), additional quadrats of the same dimensions (called **Secondary Quadrats**), were searched on the four sides of the primary quadrat. If reptiles were detected in any of these quadrats, further quadrats (**Tertiary Quadrats**), were laid around them until the quadrats with reptiles were bound or surrounded by quadrats (**Edge Quadrats**), without reptiles. The primary quadrats along with the secondary, tertiary and edge quadrats then formed a cluster of quadrats. The boundaries of the quadrats within the cluster were spaced apart by a

metre. This was required since it was probable that the area immediately adjoining the quadrat would be disturbed during the search, thereby reducing the chance of reptile detection. If the primary quadrat did not record any reptile, the sampling was carried out in the next randomly selected primary quadrat. When reptiles were not detected in the primary quadrat, cluster size is equal to one, while for primary quadrats with reptiles the cluster size was the total number of quadrats sampled including the primary, secondary, tertiary and edge quadrats. While sampling a distance of at least 25 m was maintained between two clusters. All reptiles sighted in a cluster were collected to prevent their re-sightings in the cluster. After identification and taking morphometric measurements the reptiles were released in the area of their collection.

For the purpose of analysis, the term 'network' is defined as the aggregation of quadrats with reptile sightings, within a cluster. The following parameters were estimated from the data:

- The percentage of primary quadrats with reptiles: This is an indicator of the abundance of networks in an area.
- Network size: The number of quadrats with reptiles in a cluster, as an indicator of the area occupied by an assemblage of reptiles.
- Species richness: As an indicator of species richness in the area.
- Density ( $w_j$ ): As an indicator of the abundance of reptiles in a network. This is calculated by dividing number of reptiles in the network by the network size.
- Density in the area ( $d$ ): As an estimate of the population density in the area. This is the mean of the densities in networks, including primary quadrats without any animal detection (density of zero).
- Variance ( $\text{var } d$ ): The variance associated with density ( $d$ ) is expressed as a unbiased estimator of variance (Thompson et al. 1992), by the equation

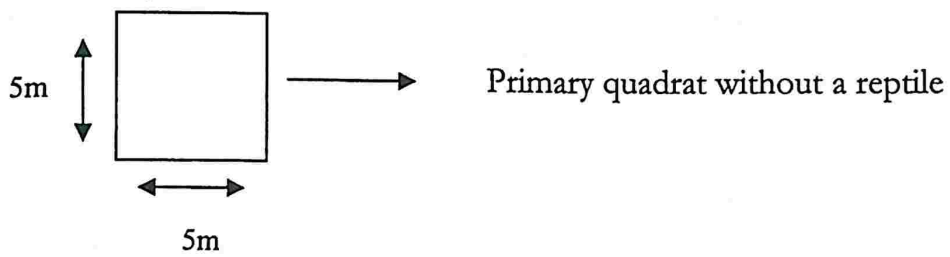
$$\text{var } d = \frac{(Y - N) \sum_{i=1}^n (w_j - d)^2}{YN (N - 1)}$$

where  $\text{var } d$  is the variance,  $Y$ =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<sup>2</sup>) of the target area that was sampled, and  $N$ = the number of primary quadrats laid in the area.

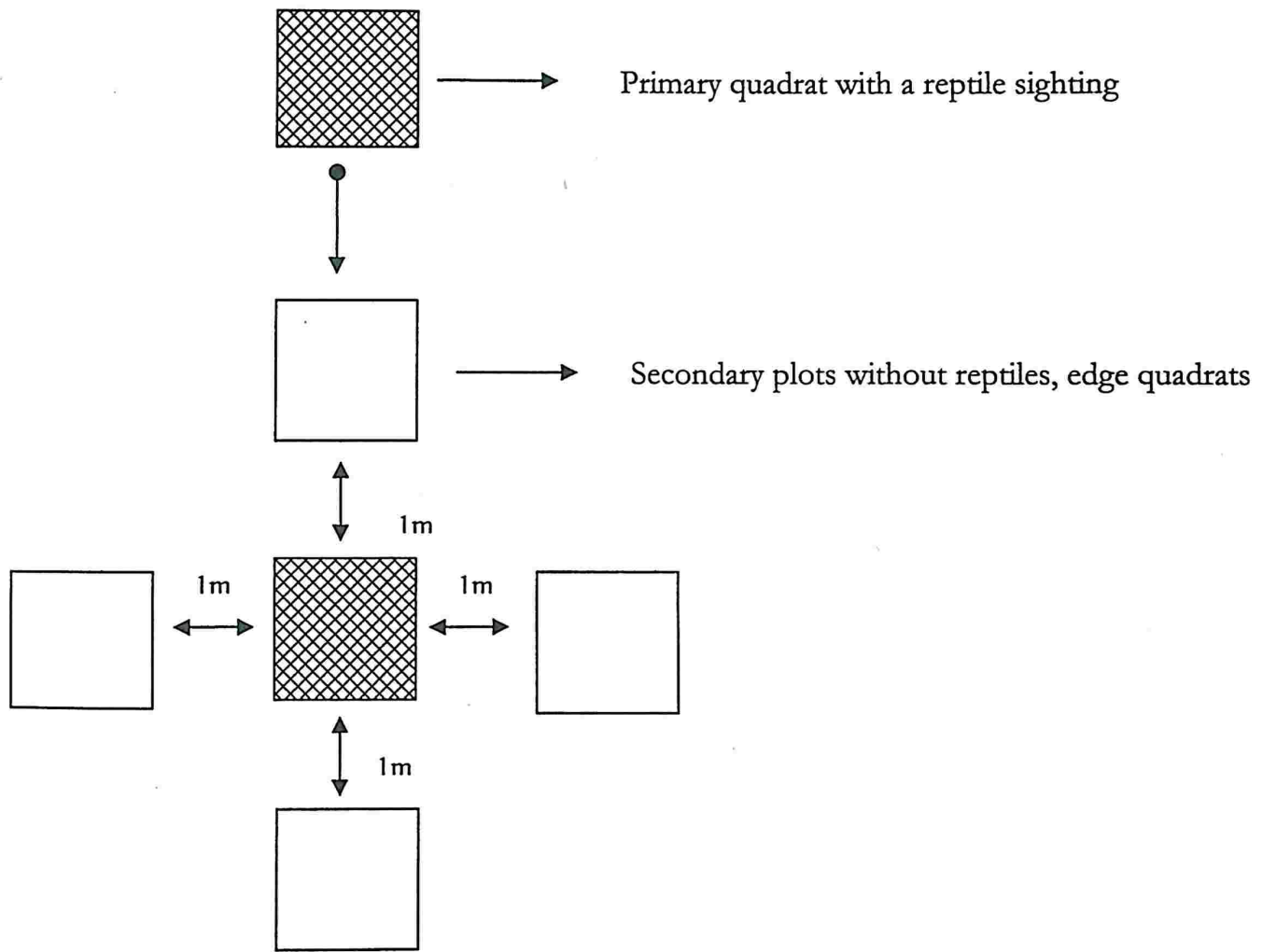
- Community composition: The percentage of different taxa of reptiles (geckos, skinks, agamids and snakes), out of the total number of reptiles recorded from the quadrats.

A schematic representation of the adaptive cluster sampling design and the calculations used therein is given in Figure 3.1.

As this method was mainly directed towards the leaf litter habitat or the forest floor the targeted animals were the leaf litter dwelling rainforest reptiles like geckos, skinks and a few species of snakes. Adaptive cluster sampling was carried out between 0700 hrs to 1730 hrs. An approximate area of one square kilometre was identified as the target area for adaptive cluster sampling at each of the three sites in KMTR for intensive sampling. Adaptive cluster sampling was also carried out in the rainforest fragments and the number of primary quadrats laid was in proportion to the area of the fragment.

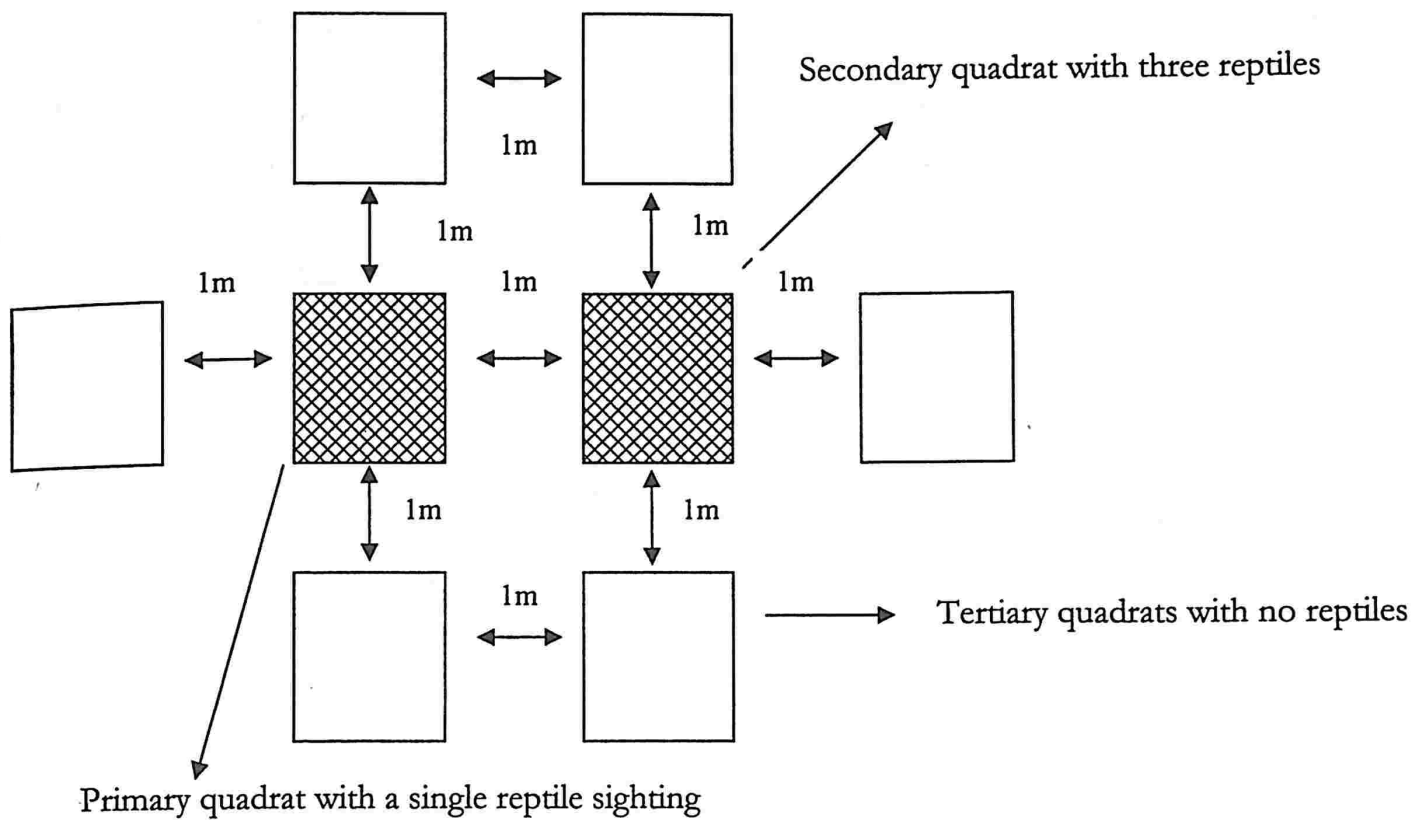


a) A primary quadrat with no reptile detection. Network size = 0, Density = 0 animal/quadrat.



b) Primary quadrat recording at least one reptile. This leads to the placement of four secondary quadrats. Since no reptiles were recorded in these secondary quadrats, these are the edge plots. Network size = 1, Density = 1 animal/quadrat.

Figure 3.1. Placement rules and design for adaptive cluster sampling. The calculations for network size and density estimates are outlined in Figures a to c.



c) A secondary quadrat records three reptiles. This leads to the placement of three additional tertiary quadrats. Since no reptiles were recorded in these quadrats, they are the edge quadrats. Network size = 2, Density = 2 animals/quadrat.

Figure 3.1. Placement rules and design for adaptive cluster sampling. The calculation for network size and density estimates is outlined in Figures a to c.

### 3.1.3 Forest transects: A sampling protocol for arboreal rainforest reptiles

Forest transects were either existing forest trails or freshly cut on a fixed compass bearing before the commencement of intensive sampling. Each transect was 250 m in length and was permanently marked at every 25 m interval. Forest transects were slowly walked by two observers without causing any disturbance to the understorey, and scanning the understorey (on tree trunks, herbs and shrubs up to 8 m in height). The average time taken to walk a transect was about 90 minutes. Reptiles encountered were recorded along with details of their microhabitats and activity. This survey method was nondestructive search (*i.e.* it did not involve active turning over of leaf litter and rocks or the pulling apart of fallen logs as done in the quadrat search). Sightings were generally restricted to 3 m on either side of the transect, and up to a height of 8 m, since the visibility decreased beyond these distances in the rainforest.

Care was taken to lay transects as far apart from each other as possible within the area identified for intensive sampling. The variation in altitude within any individual transect was  $< 50$  m. Most of the reptiles sighted in the transects were collected for identification and after recording morphometric measurements were released at the same point where they were captured after transect sampling was completed.

Variations of the forest transect method, mainly in transect length, have been used in the study of herpetofauna in Costa Rica (Heyer 1967), and in the study of *Anolis* lizards in the rainforest of Puerto Rico (Regan 1992). It was decided to limit the transect length to 250 m for this study so as to minimize the variation in altitude within individual transects, as the rainforests in the Western Ghats are in a highly undulating terrain. Transects  $> 250$  m will increase the variation in altitude, and introduce an additional source of variation, as altitude is known to cause a turnover of reptile species.

The following parameters were estimated from this data set for each forest transect:

- Encounter rates: estimated as the mean of the number of individual reptiles recorded in the nine replicates.
- Reptile species richness: the total number of species recorded in all the replicates.
- Species composition: the percentage of individuals in each taxa such as agamids, snakes and geckos out of the total number of individuals recorded from all the transects, including replicates in each of the study sites.

As this method was directed towards the understorey, the animals sampled were the arboreal reptiles like agamids, snakes and a few species of arboreal geckos.

#### **3.1.4 Stream surveys/Visual encounter surveys (VES)**

This method has been formalized as time constrained search by Corn and Bury (1990). This method was carried out along second order streams between 1930 hrs to 2300 hrs and involved two persons with spotlights walking abreast, along streams. The observers walked on either side of the stream looking along the water edge, rocks, rocky crevices and over hanging roots for reptiles. All reptile sightings were recorded along with details of microhabitat and time of sighting. This method involved minimal disturbance to the area sampled. The stream stretches were 100 m in length and permanently marked at intervals of 25 m. The duration of sampling was ca. 60 minutes. For a detailed discussion on VES refer to Crump and Scott (p.85, 1994).

Primarily nocturnal snakes (pit vipers and cat snakes), and a few species of geckos were sampled by this method. I have used data from this method, only to estimate overall species richness at each site.

#### **3.1.5 Opportunistic sampling**

Apart from the methods mentioned earlier, records of opportunistic sightings of reptiles were maintained along with the associated microhabitat information. This enabled the preparation of a more comprehensive species list for each of the sites sampled.

## **3.2 HABITAT SAMPLING**

### **3.2.1 Leaf litter reptiles: Adaptive cluster sampling**

Habitat parameters recorded within a quadrat can be categorized into (1) Physiographic variables such as elevation, slope, soil moisture, soil and atmospheric temperature and soil pH; (2) Vegetation variables such as canopy height and cover, number of trees in a quadrat and basal area, number of buttressed trees, root cover, rock cover, litter cover, shrub density, herb density and fallen logs; and (3) Other microhabitat features such as rocks, litter depth, number of burrows and tree holes (Appendix 1).

### **3.2.2 Arboreal reptiles: Forest transects**

Habitat data were collected at every 25 m along each transect, by laying 3 m x 3 m plots. Apart from this, similar 3 m x 3 m plots were also laid for collecting vegetation and microclimate details around the site of each reptile sighting. Information on variables like soil and atmospheric temperature, soil moisture, and soil pH for each sampling session for each transect were recorded at every 25 m interval. The habitat variables recorded in the 3 m x 3 m plots were similar to those recorded in the quadrats reflecting topography, vegetation and microclimate of the transect sampled (Appendix 1).

## **3.3 SAMPLING SEASONS**

Reptiles were sampled on a seasonal basis in both study areas. Three distinct seasons were identified based on rainfall patterns; south-west monsoon (June to September), north-east monsoon (October to January), and dry season or summer (February to May). Forest transects were replicated thrice per season, hence each transect was replicated nine times, while fresh quadrats were laid in each of the study sites for every new season.

### 3.4 SAMPLING INTENSITY

#### 3.4.1 Contiguous rainforests

Sampling was carried out in the contiguous rainforests of KMTR from March 1997 to May 1998. The sampling intensity was equal in the three study sites, and the realised sampling effort for the three methods is given in Table 3.1.

#### 3.4.2 Forest fragments

Sampling was carried out in the rainforest fragments of Anamalai Hills from June 1998 to May 1999. Area of the fragment dictated the sampling intensity. Based on area, fragments were categorized into four size classes. The sampling intensity that was realized in these rainforest fragments is given in Table 3.2.

**Table 3.1. Sampling intensity in the contiguous rainforests of KMTR during 1997-1998.**

Site	Adaptive cluster sampling		No. of transects*	No. of stream surveys†
	No. of primary quadrats	Total no. of quadrats		
Kakachi	218	234	6	2
Sengaltheri	212	236	6	2
Kannikatti	146	161	6	2
Total	576	631	18	6

\* each transect was replicated thrice in each of the three seasons

† each stream segment was replicated twice in each of the three seasons.

**Table 3.2. Sampling intensity in the rainforest fragments in Anamalai Hills during 1998-1999. Figures in parenthesis are the number of fragments in each of the size categories.**

Fragment size (# fragments)	Adaptive cluster sampling		No. of transects*	No. of stream surveys†
	No. of primary quadrats	Total no. of quadrats		
Very large (1) >200 ha	109	121	8	2
Large (3) 50-200 ha	148	162	12	6
Medium (5) 10-50 ha	125	148	8	3
Small (5) <10 ha	78	93	5	nil
Total (14)	460	524	33	11

\* each transect was replicated thrice in each of the three seasons

† the small fragments do not have stream segments. The stream surveys were replicated twice in each of the three seasons.

### 3.5 DATA ANALYSIS

#### 3.5.1 General considerations for statistical analysis

All variables measured were tested for normal distribution using Kolmogorov – Smirnov One Sample Test and parametric procedures were adopted for normally distributed data (Sokal and Rohlf 1995). When data were not normally distributed, non-parametric tests were preferred; Mann-Whitney U test was used to test for significant differences between two independent samples, while the Kruskal-Wallis one-way analysis of variance was used for independent samples (Siegel and Castellan 1988). For correlation analysis, Pearson's product moment correlation coefficient was used for normally distributed data while Spearman's rank and Kendall's coefficients were computed for non-normal and ordinal data. Ordination and classification were performed using appropriate multivariate techniques (Harris 1985; Manly 1994). All the analyses (unless stated otherwise), were carried out using the statistical packages SPSS<sup>®</sup> (version 8.0), and S-Plus 2000 on a Windows NT platform.

All abundance comparisons among taxonomic groups were based on equal sample effort across taxa. In addition, I assumed that all species were detected in equal proportions in quadrat and transect surveys.

### **3.5.2 Leaf litter reptiles**

The procedures for estimating network size, species richness and abundance per network, density per network and density in an area have already been explained while discussing adaptive cluster sampling. Spatio-temporal variation in the above-mentioned parameters was examined by pooling data from all primary quadrats for each site (in contiguous rainforests), and the different size categories of fragments (in Anamalai Hills), and for each season as the case may be.

### **3.5.3 Arboreal reptiles**

The procedures for obtaining encounter rates, species richness and abundance per forest transect have already been explained while discussing this sampling. Spatio-temporal variation in the above-mentioned parameters was examined by pooling data for all transects (including replicates), at each site (in contiguous rainforests), and the different size categories of fragments (in Anamalai Hills), and for each season as the case may be.

### **3.5.4 Overall community structure and endemism**

Data from all methods were pooled to explore patterns of species richness, while only data from the adaptive cluster sampling and transects were considered to estimate the abundance patterns of rainforest reptiles. Restricted-range (endemic), species were treated at two levels, a) species endemic to the Western Ghats region and b) species endemic and restricted to the rainforests of the Western Ghats.

### **3.5.5 Similarity measures**

The Morisita-Horn measure of similarity (Magurran 1988) was used to assess the similarity between sites in both the leaf litter and arboreal assemblages (in terms of species richness and abundance). For the leaf litter reptiles, the pooled data of the primary quadrat for each site (in contiguous rainforests), and different size classes of

fragments in Anamalai Hills were used. While for the arboreal reptiles, pooled data for each transect (including replicates), was used for each site, (for contiguous rainforests), and different size classes of fragments (for Anamalai Hills).

### **3.5.6 The effects of altitude and temperature on arboreal reptiles**

The effects of altitude, and atmospheric and substrate temperature on the arboreal reptile assemblage were examined using only the data from the forest transects. As reptile sightings were few and sampling effort was the same for all seasons, it was necessary to pool data (including replicates) for all the seasons in order to estimate reptile abundance and species richness in each transect. Linear and quadratic models were used to examine the relationship among macrohabitat variables and reptile community variables. The quadratic model 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 model.

The composition of arboreal reptiles (in terms of species richness and abundance), for each transect was used to develop similarity matrices, which were then subjected to cluster analysis using Ward's algorithm. The resultant dendrograms were examined for determining patterns in community organization.

### **3.5.7 Microhabitat associations**

The protocol for data analysis was similar for both the leaf litter and the arboreal reptile assemblages. The mean values of all the microhabitat variables measured for each network (for the leaf litter reptiles), and transect (in the case of arboreal reptiles), were used to characterize the habitat features.

The association between habitat features and reptile communities were analyzed using bivariate and multivariate techniques. To ascertain the best linear combination of habitat variables that explained the segregation of reptile species with the least degree of variation, one-way ANOVA was used. I attempted to reduce the dimensionality of the many microhabitat variables using Principal Component Analysis (PCA). As this

approach did not result in any major data reduction and as the resulting components were not ecologically meaningful, Discriminant Function Analysis (DFA), was used for micro habitat preference. For both PCA and DFA the analytical procedures followed Manly (1994). Discriminant function analysis is an useful tool when the objective is to assign a species to one of the pre-identified community classes using a set of classification functions, which are derived from species – environment associations. In order to make the discrimination stronger, only those variables that were important to the discriminating capability were included, while the other variables were removed from the analysis. Discriminant function analysis assumes homogeneity of covariance matrices between the two groups, which is tested by the Box's M test. This test is very sensitive to meeting the assumption of multivariate normality. Moreover, when n is very small or large, small deviations from homogeneity will be found significant, however, the analysis is robust even when the assumptions of homogeneity of variance is not met, provided there are no outliers, shown by minimal difference in the log determinant values of the independent variables (Norusis 1986). The results presented are the tests of equality of group means (an ANOVA table, showing the importance of the independent variable to the discriminant function), the Log determinants and the structure matrix (which identifies the largest absolute correlation associated with each discriminant function, similar to factor loading in PCA, with which one identifies the function). Box-and-Whiskers plots are presented to depict the difference in the microhabitat associations among taxa. These plots provide more summary information that includes the medians, quartiles, ranges and outliers than other graphical methods (Ellison 1993). The statistical difference in the discriminant function scores between two groups was tested using the Mann-Whitney U test. The difference in the discriminant function scores among different taxa (>2 groups), was tested using ANOVA. Bonferroni *post hoc* multiple comparison test was used when the variance was equal, while Tamhane's T2 test was used when the variance was unequal.

The majority of the analyses were restricted to the higher-level taxon such as Family for geckos, skinks and agamids and Order for snakes. Species-level analysis was not attempted due to low encounter rates of several species. Since there might be differences between adult and juvenile reptiles in their habitat preferences (Reinert 1993), only adult reptiles (classified based on size), were included in the analysis.

For the leaf litter assemblage, the low number of detections of agamids and snakes necessitated the grouping of these two into a single group, labelled Others. The likelihood of reptiles forming aggregations of the different species/taxa was rare. As the total number of such aggregations, were fewer than five it was necessary to combine them into the category labelled Others. Consequently, too much should not be read into the pattern that was observed in the group, labelled Others.

### **3.5.8 Nested subset analysis**

MacArthur and Wilson (1967) first established the relationship between species richness and island size, and this model was later applied to rainforest fragments (Blake 1991). Island biogeography theory (MacArthur and Wilson 1967) predicts that larger islands will support more species than the smaller ones. In other words, smaller islands in terms of species composition would tend to be a subset of larger islands showing a time-series gradient of species-area relationship. The present study tested this prediction for reptile communities and rainforest fragments. This was also used to find out sensitive and vulnerable species that may be in danger of extinction due to habitat fragmentation. In this study, the forest fragments are habitat islands.

To test the hypothesis that reptilian communities in the rainforest fragments were nested, the 'Temperature Calculator', a Windows-based Visual Basic program was used to calculate 'T' (the temperature of the matrix) (Atmar and Patterson 1995). The system temperature 'T' is a measure of disorder apparent in extinction order and is defined to vary from 0° (completely replicable extinction order) to 100° (completely random extinction order). In other words species composition shows a completely nested distribution to being a completely random species composition. As the system

randomness increases, the unexpected presences and absences move further away from the extinction line and hence raises the temperature of the system (Patterson and Atmar 2000). The reorganized vectors were used to prioritize fragments based on the species richness information and also to identify the species that are likely to go extinct due to rainforest fragmentation.

### **3.5.9 Species richness and habitat fragmentation**

To test the hypothesis that rainforest fragmentation is the actual cause for the decline in species richness and not fragment size, it is necessary to control for the effects of area. The influence of altitude on reptilian species distribution and abundance has been well established (see the following chapters), consequently, altitude, in addition to area, has also to be controlled for. This analysis was carried out only for the leaf litter reptiles. The expected values of species richness were obtained from the contiguous, relatively undisturbed sites of KMTR, and the observed values were from the fragmented, disturbed sites of Anamalai Hills (the pooled data from all the size categories of remnant fragments). For the leaf litter assemblage, a total of 100 network plots were used to construct species accumulation curves. Four separate species accumulation curves were drawn using the data set from the four size categories of fragments (observed values), and from comparable altitudinal ranges from KMTR (as expected values).

## **3.6 COLLECTIONS AND IDENTIFICATION OF SPECIES**

The identification of reptiles encountered in a study and the re-evaluation of the findings of past studies are greatly aided by the availability of voucher specimens. Accurate identification of species belonging to some genera of reptiles is rarely possible, largely due to the lack of a comprehensive field guide and the rather obscure features used for identification. Under the present circumstances, it is essential that voucher specimens are collected and maintained under standard conditions. This will enable the taxonomists to examine the specimens and improve the existing dichotomous keys.

Representative samples of reptiles belonging to all species encountered were collected during sampling in plastic bags (for geckos, skinks and agamids) and in cloth bags (for snakes). The collected animals were euthanised in ether or chloroform and later fixed in 10% formaldehyde solution. Initially these were fixed (to maintain the specimen in its natural position, so as to enable easy examination later on), by keeping them in a tray with small quantity of 30 % formalin and covered with a clean cloth soaked in formalin. After 24 hrs, they were washed and kept in large containers with 10% formalin. The procedure for preservation follows Simmons (1987) and Reynolds et al. (1994). Specimens were individually tagged with records of the locality, date, altitude and the tentative identity of the species. These containers were stored in a dark place that had relatively low temperature fluctuations.

Species identification was done by examining the individuals using the taxa specific keys. The taxonomic keys that were largely followed were the ones published by Smith (1933, 1935, 1943). Some of the other keys that were also referred to were Murthy (1985, 1990; for lizards and snakes), Rajendran (1985; for uropeltids), and Wall (1923; for snakes). Doubtful species were not assigned specific names, but were identified with some distinct morphological characters. These were then assigned numbers, and considered as valid species for the purpose of analysis. This was a common problem for reptiles belonging to the genus *Cnemaspis* and *Scincella*.

## CHAPTER 4

# REPTILES IN THE CONTIGUOUS RAINFORESTS: DISTRIBUTION PATTERNS IN KALAKAD-MUNDANTHURAI TIGER RESERVE

### 4.1 INTRODUCTION

The distributions of plants and animals on local, regional and global scales have been of great interest to biologists (MacArthur 1972; Owen 1989; Pianka 1983). An understanding of the distribution patterns and their causative factors are not only of academic interest, but is fundamental to the conservation of biodiversity. There are a number of factors that influence the species richness and distribution of fauna and flora. Broadly, they operate at two spatial scales; the life zone and the biotic zone (Stuart 1955). As defined by Heyer (1967) the life zone is an ecological, altitudinal or latitudinal zone characterized by specific climatic parameters and secondarily by vegetation. A biotic zone is a geographic region characterized by an unique combination of fauna and flora, and may encompass several life zones. The biotic zone seems to have gained credence over the life zone concept in explaining the pattern and reasons for species distribution.

Species richness and distribution of plants and animals have been known to vary along several gradients, and a few of these gradients have been documented to be universal across time and geographical scale (Rosenzweig 1995). One such universally recognized pattern in species richness is the latitudinal gradient, *i.e.* the concomitant increase in species richness from the poles to the tropics (for reviews see Stevens 1989; Rhode 1992). This has been documented across taxa that include trees, invertebrates, marine fish, lizards and birds (Stevens 1989; Rhode 1992; Rosenzweig 1995). The other most widely recognized pattern is the decrease in species richness along an elevational gradient that is often claimed to mirror the latitudinal gradient (for reviews see Stevens 1992; Blackburn and Gaston 1996; Rahbek 1997). Other gradients documented include a positive correlation between species richness and temperature and increase in species richness with an increase in spatial heterogeneity with an associated decrease in temporal heterogeneity. These patterns largely explain why tropical areas are species rich in fauna and flora

compared to temperate areas. The explanations for these patterns, like higher productivity, higher niche diversity, greater predation, greater evolutionary age and stable climate in the tropics are debatable (Rosenzweig 1995). Another interesting explanation for the latitudinal gradient is that the tropics cover greater geographical area than any other region (Terborgh 1973). Although greater species richness in the tropics is unmistakable, there is considerable disagreement on the mechanisms that mediate these patterns, with greater productivity and evolutionary age gaining greater acceptance.

Patterns of reptile species distribution and abundance in the various geographic regions, across vegetation and elevation gradients have been well documented. Arnold (1972), found a latitudinal gradient on a global scale while Schall and Pianka (1978) showed the same pattern for the Nearctic region. The presence of a elevation gradient in reptile species richness has been shown by many studies in the tropical and extra-tropical areas (Brown and Alcala 1961; Heyer 1967; Heatwole 1982; Scott 1976; Fauth et al. 1989; Owen 1989; Woinarski and Gambold 1992), all confirming that reptiles are restricted latitudinally and altitudinally, primarily by low temperature (Porter 1972). Duellman (1989) hypothesized that areas with higher environmental stability and vegetational heterogeneity may support greater number of herpetofaunal species than less stable and less heterogeneous areas, while Inger (1980a), hypothesized that litter productivity could be the main factor determining reptile abundance and species richness.

The rich reptilian fauna of South Asia has received very little attention in the search for patterns of species richness and their spatial distribution along various gradients. Most of the studies mentioned above on reptile species richness, distribution and community assemblage are in tropical areas, but outside the Indian subcontinent. This is very surprising given the high levels of endemism in the tropical rainforests of Asia, especially the Western Ghats that has been identified as one of the 25 hotspots of diversity in the world (Myers et al. 2000). Inger's study on the ecological structure of a herpetofaunal assemblage in a small area of tropical forest in South

India has been the only noteworthy work in this region (Inger et al. 1987), while Bhupathy and Kannan (1997), studied the distribution of agamids in the Western Ghats. It is against this backdrop that the present study on the distribution, species richness and abundance of rainforest reptiles in the Western Ghats, gains significance.

## **4.2 OBJECTIVES**

The major objectives in this component of the study were:

- To determine the species composition of the leaf litter and arboreal reptilian assemblages in the contiguous rainforests of Kalakad-Mundanthurai Tiger Reserve.
- To compare the distribution patterns of leaf litter and arboreal reptiles in the contiguous rainforests between seasons and sites.

## **4.3 STUDY AREA**

Three sites, namely Kannikatti, Sengaltheri and Kakachi, were selected for intensive sampling in the contiguous rainforests of Kalakad-Mundanthurai Tiger Reserve (Figure 2.1).

## **4.4 METHODS AND ANALYSIS**

The leaf litter and arboreal reptile assemblages were sampled using adaptive cluster sampling and forest transects, respectively. Details on the sampling protocol and the framework for analysis have been given in the preceding chapter (Chapter 3, section 3.5).

## 4.5 RESULTS

### 4.5.1 Leaf litter reptiles

#### 4.5.1.1 *Distribution patterns*

A total of 576 primary quadrats, 143 secondary quadrats and 310 edge quadrats were sampled in three seasons and at the three sites. Seventeen species, totalling 243 individuals were recorded by adaptive cluster sampling. Reptiles were sparsely distributed with only 91 (15.77%), of the primary quadrats recording detections.

Reptiles did not form large clusters, since 80 quadrats (87.91%), had a network size of  $\leq 2$ . Of these 80 quadrats, 55 (60.43%), quadrats had a network size of only one (a single quadrat with  $\mu = 1$  reptile), indicating that the rainforest litter reptiles are not clumped in their distribution (Figure 4.1).

The total number of species in a network varied from one to four, with only five (5.49%,  $n=91$ ), of the networks recording more than two species and as many as 69.24% of the networks recording only a single reptile species. The rainforest leaf litter reptiles, therefore, do not form local-scale, multi-species assemblages (Figure 4.2). The number of reptiles in a network varied from one to seven with a mean of 2.78 (SE= 0.17), and a median of two individuals. Leaf litter reptiles did not form large aggregations, since 58.24% (53), of the networks supported  $\leq 2$  individuals (Figure 4.3).

Figure 4.1. Network size of leaf litter reptiles, KMTR (1997-98)

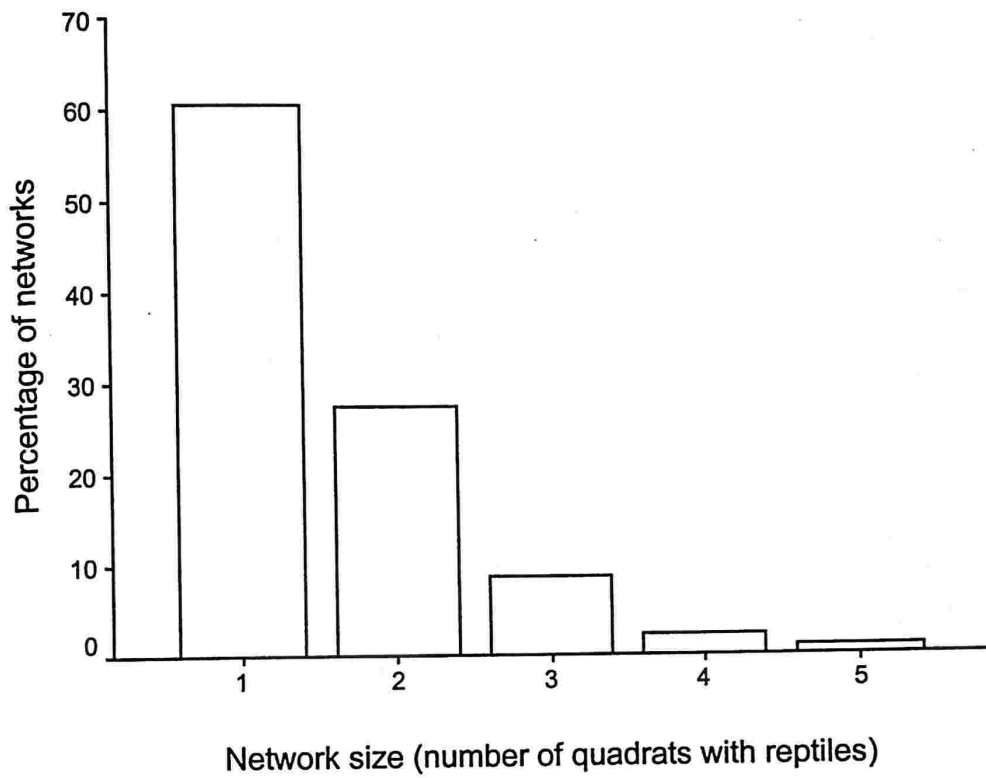


Figure 4.2 Number of reptile species/network, KMTR (1997-98)

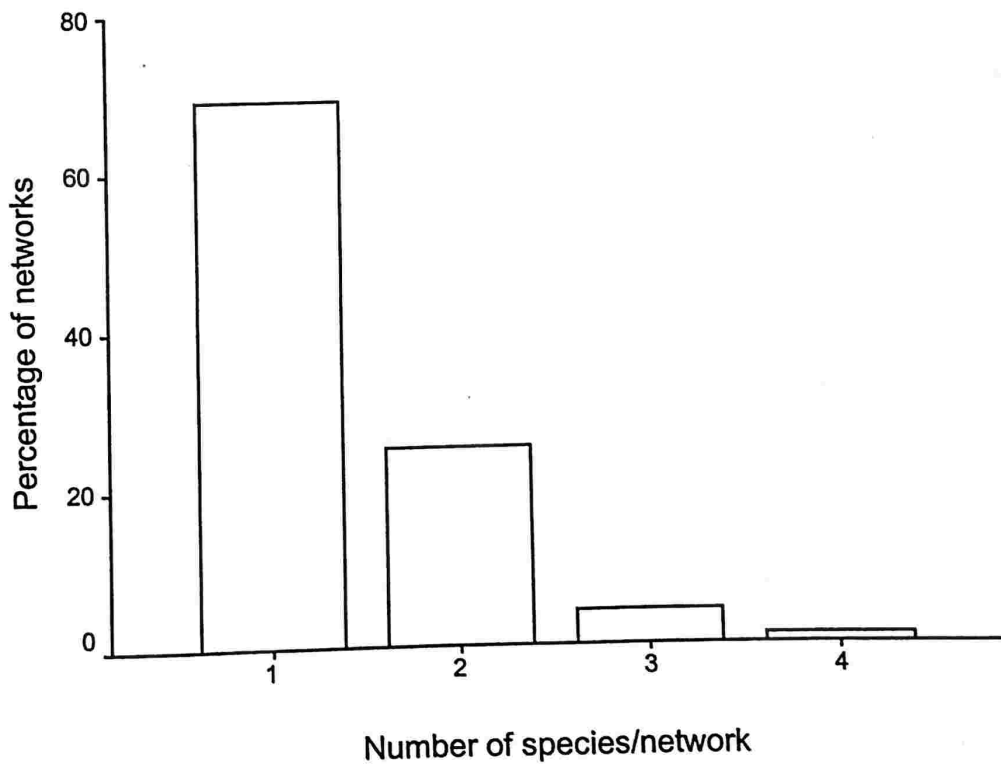
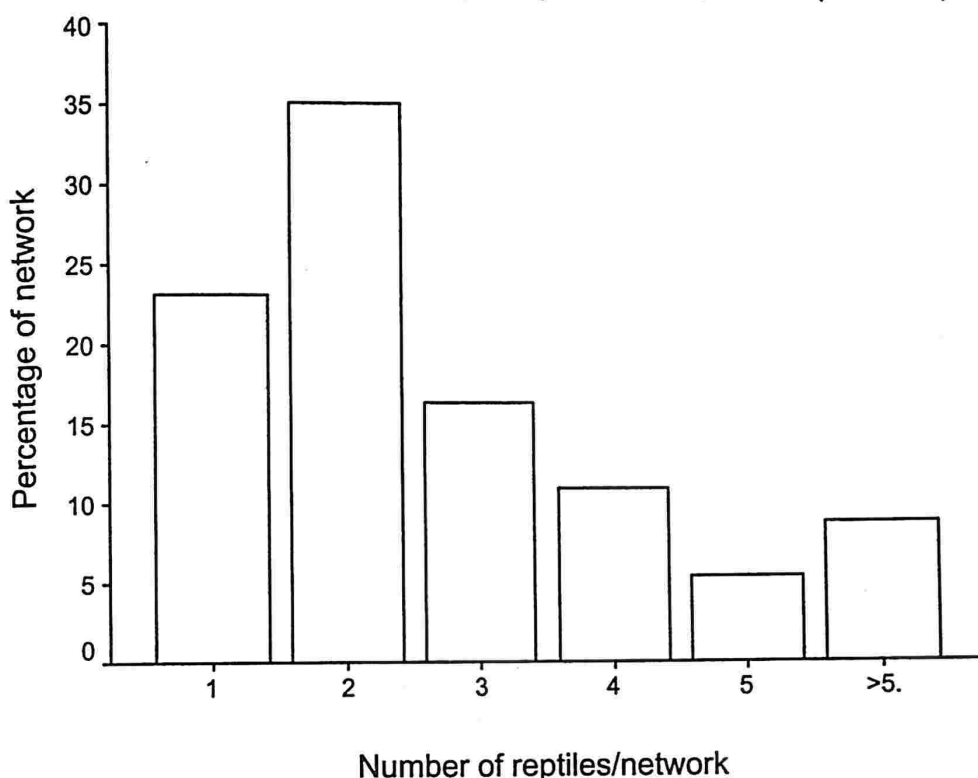


Figure 4.3. Number of reptiles per network, KMTR (1997-98)



#### 4.5.1.2 Abundance and community composition

The abundance of leaf litter reptiles in the contiguous rainforests was low, with 10 (58.88%), of the 17 species represented by  $\leq 5$  individuals (Table 4.1). Consequently, the analysis of community composition was done at a higher taxa level, namely Families for geckos, skinks and agamids, while for snakes it was at the Order level.

Geckos of the genus *Cnemaspis* (the dwarf/day geckos), were the most dominant taxon accounting for 48.14% (117), of the individuals. Skinks, mainly of two genera (*Mabuya* and *Scincella*), were the second most dominant taxon, totalling 101 individuals (41.56%). Agamids normally arboreal in their habit were also recorded in the litter and accounted for 6.99% of the sightings. Snakes were represented in the leaf litter community by five species totalling only eight individuals.

Table 4.1. Leaf litter reptile species and number of individuals recorded by adaptive cluster sampling in the contiguous rainforest of KMTR, (1997-98).

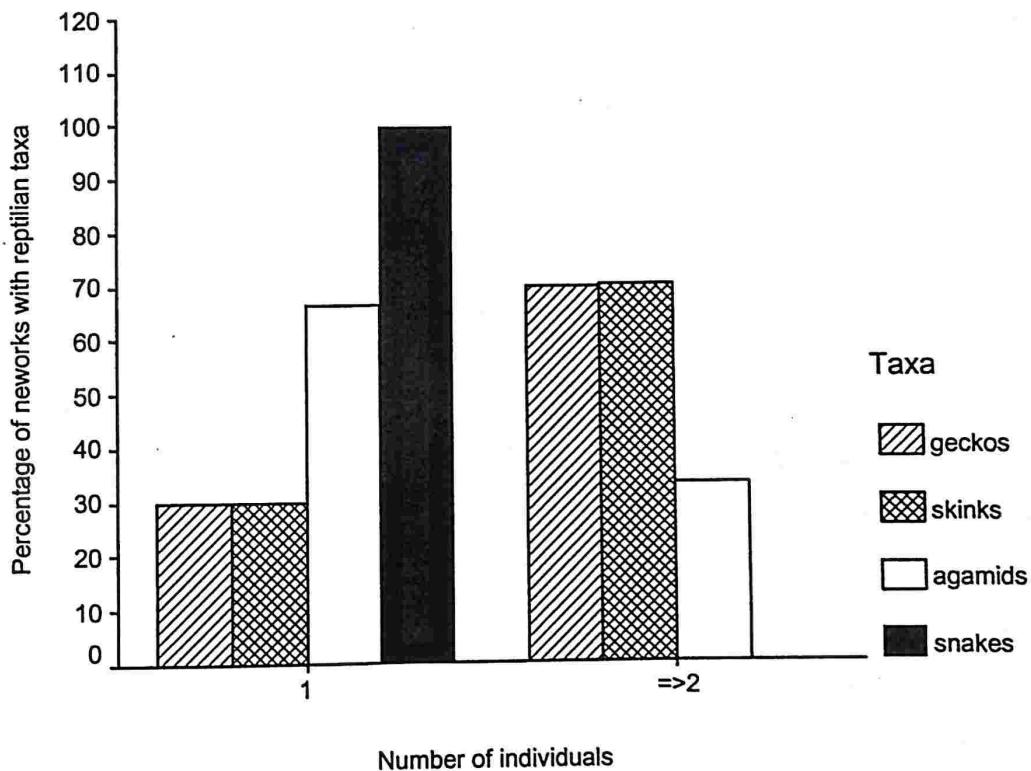
SPECIES	SITE			
	Kannikatti	Sengaltheri	Kakachi	Total
<i>Cnemaspis indica</i>	26	32	2	60
<i>C. ornatus</i>	16	20	4	40
<i>C. mysoriensis</i>	0	2	0	2
<i>Cnemaspis</i> spp 1 (white belly)	3	1	0	4
<i>Cnemaspis</i> spp 3 (red eye)	1	0	10	11
<i>Calotes ellioti</i>	9	1	0	10
<i>C. rouxii</i>	0	1	0	1
<i>Draco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

Geckos and skinks dominated the assemblage with almost 90% (n=243), of all the sightings. At a species level, *Cnemaspis indica* was the most abundant species accounting for 24.69% of the assemblage, followed by *Mabuya beddomii* (20.16%), and *Scincella travancoricum*, a species endemic to the rainforests of the Western Ghats (19.34%).

To test the hypothesis that the taxa differed in their tendency to form aggregations, a contingency table analysis to test for the homogeneity of proportions among the

taxa with respect to the number of individuals in a network was carried out. The taxa varied in their tendency to be found in aggregations of more than two individuals per network (Pearson  $\chi^2 = 18.19$ ,  $df = 6$ ,  $P < 0.01$ ). Geckos and skinks were more likely to occur in aggregations than the other taxa of reptiles. Skinks were recorded from 51.64% (n=91), of networks, 70.20% of which supported 2 to 7 individuals. Similarly, of the 54.94% (n=91), networks recording geckos, 70% supported 2 to 7 individuals. Snakes were always recorded as solitary individuals, while agamids were recorded from only 13.19% (n=91), of networks, with only four networks (33.30%), recording more than 2 individuals, with a maximum of 3 individuals (Figure 4.4).

Figure 4.4. Aggregation of leaf litter reptiles/network, KMTR (1997-98)



#### 4.5.1.3 Density estimates

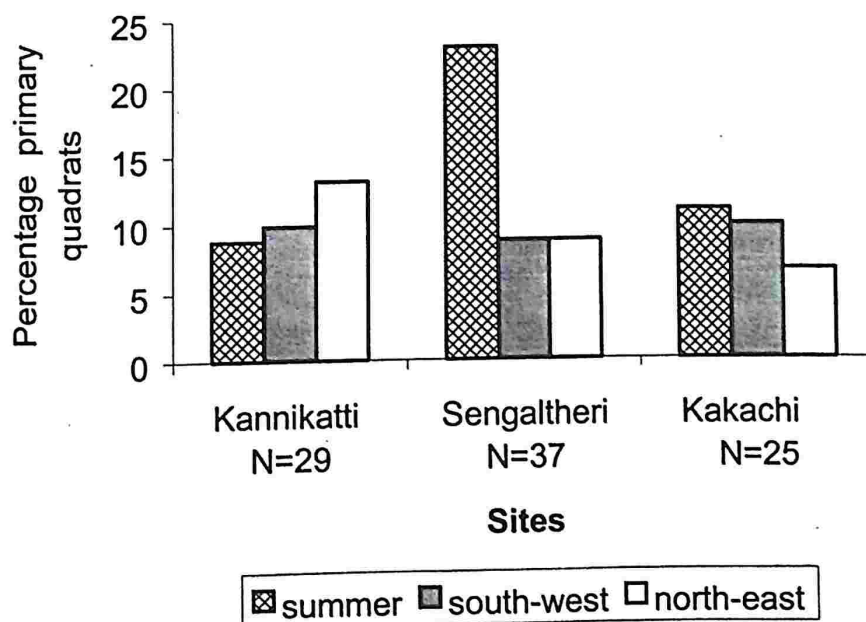
The overall density of leaf litter reptiles was 0.28 animals/25 m<sup>2</sup> quadrat, with a variance ( $y$ ), of 0.001 ( $n= 576$ ). Geckos had the highest densities (0.13 animals/quadrat), followed by skinks (0.12 animals/quadrat). The densities of agamids (0.02 animals/quadrat), and snakes (0.01 animals/quadrat), were considerably lower.

#### 4.5.1.4 Inter-site and seasonal variation

##### Network abundance

The number of primary quadrats with reptiles varied between sites and seasons. Among sites it was maximum in Sengaltheri, with reptile detections in 37 primary quadrats (40.66%,  $n=91$ ), and lowest in Kakachi with detections in 25 primary quadrats (27.47%,  $n=91$ ). Among seasons, the maximum detections were in summer with 39 of the primary quadrats recording reptiles (42.86%,  $n=91$ ), while for both south-west and north-east monsoon the number of primary quadrats with litter reptiles was 26 each (28.57%,  $n=91$ ) (Figure 4.5).

Figure 4.5. Percentage of primary quadrats with reptiles across seasons, KMTR (1997-1998) N=91



There was a difference in the number of primary quadrats with reptiles among sites, when data were pooled for seasons (KW  $\chi^2 = 5.71$ , df=2, P= 0.05), and for seasons when data were pooled for sites (KW  $\chi^2 = 12.64$ , df=2, P= 0.002).

#### Network size

Network size did not show any variation among sites, when data were pooled across seasons (KW  $\chi^2 = 0.17$ , df=2, P= 0.92). Seasonal variation in network size was also insignificant when data were pooled across sites (KW  $\chi^2 = 1.61$ , df=2, P= 0.45).

#### Total abundance

Sengaltheri had greater abundance of leaf litter reptiles in south-west monsoon with 57 individuals (54.81%, n=104), while at Kakachi, abundance was greater in summer with 27 individuals (45.76%, n=59). Kannikatti had greater abundance during the north-east monsoon with 32 individuals (40%, n=80).

#### Abundance per network

The number of litter reptiles per network varied between sites and seasons, but the difference was not statistically significant. When data were pooled for the three seasons, abundance was highest in Sengaltheri and lowest in Kakachi. There was no difference between sites (KW  $\chi^2 = 1.44$ , df=2, P= 0.49), and between seasons (KW  $\chi^2 = 0.35$ , df=2, P= 0.85), in the abundance of leaf litter reptiles per network when data was pooled for seasons and sites respectively.

#### Species richness per network

The number of reptile species per network was different among sites when data were pooled across seasons (KW  $\chi^2 = 12.06$ , df=2, P= 0.002). Between seasons the difference in the number of reptiles species per network was insignificant (KW  $\chi^2 = 0.17$ , df=2, P= 0.92). Reptile species richness per network varied between the three sites but there was no difference between the individual seasons (Table 4.2).

**Table 4.2. Mann-Whitney U Test for 2 Independent samples (Z Statistic), to test for differences in the number of reptile species per network between sites and seasons, KMTR (1997-98). Figures in parenthesis give the mean and SE values of reptile species per network.**

SITE			SEASON				
	Kannikatti (1.62 ± 0.13)	Sengaltheri (1.38 ± 0.11)	Kakachi (1.08 ± 0.05)		Summer (1.38 ± 0.11)	SW monsoon (1.38 ± 0.11)	NE monsoon (1.35 ± 0.11)
Kannikatti		1.766	3.446***	Summer		0.398	0.101
Sengaltheri			2.078*	SW monsoon			0.279

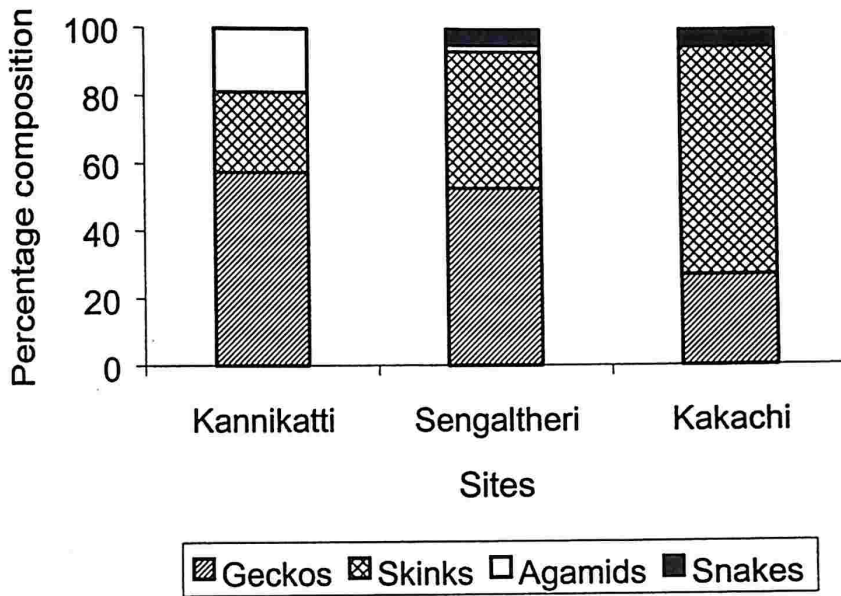
\*Significant at P<0.05, \*\*\*Significant at P<0.001. (two tailed test).

### Community composition

The community composition of leaf litter reptiles varied considerably among the three sites. The abundance of reptiles was highest in Sengaltheri and lowest in Kakachi. Geckos dominated the assemblage in both Sengaltheri (52.88%, n=104), and Kannikatti (57.5%, n=80). In Kakachi, skinks (69.49%, n=59), were the most dominant taxon. In all the three sites, the contribution of agamids and snakes was minimal (Figure 4.6). However, agamids were relatively more abundant in Kannikatti (7.5%), and absent in Kakachi, while snakes were more abundant in Kakachi (3.39%), and absent in Kannikatti.

In the leaf litter assemblage, all geckos belonged to the genus *Cnemaspis* (dwarf or day geckos). *Cnemaspis indica* was the most abundant species among all reptiles in Kannikatti with 26 individuals (32.5%, n=80), and in Sengaltheri with 32 individuals (30.77%, n=104). In Kakachi, however, only 16 individuals of genus *Cnemaspis* were recorded.

Figure 4.6 The percentage composition of leaf litter reptiles in three sites, KMTR (1997-98)



An unidentified *Cnemaspis* species, provisionally called the red eye gecko, was the most abundant species in Kakachi with 10 (62.5%, n=16), of all gecko sightings. This species was more commonly recorded from Kakachi, except for a single record from Kannikatti. Among skinks, *Mabuya beddomii* was the most abundant skink in the drier areas of Kannikatti and Sengaltheri, while in Kakachi this species was absent, being replaced by a smaller and endemic skink *Scincella travancoricum* that was also the most dominant reptile species at this site (66.10%). This species was recorded very rarely at higher elevations (>1100 m), in Sengaltheri. Agamids were most commonly sighted from Kannikatti (n=17), except for two individuals in Sengaltheri. The pitvipers were recorded from Kakachi and Sengaltheri, while shield tailed snakes were recorded only from Sengaltheri. Kannikatti had no records of snakes in the leaf litter assemblage.

### Density

Leaf litter reptile densities also varied among the three sites, with Kakachi having the lowest densities (0.17 animals/quadrat,  $y = 0.001$ ,  $n = 218$ ), Kannikatti with the highest densities (0.39 animals/quadrat,  $y = 0.006$ ,  $n = 146$ ), and Sengaltheri had 0.32 animals/quadrat,  $y = 0.003$ ,  $n = 212$ . The densities of individual taxa in each of the three sites showed considerable variation (Table 4.3).

**Table 4.3. Densities of leaf litter reptiles in KMTR, (1997-98). Densities expressed as animals/quadrat (5 m x 5 m).**

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

### Similarity

The taxa composition in Kakachi was unique with very little similarity with Kannikatti ( $C_{MH} = 0.09$ ), or with Sengaltheri ( $C_{MH} = 0.21$ ). The community composition in Kannikatti and Sengaltheri were very similar ( $C_{MH} = 0.93$ ).

## **4.5.2 Arboreal reptiles**

### **4.5.2.1 Abundance and community composition**

A total of 314 arboreal reptiles belonging to 22 species were recorded from the 18 transects. Species richness was highest among snakes belonging to the Families Colubridae and Viperidae, totalling eight species (Table 4.4), but was low in abundance with only 12.10% individuals. Agamids and snakes were equal in species richness (8 species), but agamids were the most abundant taxa accounting for 83.76% of all sightings. Geckos and skinks were low both in species richness and in abundance with only five species totalling 12 individuals (3.82%). The monitor

lizard, *Varanus bengalensis*, was recorded only once by this method, but was opportunistically recorded on a few more occasions.

Table 4.4. The species and number of individuals of arboreal reptiles recorded by forest transects in the contiguous rainforest of KMTR, (1997-98).

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

At the species level, two agamids dominated the arboreal reptile community accounting for 78.57% (n=314) of all the sightings. The flying lizard *Draco dussumieri* was the most abundant species accounting for 50.63% of the sightings. Another agamid, *Calotes ellioti* accounted for 27.94%. Out of the 22 species that were recorded by this method, 15 (68.18%), were recorded  $\leq 5$  times each, suggesting that the arboreal reptiles in the contiguous rainforest were low in abundance. Among snakes, six of the eight species detected were recorded  $\leq 5$  times suggesting that they were particularly rare in the assemblage. The most abundant snake was the common green vine snake *Ahaetulla nasutus*, with 14 individuals (36.84%, n=38).

#### 4.5.2.2 *Encounter rates*

The overall encounter rates of arboreal reptiles was 1.94 animals /transect (250 m). Agamids were the most frequently encountered taxa (1.63 animals/transect), followed by geckos and skinks (0.17 animal/transect), and then by snakes (0.13 animal/transect).

#### 4.5.2.3 *Inter-site and seasonal variation*

##### Species richness

The arboreal reptile species richness recorded from the individual transects (including replicates) varied from one to eight with a mean of 4.61 and SE of 0.55 species. Species richness for all transects (including replicates) was lowest in Kakachi with only seven species totalling 16 individuals. Species richness was greatest in Sengaltheri (15 species and 95 individuals), while abundance was highest in Kannikatti (203 individuals and 12 species). The inter-site variation in species richness was significant (KW  $\chi^2 = 14.882$ , df=2, P= 0.001) the difference being greatest between Kannikatti and Kakachi and between Kakachi and Sengaltheri, while minimal difference was recorded between Kannikatti and Sengaltheri (Table 4.5). Arboreal reptile species richness also showed seasonal difference (KW  $\chi^2 = 9.763$ , df=2, P= 0.008) the difference was detected between summer and the south-west and south-west and north-east monsoon seasons (Table 4.5).

**Table 4.5. Mann-Whitney U Test for 2 Independent samples (Z Statistic), to test for difference in arboreal reptile species richness between sampling sites and seasons, KMTR (1997-98). Figures in parenthesis give the mean and SE values of species richness.**

SAMPLING SITES			SEASONS				
	Kannikatti (3.22 ± 0.19)	Sengaltheri (3.0 ± 0.22)	Kakachi (1.5 ± 0.38)		Summer (2.65 ± 0.24)	SW Monsoon (3.61 ± 0.43)	NE Monsoon (2.07 ± 0.22)
Kannikatti		-0.863	-3.878***	Summer		-1.987*	-1.697
Sengaltheri			-2.771***	SW monsoon			-2.848**

\*Significant at  $P < 0.05$ , \*\*\*Significant at  $P < 0.001$ . (two tailed test).

### Abundance

The frequency of sighting of arboreal reptiles varied among individual transects (including replicates) from 1 to 46, with a mean of 17.44 and SE of 3.6 individuals. The difference in abundance was significant (KW  $\chi^2 = 22.503$ ,  $df=2$ ,  $P= 0.001$ ), between sites, being highest between Kannikatti and Kakachi and between Kakachi and Sengaltheri, while minimal variation was recorded between Kannikatti and Sengaltheri (Table 4.6). Seasonal difference in the abundance of arboreal reptiles was marginally significant (KW  $\chi^2 = 3.261$ ,  $df=2$ ,  $P= 0.196$ ). The difference was highest between the south-west monsoon and north-east monsoon, while no difference was detected between summer and the two monsoon seasons (Table 4.6).

**Table 4.6. Mann-Whitney U Test for 2 Independent samples (Z Statistic) to test for difference in arboreal reptile abundance between sampling sites and seasons, KMTR (1997-98). Figures in parenthesis give the mean and SE values of species richness.**

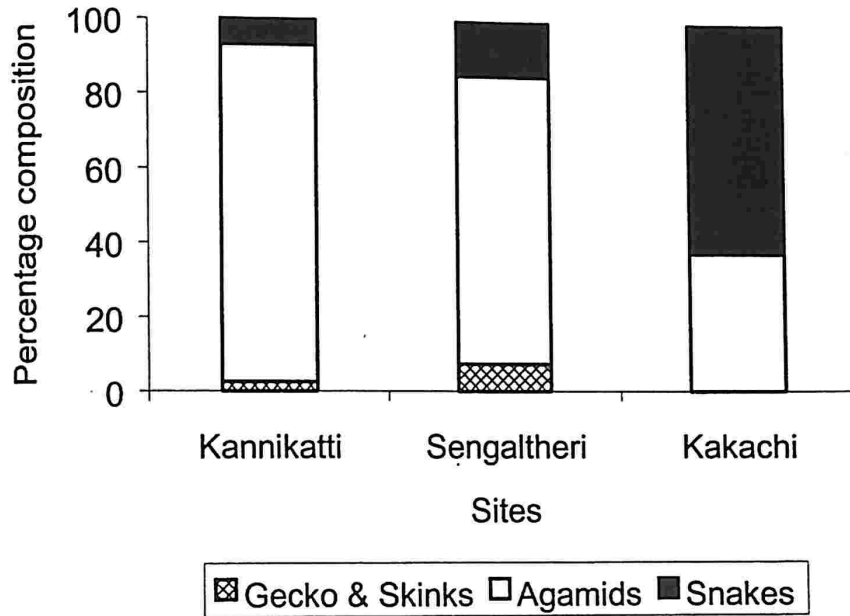
SAMPLING SITES			SEASONS				
	Kannikatti (11.28 ± 1.46)	Kakachi (1.6 ± 0.27)	Sengaltheri (5.94 ± 0.86)		Summer (8.06 ± 1.69)	SW Monsoon (8.38 ± 1.49)	NE Monsoon 4.86 ± 1.17)
Kannikatti		-4.249***	-2.490*	Summer		-0.567	-1.259
Kakachi			-3.324**	SW monsoon			-1.756*

\*Significant at P<0.05, \*\*Significant at P<0.01, \*\*\*Significant at P<0.001. (two tailed test).

#### Community composition

The arboreal community in Kakachi was represented only by agamids and snakes, while in the other two sites geckos and skinks were also recorded. Two species of skinks were recorded from Sengaltheri, while only one species was recorded from Kannikatti. The two species, namely *Mabuya beddomii* (5 individuals), and a single individual of *Ristella* spp. were recorded from tree holes ranging in height from 1 to 2 m in the understorey. However, as both these species are terrestrial species, their occurrence in the arboreal assemblage is interesting. 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. The taxa wise composition of arboreal reptiles in the three sites is given in Figure 4.7.

Figure 4.7. The percentage composition of arboreal reptiles in three sites, KMTR(1997-98)



Encounter rates of arboreal reptiles also showed variation among sites and taxa (Table 4.7). Kannikatti had the highest encounter rate followed by Sengaltheri and Kakachi. As mentioned earlier, agamids dominated the community in Kannikatti and Sengaltheri, while snakes were the dominant taxon in Kakachi. The encounter rate of geckos and skinks were similar in both Kannikatti and Sengaltheri, while this group was conspicuous by their absence in this assemblage at Kakachi. Snakes were in general low in abundance at all the three sites in the arboreal assemblage.

Table 4.7. Encounter rates (animals/250 m), of arboreal reptiles in KMTR, (1997-98).

TAXA	SITES		
	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
<b>Total</b>	3.7600	1.7583	0.2950

### Similarity

When data were pooled from the six transects (the replicates included), for each site, the arboreal reptile community of Kakachi had very little overlap with Kannikatti ( $C_{MH} = 0.05$ ), and Sengaltheri ( $C_{MH} = 0.11$ ). The communities of Kannikatti and Sengaltheri showed a very high overlap ( $C_{MH} = 0.93$ ).

#### 4.5.2.4 *Altitudinal effects on arboreal reptile species richness and abundance*

A quadratic model gave the best fit between altitude and arboreal reptile species richness with highest  $R^2$  value and lowest probability ( $R^2 = 0.473$ ,  $P = 0.008$ ). The number of species per transect showed an initial increase with an increase in the altitude of the transect, reaching a maximum at mid altitudes (900 m to 1100 m), and then declined at higher altitude (Figure 4.8). This pattern in species richness along an altitudinal gradient was reflected in the fact that the species richness was greatest in transects of Sengaltheri (mean altitude 980 m), compared to Kannikatti (760 m), and Kakachi (1,200 m). Arboreal reptile abundance, however, showed a linear, negative relationship with altitude ( $R^2 = 0.85$ ,  $P < 0.001$ ; Figure 4.9). Unlike species richness, abundance was greater in Kannikatti, followed by Sengaltheri and Kakachi.

Figure 4.8. Arboreal reptile species richness along an altitudinal gradient, KMTR (1997-98).

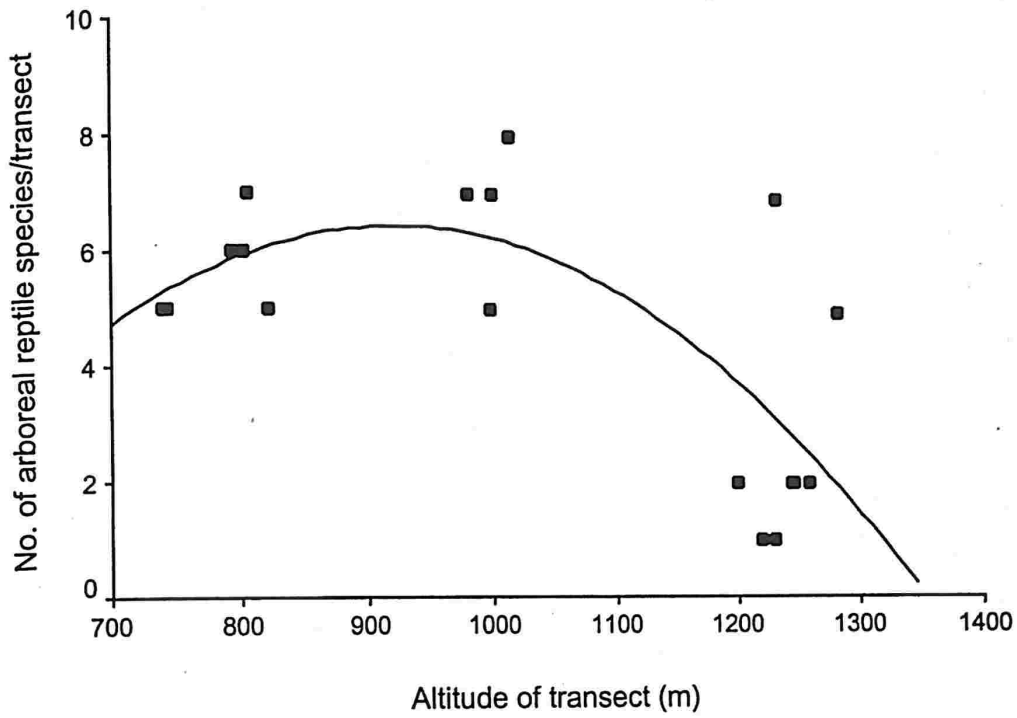
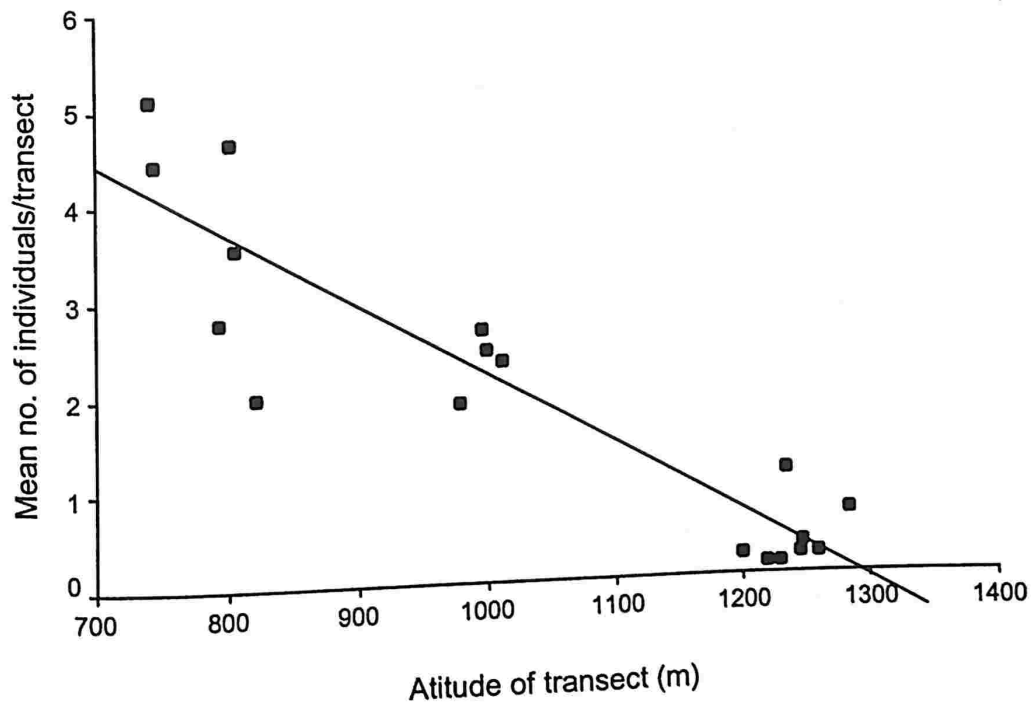
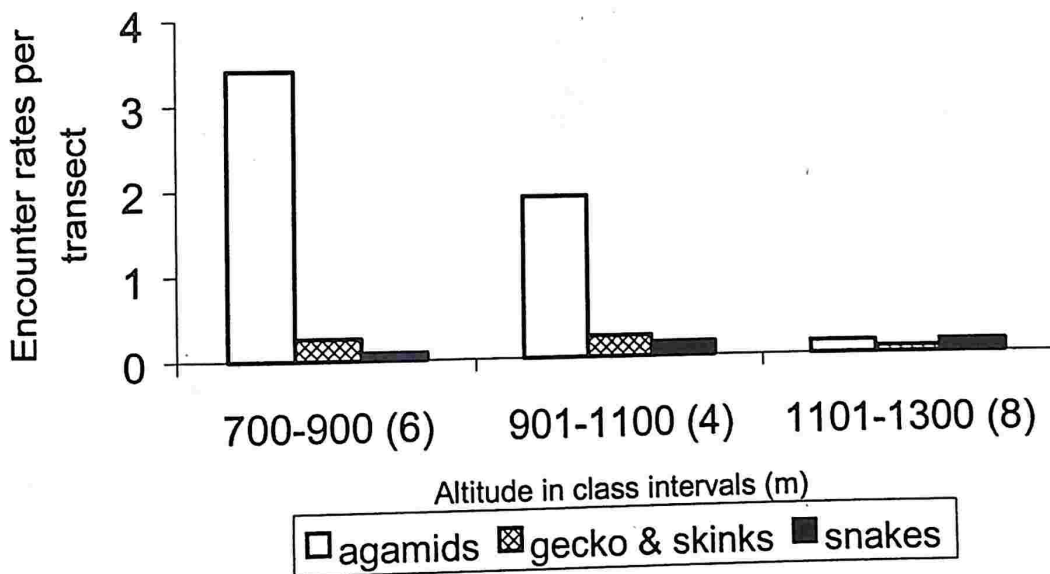


Figure 4.9. Arboreal reptile abundance along an altitudinal gradient, KMTR (1997-98).



Although the overall arboreal reptile abundance showed a linear decline with altitude, individual taxa varied in their response to altitude (Figure 4.10). 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 4.10. Encounter rates of arboreal reptile taxa along an altitudinal gradient, KMTR (1997-98)



The number of transects in each altitudinal class is given in parenthesis.

A dendrogram was constructed using the data on arboreal reptile species richness and abundance for each transect. This was done to examine the similarity in arboreal reptile community assemblage between the 18 transects in the contiguous rainforests (Figure 4.11). The cluster analysis identified only two major assemblages in the arboreal guild. The first assemblage consisted of all transects in Kakachi, (transect ID 1 to 6), and two transects in Sengaltheri (transect ID 17 and 18). These transects



Figure 4.12. Arboreal reptile abundance along an atmospheric temperature gradient, KMTR (1997-88).

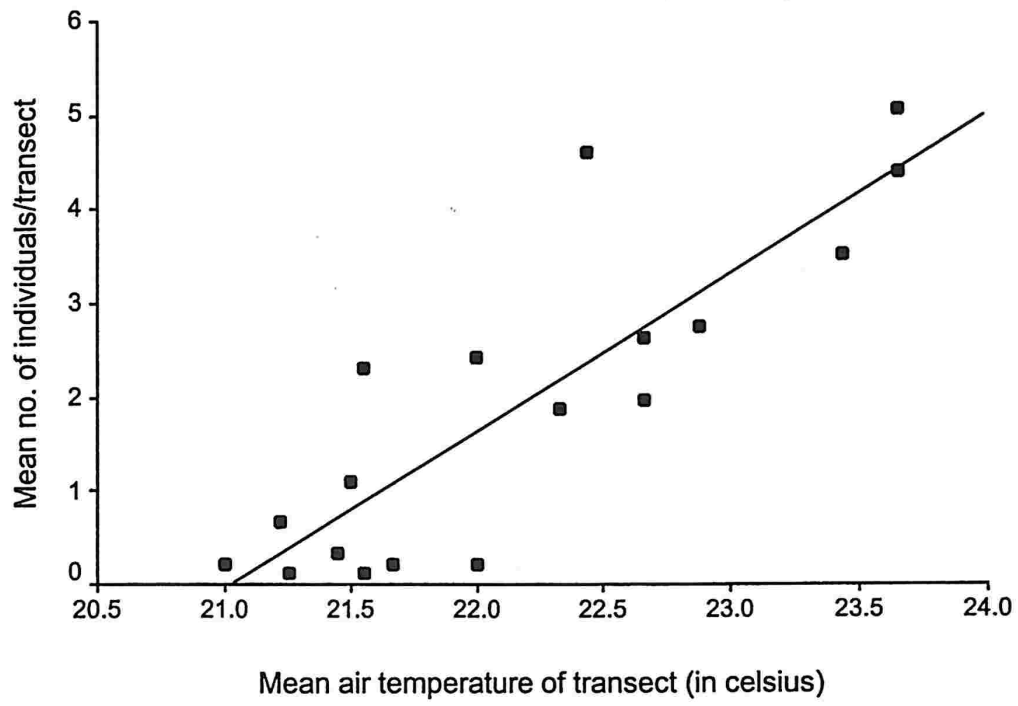
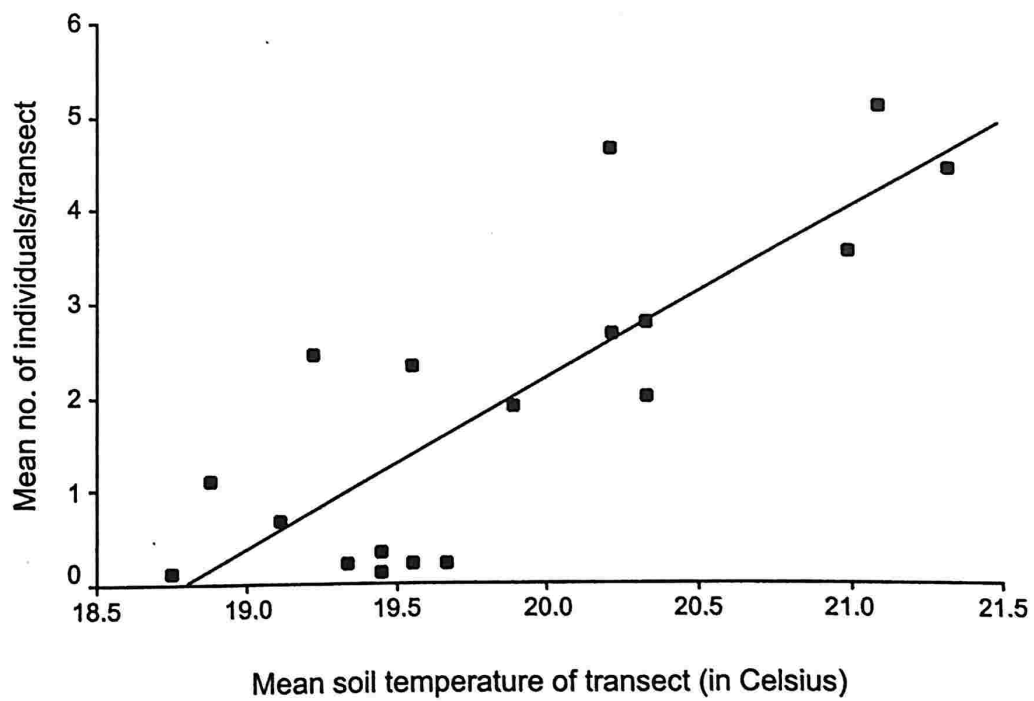


Figure 4.13. Arboreal reptile abundance along an substrate temperature gradient, KMTR (1997-98).



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 (Figure 4.14).

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 (Figure 4.15).

Figure 4.14. Taxa-wise response of arboreal reptiles to atmospheric temperature, KMTR (1997-98).

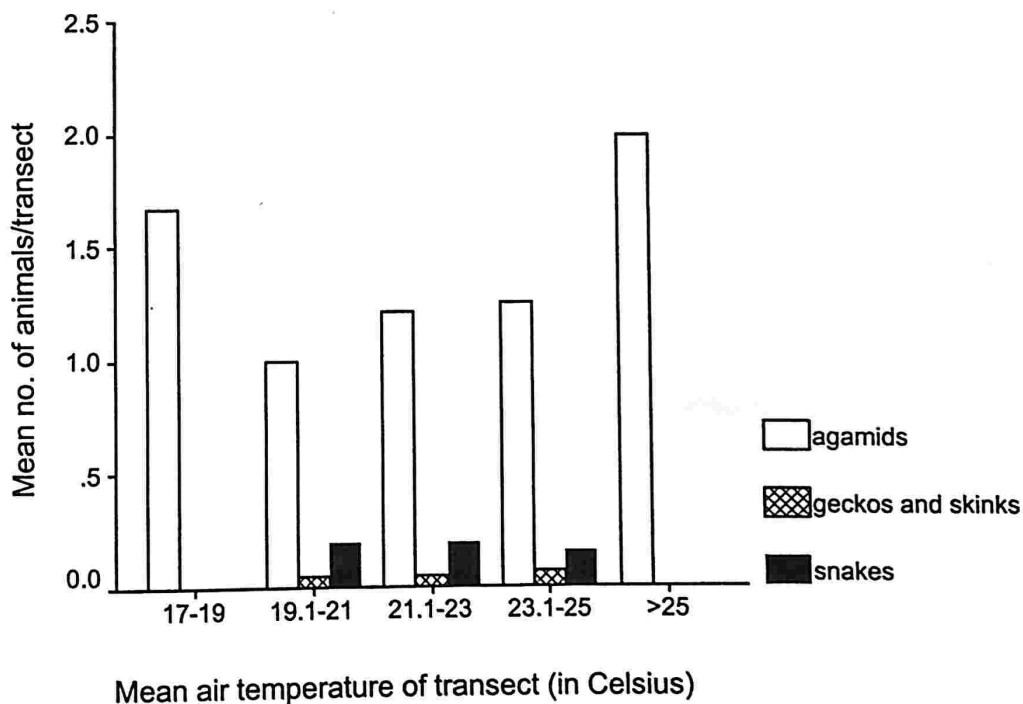
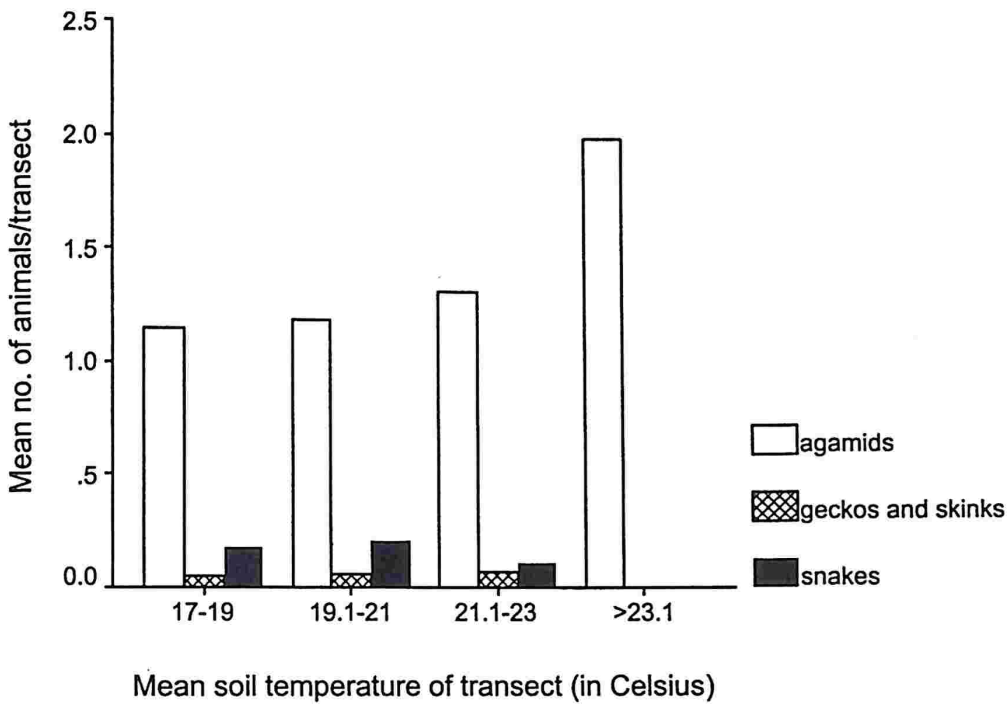


Figure 4.15. Taxa-wise response of arboreal reptiles to substrate temperature, KMTR (1997-98).



### 4.5.3 Reptile species richness and endemism

Reptiles recorded in the contiguous rainforest of KMTR belonged to 9 families, 26 genera and 54 species (Appendix 2). Order Sauria was represented by 22 species (40.74%), while Serpentes was represented by 31 species (57.41%). Only one species of Testudine, *Melanochelys trijuga* was recorded from the contiguous rainforests. Family Gekkonidae was dominated by the genus *Cnemaspis* (6 species), majority of which are endemic to the rainforest of Western Ghats. The only other genus of gecko recorded was *Hemidactylus anamallensis* (= *Dravidogecko anamallensis*), which is also known only from the rainforests of the Western Ghats. Family Agamidae was dominated by the genus *Calotes*, with six species. The rare and endemic *Otocryptis beddomii* was recorded from the higher reaches of KMTR bordering Kerala. The other agamids in the assemblage were the *C. calotes*, *C. rouxii* and the genus *Psammophilus* was represented by two species (*P. blanfordanus* and *P. dorsalis*). These are not typical rainforest species but are known to occur along the edges of rainforest, mainly in rocky areas. Genus *Mabuya* dominated Scincidae (skinks), while two other

genera of fossorial skinks *Scincella* and *Ristella*, the latter being endemic to the rainforests of the Western Ghats, were also recorded. The fossorial family of Uropeltidae was represented by three genera, of which *Uropeltis* had more species. Colubridae was the most species rich family with eight genera and 18 species. Elapidae was represented by two genera with one species each. In Viperidae two genera with five 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.

## 4.6 DISCUSSION

### 4.6.1 Community structure and composition

#### 4.6.1.1 *Leaf litter reptiles*

The leaf litter reptiles in the contiguous rainforests were sparsely distributed when compared with amphibians in the same area (Vasudevan et al. 2001). The assemblage was dominated by geckos and skinks, which were more likely to form multi-species assemblages and to be detected in aggregations of more than two individuals. However, there was considerable variation in species richness, density and abundance per network among the three sites within the contiguous rainforest. Agamids and snakes formed a small part of the leaf litter assemblage in the contiguous forests, which has also been reported by Inger et al. (1987) and Pawar (1999). The low abundance and low density of snakes is surprising since many of the species are terrestrial and semi-fossorial in habit. This may be because snakes in the leaf litter are (a) very rare and low in abundance and much more intense sampling is necessary to detect adequate numbers of snakes (Seigel and Collins 1993), (b) or the community is dominated by the fossorial species like the shield tailed snakes and blind worm snakes that go undetected by the methods that I used. A combination of the two may be the reason for the low abundance of snakes detected in the leaf litter. It should be noted that the sampling method used did not target the fossorial

species. The agamids in the contiguous rainforests are arboreal in habit and this explains their low abundance in the leaf litter assemblage.

#### 4.6.1.2 *Arboreal reptiles*

The arboreal assemblage was dominated by the agamids mainly of the genus *Calotes* while snakes, though rich in species were low in abundance. The assemblage was highly uneven in its abundance distribution with the flying lizard *Draco dussumieri* and *Calotes ellioti* dominating at the two lower elevation sites. The rainforest endemic members of the genus *Calotes* (*C. grandisquamis* and *C. nemoricola*) dominated at the higher elevation. This pattern of an uneven assemblage in agamids has also been recorded in another study in the nearby hill ranges (Bhupathy and Kannan 1997). Arboreal geckos, the flying lizard *Draco dussumieri*, and the pit viper *Trimeresurus malabaricus* were absent in the high altitude site of Kakachi. Given their distribution, which is mostly in areas with lower levels of moisture, it is probable that the greater moisture content and lower temperature in Kakachi may be a limiting factor in their distribution. The occurrence of the terrestrial species such as *Mabuya beddomii* and *Ristella* species, on tree holes of up to a height of 2 m can be attributed to disturbance in the area leading to loss of ground cover.

#### 4.6.2 Species richness and density

The densities of lizards (all saurians), reported from six sites of lowland tropical rainforests of south-east Asia and central America (Inger 1980a), range from 0.25 individuals per 100 m<sup>2</sup> in Nanga Tekalit, Borneo to a maximum of 15.4 individuals per 100 m<sup>2</sup> in Panama. In comparison, the densities of lizards (geckos, skinks and agamids included), in the present study is 1.08 individuals per 100 m<sup>2</sup>. The low density of lizards in the contiguous rainforests is consistent with previous findings of low densities in south-east Asian rainforests (Inger 1980a) when compared with New World tropics (Scott 1976; Inger 1980a, 1980b; Duellman and Trueb 1986; Lieberman 1986). This difference in densities has been attributed to the structure of the Indo-Malayan rainforests and the related decline in seed-eating insects and associated arthropods, which are the primary food source for the reptiles (Inger

1980a). Nevertheless, the density from the contiguous rainforests of KMTR ranks higher when compared with the densities reported from south-east Asian rainforests sites studied by Inger (1980a).

Comparison of species richness and density estimates between studies should be viewed with caution, mainly due to the lack of common sampling techniques and differences in sampling effort and area of sampling. In some studies combined density values for amphibians and reptiles are given, while in most others density estimates are not provided. Hence in many situations density estimate comparisons are biased, and one is left with the alternative of only comparing species richness between sites.

Reliable estimates of the overall reptile species richness are available for many sites in south-east Asian rainforests and New World tropics. This information has been compiled only for lizards (Inger 1980a, b), and ranges from eight species in the Ulu Gombak primary rainforests in Malaya 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 Western Ghats (Inger et al. 1984). In the present study, 23 species of lizards have been recorded. Though this is 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 ranks the highest compared to other reports from India, namely 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 and Kannan 1997). However, species richness is comparatively lower when compared to other tropical sites and Australia. Nevertheless, from the available information it is 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.

### 4.6.3 Altitudinal gradient causes turnover of species

One of the reasons for the differences in the community structure and composition among the three sites within the contiguous rainforests is the response of reptiles to environmental gradients. Reptilian species richness and abundance have been documented to change along altitudinal gradients (e.g. Brown and Alcalá 1961; Porter 1972; Scott 1976; Heatwole 1982; Duellman and Trueb 1986; Inger et al. 1987; Fauth et al. 1989; Woinarski and Gambold 1992; Bhupathy and 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 and Gambold 1992). Individual species within taxa might also vary in their response to altitude (Bhupathy and 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). Due to the low number of individuals, I could not examine differences among the species in their relationship with altitude. However, the low degree of species overlap between transects and the clustering of the transects into two distinct sets based on their species assemblage with the cut-off point being 1,200 m strengthens the argument of a species turnover along an elevation gradient.

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 also 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 effect (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. However, the increase in the abundance of arboreal reptiles with an associated increase in the atmospheric temperature upto ca. 23°C is of importance. Reptiles are known to be active at particular temperature regimes to facilitate thermoregulation and other associated activities (Adolph and Porter 1993). The finding that there is a decrease in the sighting of reptiles at temperatures greater than 23°C suggests that this temperature exceeds the optimum temperature required by the reptiles in these rainforests.

This study was restricted both in altitudinal range (700 m to 1350 m) and vegetation type (tropical rainforest). The restriction in altitudinal range, especially the lack of samples at < 700 m, might be a reason for the linear relationship between abundance and altitude, rather than a unimodal relationship reported by many other studies. This possibility together with the restriction of sampling to rainforest might be the reason for a relatively weak unimodal relationship between species richness and altitude documented in this study.

#### **4.6.4 Reptile species richness and endemism in the contiguous forests**

The rainforest in the Ashambu Hills, being in the southern-most hill range in the Western Ghats and closest to the equator, is believed to be a centre of species richness and endemism within the Western Ghats (Ramesh et al. 1997). A review of literature shows the presence of ca. 190 species of reptiles in the Western Ghats across all habitat types and about 130 species are known to be present in the rainforests of Western Ghats (Ishwar et al. 2001). Murthy (1989, 1990), reported 26 species of reptiles from the Kalakad Wildlife Sanctuary, which includes the drier parts of the Reserve. In spite of intensive sampling for more than a year, the present

study recorded only 54 species from the rainforests. This accounts for 42% of the reptiles that are known only from the rainforests of the Western Ghats. This includes the new record of *Calotes andamanensis*, re-discovered after almost 100 years (Ishwar and Das 1998), and three unidentified and possibly two new species of *Cnemaspis*. Nevertheless, 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 finding receives further support from the present study with at least seven species likely to be endemic to this mountain range/rainforests alone.

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.

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 (Murthy 1992a). 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

that I adopted was not directed towards sampling fossorial reptiles. In fact there are no known 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.

#### 4.6.5 Adaptive cluster sampling: An efficient sampling protocol

The adaptive cluster sampling was formalized by Thompson (1991) for obtaining unbiased estimates of population densities of rare and low density animals that form aggregations (whales and walrus). This procedure has for the first time been adapted to sample leaf litter reptiles in rainforests and has been fairly efficient and successful. An obvious advantage of this method over the random quadrat sampling is the opportunity to examine the spatial distribution of rainforest leaf litter reptiles. This sampling also provides an unbiased estimator of the mean density and the variance, the latter being often large when estimated using the random quadrat sampling (Thompson and Seber 1994). In addition adaptive cluster sampling provides new descriptors of the reptilian community like network size, mean number of species per network and mean number of individuals per network. The use of this sampling protocol has resulted in the finding that in rainforests, leaf litter reptiles are rare, a majority of the assemblages are not comprised of more than two species and the reptiles occur in small clusters of a few individuals. This understanding of the distribution patterns of rainforest litter reptiles would not have been possible with the usage of the random quadrats.

## 4.7 SUMMARY

The contiguous rainforests of KMTR support a rich and diverse assemblage of rainforest reptiles in the Western Ghats. In general, the leaf litter assemblage, dominated by geckos and skinks do not form multi-species or multi individual aggregations. The arboreal assemblage was dominated by agamids. Although inter-site differences were observed in the two assemblages, there was no significant seasonal variation. The densities of reptiles were relatively low when compared with other tropical sites. Species richness peaked at mid elevations while abundance declined along an elevation gradient in the arboreal assemblage. Similarly, atmospheric and substrate temperature affected the arboreal assemblage. The adaptive cluster sampling and the forest transects are appropriate methods for sampling reptiles in the rainforests. These can be adopted as standardized protocols for reptilian studies in the tropical forests.

## CHAPTER 5

# REPTILES IN A FRAGMENTED LANDSCAPE: DISTRIBUTION PATTERNS IN THE ANAMALAI HILLS

### 5.1 INTRODUCTION

Habitat fragmentation results in the reduction of the once contiguous and relatively undisturbed forest into small isolated forest patches, located in a matrix of altered and often human planted vegetation. Habitat fragmentation influences biological communities in various ways; in general species richness and population densities decline dramatically after fragmentation (Lovejoy et al. 1986; Turner 1996; Saunders et al. 1991). Species richness and population densities are also known to decrease with a decrease in fragment size (Saunders et al. 1991; Bellamy et al. 1996; Turner 1996). The effects of habitat fragmentation differ among individual species or taxa, mainly due to their food and microhabitat preferences (Lovejoy et al. 1986; Bellamy et al. 1996; Turner 1996). The loss of species and related changes in the community structure due to habitat fragmentation has been attributed to several factors; disturbance during and after fragmentation, reduction in population sizes, immigration of exotic species and the effects of forest edge. However, the relative importance of these factors still remains obscure and is likely to depend on the target taxon.

There are numerous factors affecting the variation in species diversity and richness, but there are no definite explanations for these patterns. Nevertheless, certain general patterns seem to emerge. An understanding of these patterns is fundamental for the conservation of biodiversity (Schall and Pianka 1978; Owen 1989; Stevens 1989). Numerous hypotheses exist which explain the variation in species diversity and richness (for review see Schluter and Ricklefs 1993). One of the hypothesis that has gained credibility is the intermediate disturbance hypothesis that is, disturbance plays a role in determining the diversity and abundance of species in ecological communities (for reviews see Levin and Paine 1974; Connell 1975, 1978; Wootton 1998; Mackey and Currie 2000). This hypothesis postulates that at low levels of disturbance a single species will effectively monopolize the limiting resource leading to a reduction in

diversity due to competition, while at high levels of disturbance, species diversity declines, as some species are incapable of reproducing fast enough to compensate for the increased mortality imposed by the disturbance. Although this hypothesis holds good for a majority of the systems (Petraits et al. 1989), it does not hold good for highly mobile animals, as they are capable of movement between remnant fragments, altering the immigration rates and affecting the predicted pattern of the intermediate disturbance hypothesis (Wootton 1998).

The decline in the habitat heterogeneity (Duellman 1989), and the increase in disturbance (Hecnar and M'Closkey 1998) are likely to have a negative impact on reptilian communities. However, the effects of tropical rainforest fragmentation on reptilian communities are yet to be documented. Consequently, the present study addresses this important conservation issue.

The word remnant or fragment is used to define a patch of native rainforest vegetation around which most or all of the original vegetation has been removed. These forest fragments are isolated from each other, being surrounded by a different habitat type (Dustan and Fox 1996), mainly commercial plantation like tea and coffee with very few trees.

## **5.2 OBJECTIVES**

The major objectives in this component of the study were:

- 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.

## 5.3 STUDY AREA

The fragmented landscape in the Indira Gandhi Wildlife Sanctuary and National Park (IGWLS), which is part of the Anamalai Hill range, formed the study area. The rainforest fragments selected for intensive sampling were located within a 15 km radius from the town of Valparai where the field camp was located. In total, 14 rainforest fragments varying in size, ownership, disturbance and distance from the Largest fragment were selected (Figure 2.2). Details of the study area and on the rainforest fragments have been given in Chapter 2.

## 5.4 METHODS AND DATA ANALYSIS

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 Chapter 3. In total, 14 rainforest fragments in four size categories were sampled in the three seasons (south-west monsoon, north-east monsoon and summer), except for one Large fragment (Sankarankudi), which was not sampled in the south-west monsoon.

## 5.5 RESULTS

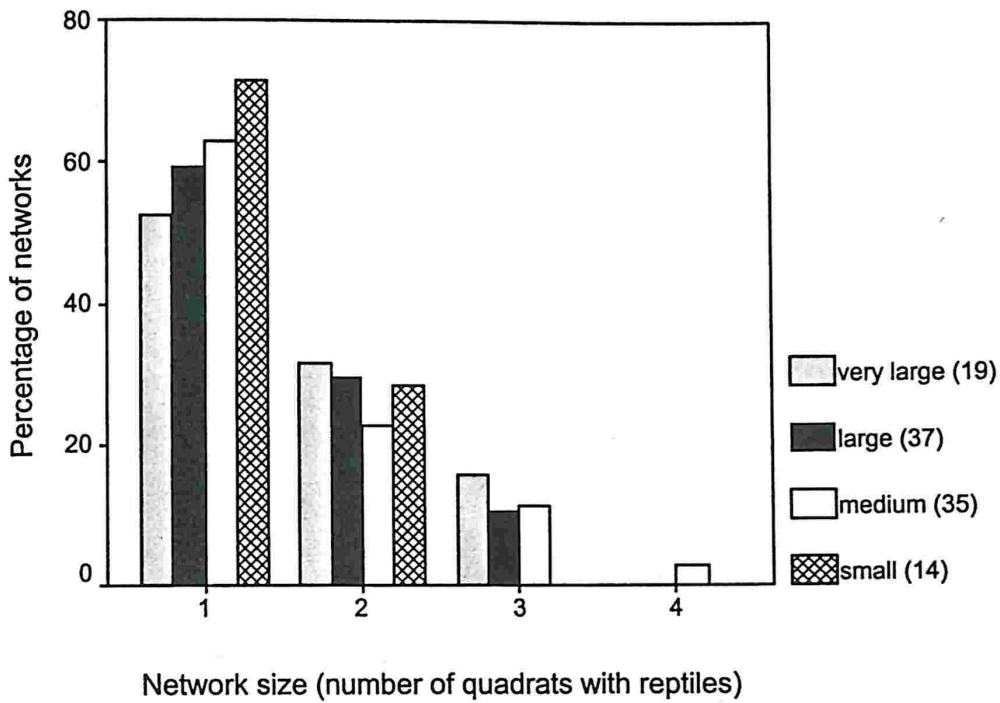
### 5.5.1 Leaf litter reptiles

#### 5.5.1.1 *Distribution patterns*

A total of 460 primary quadrats and 54 secondary and tertiary quadrats were sampled in the 14 fragments. In all, 260 leaf litter reptiles belonging to 20 species were recorded. Only 105 of the primary quadrats (22.8 %) recorded reptiles suggesting their sparse distribution. Network size varied from one to a maximum of four quadrats, with a mean of 1.51 (SE=0.07). The Very Large fragment (Akkamalai), had a greater percentage of large networks when compared to the smaller sized fragments (Figure 5.1).

Figure 5.1. Network size of leaf litter reptiles, Anamalai Hills

(1998-99). Figures in parenthesis gives sample size



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 5.2). 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  $\geq 5$  reptiles (Figure 5.3).

Figure 5.2. Number of reptile species/network, Anamalai Hills (1998-99).

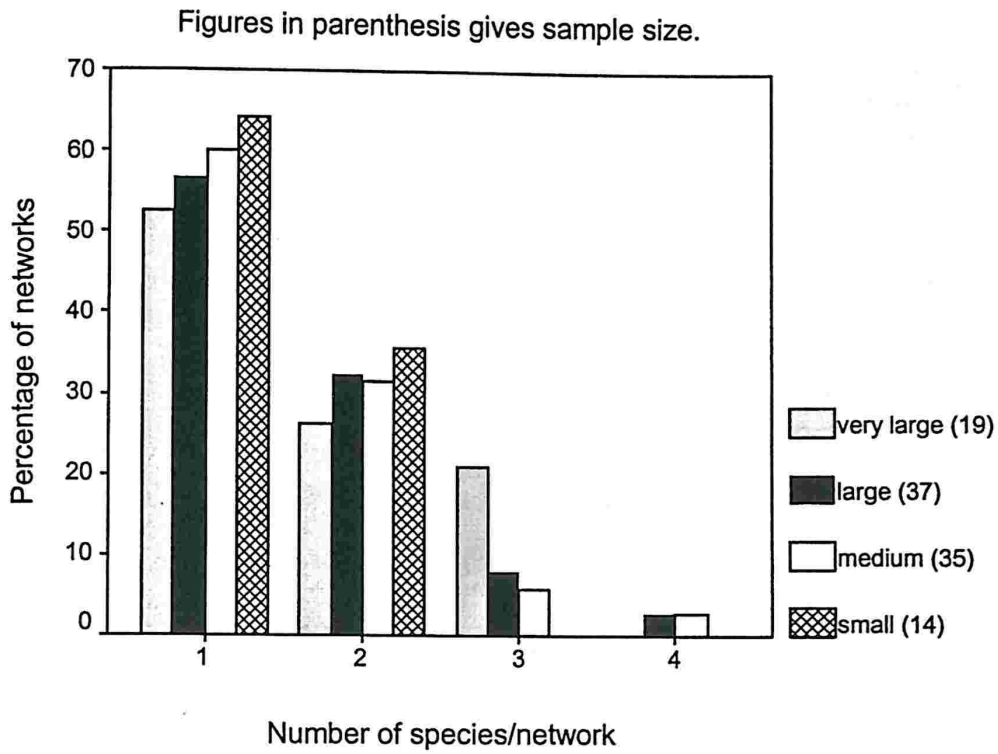
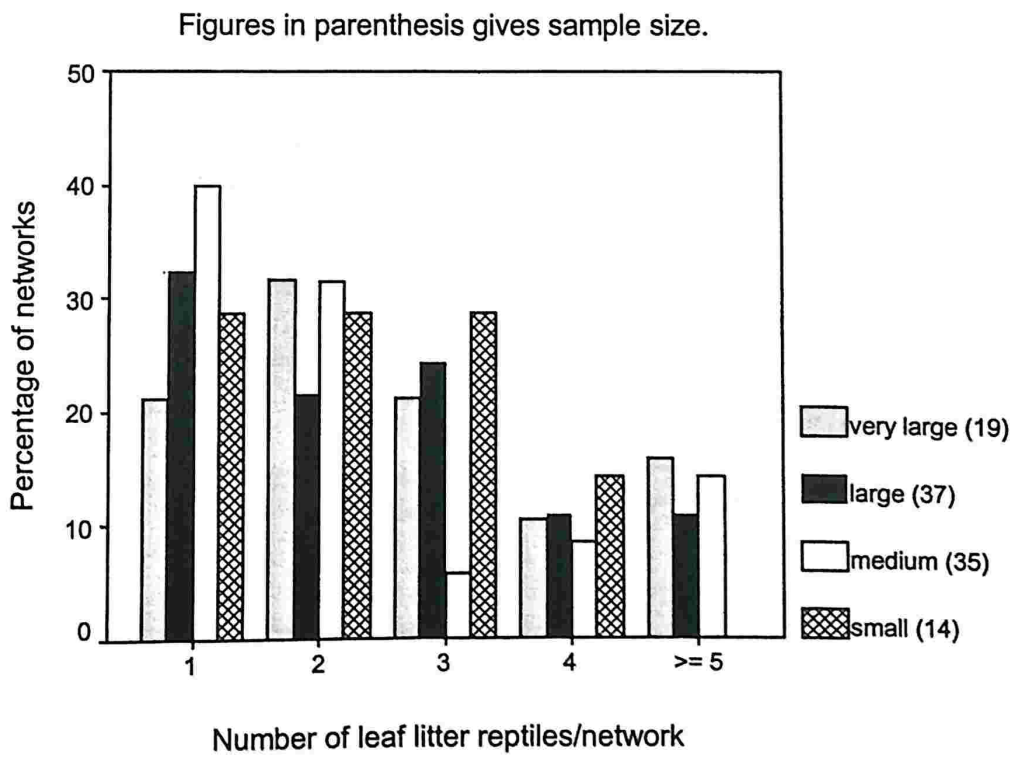


Figure 5.3. Number of reptiles/network, Anamalai Hills (1998-99).



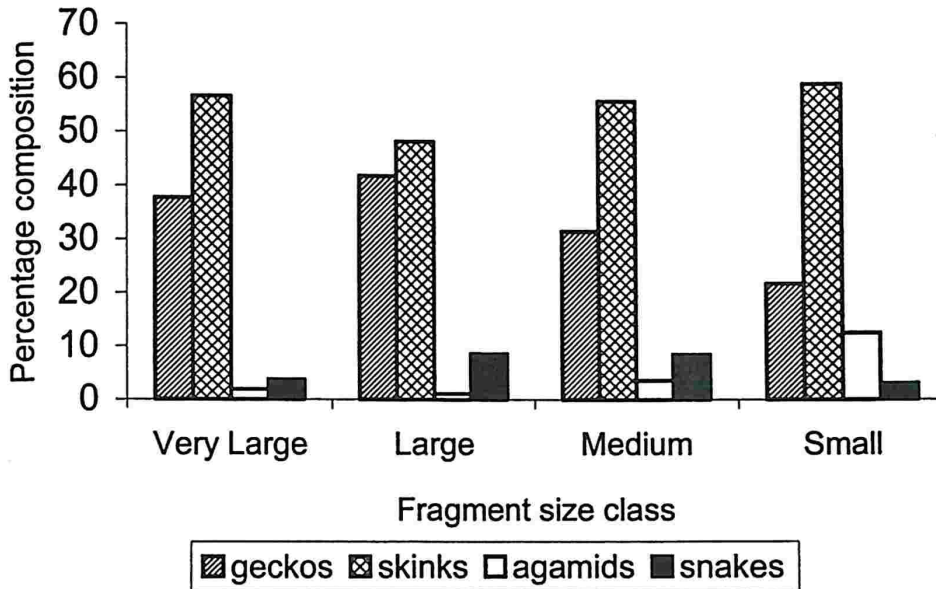
### 5.5.1.2 *Abundance and community composition*

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  $\leq 5$  individuals (Table 5.1), 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 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 5.4). 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.

Figure 5.4. Percentage composition of leaf litter reptiles in rainforest fragments, Anamalai Hills (1998-99).



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 5.1).

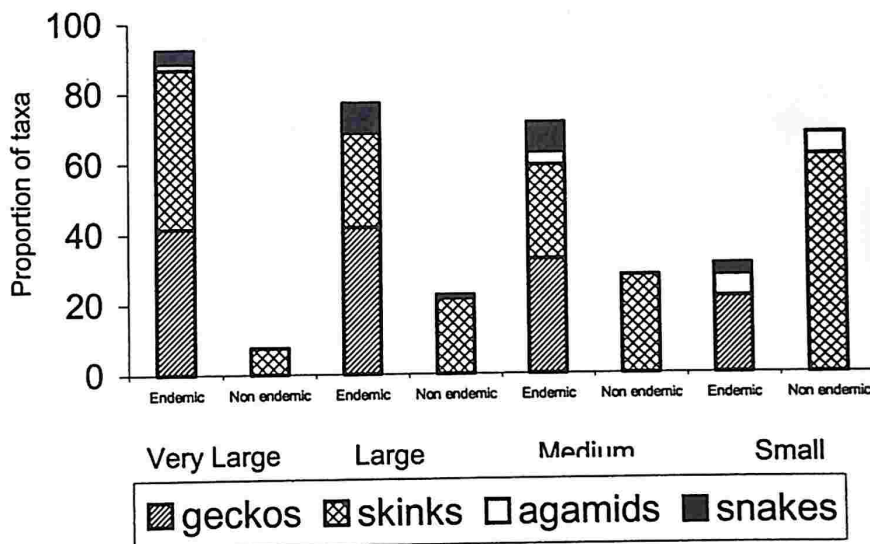
Table 5.1. The species and number of individuals of leaf litter reptiles recorded from adaptive cluster sampling in the 14 rainforest fragments of Anamalai Hills, (1998-99).

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

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

In general, the abundance of non-endemic litter reptiles increased 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 5.5).

Figure 5.5. The proportion of endemic and non-endemic leaf litter reptile taxa in various size categories of fragments, Anamalai Hills (1998-99).



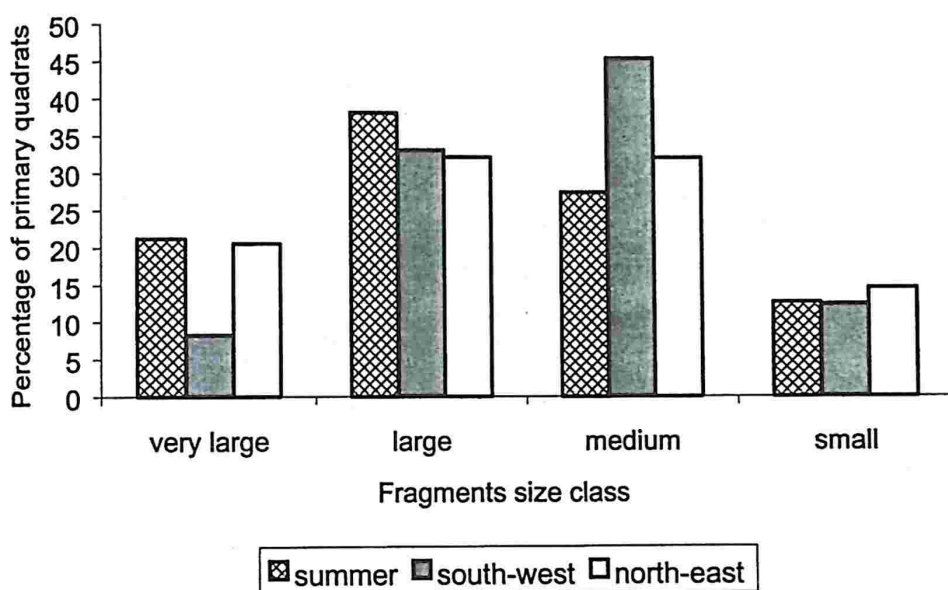
### 5.5.1.3 Variation between forest fragments and seasons

#### Network abundance

The percentage of primary quadrats with reptiles varied between seasons and between fragments. When data were pooled across fragments, the percentage of primary quadrats with leaf litter reptiles was greatest in summer (44.76 %), followed by the north-east monsoon (32.38%) and the south-west monsoon (22.86%). The Large and Medium sized fragments had greater percentage of primary quadrats with reptiles in

all the seasons (Figure 5.6) however, the difference was not significant ( $KW\chi^2 = 1.602$ ,  $df=2$ ,  $P=0.449$ ). The number of primary quadrats with reptiles was greater in the Large and Medium sized fragments while it was lowest in the Small fragments and this difference was statistically significant ( $KW\chi^2 = 40.28$ ,  $df=3$ ,  $P<0.001$ ).

Figure 5.6. Percentage of primary quadrats with leaf litter reptiles in rainforest fragments across seasons, Anamalai Hills (1998-99)



### Network size

There was no seasonal variation in network size when data were pooled across fragments ( $KW\chi^2 = 0.67$ ,  $df=2$ ,  $P=0.72$ ). There was also no difference in network size among the four fragment size classes ( $KW\chi^2 = 1.66$ ,  $df=3$ ,  $P=0.65$ ). Network size did not differ even when data were pooled for fragments into two size classes (Large < 50 ha and Small > 50 ha) ( $KW\chi^2 = 0.64$ ,  $df=1$ ,  $P=0.42$ ). The mean and SE values of network size for the different size class of fragments and for different seasons is given in Table 5.2 a,b.

### Abundance per network

Seasonally, the number of leaf litter reptiles per network did not vary when data was pooled across fragments ( $KW\chi^2 = 4.12$ ,  $df=2$ ,  $P=0.12$ ). The abundance of litter reptiles did not differ between fragment size classes when data were pooled across seasons ( $KW\chi^2 = 1.94$ ,  $df=3$ ,  $P=0.58$ ). The mean and SE values of the abundance per network for the different size class of fragments and for different seasons is given in Table 5.2 a,b.

### Species richness per network

Species richness per network showed seasonal variation when data were pooled across fragments ( $KW\chi^2 = 6.30$ ,  $df=2$ ,  $P=0.04$ ), while there was no variation between fragment size classes, when data were pooled across seasons ( $KW\chi^2 = 1.23$ ,  $df=3$ ,  $P=0.75$ ). Seasonally, species richness was highest during the north-east monsoon and lowest during the south-west monsoon, while among fragments it was highest in the Very Large fragment and lowest in the Small fragments. The mean and SE values of species richness per network for the different size classes of fragments and for different seasons is given in Table 5.2 a,b.

**Table 5.2. Mean and SE values for network size, abundance and species per network in a) size classes of fragments and b) seasons.**

#### 5.2. (a) Size classes of fragments

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

## 5.2. (b) Seasons

	Network size Mean $\pm$ SE	Abundance per network Mean $\pm$ SE	Species richness per network Mean $\pm$ SE
Summer	1.47 $\pm$ 0.10	2.30 $\pm$ 0.21	1.51 $\pm$ 0.11
South-west monsoon	1.50 $\pm$ 0.15	2.29 $\pm$ 0.30	1.33 $\pm$ 0.13
North-east monsoon	1.59 $\pm$ 0.13	2.85 $\pm$ 0.27	1.74 $\pm$ 0.12

### Density estimates

When data were pooled across all the fragments the overall density of leaf litter 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 animals/quadrat). The other two taxa namely, snakes (0.03 animals/quadrat), and agamids (0.01 animals/quadrat), 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 5.3). 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 5.3).

**Table 5.3. Density (number of animals/quadrat) of leaf litter 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

### Similarity

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 areas increased (Table 5.4).

**Table 5.4. 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

### **5.5.2 Arboreal reptiles**

#### **5.5.2.1 Distribution patterns**

Sampling for arboreal reptile assemblage in the rainforest 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). Arboreal reptile abundance per transect (including replicates), varied from 6 to 39 individuals, with a mean of 16.64 (SE=1.17). 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 5.5).

**Table 5.5. Arboreal reptile species and number of individuals recorded by Forest transects in the rainforest fragments of Anamalai Hills, (1998-99).**

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

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

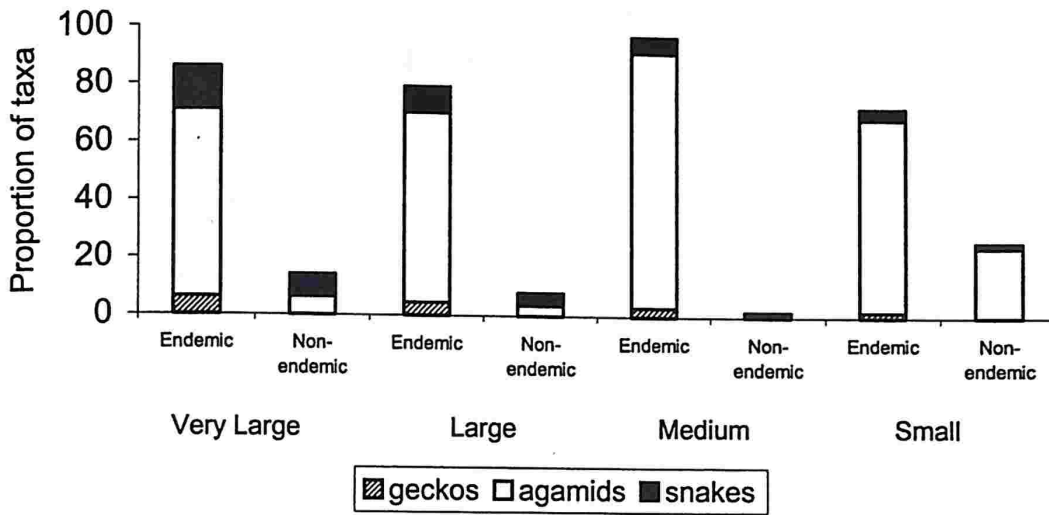
### 5.5.2.2 *Abundance and species composition*

The dominant taxa in the arboreal assemblage were the agamids represented by six species and accounting for 83.61% of all sightings (Table 5.5). 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 4.2% of the sightings. Many arboreal reptiles were low in abundance, with nine of the 19 species being recorded  $\leq 5$  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 (Table 5.5).

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 5.7).

Figure 5.7. The proportion of endemic and non endemic arboreal reptile taxa in the different size categories of fragments, Anamalai Hills (1998-99).



The overall encounter rates of arboreal reptiles in the fragments of Anamalai Hills were 1.84 animals/250 m. Agamids were the dominant taxon (1.53 animals/250 m), followed by snakes (0.23 animals/250 m), and geckos (0.08 animals/250 m).

### 5.5.2.3 Variation between forest fragments and seasons

#### Species richness

When data were pooled across seasons arboreal reptile species richness per transect showed a significant difference between fragment size classes (KW  $\chi^2 = 16.97$ ,  $df=3$ ,  $p= 0.001$ ) (Figure 5.8 a). The difference in species richness was greatest between the Large and Medium, and Large and Small sized fragments (Table 5.6). Seasonal difference was also exhibited by arboreal reptile species richness (KW  $\chi^2 = 7.02$ ,  $df=2$ ,  $p= 0.03$ ) when data were pooled across fragments (Figure 5.8 b). There was no difference between the south-west and north-east monsoons (Table 5.6, Figure 5.8 a,b).

Table 5.6. Mann-Whitney U Test for 2 Independent samples (Z Statistic) to test for differences in species richness between different size classes of fragments and seasons, Anamalai Hills (1998-99).

FRAGMENT SIZE CLASSES					SEASONS			
	Very Large	Large	Medium	Small		Summer	SW Monsoon	NE Monsoon
Very Large		-0.861	-2.527**	-2.433*	Summer		-2.134*	-2.355*
Large			-3.264***	-3.020**	SW monsoon			-0.292
Medium				-0.329	NE monsoon			

\*Significant at  $P < 0.05$ , \*\*Significant at  $P < 0.01$ , \*\*\*Significant at  $P < 0.001$ . (two tailed test).

### Abundance

Arboreal reptile abundance also showed significant difference between fragments size classes (KW  $\chi^2 = 14.92$ ,  $df=3$ ,  $P= 0.002$ ) and seasons (KW  $\chi^2 = 12.77$ ,  $df=2$ ,  $P= 0.002$ ). The difference in abundance was highest between the Large and Small sized fragments. Seasonally, the difference in abundance was greatest between summer and south-west monsoon. There was no difference between the south-west and north-east monsoons (Table 5.7, Figure 5.8 c,d).

**Table 5.7. Mann-Whitney U Test for 2 Independent samples (Z Statistic) to test for differences in reptile abundance between different size classes of fragments and seasons, Anamalai Hills (1998-99).**

FRAGMENT SIZE CLASSES					SEASONS			
	Very Large	Large	Medium	Small		Summer	SW Monsoon	NE Monsoon
Very Large		-2.668**	-1.822	0.251	Summer		-3.538***	-2.588**
Large			-0.734	-3.280***	SW monsoon			-0.183
Medium				-2.601**	NE monsoon			

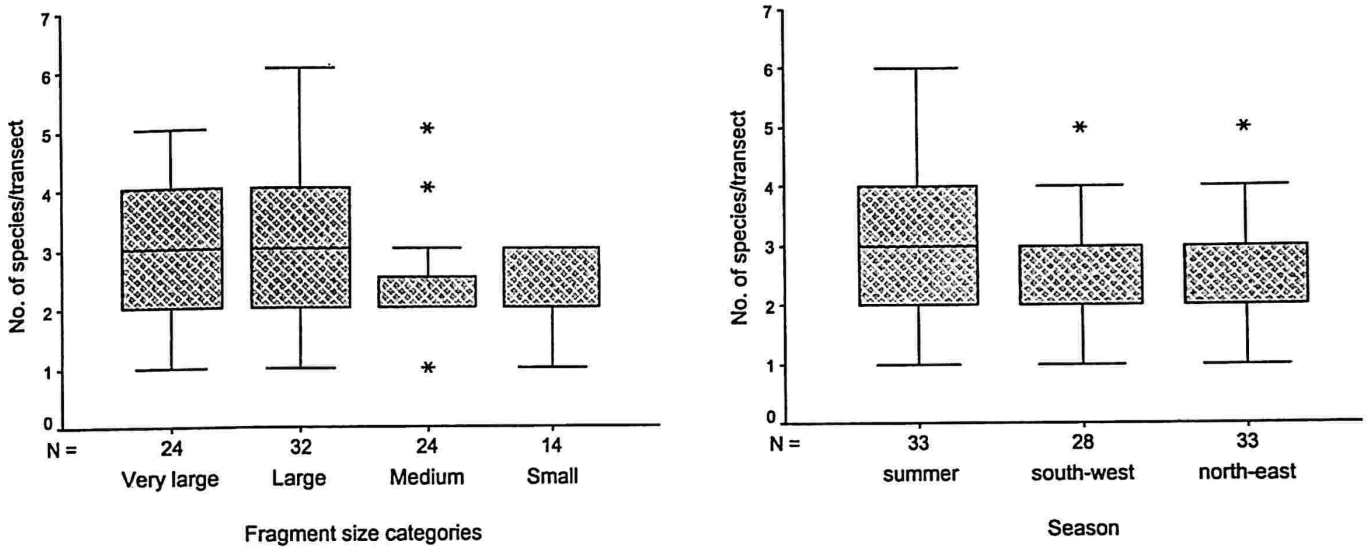
\*Significant at  $P < 0.05$ , \*\*Significant at  $P < 0.01$ , \*\*\*Significant at  $P < 0.001$ . (two tailed test).

### Community composition

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 highest abundance in the Medium sized fragments (Figure 5.9). 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 decrease in the area of the fragment while the abundance of agamids peaked in the Medium sized fragments.

Figure 5.8. Variation in arboreal reptile species richness between (a) the different size categories of fragments, (b) seasons; and abundance between (c) the different size categories of fragments and (d) seasons, Anamalai Hills (1998-99).

(a) species richness in four fragment size categories (b) species richness in three seasons categories



(c) abundance in four fragment size categories (d) abundance in three seasons categories

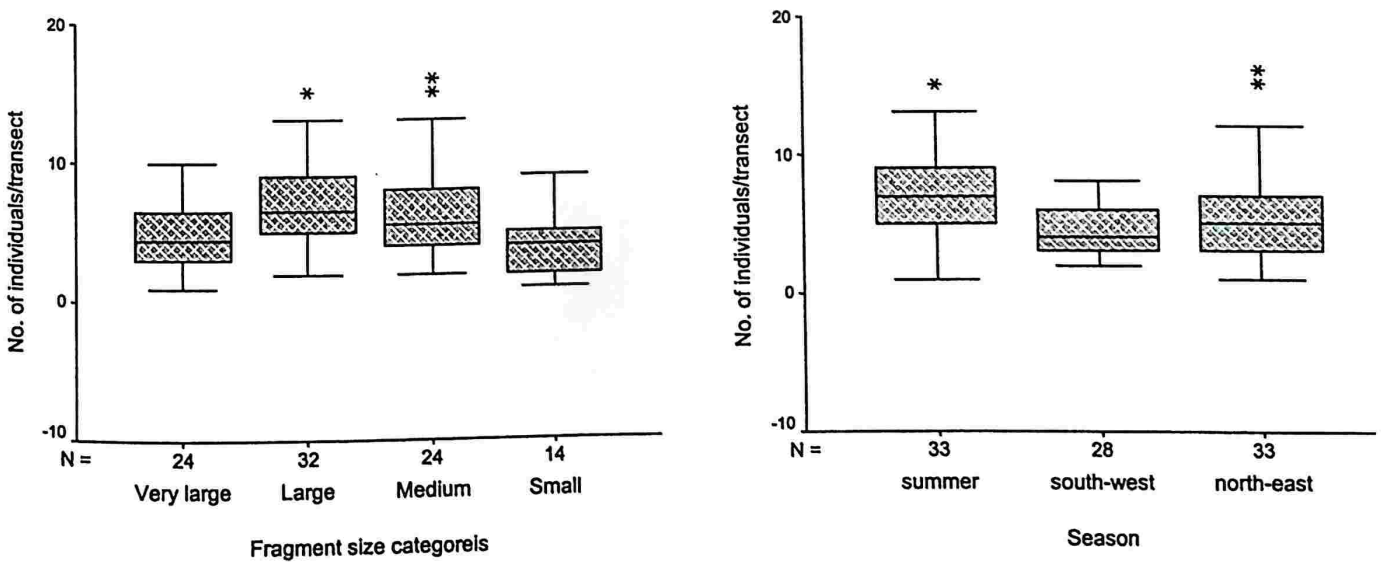
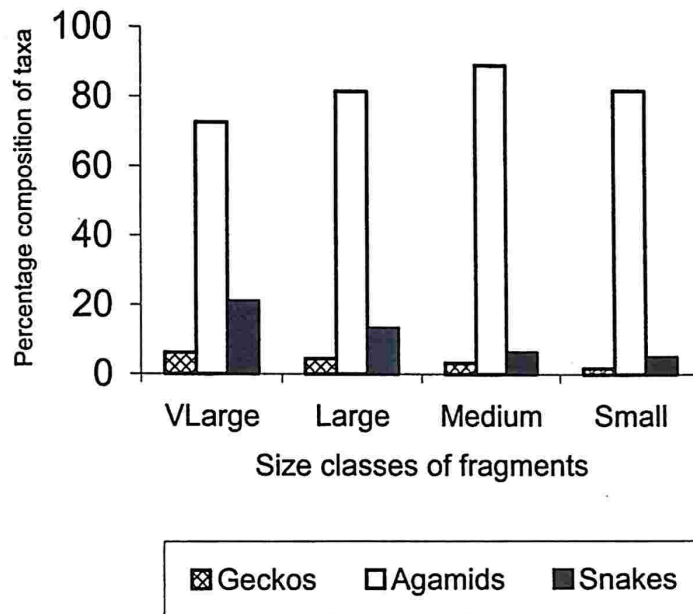


Figure 5.9. The percentage composition of various taxa of arboreal reptiles in rainforest fragments, Anamalai Hills (1998-99).



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.

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 5.8).

**Table 5.8. 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

*Similarity*

The arboreal reptile assemblages in the different fragment size classes were highly similar, as seen from the Morisita-Horn's measure of similarity (Table 5.9). The similarity was highest between the Large and Medium sized fragments, and lowest between the Very Large and Medium sized fragments.

**Table 5.9. Morisita-Horn's measure of similarity of arboreal reptile assemblage in the different size classes of rainforest fragments in Anamalai Hills (1998-99).**

	Large	Medium	Small
Very Large	0.827	0.700	0.780
Large		0.963	0.884
Medium			0.838

**5.5.2.4 Effects of altitude**

Altitude was not significantly related to variation in arboreal reptile species richness and abundance in the rainforest fragments. The relationship of altitude with species richness and abundance was very weak when all the species were included (Table 5.10). The relationship improved marginally when only the rainforest species were

included in the analysis (Table 5.10). The relationship of altitude with species richness and abundance was strong and significant only for the Medium fragments, when the different size categories of fragments were examined individually (Table 5.10).

**Table 5.10. R<sup>2</sup> values for the relationship of arboreal reptile species richness and abundance with altitude in the rainforest fragments in Anamalai Hills, 1998-99. (L=linear model; Q=Quadratic Model). The figures in parenthesis give the altitudinal range sampled.**

	Number of transects	All species		Rainforest species only	
		Species richness	Abundance	Species richness	Abundance
All fragments (928-1418 m)	33	0.086 (Q)	0.032 (L)	0.105 (L)*	0.032 (L)
Very Large (1355-1418 m)	8	0.037 (L)	0.007 (L)	0.070 (L)	0.008 (L)
Large (928-1309 m)	12	0.138 (Q)	0.129 (L)	0.107 (Q)	0.129 (L)
Medium (1003-1126 m)	8	0.539 (Q)	0.438 (L) *	0.539 (Q)	0.438 (L) *
Small (1008-1031 m)	5	0.404 (Q)	0.412 (L)	0.485 (Q)	0.412 (L)

\* P<0.1.

### 5.5.3 Species richness and endemism

In total, reptiles in the rainforest fragments of the Anamalai Hills belonged to 9 families, 23 genera and 40 species (Appendix 3). Order Sauria was represented by 21 species (52.5%), while Serpentes were represented by 19 species (47.5%). I did not record any species of the order Testudine. 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 the *Uropeltis* was

represented by 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.

In total, of the 40 species recorded from 14 rainforest fragments, 72.5% (29 species) were endemic to the Western Ghats, while 45% (18 species) were endemic to the rainforests of the Western Ghats (Table 5.11). The Very Large fragment had a greater number of species that were endemic to both the Western Ghats and to the rainforests. All fragments taken together, excluding the Very Large fragment supported only 16 rainforest endemic species compared to 17 rainforest endemic species in the Very Large fragment. 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 5.11). This pattern was consistent with the contiguous and relatively undisturbed site of KMTR. Among the five Small fragments (< 10 ha) sampled, three supported  $\leq 5$  species each while many of the other species recorded in these Small fragments were secondary forest species.

**Table 5.11. Reptilian species richness and endemism in the rainforest fragments, Anamalai Hills (1998-99). 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

#### 5.5.4 Comparison between contiguous and fragmented rainforest sites

##### Reptilian species richness

In total, 66 species of reptiles were recorded from both study sites in the state of Tamil Nadu. The contiguous rainforests of KMTR (54 species) had 26 (39.39%) unique reptilian species, while the rainforest fragments of the Anamalai Hills (40 species) had only 12 (18.18%) unique species *i.e.* they were not seen in KMTR. Both the sites shared 42.42% (28 species) of reptiles.

##### Reptilian species composition and abundance in the rainforests

Data pooled from both the adaptive cluster sampling and the transects, showed the species richness in the two sites to be almost equal, with KMTR recording 28 species while the fragments recording 29 species (Table 5.12). Although, species richness was similar in both the sites, abundance was greater in fragments (Table 5.12). The reptilian communities in both the contiguous rainforest and in the fragments were dominated by agamids. These taxa were mainly arboreal in the contiguous rainforests, but were also terrestrial in the fragments. Snakes, in spite of being the taxa with greater species richness, was the taxon with the lowest abundance in both the sites (Table 5.12). The rainforest fragments of Anamalai Hills had greater species richness for geckos, than the contiguous rainforests.

**Table 5.12. Percentage composition of reptilian taxa in the contiguous rainforests (KMTR, 1997-1998) and the fragments of Anamalai Hills, (1998-99).**

Taxa	Contiguous rainforest (KMTR)		Forest fragments (Anamalais)	
	No. of species (n=28)	% individuals (n=557)	No. of species (n=29)	% individuals (n=809)
Geckos	5	22.08%	9	14.58%
Skinks	5	20.29%	4	17.06%
Agamids	8	49.37%	6	57.48%
Snakes	10	8.26%	10	10.88%

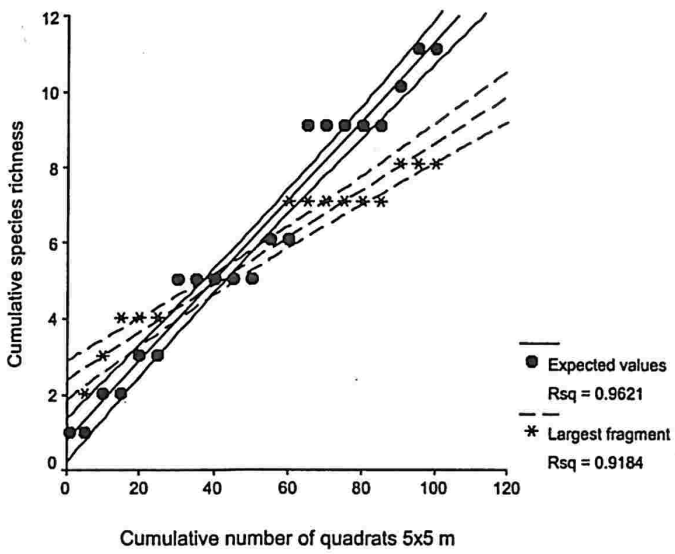
### 5.5.5. Effects of fragmentation: Accumulation curves for the observed decline in species richness

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 expected values of species richness were estimated from the contiguous rainforests samples, while the observed values were obtained from the different size classes of fragments. This analysis was controlled 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 5.10 a). The rate of species accumulation in Large fragments was lower than that in the contiguous rainforests (Figure 5.10 b) and that of Medium and Small fragments even less (Figure 5.10 c and d). These patterns further suggests that the species decline in the fragments is more due to the process of rainforest fragmentation than other factors like altitude and area.

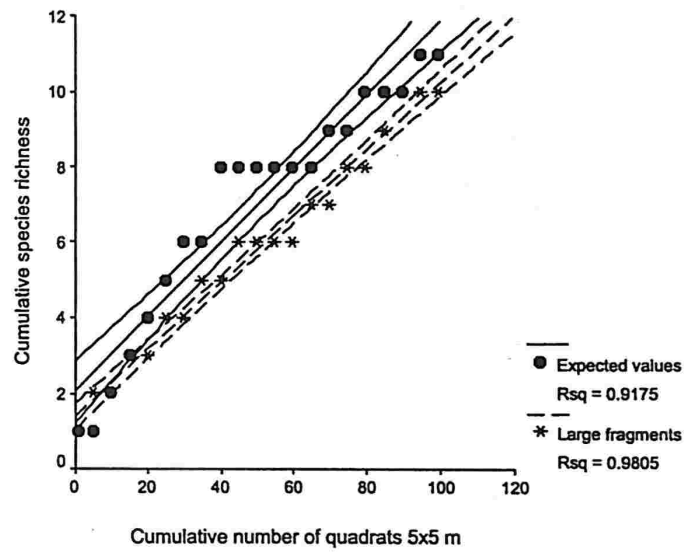
When the species accumulation curves were compared only among the rainforest fragments, species richness was highest in the Large fragments and was lowest in the Small fragments. There was no difference in species accumulation between the Very Large and the Medium fragments (Figure 5.11).

Figure 5.10. Species accumulation of rainforest 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).

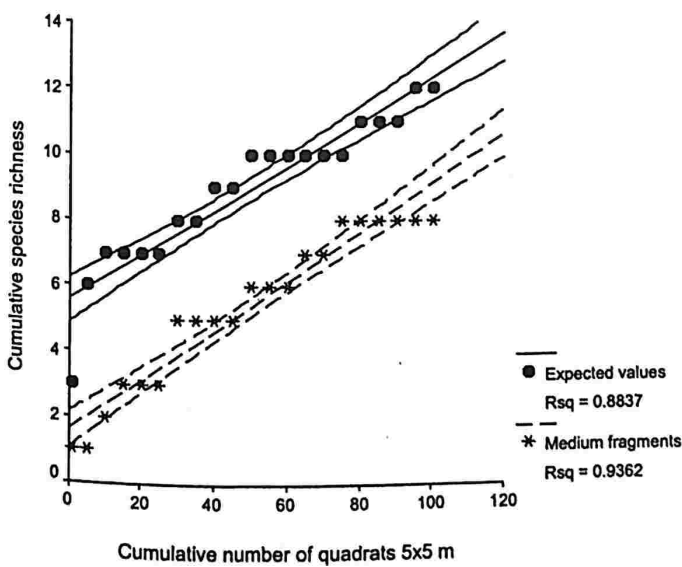
(a) Very Large fragment



(b) Large fragments



(c) Medium fragments



(d) Small fragments

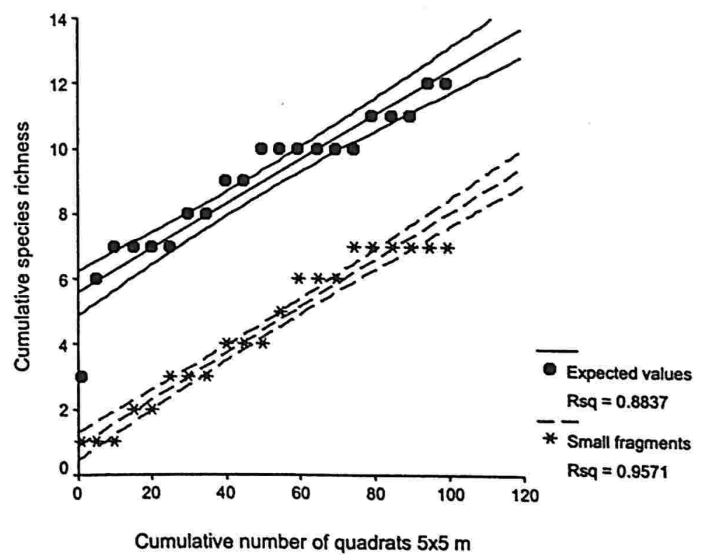
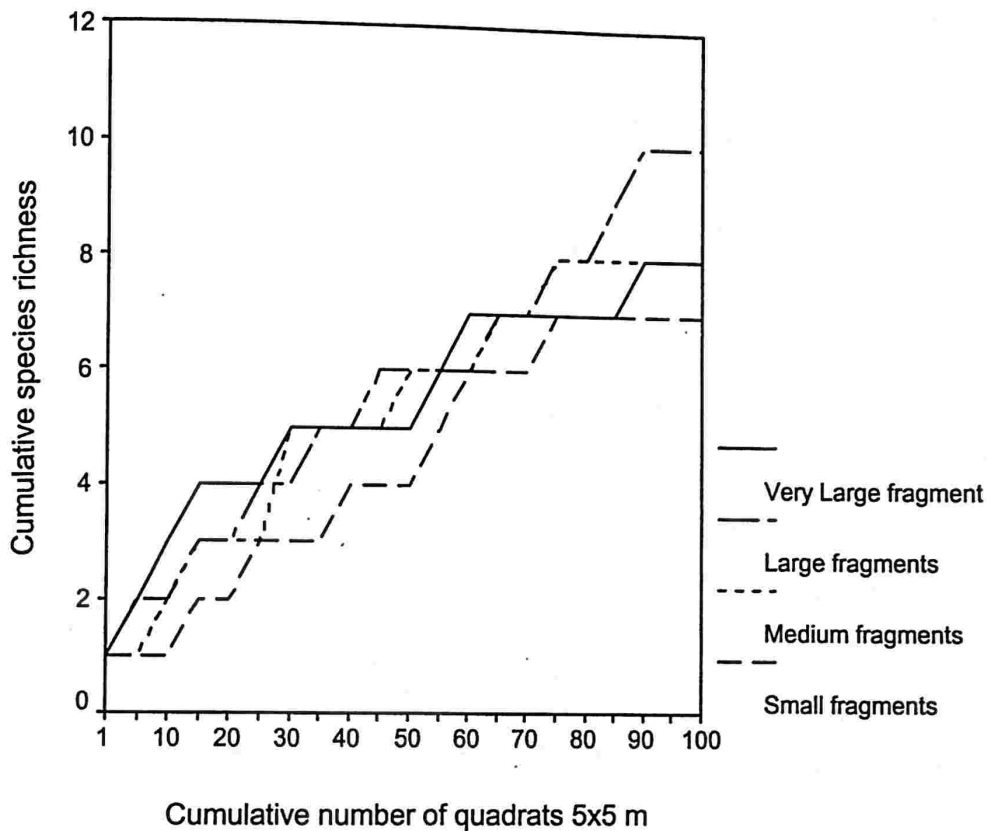


Figure 5.11. Species accumulation of rainforest reptiles in 100 random quadrats in a) Very Large fragment (>200 ha), b) Large fragments (50-200 ha), c) Medium fragments (10-50 ha) d) Small fragments (<10 ha) in the Anamalai Hills.



## 5.6 DISCUSSION

### 5.6.1 Reptilian species richness and endemism in the rainforest fragments

The rainforest fragments in the Anamalai Hills have been under anthropogenic pressure from about 1860 (Umapathy and Kumar 2000). Plantation practices in the area have resulted in areas of cardamom and coffee in few of these fragments. These forests are subjected to continuous pressures for fuel wood collection. Consequently, majority of these rainforest fragments are under varying stages of habitat succession, almost completely isolated from each other and are embedded in a vegetation matrix mainly of tea, cardamom, coffee and eucalyptus. This varying habitat quality after fragmentation enables the influx of non-native and secondary forest species into previously inaccessible areas (Saunders et al. 1991; Burkey 1995). The only recent survey of reptiles in the rainforest fragments and the surrounding matrix in the

Anamalai Hills reported only 7 species (Aengals 1995), while in the present study 40 species are reported from only the rainforest fragments. The rainforest fragments had 18 rainforest endemic species, 72.22% (13 species) belonging to two groups, namely geckos of the genus *Cnemaspis* and the fossorial shield tailed snakes of the genus *Uropeltis*. These species were recorded from all fragments, while other endemic species like *Salea anamallayana* and the skinks *Ristella* and *Scincella* were mainly restricted to the Very Large and Large fragments. Snakes were largely restricted to the Very Large and Large fragments.

### 5.6.2 Community structure and composition

Habitat fragmentation affects the flora and fauna of an area by replacing a naturally occurring ecosystem with a human-dominated landscape, which may be inhospitable to several of the original species (Saunders et al. 1991; Laurance and Yensen 1991; Terborgh 1992; Burkey 1995; Murcia 1995). This change contributes greatly to the extinction of species within remnant fragments by slanting the ecosystem balance in favour of species that are highly adaptable to changing conditions and causing interior species populations and ranges to decline (Saunders 1989). Similar patterns was also seen in the present study, the 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 abundance increasing 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 forest floors in the Small fragments had low leaf litter cover and canopy cover and were highly disturbed (details in Chapter 6). Consequently, the forest floor is exposed to more direct sunlight, thus increasing the soil temperature. A combination of these factors has led to the presence of non-endemic species in these Small and disturbed fragments. This resulted in a pronounced decrease in the proportion of

geckos with an associated increase of agamids. It is probable that the changes in habitat structure due to fragmentation-induced disturbance may not provide suitable conditions for typical rainforest species like *Cnemaspis*, thus causing their decline in smaller fragments. Habitat changes following fragmentation is likely to have affected the distribution of skinks also. In the larger and less disturbed fragments endemic skinks were most common, being replaced by non-endemic species like *Mabuya carinata* and *M. beddomii* in smaller and disturbed fragments.

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 fragments were generally non-endemic species, being also recorded from disturbed areas adjoining the rainforests. These species have colonized previously inhospitable rainforest fragments and perhaps competitively 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 KMTR (24 species). The snakes in the forest fragments were largely dominated by the pit vipers, which were largely restricted to the Large and Medium 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. It is believed that among reptiles, snakes are more restricted in their distribution and abundance by their food preference than by habitat complexity and disturbance (Reinert 1993).

### 5.6.3 Species richness declines with decreasing fragment size

A clear interpretation of a species-area relationship is epiphenomeral because changes in area are confounded by other variables such as changes in 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 than area per se. Recent studies have demonstrated that the persistence of species in a fragmented habitat is related more to habitat quality within and surrounding the fragments (Bierregaard et al. 1992) and the presence/absence of specific microhabitats (Bright and Morris 1996; the present study), than to the actual area of the fragment, whose influence seems to have been over-emphasized.

The present study has established the decrease in reptilian species richness in fragments, when area and altitude were controlled. This demonstrates that rainforest fragmentation and the associated changes in the habitat complexity (Bellamy et al. 1996) *per se* is the reason for the observed decline in species richness and endemism. Species richness was lowest in areas where the habitat quality and human related disturbance was greater, namely the Small fragments. The larger sized fragments seem to have similar number of species when compared with an unfragmented area, albeit lower than that recorded in the contiguous rainforest.

It has been suggested that species richness in a fragment is a function of both immigration and extinction rates, while the percentage of endemic species in a fragment depends largely on extinction rates (Diamond 1984). The Small fragments in the present study recorded very few endemic reptiles, and this may be largely attributed to the process of extinction in these fragments (also see Chapter 7). Although these species were recorded from other fragments, it is essential that the fragments supporting these species be protected as these may act as the source population, and their loss can lead to extinction of the metapopulation (Primack 1993).

Of the rainforest reptiles that were studied, snakes showed the largest difference in occurrence in the fragments, being completely absent in the Small fragments. The response of the other taxa was also similar with the abundance of endemic species declining with increase in non-endemic species. In agamids and skinks, the non-endemic species were also more abundant in the smaller and more disturbed fragments. The increase in the occurrence of non-endemic species is caused by greater disturbance levels rather than reduction in the area of the fragment.

#### **5.6.4 Altitude relationships; insignificant**

In the contiguous rainforest of KMTR altitude was an important factor correlated with the distribution and abundance of arboreal reptiles, while in the rainforest fragments its effect on species richness and abundance was insignificant. This difference may arise because reptilian assemblages in rainforest fragments are largely comprised of species that were and non-endemic species. The presence of these non-endemic species in this assemblage is due to rainforest fragmentation. When the non-endemic species were removed from the data set, the relationship with altitude became marginally stronger. The appearance of these species in the assemblage is likely to be the reason for the insignificant relation of altitude with species richness and abundance. The ecological effects of rainforest fragmentation allows for the immigration of non-native species, and could potentially competitively exclude drive rainforest species from these forest fragments. The forest fragments of each of the four size classes, sampled were all within a narrow altitudinal range. This could also partly explain the insignificant relationship with altitude.

The low variation in the altitude of the sampled fragments could be the reason for the very high similarity of taxa in the arboreal assemblage among the fragments, compared to the different species composition between the three sites in KMTR. Moreover, a majority of the species that structure this assemblage are secondary forest species that thrive in a disturbed and fragmented landscape and may not be controlled by the same factors that govern the distribution of typical rainforest species. While rainforest fragmentation seems to have its dominant effects on the arboreal

assemblage, its effect on the leaf litter assemblage seems to be minimal. This inference is supported by the fact that there has been only a marginal increase in the abundance of secondary forest species in the larger and relatively undisturbed fragments. A few of the rainforest species still continue to remain in these smaller and disturbed remnants indicating that the micro environment is still not completely adverse for their survival.

#### **5.6.5 Species richness and abundance peaks in Medium and Large fragments**

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 and 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. This was also true for species richness. It is likely that larger fragments hypothetically will support increased topographical relief and habitat diversity. If altitude and the climatic conditions are controlled for, 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 greater species richness and abundance in Large and Medium sized fragments is that Very Large fragment by virtue of being greater in area may have reached a state of equilibrium, while an equilibrium state has not been attained in Large and Medium fragments. Apart from this, it is also interesting to note that the Large and Medium fragments have moderate levels of disturbance (see Chapter 6). This finding also lends credibility for the intermediate disturbance hypothesis (Levin and Paine 1974; Connell 1978). It is also probable that fragments in the Anamalai Hills are in different successional stages with disturbance affecting the structural diversity as well as the overall species diversity, thus explaining the high species similarity in the forest fragments of Anamalai Hills.

The increase in species richness and abundance in the Large and Medium fragments is largely 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. The lack of competition and the presence of only a few species in this new habitat had led to an increase in abundance of these species. Consequently, these fragments tend to be super saturated with species and individuals, referred to as the 'crowding effect' (Case and Bolger 1991).

## 5.7 SUMMARY

Fragmentation of once contiguous rainforest into smaller isolated fragments has led to changes in the distribution and structure of both the leaf litter and arboreal reptile assemblages. 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 that were recorded from the Small disturbed remnants were non-endemic species while the typical rainforest species appear to have become locally extinct. 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 Medium 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. The arboreal assemblage seems to be more adversely affected by rainforest fragmentation and the disturbance that has followed than the leaf litter assemblage. Rainforest fragmentation alone is the reason for this observed decrease in species richness rather than effects of fragmentation size and altitude. 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.

## CHAPTER 6 MICROHABITAT ASSOCIATION

### 6.1 INTRODUCTION

Species often show preferences for certain characteristics of the habitat mosaic, and this affinity can be used to delineate the habitat of that species (Reinert 1993). The concept of habitat specificity in species has played a major role in the formulation of theories regarding evolution, the maintenance of species diversity and the organization of community structure (Rosenzweig 1981; Heatwole 1982). It has long been recognized that reptilian species in an assemblage are not randomly distributed in space either horizontally or vertically, but occupy discrete microhabitats (Heatwole 1977, 1982). However, information on habitat associations are lacking for the reptiles in the Indian sub-continent. An understanding of the nature of the microhabitat association for each species is essential to provide recommendations for the conservation of the many endemic species found in these habitats.

Many current concepts regarding microhabitat use in reptiles, and the methods to carry out such studies, are adapted from the framework developed by Inger and Colwell (1977). The earlier hypothesis that the zonation of reptilian assemblages is primarily affected by macrohabitat factors is inadequate to explain the structure of reptilian assemblages. Therefore, vegetation structure and other microhabitat features have also been considered (Heatwole 1982). The correlation between the number of faunal species and the heterogeneity of the habitat was first documented in birds (MacArthur 1972). Later Schoener (1974), Heatwole (1982) and Toft (1985), indicated that the structural complexity of the habitat is the dimension that is partitioned foremost among reptiles. This correlation with habitat heterogeneity has also been shown to be true for lizards (Vitt 1996). Apart from habitat heterogeneity, factors like food and thermoregulation also play a role and the structuring of reptilian assemblages may depend on the many ways in which species interact in partitioning such resources. Resource partitioning in reptiles along food, time and habitat gradients has been well documented (for reviews see Pianka 1973; Heatwole 1982; Toft 1985).

Studies on the structure of reptilian communities in a single habitat have recognized habitat complexity to be the most important dimension for lizards (Heatwole 1977; Toft 1985). Microhabitat separation has been shown among arboreal lizards in structurally complex habitats (Howard and 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 were limited by climatic factors, 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. This rule may not be applicable to snakes, as prey availability may be a greater factor limiting their distribution than other habitat requirements (Toft 1985). This is because snakes are at or near the top of most food chains and are likely to be subject to competition for food (Arnold 1972; Hairston et al. 1960; Reinert 1993). Given this difference in the nature of community structure, it is essential that microhabitat associations be examined at an individual taxa level.

Reptiles are restricted to certain structures such as leaf litter, rocks, trees, logs, shrubs and herbs, which they use for various activities (Heatwole and Taylor 1987). The greater the number and variety of such specific structures in the habitat, the greater will be the potential for supporting high numbers of individuals and species (Heatwole and Taylor 1987). The term microhabitat is defined in the present study as special features in the broader habitat context with which reptiles are known to be associated.

Studies of associations between species and habitat characteristics have considerable value as they allow predictions to be made about the response of a species or taxon to various habitat features. Such information is essential to conserve their populations and to manage their habitats.

## 6.2 OBJECTIVES

The objectives in this chapter are to:

- Determine the relationship between microhabitat elements and the distribution of rainforest reptiles.
- Compare the microhabitat associations of rainforest reptiles in a contiguous forest with those in forest fragments.
- Determine the changes in the reptilian community composition due to the changes in microhabitats associated with rainforest fragmentation.

## 6.3 METHODS

### 6.3.1 Sampling animals

Adaptive cluster sampling was used to sample leaf litter reptiles while forest transect was the sampling protocol for arboreal reptiles in both the relatively undisturbed, contiguous rainforests in Kalakad-Mundanthurai Tiger Reserve and in the rainforest fragments in Anamalai Hills (see Chapter 3).

### 6.3.2 Measurement of microhabitat variables and data analysis

In total, 34 habitat variables were measured from each sampling unit (Appendix 1). Variables were selected to represent the physiographic, vegetation and other microhabitat features of the environment. Microhabitat variables were recorded within 5 m x 5 m quadrats for leaf litter reptiles. For the arboreal reptiles, the variables were recorded along each of the 250 m forest transects, using 3 m x 3 m plots at every 25 m interval. Similar measurements were also made from plots laid around the location of each reptile sighting. The data analysis was similar for both the leaf litter and the arboreal reptile assemblages (See Chapter 3, Section 3.5.7).

## 6.4 RESULTS

### 6.4.1 Leaf litter reptiles

#### 6.4.1.1 *Microhabitat associations in the contiguous rainforests*

Bivariate analysis showed significant differences in the mean values of only two microhabitat variables, between quadrats with and without reptile detections (Table 6.1).

Table 6.1. Mean and SE of microhabitat variables that were significantly different between quadrats with and without leaf litter reptiles using Oneway ANOVA, KMTR (1997-98). Figures in parenthesis give sample size.

Habitat variable	Quadrats		F	Significance level
	with reptiles	without reptiles		
	Mean $\pm$ SE (N = 91)	Mean $\pm$ SE (N = 486)		
<b>Substrate characteristics</b>				
Rock cover	13.30 $\pm$ 1.94	9.44 $\pm$ 0.69	4.54	< 0.05
<b>Vegetation characteristics</b>				
Woody climbers	1.21 $\pm$ 0.10	0.93 $\pm$ 0.04	6.42	< 0.01

Many of the microhabitat variables showed correlations amongst themselves (Appendix 4). However, a principal component analysis of the microhabitat data required five components to collectively account for 65.5% of the variance. Moreover, the components were not easily interpretable. Therefore, discriminant function analysis (DFA) was used to test for differences among the reptilian taxa in their microhabitat associations.

The groups used for DFA 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 combined detections of agamids, snakes and other taxa associations, 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 observed variation. As only the first discriminant function was significant (Wilk's  $\lambda = 0.860$ ,  $\chi^2 = 86.29$ ,  $df = 20$ ,  $P < 0.001$ ), only this function was used in further analysis. The Wilk's  $\lambda$ , log determinants and the structure matrix are given in Table 6.2. The number of tree buttresses and the number of burrows in a quadrat were the most important independent variables in the discriminant function (Table 6.2 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 6.2 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 6.2 c). The positive axis explained a gradient of greater complexity of habitat in the forest floor, *i.e.* more microhabitats 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 (MW U Z = -5.396,  $P < 0.001$ ), along function 1 (Figure 6.1). 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 6.3).

Table 6.2. The values for Wilk's  $\lambda$ , log determinants and the structure matrix for the discriminant function analysis of leaf litter reptiles in the contiguous rainforests, KMTR (1997-98).

6.2a Tests of Equality of Group Means

	Wilks' $\lambda$	F	df 1	df 2	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

6.2b 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

6.2c 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 6.1. Discrimination of quadrats with and without leaf litter reptiles along discriminant function 1, KMTR (1997-98).

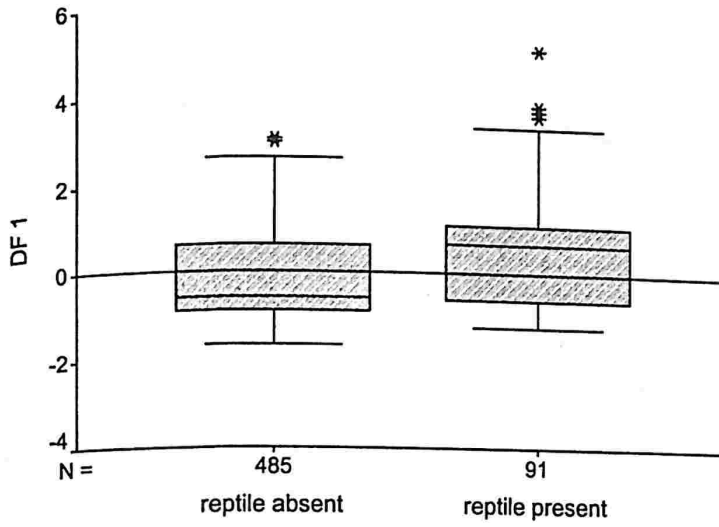


Figure 6.2. Discrimination of quadrats with different reptilian taxa along discriminant function 1, KMTR (1997-98).

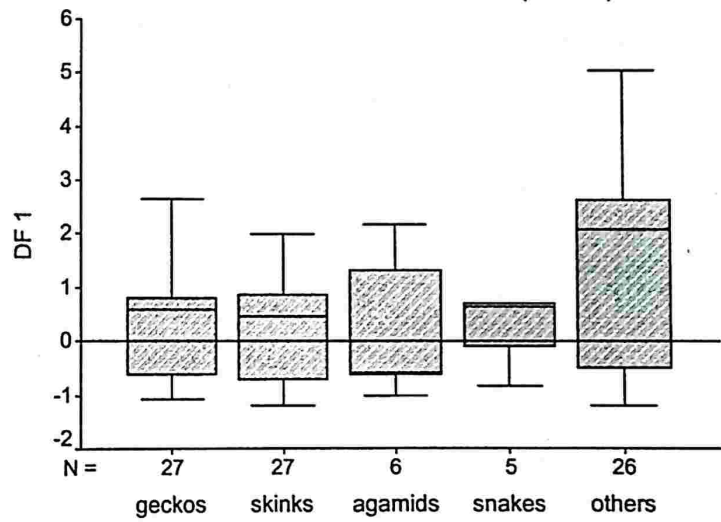
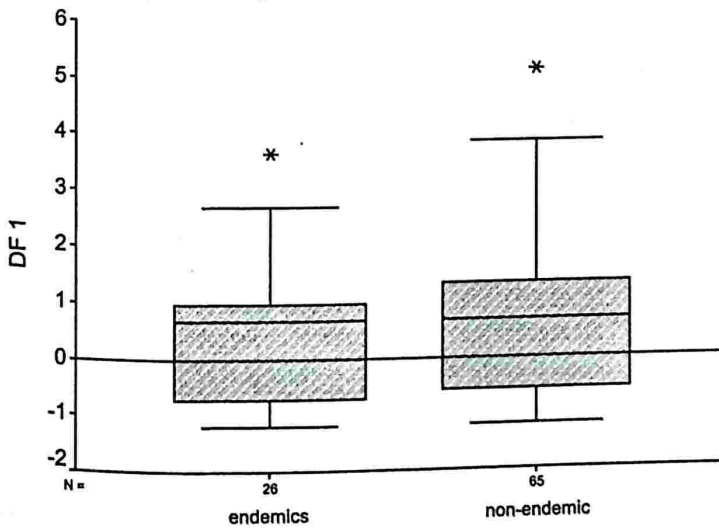


Figure 6.3. Discrimination of quadrats with endemics and non-endemic species along discriminant function 1, KMTR (1997-98).



### 6.4.1.2 Microhabitat associations in rainforest fragments

In bivariate analysis, a significant difference was detected in the mean values of six microhabitat variables representing mainly the litter and vegetation characteristics of the quadrat (Table 6.3). It is interesting to note that the variable (cut trees), that quantified the disturbance factor in the fragments is a significant variable that characterizing sites without leaf litter reptiles.

**Table 6.3.** Mean and SE of microhabitat variables that were significantly different between quadrats with and without leaf litter reptiles using Oneway ANOVA, Anamalai Hills (1998-99). Figures in parenthesis give sample size.

Habitat variable	Quadrats		F	Significance level
	with reptiles	without reptiles		
	Mean $\pm$ SE (N = 105)	Mean $\pm$ SE (N = 355)		
<b>Substrate characteristics</b>				
Small rocks	9.02 $\pm$ 0.83	7.18 $\pm$ 0.44	3.92	< 0.05
<b>Vegetation characteristics</b>				
Shrubs	8.46 $\pm$ 0.42	9.60 $\pm$ 0.21	3.90	< 0.01
Small logs	0.90 $\pm$ 0.02	0.80 $\pm$ 0.02	5.51	< 0.05
Tree buttresses	0.56 $\pm$ 0.06	0.44 $\pm$ 0.02	3.69	< 0.10
Cut trees	0.46 $\pm$ 0.07	0.30 $\pm$ 0.03	5.14	< 0.05

Many of the microhabitat variables showed correlations amongst themselves (Appendix 5). However, a principal component analysis required 9 components to collectively account for 71.3% of the variance. As the variation explained was low given the large number of components and the fact that the components were not easily interpreted, discriminant function analysis was used.

The groups that were used in 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 taxa associations, labelled as others. The first discriminant function explained 82.1% of the variance in the discrimination of quadrats with reptiles and

those without reptiles. The variation accounted by the second function was 10.4%, the third function 5.2%, while the fourth function accounted for only 2.3%. Only the first function was significant (Wilk's  $\lambda = 0.746$ ,  $\chi^2 = 133.1$ ,  $df = 32$ ,  $P < 0.001$ ), hence only this function was used in further analysis. The Wilk's  $\lambda$ , log determinants and the structure matrix are given in Table 6.4. The independent variables that were most important in the discriminating ability were the number of tree buttresses and number of cut trees (Table 6.4 a). The group covariance did vary among the groups with snakes showing greater deviation from the pooled within group covariance (Table 6.4 b). This is mainly due to the low detections of this group in the litter assemblage. The first function showed a strong positive correlation with the number of tree buttresses and to a lesser extent to the variables that quantified disturbance levels in the sites namely the number of cut trees and saplings, number of cardamom and coffee stems, while the negative axis was related to the herb and shrub layer (Table 6.4 c). The positive side of the axis explained a gradient of disturbance levels, from low disturbance to greater structural complexity in the forest floor, while the negative axis explained very dense understorey. Quadrats with leaf litter reptiles differed significantly from those without reptiles (MW U Z = -3.903,  $P < 0.001$ ), along the discriminant function 1 (Figure 6.4). The litter reptiles in the rainforest fragments were associated with quadrats with lower disturbance and greater forest floor complexity. Even though there was a significant difference in the discrimination of the quadrats along DF 1 by the different taxa of reptiles ( $F = 9.809$ ,  $df = 3$ ,  $P < 0.001$ ), the difference between geckos and skinks was again not significant along the DF 1, with these two taxa preferring areas with similar microhabitats (Figure 6.5). The difference was significant only between geckos and others, skinks and snakes and skinks and others (Tamhane's post hoc test). There was no difference between quadrats with endemic species and non-endemic species (Figure 6.6), along DF 1 (MW U Z = -1.327,  $P = 0.184$ ).

Table 6.4. The values for Wilk's  $\lambda$ , log determinants and the structure matrix for the discriminant function analysis for leaf litter reptiles in the fragmented landscape, Anamalai Hills (1998-99).

6.4a Tests of Equality of Group Means

	Wilks' $\lambda$	F	df 1	df 2	Sig.
Herb layer	.991	1.006	4	456	.404
Shrub layer	.988	1.358	4	456	.248
Rock cover	.997	.395	4	456	.812
Tree buttresses	.817	25.580	4	456	<.001
Cardamom	.985	1.678	4	456	.154
Coffee	.987	1.515	4	456	.197
Cut trees	.980	2.317	4	456	.056
Cut saplings	.988	1.405	4	456	.231

6.4b Log Determinants

Taxa	Rank	Log Determinant
Reptiles absent	8	10.672
Geckos	8	9.567
Skinks	8	13.368
Snakes	*	*
Others	8	11.750
Pooled within-groups	8	11.772

\* too few case for computation.

6.4c The Structure Matrix

	Functions			
	1	2	3	4
Tree buttresses	.915*	-.201	-.046	.124
Cut saplings	.206*	.094	-.203	-.075
Cut trees	.095	.699*	-.271	-.165
Herb layer	-.026	-.501*	-.057	.146
Cardamom	.049	.349	.759*	-.177
Rock cover	.090	.444	-.072	.767*
Coffee	.021	.203	-.266	-.322*
Shrub layer	-.183	-.235	.164	.300*

\* Largest absolute correlation between each variable and any discriminant function

Figure 6.4. Discrimination of quadrats with and without leaf litter reptiles along discriminant function 1. Anamalai Hills (1998-99).

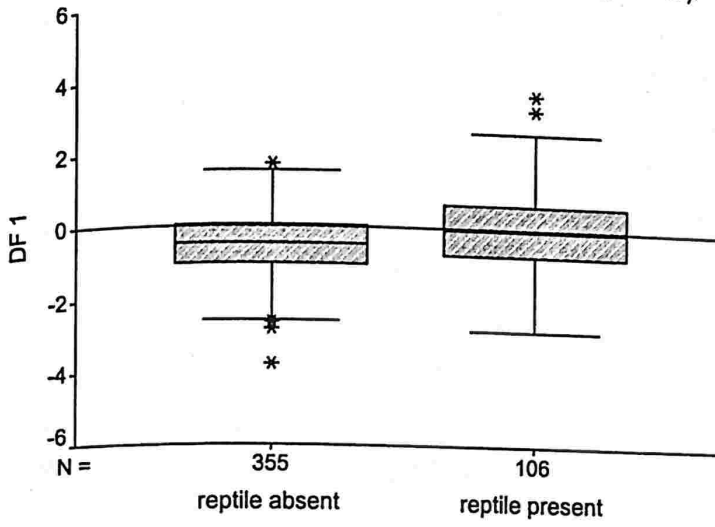


Figure 6.5. Discrimination of quadrats with different reptilian taxa along discrimination function 1, Anamalai Hills (1998-99).

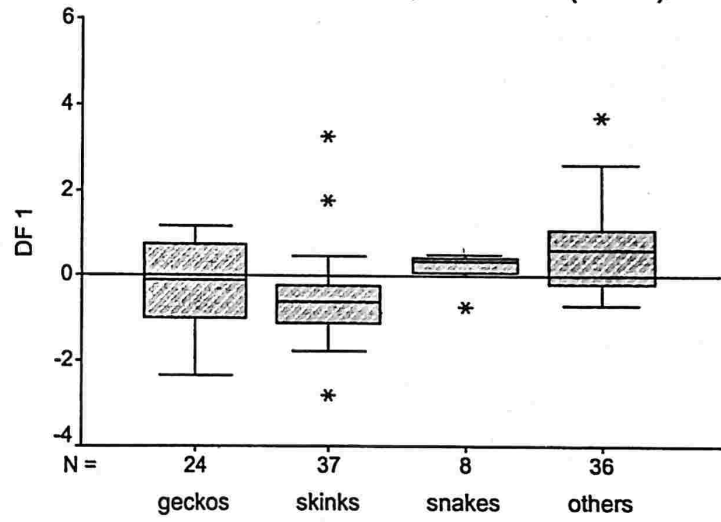
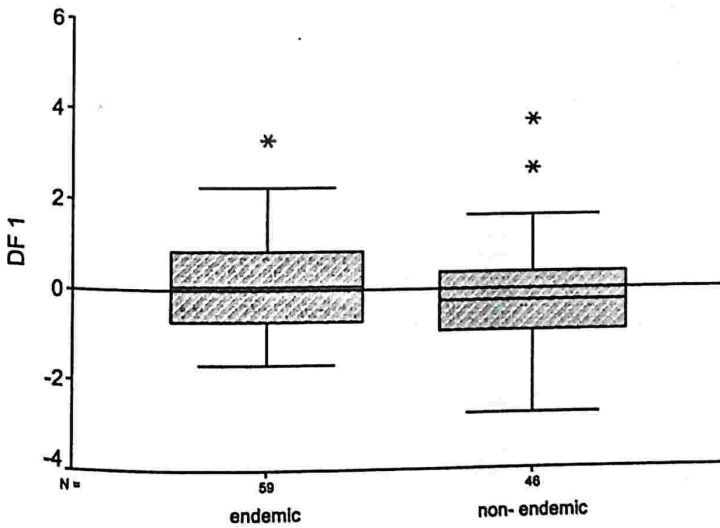


Figure 6.6. Discrimination of quadrats with endemics and non-endemic species along discriminant function 1, Anamalai Hills (1998-99).



## 6.4.2 Arboreal reptiles

### 6.4.2.1 Microhabitat associations in the contiguous forests

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 6.5).

**Table 6.5.** Mean and standard errors of microhabitat variables that were significantly different between plots with and without arboreal reptiles using Oneway ANOVA, KMTR (1997-98). Figures in parenthesis give sample size.

Habitat variable	Plots (3 m x 3 m)		F	Significance level
	with reptiles	without reptiles		
	Mean $\pm$ SE (N = 198)	Mean $\pm$ SE (N = 216)		
<b>Substrate characteristics</b>				
Litter depth	2.78 $\pm$ 0.04	3.36 $\pm$ 0.06	53.58	< 0.001
Rock cover	11.13 $\pm$ 1.27	15.91 $\pm$ 1.59	5.60	< 0.05
Litter cover	91.16 $\pm$ 0.96	84.85 $\pm$ 1.40	14.21	<0.001
<b>Vegetation characteristics</b>				
a) Understorey (<10 m)				
Herb layer	11.98 $\pm$ 0.33	4.74 $\pm$ 0.51	21.43	< 0.001
Shrub layer	9.67 $\pm$ 0.35	12.73 $\pm$ 0.52	24.76	< 0.001
Tree buttresses	0.37 $\pm$ 0.03	0.22 $\pm$ 0.03	10.70	< 0.001
Woody climbers	0.81 $\pm$ 0.06	0.34 $\pm$ 0.04	35.65	<0.001
Basal area	1496.03 $\pm$ 162.07	767.46 $\pm$ 88.98	14.78	<0.001
b) Canopy (>10 m)				
Canopy height	23.81 $\pm$ 0.26	24.95 $\pm$ 0.37	6.49	<0.01
Canopy cover	89.62 $\pm$ 0.52	93.00 $\pm$ 0.33	29.29	<0.001

Although many of the microhabitat variables showed correlations amongst themselves (Appendix 6), a principal component analyses required 4 components to collectively account for 71.85 % of the variance. Hence, discriminant function analysis was used to look at habitat associations in arboreal reptiles.

The groups that were 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 of reptiles and those without reptiles. The variance accounted by the second function was 13.3%, while the third function accounted for only 6.9%. The first two functions were significant (Wilk's  $\lambda = 0.590$ ,  $\chi^2 = 213.945$ ,  $df = 33$ ,  $P < 0.001$  and Wilk's  $\lambda = 0.884$ ,  $\chi^2 = 49.791$ ,  $df = 20$ ,  $p < 0.001$ ). Consequently, functions 1 and 2 were used in further analysis. The Wilk's  $\lambda$ , log determinants and the structure matrix are given in Table 6.6. Microhabitat variables that quantified the vegetation characteristics were important in the discriminating ability of the two functions (Table 6.6 a). The different groups of arboreal reptiles did vary in their covariance as shown by the log determinant values (Table 6.6 b). The first function showed a positive relationship with the variables that quantified the forest floor structure and the understorey variables like litter depth and litter cover, herb and shrub layer, while 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 6.6 c). Areas with arboreal reptiles differed significantly with areas 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 6.7 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 6.7 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 6.8 a,b).

Table 6.6. The values for Wilk's  $\lambda$ , log determinants and the structure matrix for the discriminant function analysis of arboreal reptiles in contiguous rainforests, KMTR (1997-98).

6.6a Tests of Equality of Group Means

	Wilks' $\lambda$	F	df 1	df 2	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

6.6b 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

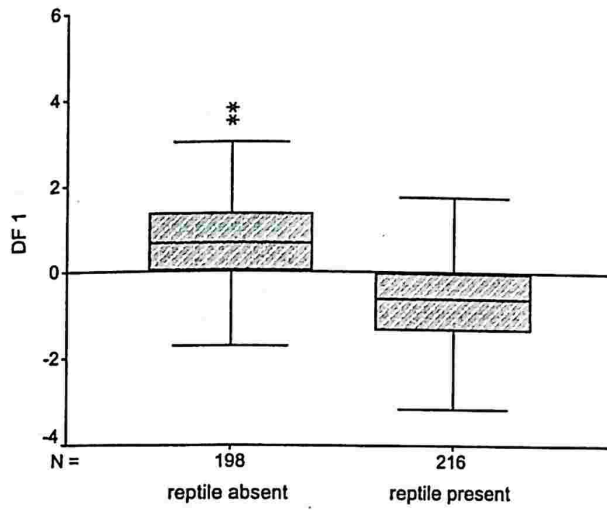
6.6c The Structure Matrix

	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*

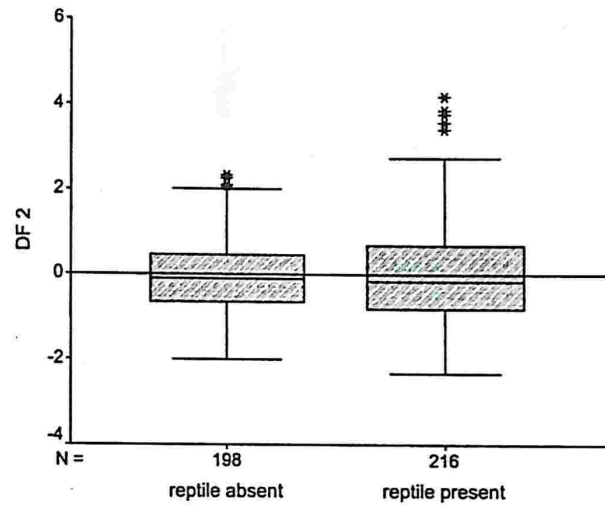
\* Largest absolute correlation between each variable and any discriminant function

Figure 6.7. 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).

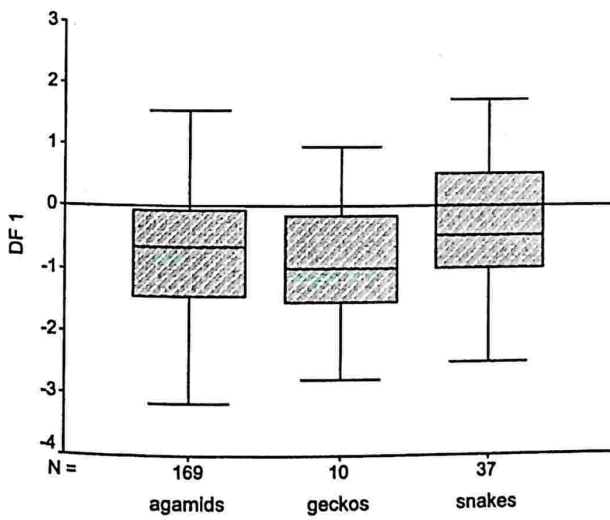
(a) DF 1



(b) DF 2



(c) DF 1



(d) DF 2

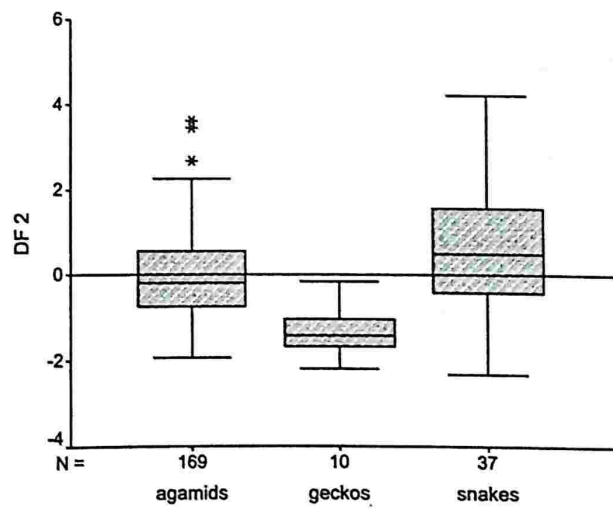
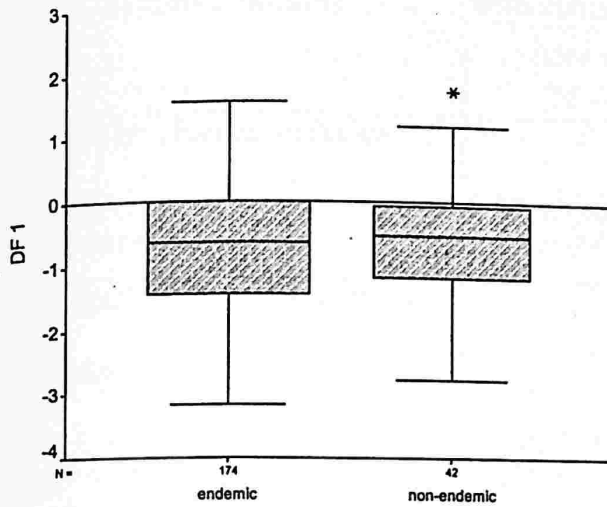
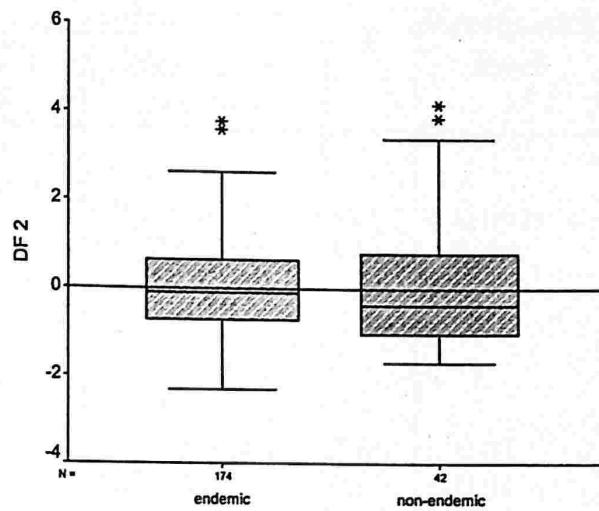


Figure 6.8. Discrimination of plots with endemic and non-endemic species of arboreal reptile along (a) DF 1 and (b) DF 2, KMTR (1997-98).

(a) DF 1



(b) DF 2



#### 6.4.2.2 *Microhabitat associations in rainforest fragments*

Significant differences were detected using bivariate analysis in the mean values of 13 microhabitat variables among plots with arboreal reptiles and those without arboreal reptiles. These variables mainly represented the forest floor, the vegetation and the disturbance characteristics of the plots. (Table 6.7).

Table 6.7. Mean and standard errors of microhabitat variables that were significantly different between plots with and without arboreal reptiles using Oneway ANOVA, Anamalai Hills (1998-99). Figures in parenthesis give the sample size.

Habitat variable	Plots (3 m x 3 m)		F	Significance level
	with reptiles	without reptiles		
	Mean $\pm$ SE (N = 453)	Mean $\pm$ SE (N = 363)		
<b>Substrate characteristics</b>				
Burrows	0.46 $\pm$ 0.03	0.25 $\pm$ 0.03	19.25	< 0.001
Rock cover	9.79 $\pm$ 0.64	14.17 $\pm$ 1.00	14.65	<0.001
<b>Vegetation characteristics</b>				
a) Understorey (< 10 m)				
Herb layer	16.46 $\pm$ 0.44	15.40 $\pm$ 0.45	2.80	< 0.01
Shrub layer	10.35 $\pm$ 0.29	9.25 $\pm$ 0.29	6.90	< 0.01
Tree buttresses	0.34 $\pm$ 0.02	0.26 $\pm$ 0.02	6.53	< 0.01
Woody climbers	1.03 $\pm$ 0.03	0.85 $\pm$ 0.04	11.51	<0.001
Rattan	0.32 $\pm$ 0.03	0.19 $\pm$ 0.02	9.05	<0.01
b) Canopy (> 10 m)				
Canopy height	32.42 $\pm$ 0.31	28.07 $\pm$ 0.33	90.99	<0.001
<b>Disturbance characteristics</b>				
Small cut trees	1.21 $\pm$ 1.67	0.85 $\pm$ 1.50	9.89	<0.001
Large cut trees	0.29 $\pm$ 0.54	0.15 $\pm$ 0.39	19.29	<0.001
Cut basal area	72.20 $\pm$ 325.16	33.60 $\pm$ 156.13	4.32	<0.05
Cardamom stems	0.78 $\pm$ 2.17	0.45 $\pm$ 1.41	6.36	<0.01
Coffee stems	0.31 $\pm$ 1.08	0.56 $\pm$ 2.04	4.85	<0.05

Although, many of the microhabitat variables showed significant correlations amongst themselves (Appendix 7), principal component analyses required 9 components to collectively account for 58.15 % of the variance. Consequently, discriminant function analysis was used to determine the microhabitat associations in the arboreal reptiles in the rainforest fragments of Anamalai Hills.

The groups that were 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 70.6% of the variance in the discrimination between plots with reptiles and

without reptiles. The total variance accounted by the second function was only 18.4%, and the third function accounted by only 11%. All the three functions were important in the discrimination of areas with the different taxa of arboreal reptiles (Wilk's  $\lambda = 0.734$ ,  $\chi^2 = 249.527$ ,  $df = 45$ ,  $P < 0.001$ ; Wilk's  $\lambda = 0.908$ ,  $\chi^2 = 77.73$ ,  $df = 28$ ,  $P < 0.001$ ; Wilk's  $\lambda = 0.964$ ,  $\chi^2 = 29.397$ ,  $df = 13$ ,  $P < 0.01$  respectively). However, as 89% of the variance was explained by the first two functions, only these two were used in further analysis. The Wilk's  $\lambda$ , log determinants and the structure matrix are given in Table 6.8. The independent microhabitat variables that were effective in the discrimination of the areas with the different taxa of reptiles were those that quantified the forest floor characteristics, the vegetation characteristics and the disturbance levels (Table 6.8 a). Due to the low sample size for geckos and snakes, the taxa were not equal in their covariance as shown by variation in the log determinant values (Table 6.8 b). The first function showed a strong positive relation to the variables that quantified canopy height, number of trees and coffee stems, and was also related to areas with greater number of cut saplings. The second function was related to understorey variables (shrubs and cardamom) and rock cover, while being negatively related to disturbance variables (Table 6.8 c). Only discriminant function 1 was important in the discrimination of areas with and without reptiles (MW U Z = -12.548,  $P < 0.001$ ), while the other two functions were not significant (Figure 6.9 a,b). Although the two functions were important in the discrimination of areas with the different reptilian taxa ( $F = 2.761$ ,  $df = 2$ ,  $P = 0.06$ ;  $F = 24.242$ ,  $df = 2$ ,  $P < 0.001$  respectively), Tamhane's post hoc test identified greater difference in the areas occupied by the three taxa only along DF 2 (Figure 6.9 c,d). The areas that supported endemic and those with non-endemic species did not differ in their microhabitat characteristics along DF 1 and DF 2 (Figure 6.10, a,b).

Table 6.8. The values for Wilk's  $\lambda$ , log determinants and the structure matrix for the discriminant function analysis of arboreal reptiles in the rainforest fragments, Anamalai Hills (1998-99).

6.8a Tests of Equality of Group Means

	Wilks' $\lambda$	F	df 1	df 2	Sig.
Canopy height	.890	33.517	3	812	<.001
Trees (> 20 gbh)	.990	2.623	3	812	.050
Tree Buttresses	.987	3.544	3	812	.014
Herb layer	.991	2.466	3	812	.061
Shrub layer	.986	3.896	3	812	.009
Rock cover	.969	8.516	3	812	<.001
Liana	.980	5.527	3	812	.001
Tree hollows	.970	8.317	3	812	<.001
Lantana	.996	1.120	3	812	.340
Cut saplings	.986	3.856	3	812	.009
Large cut trees	.961	10.934	3	812	<.001
Cardamom stems	.988	3.379	3	812	.018
Coffee stems	.993	1.915	3	812	.126
Total basal area	.988	3.273	3	812	.021
Total cut basal area	.980	5.609	3	812	.001

6.8b Log Determinants

Taxa	Rank	Log Determinant
Reptile absent	15	43.539
Geckos	15	25.147
Agamids	15	44.068
Snakes	15	36.169
Pooled within-groups	15	45.174

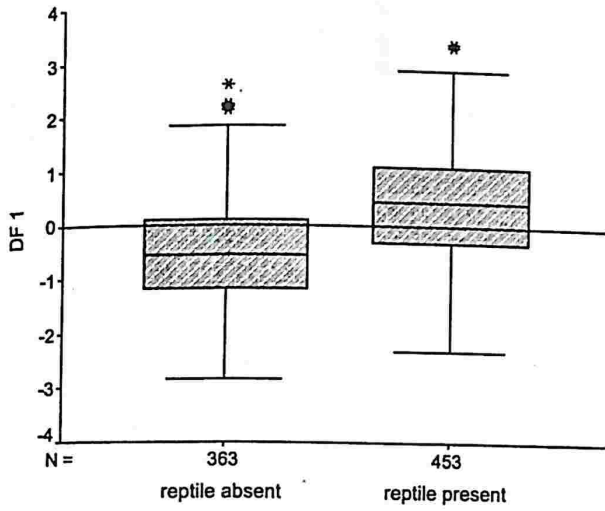
### 6.8c The Structure Matrix

	Functions		
	1	2	3
Canopy height	.705*	.118	-.116
Tree hollows	.340*	.043	-.239
Trees (> 20 gbh)	.181*	-.165	.032
Coffee stems	-.166*	-.022	.077
Large cut trees	.326	.483*	-.106
Rock cover	-.274	.458*	-.112
Total basal area	.008	.435*	.154
Shrub layer	.186	-.306*	.092
Cardamom stems	.166	.284*	.158
Tree buttresses	.160	.270*	.260
Liana	.198	-.006	.549*
Total cut basal area	.201	-.062	-.541*
Cut saplings	.205	-.143	.271*
Lantana	.085	.106	.218*
Herb layer	.143	-.206	-.210*

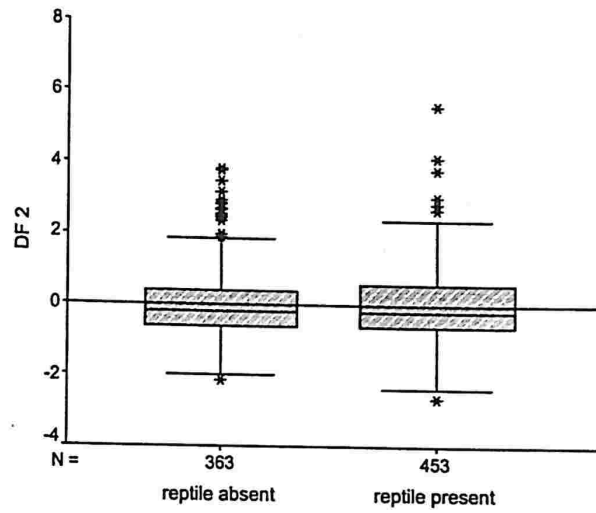
\* Largest absolute correlation between each variable and any discriminant function

Figure 6.9. 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, 1 and (d) DF 2, Anamalai Hills (1998-99).

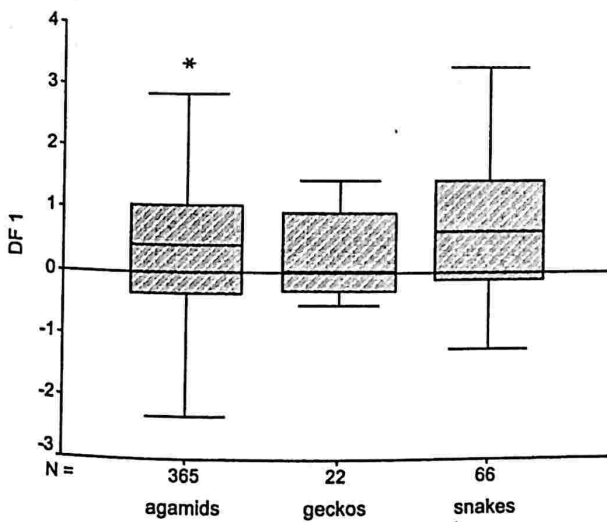
(a) DF 1



(b) DF 2



(c) DF 1



(d) DF 2

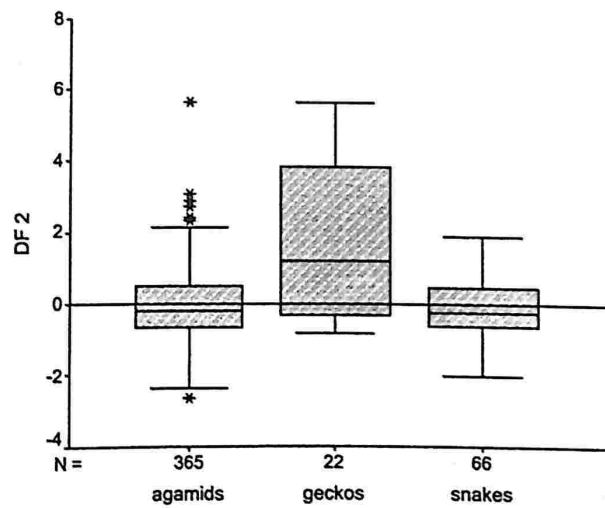
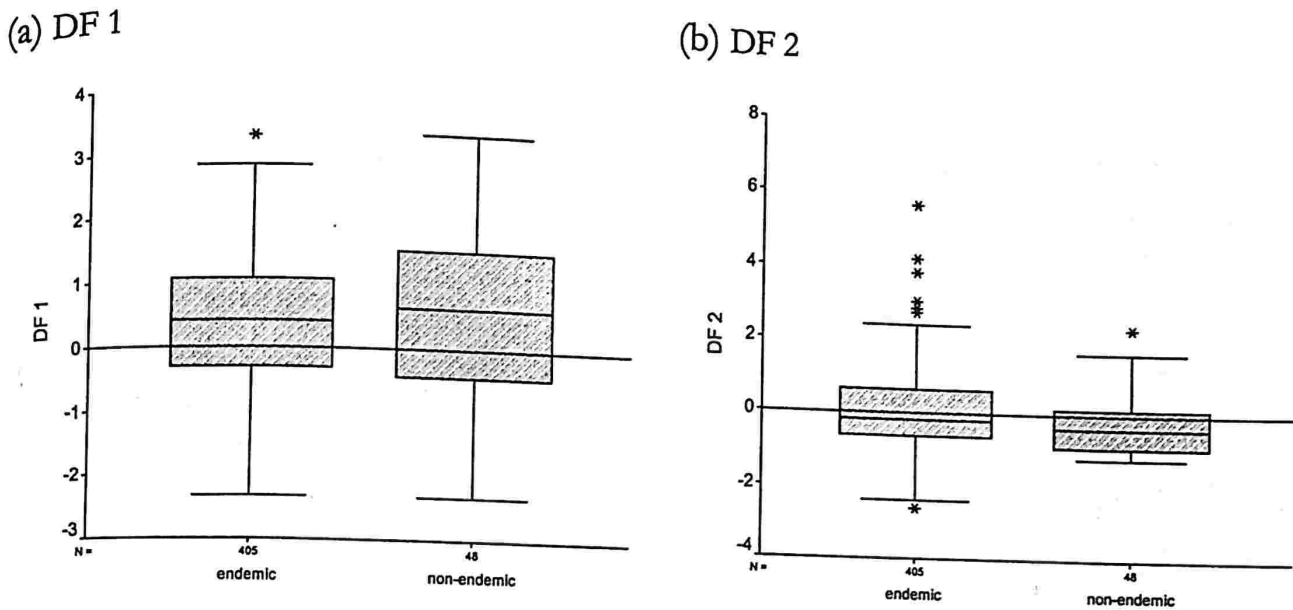


Figure 6.10. The discrimination of plots with arboreal reptile endemic and non-endemic species along (a) DF 1 and (b) DF 2, Anamalai Hills (1998-99).

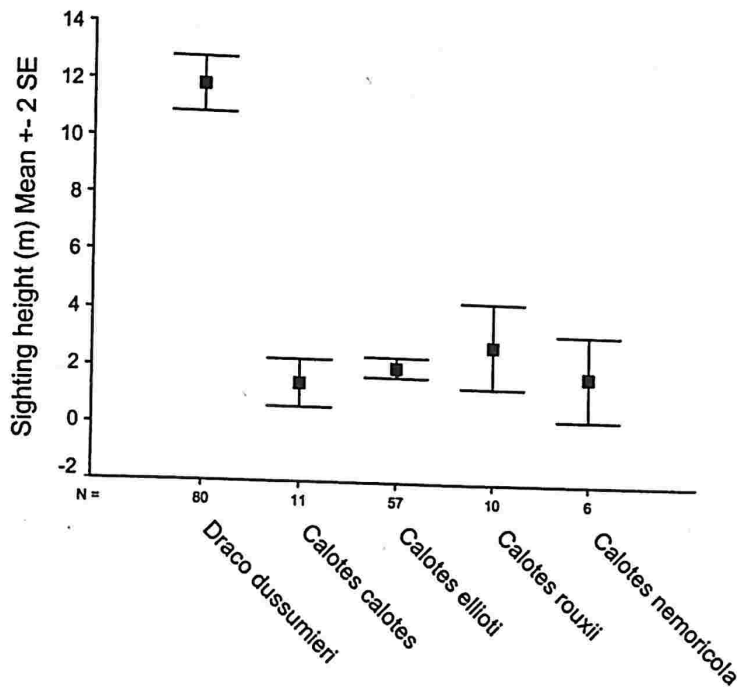


### 6.4.2.3 Partitioning of the vertical habitat by agamids

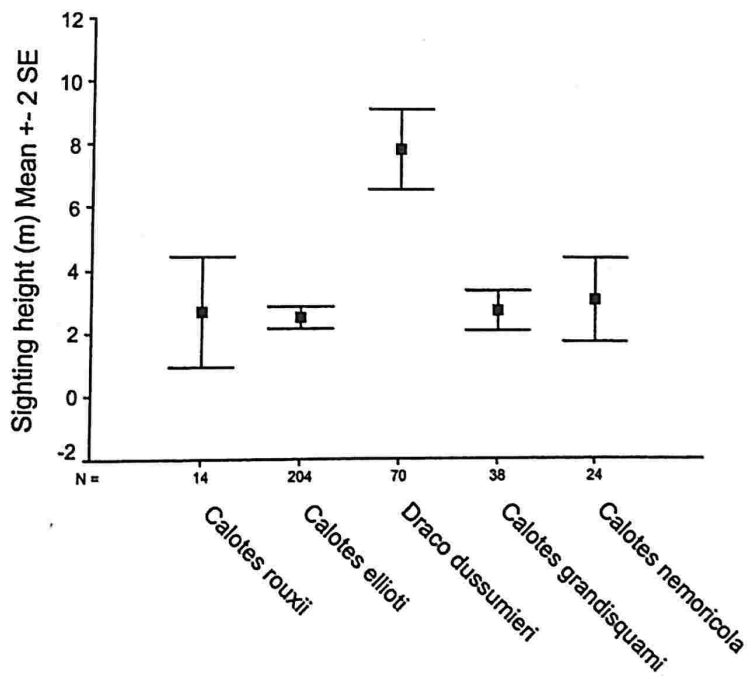
Agamids in both the contiguous rainforest of KMTR and in the rainforest fragments of Anamalai Hills partitioned the vegetation along a vertical scale. Although agamids in the rainforest fragments were associated with the understorey at lower heights than in the contiguous rainforests, still there was no significant difference in the mean heights at which the four species of *Calotes* were found. The non-endemic species like *Calotes ellioti* and *C. rouxii* took to a almost terrestrial mode of life in the fragments while in the contiguous rainforests these species were within a range of 1 to 4 m in height above the ground (Figure 6.11 a,b).

Figure 6.11. The partitioning of the vertical stratum by the agamids in (a) KMTR (1997-1998) and (b) Anamalai Hills, (1998-99). Only species with >5 sightings are included.

(a) KMTR



(b) Anamalai Hills



## 6.5 DISCUSSION

### 6.5.1 Microhabitat associations in reptiles

Ecological and behavioral requirements of reptiles direct the non-random associations of reptiles with specific structural features of the microhabitat. Precise use of the habitat is required as reptiles spend a lot of their daily activity on thermoregulation (Adolph 1990), and consequently, at high altitudes the availability of basking sites is a potential limiting factor for agamids and geckos (Hertz and Huey 1981) and for snakes (Reinert 1993). Therefore, habitat use or habitat associations in reptiles cannot be viewed independent of thermoregulation. In addition, the ordering of species in space could be due to the many ways in which species differ in their spectrum of response and tolerance to various microhabitats and the inter-specific variation in habitat selection (Schoener 1974, 1977). Rubio and Carrascal (1994) hypothesized that the distribution of reptiles at larger scales would be the combined response to local conditions, with respect to prominent factors influencing physiological tolerance. It has also been shown that reptiles that are at higher altitudes are in general small in size and they are capable of attaining faster rates of heat exchange (Carrascal et al. 1992) and high relative evaporative water loss (Mautz 1982). Given this inherent difference in the habitat associations in reptiles across various taxa and size categories, it is imperative to gain an understanding of microhabitat associations at these levels in rainforest reptiles before one can assess what fraction of the change in the assemblage is attributed to the direct effects of habitat fragmentation.

#### 6.5.1.1 *Leaf litter reptiles*

##### *In the contiguous rainforests*

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, which in turn allow greater penetrability for reptiles. 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 and

Hailey 1999). Forest floor environments with greater presence of burrows, tree hollows and buttress trees led to the greater availability of crevices, which are mostly absent in disturbed fragments. Such 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 and 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. Greater penetrability of the forest floor also offers these reptiles more numerous escape routes from their predators, than areas where the forest floor is completely devoid of any such structural features.

As the assemblage in the contiguous rainforests had few non-endemic species, there was no significant difference in the microhabitat attributes between areas that were used by endemic and the non-endemic reptiles (low statistical power). This lack of difference is mainly due to the low abundance of non-endemic reptiles in the litter assemblage in the contiguous rainforests.

#### *In the rainforest fragments*

Geckos and skinks were recorded in all size categories of fragments and these taxa dominated the leaf litter assemblage. These reptiles also showed preference for similar microhabitat features as recorded in the contiguous rainforests. Although members of these two taxa were also recorded from many of the rainforest fragments, only the non-endemic species were found in areas with higher levels of disturbance. These fragments were in general devoid of tree buttresses and leaf litter, and with greater substrate temperatures. A majority of the endemic species were absent in these disturbed areas.

The accumulation of leaf litter in the rainforests is essential for the survival of the leaf litter reptile assemblage as it helps to maintain a more constant microclimate in this habitat. As the body temperature of litter reptiles has to be maintained within a

narrow range through behavioral thermoregulation, they prefer areas that maximize their performance levels (Margules 1996; Sarre et al. 1996). Due to habitat fragmentation and the related modification of the physical and structural, micro-climatic features (Saunders et al. 1991; section 6.6.1.4, this chapter), the habitat specialists are more likely to disappear in Small and disturbed fragments than in the Large and less disturbed fragments.

#### 6.5.1.2 *Arboreal reptiles* *In the contiguous rainforest*

Agamids dominated the assemblage in the contiguous rainforest. As a taxon, the species that are known from the rainforests of the Western Ghats are exclusively arboreal in habit. In the contiguous rainforests they exhibited strong associations with locations supporting greater tree basal area with medium levels of understorey and canopy cover. The association of arboreal reptiles with such structural features of the habitat has also been recorded in other studies (Vitt 1995; Vitt and Zani 1996). The agamids in this assemblage were dominated by *Calotes*, represented by 6 of a total of 8 species. These species, though varying in their body size (Murthy 1985), prefer similar prey species and therefore are likely to partition their habitat to avoid competition. Data on the partitioning of the habitat were limited to five species due to low sightings of the other species. Among the four species of *Calotes* recorded (>5 times), the smaller species, *Calotes rouxii* and *C. ellioti*, 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.

#### *In the rainforest fragments*

Agamids dominated this assemblage also, being found in all the rainforest fragments, but the diversity was low with only five species being recorded. Arboreal geckos were more diverse in the rainforest fragments (6 species) than in the contiguous rainforests (3 species). Although habitat generalists (*Calotes ellioti* and *C. rouxii*) were more

abundant in this assemblage, in general the microhabitat associations of agamids were similar to that seen in the contiguous rainforest. The endemic species (*C. grandisquamis* and *C. nemoricola*) were more restricted to areas with minimal disturbance and greater habitat complexity than the non-endemic species. The associations with these structural features by agamids become apparent when their behavioural thermoregulation is also considered. Locations with greater basal area and numerous trees present basking sites that are superior in their characteristics than areas that are disturbed. This small-scale structural heterogeneity provides the endemic reptiles with a range of basking sites and a wide range of prey base to choose from. Areas lacking in these habitat features would be unsuitable for these endemic reptiles and is more suitable for the non-endemic and habitat generalists species as seen in the Small and disturbed fragments.

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 and Burghardt 1993). The snakes recorded from KMTR and Anamalai Hills 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 viperids (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 provides greater microhabitat heterogeneity and suitable sites for basking. A majority of these sites are 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 may be 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 and de Carvalho 1995).

#### 6.5.1.3 *Change in the reptilian assemblage due to forest fragmentation*

Habitat fragmentation leads to changes in the physical and structural characteristics of the fragments (Saunders et al. 1991; Laurance and Bierregaard 1997). The resistance or susceptibility of fragments to such changes may be more vital than stochastic fluctuations in population size, in deciding which species will move towards extinction and which will survive in the fragments (Bender et al. 1996; Kitchener 1980; Margules 1996; Martens et al 1996; Saunders et al. 1991; Sarre et al. 1996). The results of my study supported the hypothesis that the response of a species to habitat fragmentation is a function of its degree of habitat specialization.

Among the four size categories of rainforest fragments studied, the Medium and Large fragments showed moderate levels of disturbance and the Very Large fragment had minimal disturbance, while the Small fragments showed high levels of disturbance. There was an increase in the microhabitat variables that quantified the disturbance levels in the Small and Medium fragments (namely, number of cut trees and saplings and the presence of cardamom stems), along with an increase in herb layer. The leaf litter and arboreal assemblage, apart from associating with microhabitats discussed above, were also associated with areas that had minimal disturbance levels. The reptiles recorded from areas with high levels of disturbance, were the non-endemic species and habitat generalists. Some of the probable reasons for this are discussed below.

Areas with very low litter cover and greater number of cut trees, characteristics of highly disturbed Small fragments, have larger greater canopy openings resulting in an increase in substrate temperatures. Temperatures attained may be beyond the tolerance limits for normal activity of the litter dwelling species. This renders the area unsuitable for the survival of the endemic litter reptiles, while the non-endemic species apparently better adapted to succeed in these habitats. Similar loss of reptiles due to increased tree harvesting has also been reported from the Amazonian rainforests (Vitt et al. 1997).

Generally, the high diversity of arboreal reptiles in a habitat is correlated with the structural diversity of the habitat (Pianka 1966, 1986; Vitt 1995; Vitt and Zani 1996). This relationship is supported in the present study, as the diversity in the arboreal guild was greater than in the terrestrial guild. In the contiguous rainforests of KMTR, 22 arboreal reptiles were recorded, while only 19 species were recorded from the rainforest fragments in Anamalai Hills. The changes in the habitat structure mainly due to habitat fragmentation and human induced disturbance is presumably the reason for this decrease in species richness in the fragments.

Density compensation (Case 1975; Malcom 1997), *i.e.* the loss of some species in an assemblage is compensated by the colonization of other reptiles and by an increase in their abundance in the assemblage has been documented in the fragments.

In conclusion, it is reasonable to hypothesis that rainforest fragmentation has had a greater effect on the arboreal assemblage, with a concomitant decrease in diversity and an increase in abundance of habitat generalists. In the leaf litter assemblage, few habitat specialists species remain in the Small and disturbed fragments, while habitat generalists are uncommon in the larger and less disturbed areas.

## 6.6 SUMMARY

The organization of the leaf litter and arboreal reptiles in the rainforest is complex, and depends on the collective habitat selection of various species involved and the way they space themselves relative to other species. Although, there was no major difference between geckos and skinks in their microhabitat associations, skinks were associated with areas with greater leaf litter and understory structure, while rocks seemed to be an important habitat element for geckos. Except for the secondary forest species, these taxa were associated with areas with minimal disturbance. Among the arboreal reptiles, agamids were associated with areas with greater basal area and lower canopy while the converse is true for snakes. Both the leaf litter and arboreal assemblages also showed preference for areas with lower disturbance. With a larger sample size, it may be possible to confirm this pattern. Naming any single or a few microhabitat variables that uniquely influence the distribution of rainforest reptiles is not possible given the highly diverse requirements among the various species. It is only reasonable to state that a combination of factors that include physiological and morphological constraints, competition and predation, in addition to the structural features of the habitat operate in tandem to shape the rainforest assemblage. Change in habitat quality due to forest fragmentation has had a greater effect on the arboreal assemblage than on the leaf litter assemblage. Finally, discriminant function analysis can be used as a very useful tool to examine the habitat associations in reptiles and to develop a model that predicts the habitat requirements of rainforest reptiles.

## CHAPTER 7

# NESTEDNESS IN THE OCCURRENCE OF REPTILES IN THE RAINFOREST FRAGMENTS

### 7.1 INTRODUCTION

The effects of fragmentation of natural communities into habitat isolates continue to be a major topic of ecological research (Bierregaard et al. 1992; Terborgh 1992). The threats of habitat fragmentation is even greater to tropical organisms, which occurs in low densities due to their patchy distribution (Foster 1980), and are found in relatively small geographic ranges (Terborgh and Winter 1983). Habitat fragmentation may result in local species extinction, which results in forest fragments with impoverished fauna and flora (Terborgh et al. 1997). These fragments are expected to contain fewer species than similar sized areas in the contiguous habitat due to secondary extinction after isolation caused by a variety of processes that together comprise 'faunal relaxation' (Brown 1971; Wilcox 1980; Newmark 1987). Such systems exhibit distinctive patterns of species richness and composition termed as 'nested subsets', in which 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 and 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 et al. 1990; Cutler 1991; Wright et al. 1998; Patterson and 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 and Patterson 1993). The 'Temperature Calculator' (Atmar and Patterson 1995) is a very useful analytical software tool in examining the extent of nestedness among a set of faunal assemblages. This program is also useful in testing the hypothesis whether such a subset is significantly nested in relation to a random pattern of species distribution across fragments. The analysis performed by the software 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 and Patterson 1993, 1995; Patterson and Atmar 2000).

## 7.2 OBJECTIVES

The specific objectives in this component of the study were to:

- Examine the degree of nestedness of species distributions in the sampled forest fragments and to hypothesis causes for the observed patterns.
- Identify species that are likely to move towards local extinction and also to identify the order of extinction.
- To examine the hospitality or suitability of each fragment to support rainforest reptiles.

## 7.3 STUDY AREA

The ideal system to address the above mentioned objectives was the rainforest fragments in the Anamalais Hills. Details of the study area and on the forest fragments are provided in Chapter 2.

## 7.4 METHODS AND DATA ANALYSIS

The data set used to test for nestedness in reptile distribution was the list of the presence/absence pattern of each species from the 14 forest fragments. This data set incorporated information from all the sampling methods including the opportunistic sampling (see Chapter 3).

## 7.5 RESULTS

### 7.5.1 Nested distribution

The incidence matrix used in the temperature calculator had a total of 40 species (columns) and 14 fragments (rows). The species occurrence in the fragments showed nestedness, the temperature of the system being  $T = 16.15^\circ$ . The probability that this occurrence was random was  $<0.001$ . The maximally packed matrix, and the idiosyncratic species and sites deviating from nestedness (thus contribution to an increase in the matrix temperature), are shown in Figure 7.1. 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 7.1). The matrix reorganization vectors for sites (Table 7.4), and species (Table 7.5), gives 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 7.1.

Figure 7.1. The maximally packed species incidence matrix with idiosyncratic sites and species and the probability estimation function, for reptiles in the rainforest fragments of Anamalai Hills. The identity of species (horizontal), and fragment (vertical) are as in Table 7.4 and 7.5 respectively.

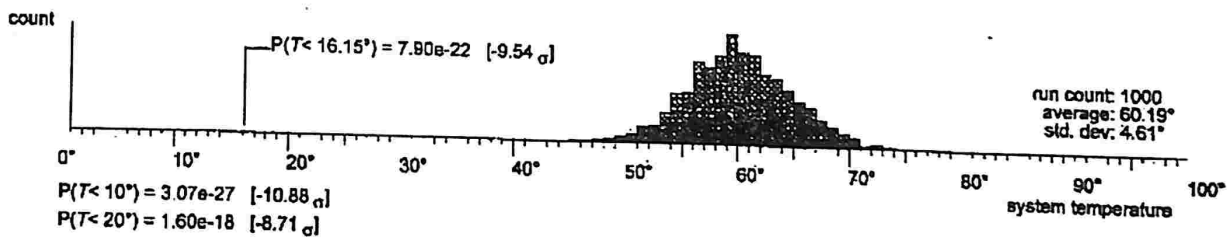
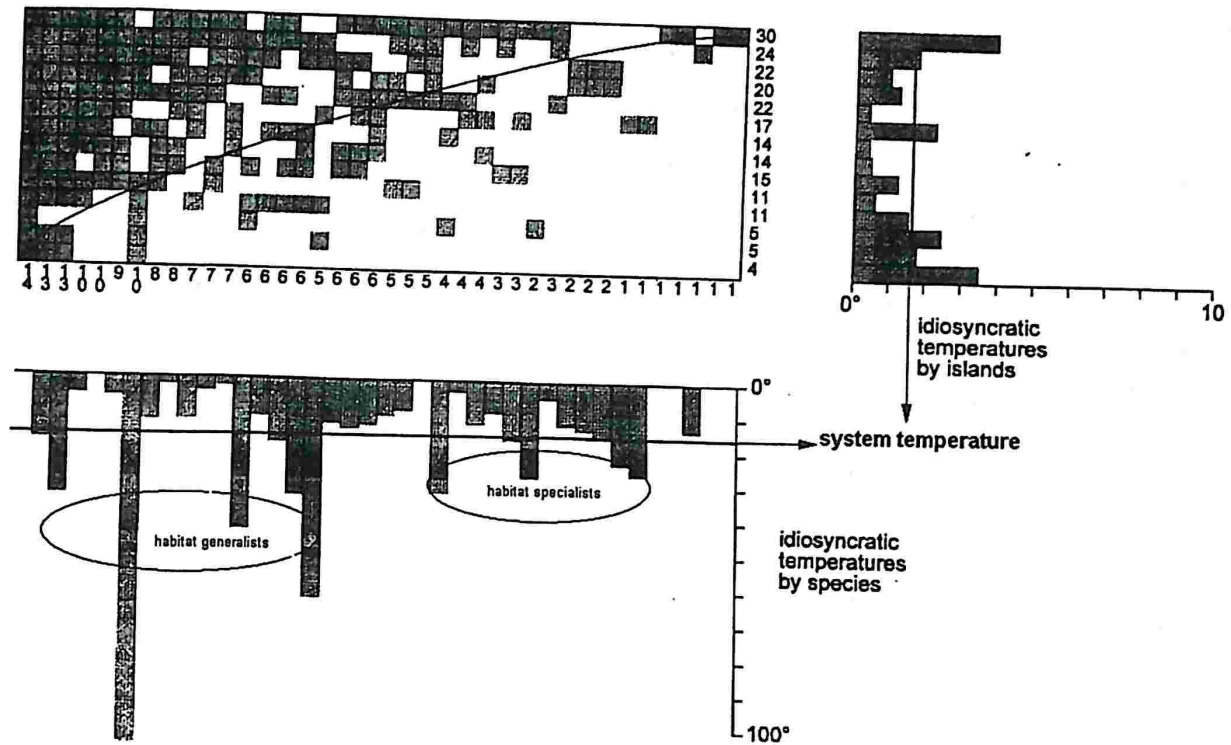


Table 7.1. The reorganization vector of the fragments in Anamalai Hills after maximal packing, using the nested temperature calculator.

Current Row Position	Original Row Position	Island 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

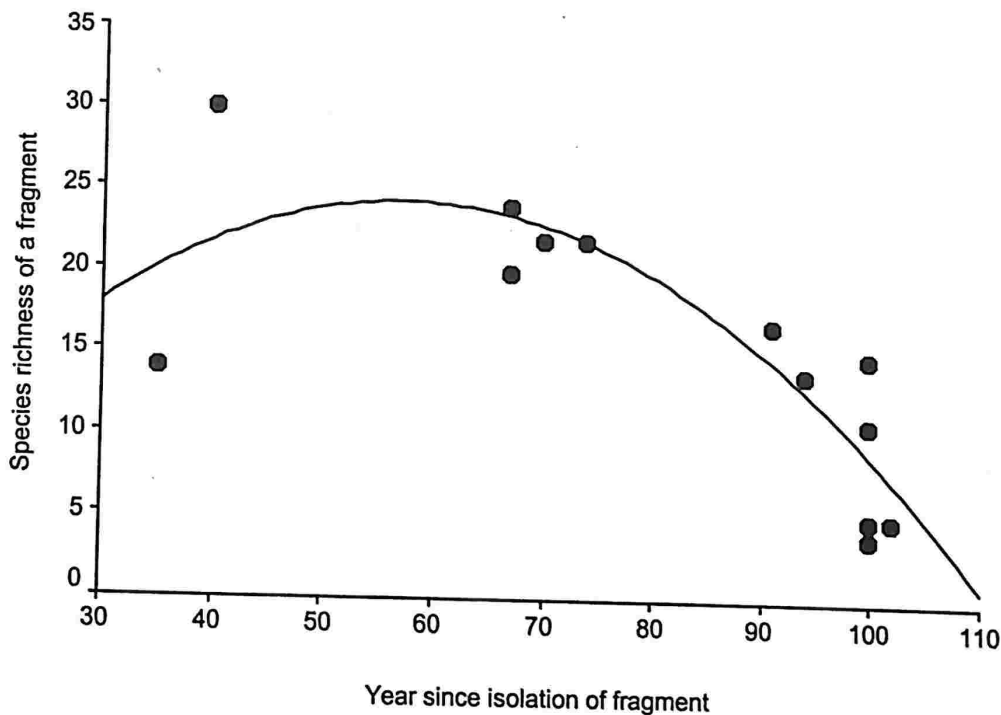
Table. 7.2. The reorganization vector of the reptilian species in Anamalai Hills after maximal packing, using the nested temperature calculator.

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

### 7.5.2 The influence of other causal 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 year since isolation and the species richness of the fragment (Spearman's  $\rho$  -0.771  $P < 0.001$ ), implying that fragments have been isolated for a greater period of time 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 7.2), 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 7.2. The relationship between species richness of a fragment and the time elapsed since its isolation



## 7.6 DISCUSSION

### 7.6.1 Nestedness

Species distributions within naturally fragmented habitat often exhibit pronounced 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 and Martin 1991; Beckon 1993; Atmar and Patterson 1993), and in habitat islands (Blake 1991; Bolger et al. 1991; Cutler 1991; Patterson and Brown 1986; Wright and Reeves 1992; Wright et al. 1998). However, few biotas exhibit perfect nestedness. The mechanisms that have been proposed to account for the nestedness in species distribution include differential extinction rates (Patterson and Atmar 1986; Cutler 1991; McDonald and Brown 1992; Yiming et al. 1998), nested distribution of habitats (Schoener and Schoener 1983; Simberloff and Martin 1991), and differential colonization of the habitat by the species (Kadmon 1995). Although, these mechanisms are not mutually exclusive, a combination of these can potentially result in nestedness (Patterson 1987; Simberloff and Martin 1991; Patterson and 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 and 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 a latency of approximately 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 may be largely attributed 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. Deviations from complete 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 to the conservation and protection of biological diversity. Inference to extinction prone species 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 and Patterson 1993, 1995; Patterson and 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 continuous forest species, and endemic to the rainforest, apparently 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.

#### 7.6.2. Susceptibility of some reptile species to rainforest fragmentation

Habitat fragmentation results in the extinction of some reptile species, while there seems to be no noticeable influence on others. This pattern is explained in part by a) larger reptiles are more susceptible to local extinction 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 that are 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, while the initial half of the curve composed mainly of habitat generalists and species which are not endemic to the rainforest.

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 near 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 impossible for these species. Also, except for the shield-tailed 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). Due to the low sample sizes and non-availability of data on the population densities for individual species, prevents arriving at an conclusion on the extinction risks due to fragmentation.

## 7.7 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 the occurrence of unexpected absences 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 possible species headed towards extinction, and in need of increased protection, and fragments that need to be conserved for their species diversity are also identified.

## CHAPTER 8 CONCLUSIONS AND RECOMMENDATIONS

### 8.1 A COMPENDIUM OF FINDINGS AND RESEARCH NEEDS

The study of reptilian community ecology is still a relatively new and emerging field in the tropics, even more so in the Indian subcontinent, and many questions still remain unanswered. The present study has tried to address some basic questions concerning the structuring of reptilian communities, and though the study has only given rise to more questions than answers, there has been a definite growth in the fundamental understanding of the rainforest reptilian community and structure. Briefly they are summed up below.

The distribution patterns and the structure of rainforest reptile assemblage was examined in Chapter 4, in terms of leaf litter and the arboreal assemblages. It is abundantly clear that the rainforest leaf litter and arboreal assemblages were highly uneven, and dominated by a few species. It was also shown that only geckos and skinks in the leaf litter reptile assemblage had a greater likelihood of being found in aggregations of more than 2 individuals. The influence of macro habitat variables like altitude and temperature was also reported. Chapter 5 examined the distribution patterns in rainforest fragments and investigated the causes for the decrease in rainforest reptile species richness. Rainforest fragmentation and the related disturbance rather than the size of the fragments and other macro habitat factors are responsible for the reduction in species richness. That the arboreal assemblage is more prone to habitat fragmentation than the leaf litter assemblage was also recorded. In Chapter 6, the microhabitat associations in the rainforest leaf litter and arboreal assemblages and the resultant change in community structure due to fragmentation was determined. The nestedness in the species distribution pattern in the rainforest fragment was examined in Chapter 7. Species that are more prone to extinction and the order of extinction was identified. The prioritization of the fragments based on their information content (species richness) was also resolved. This will help improve

the conservation and management of the remaining rainforest fragments with respect to its rich and endemic reptile species.

One problem I faced was that of comparing density estimates between studies. There is an urgent need to take a fresh look at the methods that have been used to document the reptilian assemblages in the rainforests both in the Western Ghats and in other tropical forests and from which density estimates are available. For any meaningful comparison, both across various habitat types and within particular habitats, it is necessary to standardize on the sampling protocol and also and if possible to look beyond the questions that directly relate to density estimates, at other parameters of interest which can be measured with greater precision in tropical habitats.

The influence of altitude and temperature documented in the present study needs to be validated from studies in other contiguous rainforest habitats. It is also necessary to sample altitudinal ranges and temperature regimes that were not covered in the present study, for a comprehensive understanding of the influence of these macrohabitat factors on the distribution of reptiles.

The presence of rainforest fragments in a matrix of secondary vegetation provides an ideal system to look at long-term changes in reptilian community structure due to fragmentation. It would be worthwhile to study the effects of landscape heterogeneity and connectivity on reptilian populations and the persistence of rare species in small fragments and in the surrounding matrix. Information from such a study along with the present one can help in the better understanding of the impact of a highly diverse landscape, on the distribution of rainforest reptiles.

Due to the adverse impact of habitat fragmentation and the related decline in species richness and abundance, it is likely that many reptilian species that are currently unknown or lesser known to science will never be observed or studied.

The preservation of rich biological diversity provides us with a great challenge in the face of continued habitat destruction and fragmentation. Habitat fragmentation results in the reduction in area and the creation of edges, both of which affect species in different ways, positively affecting some species and negatively affecting others. An important aspect of conservation biology is that species that are positively affected by habitat fragmentation are not in need of human management, while those that are negatively affected do. It is necessary to devise a system that heightens the odds of survival for all living species residing in the dotted landscape of habitat islands, with emphasis on rare and endemic forms. Thanks to a century or more of habitat fragmentation and destruction, the forests that remain are as a heterogeneous mosaic of large and small reserves, embedded in a matrix of secondary vegetation, largely monoculture plantations. In this scenario, a system of a single large reserve or many small reserves is not a viable alternative to protect the gamut of biological diversity in the tropical rainforests. The primary goal of conservation of biological diversity would be better served by protecting a network of reserves of varying size along with the landscape that they are found in. The advantage over several small reserve over a single large reserve is that the former could potentially support a gradient in habitat and altitude thus, provide a variety of ideal habitats for a number of fauna and flora. Such a network of reserves, supporting species in more than a single locality is the ideal design as catastrophes like epidemics, forest fires and genetic related problems, is likely to affect only a single area and would not completely drive a species to extinction.

Due to the ever-expanding anthropogenic pressures, many of our natural rainforests now exists as islands in a sea of inhospitable habitat. Ironically our present information on the distributional patterns and complete inventory of species is still lacking for many of these fragments, and it is likely that a majority of these may face extinction if corrective conservation measures are not implemented immediately. In order to design effective strategies for the conservation of reptilian biodiversity in the increasingly fragmented habitat, we need a better understanding of the impacts of habitat fragmentation on reptiles and prioritize fragments for conservation. The

present study has tried to address this lacuna in our information, although the scope of the study is limited to the fragments in the Anamalai Hills in the state of Tamil Nadu, I expect the findings to hold good for other hill ranges within the Western Ghats and possibly other regions in the county.

## **8.2 RECOMMENDATIONS**

### **8.2.1 Prioritization of rainforest fragments to conserve endemic reptilian species**

In a world that is increasingly dominated by human beings areas for natural communities are limited and the conservation of many faunal and floral species depends on their conservation in the protected areas. This is particularly true in forest fragments that contain localized or threatened biotas and source population for recolonising rehabilitated lands (Robinson and Quinn 1992; Saunders et al. 1987; Turner and Corlett 1996). In the present framework of conservation it is impractical to even consider the preservation of all species simply because not all habitats can be accorded protection. Consequently, alternative conservation strategies, based on some measure of ranking diversity in habitats are necessary (Roberts 1988; Robinson and Quinn 1992). Fundamental to the design of reserves is the protection of particular species or groups of species, whose survival and conservation may be otherwise difficult (Simberloff 1988). The SLOSS (a single large or several small reserves) debate is the core problem in the design of reserves. Though studies have argued and provided proof to support both the arguments (Brown 1986; Simberloff and Gotelli 1984; Quinn and Harrison 1988), it is still too early to favour either of the two theories on reserve design. Since the occurrence of rainforest reptiles in the fragments is related to 'habitat quality' rather than the area of the fragment, it should be possible to retain these species if we are able to prioritize the resources available. In the present study, some the Medium fragments (10 to 50 ha) supported unique species, not recorded from the other fragments. Given the present distribution of rainforests in the Western Ghats, the chance that a single large area would encompass a greater altitudinal range is remote. Hence a composite reserve design in which the

representation of a wide altitudinal ranges is likely to better serve the cause of conservation of the rich and endemic rainforest reptiles.

That the remaining forests of the Western Ghats, especially the rainforests, occur in a highly fragmented state is perhaps the most serious long-term management problem. The Agasthyamala Hills, Cardamom Hills, Silent Valley-New Amarambalam Forests, and southern parts of the South Karnataka State are the only areas where rainforests can be found in areas excess of 200 km<sup>2</sup>. Many of the small fragments of rainforests (which together might cover nearly 60% of the remaining rainforests) are privately owned, planted with tea, cardamom and coffee or are otherwise under considerable human pressure for fuel wood, timber and green manure. The long-term survival of most of the endemic species in the Western Ghats thus depends on our ability to manage rainforests in a fragmented state. The most serious threat facing reptiles and other lower vertebrates, that together account for the high levels of endemism in these hill ranges is the progressive decay of most of the forest fragments, resulting in the lack of regeneration due to the planting of cash crops, selective logging, fuel wood and fodder collection. Pollution from the intensive use of pesticides and fertilizers by the tea and coffee estates upstream of most of the fragments has also contributed to the decay of these fragments

One of the most obvious implications of the present study concerns the prioritisation of fragments based on their hospitality (species richness), without the consideration of area. This along with the identity of species that are likely to go towards extinction can help in better protection and conservation of these fragments and species. The site reorganized vector, a very useful outcome of the nested program (see Chapter 7) can be viewed as a prioritisation table. The Large fragment (Andiparai), which is liner strip and the Medium sized fragment (Tata Finley) are placed at the bottom half of the reorganised table. Both these fragments are surrounded by tea plantations and with medium to high levels of disturbance, and do not support any unique species of reptiles. These fragments along with most of the smaller fragments are not hospitable to many of the rare and endemic rainforest reptile species. It would be wise to accord

better protection to the top seven forest fragments, some of which are smaller in area and are likely to be subjected to increased disturbance and habitat modification if one needs to conserve the rare and endemic rainforest reptiles in the Anamalai Hills.

### 8.2.2 Research needs

Thanks to the experience gained during the present study, the following area of research has been identified which would help in furthering our understanding of the ecology and in the better management of the rainforest reptiles in the fragments.

1. The presence of fragments in a matrix of secondary vegetation, mainly commercial plantations offers an ideal system for a long-term study on the influence of a heterogeneous landscape on the distribution and community structure of rainforest reptiles. It will also help to know the problems that might arise due to inbreeding of populations in Small fragment by a genetic study.
2. There is an urgent need for a systematic and detailed study on reptilian taxonomy. Although, the studies on reptiles of Western Ghats dating right back into the 19th century (*e.g.* Gunther 1864; Smith 1933, 1935 and 1943; Wall 1923), even today the identity of several species, in particular those of the genus *Cnemaspis*, *Ristella*, *Scincella*, and those of the family Uropeltidae and Typhlopidae are questioned. This is mainly due to the lack of taxonomy related work on these groups of reptiles, which had resulted in the non-availability of comprehensive field guides, which can help researchers to identify these species. It is believed that the scarcity of researchers and research studies on reptiles is largely due to the uncertainty in the identification. A comprehensive field guide that integrates both field friendly taxonomic keys and photographs will greatly improve the situation.

## REFERENCES

- Abensperg-Traun, M., G. T. Smith, G. W. Arnold, and D. E. Steven. 1996. The effects of habitat fragmentation and livestock grazing on animal communities in remnants of gimlet *Eucalyptus salubris* woodland. I. Arthropods. *Journal of Applied Ecology* **33**:1281-1301.
- Adolph, S. C. 1990. Influence of behavioral thermoregulation on microhabitat use by two *Sceloporus* lizards. *Ecology* **71**: 315-327.
- Adolph, S. C., and W. P. Porter. 1993. Temperature, activity and lizard life histories. *The American Naturalist* **142**: 273-295.
- Aengals, R. 1995. Reptilian fauna in the plantations of Valparai, Western Ghats. *Cobra* **19**: 21-23.
- Ahmedullah, M., and M. P. Nayar. 1987. Endemic plants of the Indian region. *Botanical Survey of India, Calcutta, India*.
- Ali, R. 1999. Enclaves in Kalakad-Mundanthurai Tiger Reserve. Final report submitted to the Field Director, Project Tiger, KMTR. Funded by FREEP, World Bank.
- Allendorf, F. W. 1986. Genetic drift and the loss of alleles versus heterozygosity. *Zoo Biology* **5**: 181-190.
- Annaselvam, J., and N. Parthasarathy. 1999. Inventories of understorey plants in a tropical evergreen forest in the Anamalais, Western Ghats, India. *Ecotropica* **5**: 137-151.
- Arnold, S. J. 1972. Species densities of predators and their prey. *The American Naturalist* **106**: 220-236.
- Atmar, W., and B. D. Patterson. 1993. The measure of order and disorder in the distribution of species in fragmented habitat. *Oecologia* **96**: 373-382.
- Atmar, W., and B. D. Patterson. 1995. The nestedness temperature calculator: a visual basic program, including 294 presence-absence matrices. AICS Research, Inc., University Park, New Mexico, and The Field Museum. Chicago (downloaded online at <<http://aics-research.com/nestedness/tempcalc.html>>).
- Beckon, W. N. 1993. The effect of insularity on the diversity of land birds in the Fiji Islands: implications for refuge design. *Oecologia* **94**: 318-329.
- Bellamy, P. A., S. A. Hinsley, and I. Newton. 1996. Factors influencing bird species numbers in small woods in south-east England. *Journal of Applied Ecology* **33**: 49-262.
- Bender, C., H. Hildenbrandt, K. Schmidh-Loske, V. Grimm, C. Wissel and K. Henle. 1996. Consolidation of vineyards, mitigations, and survival of the common wall lizard (*Podarcis muralis*) in isolated habitat fragment. Pages 248-261 in J. Settele, C. R. Margules, P.

Poschlod and K. Henle editors. Species survival in Fragmented Landscapes. Kluwer Academic Publishers, Netherlands.

- Bhupathy, S., and P. Kannan. 1997. Status of agamid lizards in the Western Ghats of Tamil Nadu, India. Salim Ali Centre for Ornithology and Natural History, Technical Report, No. 5.
- Bierregaard, R. O., T. E. Lovejoy, V. Kapos, A. A. Dos Santos, and R. W. Hutchings. 1992. The biological dynamics of tropical rainforest fragments. *BioScience* 42: 859-866.
- Blackburn, T. M., and K. Gaston. 1996. A sideways look at patterns in species- richness, or why there are so few species outside the tropics. *Biodiversity Letters* 3: 44-53.
- Blake, J. C. 1991. Nested subsets and the distribution of birds on isolated woodlands. *Conservation Biology* 5:58-66.
- Boecklen, W. J., and D. Simberloff. 1986. Area-based extinction models in conservation. Pages 247-276 in D. K. Elliott, editor. *Dynamics of Extinction*. Wiley-Interscience Publications, John Wiley and Sons, USA.
- Bolger, D. T., A. C. Alberts, and M. E. Soulé. 1991. Occurrence patterns of bird species in habitat fragmentation: sampling, extinction and nested species subsets. *The American Naturalist* 137: 155-166.
- Boulenger, G. A. 1890. The fauna of British India, including Ceylon and Burma. Reptilia and Batrachia. Taylor and Francis.
- Bowman, D. M. J. S., J. C. Z. Woinarski, D. P. A. Sands, A. Wells, and V. J. Mcshane. 1990. Slash-and-burn agriculture in the wet coastal lowlands of Papua New Guinea: response of birds, butterflies and reptiles. *Journal of Biogeography* 17: 227-239.
- Bright, P. W., and P. A. Morris. 1996. Why are dormice rare? A case study in conservation biology. *Mammal Review* 26: 157-187.
- Brown, J. H. 1964. Relationship of the herpetofauna of the non-dipterocarp communities to that of the dipterocarp forest on southern Negros Islands, Philippines. *Senckenberg Biol.* 45:591-611.
- Brown, J. H. 1971. Mammals on mountain tops: non-equilibrium insular biogeography. *American Naturalist* 105: 467-478.
- Brown, J. H. 1986. Two decades of interaction between the MacArthur-Wilson model and the complexities of mammalian distributions. *Biological Journal of the Linnean Society* 28: 231-251.
- Brown, K. S. 1991. Conservation of Neotropical Enviornments; insects as indicators. Pages 349-404 in N. M. Collins, and J. A. Thomas, editors. *The conservation of insects and their habitats*. Academic press, San Diego.

- Brown, W. C., and A. C. Alcala. 1961. Populations of amphibians and reptiles in the submountane and mountane forests of Cuernos de Negros, Philippine Islands. *Ecology* 42: 628-636.
- Burkey, T. V. 1989. Extinction in natural reserves: the effect of fragmentation and the importance of migration between reserve fragments. *Oikos* 55: 75-81.
- Burkey, T. V. 1995. Extinction rates in archipelagos: implications for populations in fragmented habitats. *Conservation Biology* 9: 527-541.
- Carrascal, L. M., P. Lopez, J. Martin, and A. Salvador. 1992. Basking and antipredator behaviour in a high altitude lizard: Implications of heat-exchange rate. *Ethology* 92: 113-154.
- Case, T. J. 1975. Species numbers, density compensation, and colonization ability of lizards on islands in the Gulf of California. *Ecology* 56: 3-18.
- Case, T. J., and D. T. Bolger. 1991. The role of introduced species in shaping the distribution and abundance of island reptiles. *Evolutionary Ecology* 5: 272-290.
- Champion, H. G., and S. K. Seth. 1968. A revised survey of Forest Types of India. Manager of publications, Government of India, Delhi
- Chari, V. K. 1955. A new form of the burrowing snake, *Uropeltis macrolepis* (Peter) from Mahabaleshwar. *Journal of Bombay Natural History Society* 52: 901.
- Chattopadhyay, S. 1985. Deforestation in parts of Western Ghats region (Kerala), India. *Journal of Environmental Management* 20: 219-230.
- Congreve, C. R. T. 1940. The Anamallais.
- Connell, J. H. 1975. Some mechanisms producing structure in natural communities: a model and evidence from field experiments. Pages 460-490. *in* M. L. Cody and J. Diamond, editors. *Ecology and Evolution of communities*, Cambridge, Mass: Harvard University Press.
- Connell, J. H. 1978. Diversity in tropical rainforests and coral reefs. *Science* 199: 1302-1310.
- Corn, P. S., and R. B. Bury. 1990. Sampling methods for terrestrial amphibians and reptiles. U.S. Department of Agriculture, Forest Service, General Technical Report PNW-GTR-256.
- Crump, M. L., and N. J. Scott, Jr. 1994. Visual encounter surveys. Pages 84-91. *in* Heyer, W. R., M. A. Donnelly, R. W. McDiarmid, L. C. Hayek, and M. S. Foster editors. *Measuring and Monitoring Biological Diversity: Standard Methods for Amphibians*. Smithsonian Institution USA.
- Cutler, A. 1991. Nested faunas and extinction in fragmented habitats. *Conservation Biology* 5: 496-505.
- Daniel, J. C. 1983. *The Book of Indian Reptiles*. Bombay Natural History Society, Bombay.

- Daniels, R. J. R. 1993. The Nilgiri Biosphere Reserve and its role in conserving India's biodiversity. *Current Science* 64: 706-708.
- Daniels, R. J. R. 1995. Habitat selection in Western Ghats: amphibians-anura. Implications for species conservation. *Cobra* 20: 7-15.
- Das, I. 1985. Indian Turtles; A field guide. World Wide Fund-India, Eastern Region.
- Das, I. 1995. Turtles and Tortoises of India. Oxford University Press, Oxford.
- Das, I. 1996. Biogeography of the reptiles of south Asia. First edition. Krieger Publishing Company, Florida.
- Das, I. 1997. Checklist of the reptiles of India, with English common names. *Hamadryad* 22: 32-45.
- Debinski, D. M., and R. H. Holt. 2000. A survey and overview of habitat fragmentation experiments. *Conservation Biology* 14:342-355.
- Diamond, J. M. 1984. "Normal" extinctions of isolated populations. Pages 191-246 *in* M. H. Nitecki, editor. *Extinctions*. University of Chicago Press, Chicago.
- Didham, R. K. 1997. An overview of invertebrate responses to forest fragmentation. *in* A. D. Watt, N. E. Stork and M. D. Hunter, editors. *Forests and Insects*. Chapman and Hall, London.
- Duellman, W. E. 1989. Tropical herpetofaunal communities: patterns of community structure in neotropical rainforests. Pages 60-88 *in* M. L. Harmelin, and F. Bourliere, editors. *Ecological Studies* 69. Vertebrates in complex tropical systems. Springer-Verlag, Newyork Inc.
- Duellman, W. E., and L. Trueb. 1986. *Biology of amphibians*. McGraw-Hill Book Company , New York.
- Dustan, C. E., and B. J. Fox. 1996. The effects of fragmentation and disturbance of rainforest on ground-dwelling small mammals on the Robertson plateau, New South Wales, Australia. *Journal of Biogeography* 23: 187-201.
- Ellison, A.M, 1993. Exploratory data analysis and graphic display. *in* S. M Scheiner, and J. Gurevitch, editors. *Design and Analysis of ecological experiments* Chapman and Hall, USA.
- Fauth, J. E., B. I. Crother, and J. B Slowinski. 1989. Elevation patterns of species richness, evenness and abundance of the Costa Rican leaf-litter herpetofauna. *Biotropica* 21: 178-185.
- Ford, N. B., and G. M. Burghardt. 1993. Perceptual mechanisms and the behavioral ecology of snakes. Pages 117-164 *in* R. A. Seigel, and J. T Collins, editors. *Snakes-Ecology and Behaviour*. McGraw-Hill, Inc.USA

- Foster, R. B. 1980. Heterogeneity and disturbance in tropical vegetation. Pages 75-92 in M. E. Soulé, and B. A. Wilcox, editors. Conservation biology: an evolutionary-ecological approach. Sinauer Associates, Sunderland, Mass.
- FSI. 1996. Inventory of Forest Resources of India. Forest Survey of India. Dehradun, India.
- Ganesh, T., R. Ganesan, M. Soubadra, P. Davidar, and K. S. Bawa. 1996. Assessment of plant biodiversity at a mid-elevation evergreen forest of Kalakad-Mundanthurai Tiger Reserve, Western Ghats, India. Current Science 71: 379-392.
- Gans, C. 1966. Liste der rezenten Amphibien und Reptilien. Uropeltidae. Tierreich 84: 1-29.
- Gaussen, H., P. Legris, L. Labroue, V. M. Meher-Homji, and M. Virat. 1986. Carte Internationale du tapis végétal et de conditions écologiques à 1/1.000.000: Botte de la feuille Mysore. Extrait des travaux de la section scientifique et Technique de l'Institut Français de Pondichéry. Pondicherry, India. Hors série no. 7: 110 p.
- Gentry, A. H. 1986. Endemism in tropical versus temperate plant communities. Pages 153-181 in M. E. Soulé, editor. Conservation biology: the Science of Scarcity and Diversity. Sinauer Associates, Saunderland, Mass.
- Ghate, H. V., and G. M. Yazdani. 1990. First record of the pied-bellied uropeltid, *Melanophidium punctatum* Beddome (Serpents : *Uropeltidae*) from Maharashtra. Journal of Bombay Natural History Society 87: 463.
- Gopalan, P. 1997. Plant diversity in Agastyamalai Hills, Southern Western Ghats. Pages 10-22 in P.K. Hajra, and V. Mudgal editors. Plant diversity hotspots in India - An overview, Botanical Survey of India, MoEF, India.
- Groombridge, B. 1990. Comments on the rainforests of southwest India and their herpetofauna. Pages 241-251 in J. C. Daniel, and J. S. Serrao, editors. Conservation in developing countries: problems and prospects. Bombay Natural History Society, Oxford University Press, Bombay.
- Gunther, A. C. L. G. 1864. The reptiles of British India. New Delhi, Oxford and IBH publishing and Co.
- Hairston, N. G., F. E. Smith and L. B. Slobodkin. 1960. Community structure, population control, and competition. The American Naturalist 94: 421-425.
- Harris, L. D. 1984. The fragmented forest: Island Biogeography theory and preservation of biotic diversity. University of Chicago Press, Chicago, IL.
- Harris, R. J. 1985. A primer of Multivariate Statistics. Academic press, Inc., Orlando, USA.
- Heang, K. B., L. B. Liat and M. R. K Lambert. 1996. To determine the effects of logging and timber extraction, and conversion of primary forest to tree crop plantations, on herpetofaunal diversity in peninsular Malaysia. British Herpetological Society Bulletin 57: 2-20.

- Heatwole, H. 1977. Habitat selection in reptiles. Pages 137-155 in C. Gans and D. Tinkle editors. *Biology of the Reptilia*, volume 7. Academic press, New York.
- Heatwole, H. 1982. A review of structuring in herpetofaunal assemblages. Pages 1-19 in N. J. Jr. Scott, editor. *Herpetological communities. A symposium of the society for the Study of amphibians and reptiles and the Herpetologists league*, August 1977. USFWS, Report 13.
- Heatwole, H. F. and J. Taylor. 1987. *Ecology of Reptiles*. First edition, Surrey Beatty and Sons Pvt. Limited, Chipping Norton, NSW, Australia.
- Hecnar, S. J., and R. T. M'Closkey. 1998. Effects of human disturbance on five-lined skink, *Eumeces fasciatus*, abundance and distribution. *Biological Conservation* 85: 213-222.
- Henle, K. 1996. Survival of lizards in habitat islands in central Europe-Introduction and summary conclusions. Pages 237-240 in J. Settele, C. R. Margules, P. Poschlod and K. Henle editors. *Species Survival in Fragmented Landscapes*. Kluwer Academic Publishers, Netherlands.
- Hertz, P. F., and Huey, R. B. 1981. Compensation for altitudinal changes in the thermal environment by some *Anolis* lizards on Hispaniola. *Ecology* 62: 515-521.
- Heyer, W. R. 1967. A herpetofaunal study of an ecological transect through the cordillera de Tilaran, Costa Rica. *Copeia* 2: 259-271.
- Heyer, W. R, M. A. Donnelly, R. W. McDiarmid, L. C. Hayek, and M. S. Foster 1994. First editon. *Measuring and Monitoring Biological Diversity: Standard Methods for Amphibians*. Smithsonian Institution, USA.
- Howard, K. E., and A. Hailey. 1999. Microhabitat seperation among diurnal saxicolous lizrads in Zimbabwe. *Journal of Tropical Ecology* 15: 367-378.
- Hutchinson, G. E. 1978. *An introduction to Population Ecology*. Yale University Press, New Haven, Connecticut.
- Inger, R. F. 1980a. Densities of floor-dwelling frogs and lizards in lowland forests of Southeast Asia and Central America. *The American Naturalist* 115: 761-770.
- Inger, R. F. 1980b. Relative abundance of frogs and lizards in forests of Southeast Asia. *Biotropica* 12: 14-22.
- Inger, R. F. 1994. Microhabitat description. Pages 60-61 in Heyer, W. R, M. A. Donnelly, R. W. McDiarmid, L. C. Hayek, and M. S. Foster editors. *Measuring and Monitoring Biological Diversity: Standard Methods for Amphibians*. Smithsonian Institution, USA.
- Inger, R. F., and R. K. Colwell. 1977. Organisation of contiguous communities of amphibians and reptiles in Thailand. *Ecological Monograph* 47: 229-253.
- Inger, R. F., and S. K. Dutta. 1986. An overview of the amphibian fauna of India. *Journal of Bombay Natural History Society* 83: 135-146.

- Inger, R. F., H. B. Shaffer, M. Koshy, and R. Bakde. 1984. A report on a collection of amphibians and reptiles from Ponmudi, Kerala, south India. *Journal of Bombay Natural History Society* 81: 406-427 and 551-570.
- Inger, R. F., H. B. Shaffer, M. Koshy, and R. Bakde. 1987. Ecological structure of a herpetofaunal assemblage in south India. *Amphibia-Reptilia* 8: 189-202.
- Ishwar, N. M., and I. Das. 1998. Rediscovery of *Calotes andamanensis* Boulenger (1891) and a reassessment of the type locality. *Journal of the Bombay Natural History Society* 95: 513-514.
- Ishwar, N. M., R. Chellam, and A. Kumar. 2001. Distribution of forest floor reptiles in the rainforest of Kalakad-Mundanthurai Tiger Reserve, South India. *Current science*:
- Janzen, D. H. 1986. The eternal external threat. Pages 286-303 in M. E. Soulé, editor. *Conservation Biology: the Science of Scarcity and Diversity*. Sinauer Associates, Sunderland, Mass.
- Jayaram, K. C. 1974. Ecology and Distribution of fresh-water Fishes, Amphibia and Reptiles. Pages 535 in M. S. Mani, editor. *Ecology and Biogeography in India*. Dr. W. Junk, b.v. Publishers, The Hague.
- Kadmon, R. 1995. Nested species subsets and geographic isolation, a case study. *Ecology* 76: 458-465.
- Kapos, V. 1989. Effect of isolation on the water status of forest patches in the Amazon. *Journal of Tropical Ecology* 5: 173-185.
- Kapos, V., E. Wandelli, J. L. Camargo, and G. Ganade. 1997. Edge-related changes in environment and plant responses due to forest fragmentation in central Amazonia. Pages 33-44, in W. F. Laurance, and R. Bierregaard editors. *Tropical forest remnants: Ecology, Management and Conservation of Fragmented Communities*. University of Chicago Press, Chicago.
- Karthikeyan, S. 1991. Sighting of the arboreal skink, *Dasia haliana* at Mudumalai Wildlife Sanctuary, Tamil Nadu. *Journal of Bombay Natural History Society* 88: 122-123.
- Keller, M. E., and S. H. Anderson. 1992. Avian use of habitat configurations created by forest cutting in southeastern Wyoming. *Condor* 94: 55-65.
- Kitchener, D. J., A. Chapman, J. Dell and B. G. Muir. 1980. Lizard assemblage and reserve size and structure in the Western Australian wheatbelt-some implications for conservation. *Biological Conservation* 17: 25-62.
- Krishnan, M. S. 1982. *Geology of India and Burma*. Sixth edition, CBS Publishers and Distributors, New Delhi, India.
- Kumar, A. 1989. The South Indian Rain Forest. Pages 105-109 in B. Allchin, F. R. Allchin, and B. K. Thapar, editors. *Indian Heritage*. Cosmos Publications, New Delhi.

- Kumar, A., S. Walker, and S. Molur. 1998. Prioritisation of Endangered Species. Final Report submitted to WWF-India.
- Laurance, W. F. 1994. Rainforest fragmentation and the structure of small mammal communities in tropical Queensland. *Biological Conservation* **69**: 23-32.
- Laurance, W. F., and E. Yensen. 1991. Predicting the impacts of edge effects in fragmented habitats. *Biological Conservation* **55**: 77-92.
- Laurance, W. F., and R. Bierregaard. editors. 1997. *Tropical Forest Remnants: Ecology, Management And Conservation of Fragmented Communities*. University of Chicago Press, Chicago.
- Laurence, W. F. 1991. Ecological correlates of extinction proneness in Australian tropical rainforest mammals. *Conservation Biology* **5**: 79-89.
- Lenart, L. A., R. Powell, J. S. Parmerlee, Jr., A. Lathrop and D. D. Smith. 1997: Anoline diversity in three differently altered habitats in the Sierra de Baoruco, Republica Dominicana, Hispaniola. *Biotropica* **29**: 117-123.
- Levin, S. A., and R. T. Paine. 1974. Disturbance, patch formation, and community structure. *Proceedings of the National Academy of Sciences* **6**: 1246-1248.
- Lieberman, S. S. 1986. Ecology of the leaf litter herpetofauna of a neotropical rainforest: La Selva, Costa Rica. *Acta Zool. Mex.* **15**: 1-72.
- Lima, S. L., and L. M. Dill. 1990. Behavioral decisions made under the risk of predation: a review and prospectus. *Can. J. Zool.* **68**: 619-640.
- Lloyd, M., R. F. Inger, and F. W. King. 1968. On the diversity of reptile and amphibian species in a Bornean rain forest. *The American Naturalist* **102**: 497-515.
- Lovejoy, T. E., R. O. Bierregaard Jr., A. B. Rylands, J. R. Malcolm, C. E. Quintela, L. H. Harper, Jr. K. S. Brown, A.H. Powell, G. V. N. Powell, H. O. R. Schubart, and M. B. Hays. 1986. Edge and other effects of isolation on Amazon forest fragments. Pages 257-285. *in* M. E. Soulé, editor. *Conservation biology: the Science of Scarcity and Diversity*. Sinauer Associates, Sunderland, Mass.
- MacArthur, R. H. 1972. *Geographical Ecology: Patterns in the Distribution of Species*. Harper and Row, New York.
- MacArthur, R. H., and E. O. Wilson. 1967. *The Theory of Island Biogeography*. Princeton University Press, Princeton, New Jersey.
- Mackey, R. L., and D. J. Currie. 2000. A re-examination of the expected effects of disturbance on diversity. *Oikos* **88**: 483-493.
- Madison, D. M. 1978. Behavioral and sociochemical susceptibility of meadow voles (*Microtus pennsylvanicus*) to snake predators. *Amer. Midl. Nat.* **100**: 23-28.
- Magurran, A. E. 1988. *Ecological Diversity and its Measurement*. Croom Helm, London.

- Mahendra, B. C. 1939. The zoogeography of India in the light of herpetological studies. *Science and Culture* 4: 1-11.
- Malcolm, J. R. 1997. Biomass and diversity of small mammals in Amazonian forest fragments. Pages 207-221 *in* W. F. Laurance, and R. Bierregaard, editors. *Tropical Forest Remnants: Ecology, Management And Conservation of Fragmented Communities*. University of Chicago Press, Chicago.
- Mani, M. S. 1974. Limiting Factors. Pages 141 *in* M. S. Mani, editor. *Ecology and Biogeography in India*. Dr. W. Junk, b.v. Publishers, The Hague.
- Manly, B. F. J. 1994. *Multivariate Statistical Methods; A primer*. Second edition, Chapman and Hall, London, UK.
- Margules, C. R. 1996. Experimental Fragmentation. Pages 128-137 *in* J. Settele, C. R. Margules, P. Poschlod and K. Henle, editors. *Species survival in Fragmented Landscapes*. Kluwer Academic Publishers, Netherlands.
- Martens, B., K. Henle, W. Kuhn, R. Krug, K. Jost, W. R. Grobe, and C. Wissel. 1996. Survival of the sand lizard *Lacerta agilis* Linnaeus, 1758 (Sauria, Lacertidae) in relation to habitat quality and heterogeneity. Pages 241-247, *in* J. Settele, C. R. Margules, P. Poschlod and K. Henle editors. *Species survival in Fragmented Landscapes*. Kluwer Academic Publishers, Netherlands.
- Mautz, W. J. 1982. Patterns of evaporation loss. Pages 443-481 *in* C. Gans, and F. H. Pough, editors. *Biology of Reptilia*, Volume 12, Academic Press, New York.
- McDonald, K. A., and J. H. Brown. 1992. Using montane mammals to model extinctions due to global change. *Conservation Biology* 6: 409-415.
- Murcia, C. 1995. Edge effects in fragmented forests: implications for conservation. *Trends in Ecology and Evolution* 10: 58-62.
- Murthy, T. S. N. 1986. *The Snake Book of India*, International Book Distributors, Dehra Dun, India.
- Murthy, T. S. N. 1991. Reptilia. *Animal resources of India*: 637-647.
- Murthy, T. S. N. 1994. An updated handlist of reptiles of India. *Cobra* 17: 17-38.
- Murthy, T. S. N. 1971. A note on some snakes from Anamalais and Cardamon Hills, Western Ghats. *Journal of the University of Poona: Science Edition* 42: 95-102.
- Murthy, T. S. N. 1982. An illustrated field guide to the rough-tailed snakes of India, *The Snake* 14: 119-135.
- Murthy, T. S. N. 1985. Field guide to the lizards of Western Ghats. *Zoological Survey of India, Occasional papers* 72.
- Murthy, T. S. N. 1989. A collection of reptiles from the Kalakad Wildlife Sanctuary, India. *British Herpetological Society Bulletin* 28: 37-40.

- Murthy, T. S. N. 1990. Reptiles of Kalakkad Sanctuary, Tamil Nadu, India. *The Snake* 22: 44-59.
- Murthy, T. S. N. 1992. A distributional analysis of the uropeltid snakes of India and Sri Lanka. *Records of the Zoological survey of India* 91: 375-387.
- Murthy, T. S. N. 1992. An identification key to the reptiles of the Kakakad Wildlife Santuary, Tamil Nadu, India. *Records of the Zoological Survey of India* 91: 161-168.
- Myers, N. 1986. Tropical deforestation and a mega-extinction spasm. Pages 394-409 *in* M.E. Soulé, editors. *Conservation biology: The Science of Scarcity and Diversity*. Sinauer Associates, Saunderland, Mass.
- Myers, N., R. A. Mittermeier, C. G. Mittermeier, G. A. B. da Fonseca and Jennifer Kent. 2000. Biodiversity hotspots for conservation priorities *Nature* 403: 853-858.
- Nair, N.C., and P. Daniel, P. 1986. The floristic diversity of Western Ghats and its conservation: a review. *Proceedings of the Indian Academy of Sciences. (Animal/Plant Science Supplementary)*: 127-164.
- Nair, S. C. 1991. *The Southern Western Ghats: A biodiversity Conservation Plan*, INTACH, New Delhi.
- Nayar, M. P. 1980. Endemic flora of peninsular India and its significance. *Bulletin of the Botanical Survey of India* 22: 12-23.
- Newmark, W. D. 1987. A land-bridge island perspective on mammalian extinctions in western North American parks. *Nature* 325: 430-432.
- Newmark, W. D. 1991. Tropical forest fragmentation and the local extinction of understory birds in the Eastern Usambara Mountains, Tanzania. *Conservation Biology* 5: 67-78.
- Norusis, M. J. 1986. *Advanced statistics SPSS/PC+ for the IBM PC/XT/AT*. SPSS Inc. USA.
- Owen J. G. 1989. Patterns of herpetofaunal species richness: relation to temperature, precipitation and variance in elevation. *Journal of Biogeography* 16: 141-150.
- Parthasarathy, N., and A. Mahadevan. 1987. Floristic account of forest types in Kalakad reserved forest, Western Ghats, India. *Journal of Economic Botany and Taxonomy* 10: 355-360.
- Pascal, J. P. 1991. Floristic composition and distribution of evergreen forests in the Western Ghats, India. *Palaeobotanist* 39: 110-126.
- Pascal, J. P. 1988. *Wet evergreen forests of the Western Ghats of India: Ecology, Structure, Floristic Composition and Succession*. Institut de Français, Pondichéry, Travaux de la section scientifique et technique. Pondicherry, India.
- Pascal, J. P. 1996. Wild and fragile. *Down to Earth (August 15)*: 28-32.

- Patterson, B. D. 1987. The principle of nested subsets and its implications for biological conservation. *Conservation Biology* 1: 323-334.
- Patterson, B. D., and J. H. Brown. 1986. Nested subsets and the structure of insular mammalian faunas and archipelagoes. Pages 65-82 *in* L. Heaney and B. D Patterson editor. *Island Biogeography of Mammals*. *Biological Journal of the Linnaean Society* 28 (1 & 2) London: Academic Press.
- Patterson, B. D., and W. Atmar. 1986. Nested subsets and the structure of insular mammalian faunas and archipelagos. *Biol. J. Linn. Soc.* 28: 65-82.
- Patterson, B. D., P. L. Meserve, and B. K. Lang. 1990. Quantitative habitat association of small mammals along an elevational transect in temperate rainforest of Chile. *Journal of Mammology* 71: 620-633.
- Patterson, B.D., and W. Atmar. 2000. Analyzing species composition in fragments. Pages 9-24 *in* G. Rheinwald, editor. *Isolated Vertebrate Communities in the tropics*, Bonn Zool. Monograph 46, Proceedings of the 4<sup>th</sup> International symposium, Bonn.
- Pawar, S. 1999. Effect of habitat alteration on herpetofaunal assemblages of evergreen forest in Mizoram, Northeast India. MSc. Dissertation: Saurashtra University, Rajkot, Gujarat, India.
- Petraits, P S., R. E. Latham, and R. A. Niesenbaum. 1989. The maintenance of species diversity by disturbance. *Quarterly Review of Biology* 64: 393-418.
- Pianka, E. R. 1966. Convexity, desert lizards, and spatial heterogeneity. *Ecology* 47: 333-351.
- Pianka, E. R. 1969. Habitat specificity, speciation, and species density in Australian desert lizards. *Ecology* 50: 498-502.
- Pianka, E. R. 1971. Lizard species density in the Kalaharai Desert. *Ecology* 52: 1024-1029.
- Pianka, E. R. 1973. The structure of lizard communities. *Annual review of Ecology and Systematics* 4: 53-74.
- Pianka, E. R. 1983. *Evolutionary Ecology*. Third edition, Harper and Row, New York.
- Pianka, E. R. 1986. *Ecology and Natural History of Desert Lizards: analyses of the Ecological Niche and Community Structure*. First edition, Princeton University Press, New Jersey.
- Porter, K. R., 1972. *Herpetology*. W.B. Saunders, Co., Philadelphia.
- Pough, F.H. 1983. Amphibians and reptiles as low-energy systems. Pages 141-181 *in* W.P Aspey and S. I. Lustick, editors. *Behavioural Energetics: the cost of survival in vertebrates*. Ohio State University press, Columbus, OH.
- Primack, R. B. 1993. *Essentials of Conservation Biology*. Sinauer Associates, Sunderland, Mass.

- Quinn, J. F., and S. P. Harrison. 1988. Effects of habitat fragmentation and isolation on species richness: evidence from biogeographic patterns. *Oecologia* 75: 132-140.
- Rajendran, M. V. 1985. Studies in Uropeltid snakes. Madurai Kamaraj University, Madurai.
- Ramesh, B. R. and M. Guero. 2000. Assessment of vegetation types of Kalkad-Mundanthurai Tiger Reserve (Tamil Nadu, India) using GIS and Remote Sensing. Final report on the project Biodiversity conservation at KMTR in collaboration with Wildlife Institute of India and Tamil Nadu Forest Department, 1998-2000. French Institute of Pondicherry, Pondicherry,
- Ramesh, B. R., and Pascal, J. P. 1991. Distribution of endemic, arborescent evergreen species in the Western Ghats. Pages 20-29 *in* The proceedings of the Symposium on Rare, Endangered, and Endemic plants of the Western Ghats. Kerala Forest Department.
- Ramesh, B. R., S. Menon, and K. S. Bawa. 1997. A vegetation based approach to biodiversity gap analysis in the Agastyamalai region, Western Ghats, India. *Ambio* 26: 529-536.
- Rapoport, E. H, 1982. Areography: geographical strategies of species. Fund. Bariloche Ser., Pergamon Press, Oxford.
- Rawat G. S., S. Dutt and J. Joshua. 1999. Kalakad-Mundanthurai Tiger Reserve: Physical and Biological Attributes. Pages 9-19, *in* Ecological and Socio-economic studies on the Kalakad-Mundanthurai Tiger Reserve: an Eco-development approach.
- Regan, D. P. 1992. Congeneric species distribution and abundance in a three dimensional habitat. The rainforest *Anolis* of Puerto Rico. *Copeia* 2: 392-403.
- Reinert, H.K. 1993. Habitat selection in Snakes. Pages 201-240 *in* R. A. Seigel, and J. T. Collins, editors. Snakes-Ecology and Behaviour. Mcgraw-Hill, Inc.USA.
- Reynolds, R. P., R. I. Crombie and R. W. McDiarmid. 1994. Voucher Specimens. Pages 66-72 *in* Heyer, W. R, M. A. Donnelly, R. W. McDiarmid, L. C. Hayek, and M. S. Foster, editors. Measuring and Monitoring Biological Diversity: Standard Methods for Amphibians. Smithsonian Institution, USA.
- Rhabek, C. 1997. The relationship among area, elevation and regional species richness in neotropical birds. *The American Naturalist* 149: 875-902.
- Rhode, K. 1992. Latitudinal gradients in species diversity: the search for the primary cause. *Oikos* 65: 514-527.
- Richards, P. W. 1996. The Tropical Rain Forests: an Ecological Study. Second edition, Cambridge University Press, Cambridge, United Kingdom.
- Robbins, C. S. 1980. Effects of forest fragmentation on breeding bird populations in the piedmont of the Mid-Atlantic region. *Atlantic Naturalist* 33: 31-36.
- Roberts, L. 1988. Hard choices on biodiversity. *Science* 241: 1759-1761.

- Robinson, G. R., and Quinn, J. F. 1992. Habitat Fragmentation, Species Diversity, Extinction, And Design of Natural Reserves. Pages 223-248 in S. K. Jain, and L. W. Botsford, editors. Applied Population Biology, Kluwer Academic Publishers, Netherlands.
- Rodgers, W. A., and H. S. Panwar. 1988. Planning a Wildlife Protected Area Network in India. Volume I and II, Wildlife Institute of India, India.
- Rosenzweig, M. L. 1981. A theory of habitat selection, *Ecology*, **62**: 327-335.
- Rosenzweig, M. L. 1995. Species diversity in space and time. Cambridge University Press.
- Rubio, J. L and L. M. Carrasal. 1994. Habitat selection and conservation of an endemic Spanish lizard *Algyroides marchi* (Reptilia, Lacertidae). *Biological Conservation* **70**: 245-250.
- Sarre, S., K. Wiegand and K. Henle. 1996. The conservation biology of a specialist and generalist gecko in the fragmented landscape of the Western Australian wheatbelt. Pages 39-51 in J. Settele, C. R. Margules, P. Poschlod and K. Henle, editors. Species Survival in Fragmented Landscapes. Kluwer Academic Publishers, Netherlands.
- Saunders, D. A. 1989. Changes in the avifauna of a region, district, and remnant as a result of fragmentation of native vegetation: the wheatbelt of Western Australia. A case study. *Biological Conservation* **50**: 99-135.
- Saunders, D. A., Hobbs, R. J. and C. R. Margules. 1991. Biological consequences of ecosystem fragmentation: a review. *Conservation Biology* **5**: 18-32.
- Saunders, G. W., G. W. Arnold, A. A. Burbidge and J. M. Hopkins. editors. 1987. Nature Conservation: The Role of Remnant Native Vegetation. Surrey Beatty and Sons Pvt. Limited, Chipping Norton, NSW, Australia.
- Schall J. J., and E. R. Pianka 1978. Geographical trends in number of species. *Science* **201**: 679-686.
- Schoener, T. W. 1974. Resource partitioning in ecological communities. *Science* **185**: 27-39.
- Schoener, T. W. 1977. Competition and niche. Pages 35-136 in C. Gans and D. W. Tinkel, editors. *Biology of Reptilia*, Volume 7, Academic, New York.
- Schoener, T. W., and A. Schoener. 1983. The time to extinction of a colonizing propagule of lizards increases with island area. *Nature* **302**:332-334.
- Schuter, D., and R. E. Ricklefs. 1993. Species diversity: an introduction to the problem. Pages 1-10 in R. E. Ricklefs, and D. Schuter, editors. *Species Diversity In Ecological Communities: Historical and Geographical Perspectives*. The University of Chicago Press, Chicago.
- Scott, N. J, Jr., 1976. The abundance and diversity of herpetofauna of tropical forest litter. *Biotropica* **8**: 41-58.

- Seigel, R. A., and J. T. Collins. 1993. Snakes: Ecology and Behavior. McGraw-Hill, Inc., U.S.A.
- Settele, J., C. Margules, P. Poschlod, and K. Henle. 1996. Species Survival in Fragmented Landscapes. Kluwer Academic Press, Netherlands.
- Siegel, S., and N. J. Jr, Castellan. 1988. Nonparametric Statistics for the Behavioural Sciences. McGraw-Hill Book Company, New York, India.
- Simberloff, D. 1988. The contribution of population and community biology to conservation science. *Annual Review of Ecology and Systematics* 19: 473-511.
- Simberloff, D. S. 1986. Are we on the verge of a mass extinction in tropical rainforests? Pages 165-80 *in* D. K. Elliott, editor. *Dynamics of Extinction*. Wiley -Interscience, New York.
- Simberloff, D. S., J. Martin. 1991. Nestedness of insular avifauna: simple summary statistics masking complex patterns. *Ornis Fenn* 68:178-192.
- Simberloff, D., and N. Gotelli. 1984. Effects of insularization on plant species richness in the prairie-forest ecotone. *Biological Conservation* 29: 27-46.
- Simmons, J. E. 1987. Herpetological Collecting and Collection Management. Society for Study of Amphibians and Reptiles, University of Kansas.
- Smith, G. T., G. W. Arnold, S. Sarre, M. Abensperg-Traun, and D. E. Steven. 1996. The effect of habitat fragmentation and livestock grazing on animal communities in remnants of gimlet *Eucalyptus salubris* woodland in the Western Australian wheatbelt. II. Lizards. *Journal of Applied Ecology* 33:1302-1310.
- Smith, M. A. 1933. The fauna of British India, including Ceylon and Burma. Reptilia and Amphibia. Volume 1, Loricata and Testudines. London: Taylor and Francis.
- Smith, M. A. 1935. The fauna of British India, including Ceylon and Burma. Reptilia and Amphibia. Volume 2, Sauria. London : Taylor and Francis.
- Smith, M. A. 1943. The fauna of British India, including Ceylon and Burma. Reptilia and Amphibia. Volume 3, Serpentes. London : Taylor and Francis.
- Sokal, R. R. and F. J. Rohlf. 1995. Biometry. Third edition. W. H. Freeman & Company, New York, U.S.A.
- Soulé, M. E. 1986. Conservation Biology: The Science of Scarcity and Diversity. Sinauer Associates, Sunderland, Mass.
- Stamps, J. A. 1977. Social behaviour and spacing patterns in lizards. Pages 265-334 *in* C. Gans, and D. W. Tinkle, editors. *Biology of the Reptilia*. First edition, Volume 7: Ecology and Behaviour, Academic Press, Inc., London.
- Stevens, G. C. 1989. The latitudinal gradient in geographical range: how so many species coexist in the tropics. *The American Naturalist* 133: 240-256.

- Stevens, G. C. 1992. The elevational gradient in altitudinal range: An extension of Rapoport's latitudinal rule to altitude. *The American Naturalist* **140**: 893-911.
- Stuart, L. C. 1955. A brief overview of the Guatemalan lizards of the genus *Anolis*. Misc. Pub. Mus. Zool., Univ. Mich. **91**: 31 pages.
- Sundararaju, R. 1987. Management Plan for Indira Gandhi Wildlife Sanctuary, Pollachi (for the period of 1987-88 to 1992-93). Office of the Chief Wildlife Warden, Chennai..
- Swengel, F.B. 1991. The Nigiri Tahr Studbook, Minnesota Zoo, USA.
- Terborgh, J. 1973. On the notion of favorableness in plant ecology. *The American Naturalist* **107**: 481-501.
- Terborgh, J. 1992. Maintenance of diversity in tropical forests. *Biotropica*, **24**: 283-292.
- Terborgh, J. H., L. Lopez and J. Tello. 1997. Bird communities in transition: The Lago Guri islands. *Ecology* **78**: 1494-1501.
- Terborgh, J., and B. Winter. 1983. A method for siting parks and reserves with special reference to Colombia and Ecuador. *Biological Conservation* **27**: 45-58.
- Thompson, S. K. 1991. Adaptive cluster sampling: designs with primary and secondary units. *Biometrics* **47**: 1103-1115.
- Thompson, S. K., and A. F. Seber. 1994. Detectability in conventional and adaptive sampling. *Biometrics* **50**: 713-724.
- Thompson, S. K., F. L. Ramsey, G. and A. F. Seber. 1992. An adaptive procedure for sampling animal populations. *Biometrics* **48**: 1195-1199.
- Tocher, M. D., C. Gascon, B. and I. Zimmerman. 1997. Fragmentation effects on central Amazonian frog community: A ten-year study. Pages 124-137, *in* W. F. Laurance, and R. Bierregaard editors. *Tropical Forest Remnants: Ecology, Management and Conservation of Fragmented Communities*. University of Chicago Press, Chicago.
- Toft, C. A. 1985. Resource Partitioning in amphibians and reptiles. *Copeia* **1**: 1-21.
- Turner, I. M., and R. Corlett. 1996. The conservation value of small, isolated fragments of lowland tropical rain forest. *Trends in Ecology and Evolution* **11**: 330-333.
- Turner, I. M. 1996. Species loss in fragments of tropical rain forest: a review of evidence. *Journal of Applied Ecology* **33**: 200-209.
- Umapathy, G., and A. Kumar, 2000. The occurrence of arboreal mammals in the rain forest fragments in the Anamalai Hills, south India. *Biological Conservation* **82**: 311-319.
- Uetz, P. 2000a. How many reptiles? *Herpetological Review* **31**: 13-15.
- Uetz, P. 2000b <http://www.embl-heidelberg.de/~uetz/LivingReptiles.html>

- Vasudevan, K. 1997. Rediscovery of the Black Microhylid frog, *Melanobatrachus indicus* (Beddome 1878). *Journal of Bombay Natural History Society* 94: 170.
- Vasudevan, K., A. Kumar, and R. Chellam. 2001. Structure and composition of rainforest floor amphibian communities in Kalakad-Mundanthurai Tiger Reserve. *Current Science*:
- Vitt, L. J. 1991. An introduction to the ecology of cerrado lizards. *Journal of Herpetology* 25: 79-90.
- Vitt, L. J. 1995. The ecology of tropical lizards in the *caatinga* of northeast Brazil. *Occasional Papers of the Oklahoma Museum of Natural History* 1: 1-27.
- Vitt, L. J., and Carvalho, C. M. 1995. Niche partition in a tropical wet season: lizards in the lavrado area of northern Brazil. *Copeia*: 305-329.
- Vitt, L. J., and P. A. Zani. 1996. Organisation of the taxonomically diverse lizard assemblage in Amazonian Ecaudor. *Canadian Journal of Zoology* 74: 1313-1315.
- Vitt, L. J., T. C. S. Avila-Pires, J. P. Caldwell, and V. R. L. Oliveira. 1997. The impact of individual tree harvesting on thermal environments of lizards in Amazonian rain forest. *Conservation Biology* 12: 654-664.
- Vitt, L.J. 1996. Biodiversity of Amazonian lizards. Pages 89-108 in A. C. Gibson, E. Mildred, and Mathias Garden editors. *Neotropical Biodiversity and Conservation*. University of California, LA, California.
- Wall, F. 1923. How to identify the snakes of India (including Burma & Ceylon). Union press, Karachi.
- Welsh H. H. Jr., and A. Lind. 1991. The structure of the herpetofaunal assemblage in the Douglas-fir/hardwood forests of the northwestern California and western Oregon. in L.F. Ruggiero, K. B. Aubry, A. B. Carey and M. M. Huff (Technical Co-ordinators). *Wildlife & Vegetation of the Unmanaged Douglas-fir forests*, Gen. Tech. Rep. PNW-GTR-285. Portland, OR:US. Department of Agriculture, Forest Service.
- Whitaker, R. 1978. *Common Indian Snakes: A field guide*. MacMillan, New Delhi.
- Whitaker, R., and Z. Whitaker. 1990. Herpetological Conservation in India. Pages 289-299 in J. C. Daniel, and J. S. Serrao editors. *Conservation in Developing Countries: Problems and Prospects*. BNHS, Oxford University Press, Bombay.
- Whitmore, T. C. 1989. Southeast Asian tropical forests. Pages 195-218 in H. Lieth, and M. J. A. Werger, editors. *Ecosystems of the world* 14 B. Elsevier Science publishers, Netherlands.
- Wilcove, D. S., C. H. McLellan, and A. P. Dobson. 1986. Habitat fragmentation in the temperate zone: Pages 237-285 in M. E. Soulé, editor. *Conservation Biology: The Science of Scarcity and Diversity*. Sinauer Associates, Sunderland, Mass.

- Wilcox, B. A., and D. D. Murphy. 1985. Conservation strategy: effects of fragmentation on extinction. *American Naturalist* **125**: 879-887.
- Wilcox, B.A. 1986. Insular ecology and conservation Pages 95-118 *in* M. E. Soulé, editor. *Conservation Biology: The Science of Scarcity and Diversity*. Sinauer Associates, Sunderland, Mass.
- Woinarski, J. C. Z., and N. Gambold. 1992. Gradient analysis of a tropical herpetofauna: distribution patterns of terrestrial reptiles and amphibians in stage III of Kakadu National Park, Australia. *Wildlife Research* **19**: 105-127.
- Wootton, J. T. 1998. Effects of disturbance on species diversity: a multitrophic perspective, *The American Naturalist* **152**: 803-825.
- Wright, D. H., and J. H. Reeves. 1992. On the meaning and measurement of nestedness of species assemblages. *Oecologia* **92**: 416-428.
- Wright, D. H., B. D. Patterson, G. Mikkelsen, A. H. Cutler, and W. Atmar. 1998. A comparative analysis of nested subset patterns of species composition. *Oecologia* **113**: 1-20.
- Yiming, L., J. Niemela, and L. Dianmo. 1998. Nested distribution of amphibians in the Zhoushan archipelago, China: can selective extinction cause nested subsets of species? *Oecologia* **113**: 557-564.

## Appendix 1

List of macro and micro-habitat parameters recorded from quadrats (5 m x 5 m) and along forest transects (in 3 m x 3 m plots), used for sampling reptiles in the rainforests of KMTR and Anamalai Hills.

1. **Altitude (m)**  
Using an altimeter at the centre of the plot. Expressed as a mean value.
2. **Canopy height (m)**  
Visual estimation to the top layer of the canopy. Expressed as a mean value.
3. **Canopy cover (%)**  
Using a densiometer, reading taken at the centre of the plot. Mean value of readings taken at four directions used. Expressed as a mean value.
4. **Soil Temperature (°C)**  
Using a digital thermometer, readings taken at four corners and at the centre of the plot. Mean values used. Expressed as a mean value.
5. **Air Temperature (°C)**  
Using a digital thermometer, readings taken at four corners and at the centre of the plot. Mean values used. Expressed as a mean value.
6. **Soil Moisture (%)**  
Using a soil moisture and pH meter, readings taken at four corners and at the centre of the plot. Expressed as a mean value.
7. **Soil pH**  
Using a soil moisture and pH meter, readings taken at four corners and at the centre of the plot. Expressed as a mean value.
8. **Leaf litter depth (mm)**  
Measured by a scale at four corners and at the centre of the plot. Expressed as a mean value.
9. **Litter cover (%)**  
Visual estimation of the leaf litter cover in plot, expressed as percentage litter cover. Expressed as a mean value.
10. **Rock cover (%)**  
Visual estimation of the rock cover in plot, expressed as percentage rock cover. Expressed as a mean value.
11. **Root cover (%)**  
Visual estimation of the root cover in plot, expressed as percentage root cover. Expressed as a mean value.
12. **Number of trees**  
The number of trees with GBH >20 cm in a plot. Expressed as a mean value.
13. **Girth at breast height (cm)**  
The girth of trees at breast height measured using Freeman's measuring tape. Used to calculate the basal area of the plot.
14. **Number of liana**  
The number of woody climbers in a plot. Expressed as a mean value.
15. **Number of bamboo/rattan**  
The number of bamboo and or rattan in a plot. Expressed as a mean value.

16. **Number of tree hollows**  
The number of trees with cavities in a plot. Expressed as a mean value.
17. **Number of snags**  
The number of dead standing trees in a plot. Expressed as a mean value.
18. **Number of buttressed trees**  
The number of trees with buttress in a plot. Expressed as a mean value.
19. **Number of burrows**  
Number of burrows in a plot. Expressed as a mean value.
20. **Water**  
Presence absence of water in a plot.
21. **Evidence of forest fire**  
The presence or the absence of evidence of forest fire in a plot.
22. **Distance from water (m)**  
If present in the vicinity of the plot, its distance from the centre of the plot.
23. **Slope**  
The slope of the plot categorised as being flat/gentle/medium or high.
24. **Number of fallen logs**  
If the logs are > 10 cm in diameter, then its number and their dimensions.
25. **Decomposition state of plot**  
The state of decay of both leaf litter and of the fallen logs categorised as fresh, medium or total.
26. **Number of cardamom**  
The number of cardamom plants in a plot. Expressed as a mean value.
27. **Number of coffee**  
The number of coffee stems in a plot. Expressed as a mean value.
28. **Number of cut trees**  
The number of standing trees cut in a plot. Expressed as a mean value. Girth measurements also taken. Used to calculate the basal area of cut trees.
29. **Number of cut saplings**  
The number of cut saplings in a plot. Expressed as a mean value.
30. **Distance to edge of plot (m)**  
The distance of the plot from the edge of the fragment. Expressed as a mean value.
31. **Number of herbs**  
The number of herbs (saplings <1 m in height). Expressed as a mean value.
32. **Number of shrubs**  
The number of shrubs (plants <20 cm GBH). Expressed as a mean value.

## Appendix 2

List of reptiles recorded from the contiguous rainforests of the Kalakad-Mundanthurai Tiger Reserve during 1996-98. Nomenclature follows Das 1996.

### FAMILY: BATAGURIDAE

1. *Melanochelys trijuga* (Schweigger, 1812)

### FAMILY: GEKKONIDAE:

2. *Cnemaspis indica* (Gray, 1846)\*\*
3. *C. ornatus* (Beddome, 1870)\*
4. *C. beddomei* (Theobald, 1876)\*\*
5. *Cnemaspis* spp.1\*\*
6. *Cnemaspis* spp.2 (yellow throat)\*\*
7. *Cnemaspis* spp.3 (Red eyed gecko)\*\*
8. *Hemidactylus anamallensis* (Gunther, 1875) = (*Dravidogecko anamallensis*)\*\*

### FAMILY: AGAMIDAE:

9. *Calotes andamanensis* Boulenger, 1891\*\*
10. *C. calotes* (Linnaeus, 1758)
11. *C. ellioti* Gunther 1864\*
12. *C. grandisquamis* Gunther, 1875\*
13. *C. nemoricola* Jerdon, 1853\*
14. *C. rouxii* Dumeril & Bibron, 1837
15. *Draco dussumieri* Dumeril & Bibron, 1837\*
16. *Otocryptis beddomii* Boulenger, 1885\*\*
17. *Psammophilus blanfordanus* (Stoliczka, 1870)
18. *P. dorsalis* (Gray in: Griffith & Pidgeon, 1831)

### FAMILY: SCINCIDAE:

19. *Mabuya beddomii* (Jerdon, 1870)
20. *M. carinata* (Schneider, 1801)
21. *M. macularius* (Blyth, 1853)
22. *Scincella travancoricum* (Beddome, 1870) (= *Liolopisma travancoricum*)\*\*
23. *Ristella* spp.\*\*

### FAMILY: VARANIDAE:

24. *Varanus bengalensis* (Daudin, 1802)

### FAMILY: UROPELTIDAE:

25. *Brachyophidium rhodogaster* Wall, 1921\*
26. *Melanophidium punctatum* Beddome, 1871\*\*
27. *Uropeltis arcticeps* (Gunther, 1875)\*
28. *U. ellioti* (Gray, 1858)\*
29. *U. ocellata* (Beddome, 1863)\*
30. *Uropeltis* spp.\*\*

**FAMILY: COLUBRIDAE:**

31. *Ahaetulla dispar* (Gunther, 1864)\*
32. *Ahaetulla nasutus* (Lacepede, 1789)
33. *Ahaetulla perroteti* (Dumeril, Bibron, 1854)\*\*
34. *Ahaetulla pulverulentus* (Dumeril, Bibron 1854)
35. *Amphiesma beddomei* (Gunther, 1864) \*
36. *Boiga ceylonensis* (Gunther, 1858)\*\*
37. *B. forsteni* (Dumeril, Bibron & Dumeril, 1854)
38. *Coluber mucosus* (Linnaeus, 1758)
39. *Dendrelaphis grandoculis* (Boulenger, 1890)\*
40. *D. tristis* (Daudin, 1803)
41. *Lycodon aulicus* (Linnaeus, 1758)
42. *L. travancoricus* (Beddome, 1870)\*\*
43. *Lycodon spp.*\*
44. *Macropisthodon plumbicolor* (Cantor, 1839)
45. *Oligodon arnensis* (Shaw, 1802)
46. *O. brevicaudus* (Gunther, 1862)\*
47. *Xenochropis piscator* (Schneider, 1799)

**FAMILY: ELAPIDAE:**

48. *Calliophis melanurus nigrescens* (Gunther, 1862) \*
49. *Ophiophagus hannah* (Cantor, 1836)

**FAMILY: VIPERIDAE:**

50. *Hypnale hypnale* (Merrem, 1820)
51. *Trimeresurus gramineus* (Shaw, 1802)
52. *T. macrolepis* Beddome, 1862\*\*
53. *T. malabaricus* (Jerdon, 1854)\*
54. *T. strigatus* Gray, 1842

\* Endemic to the Western Ghats

\*\* Endemic to the rainforests of Western Ghats

Appendix 3

List of reptiles recorded in the 14-rainforest fragments in the Anamalai Hills, during 1998-99. Nomenclature follows Das 1996.

No	Species	AKK	AND	MAN	SAN	IYE	PUT	KOR	TAF	PAN	VA1	VA2	VA3	VA4	TA2	Total
<b>Geckos (Geckonidae)</b>																
1	<i>Cnemaspis indica**</i>		X		X		X						X	X		5
2	<i>C.mysorensis**</i>	X	X	X	X				X				X			6
3	<i>C.ornatus*</i>	X		X					X						X	4
4	<i>C. spp 1 (white belly)**</i>	X	X	X											X	4
5	<i>C. spp 2 (yellow throat)**</i>	X	X	X			X									9
6	<i>C. spp 3 (red eye)**</i>	X		X	X		X	X		X						2
7	<i>C. spp 4 (total black)**</i>	X	X	X											X	8
8	<i>C. spp 5 (black throat)**</i>	X	X		X			X	X	X						3
9	<i>C. spp 6 (?)**</i>	X		X	X			X		X						6
<b>Lizards (Agamidae)</b>																
10	<i>Calotes ellioti*</i>	X	X	X	X	X	X	X	X	X	X	X	X	X	X	14
11	<i>C.grandisquamis*</i>	X	X	X	X	X	X		X	X			X	X	X	10
12	<i>C.nemoricala*</i>	X	X	X	X	X			X	X			X			7
13	<i>C.rouxii</i>		X	X	X	X		X					X	X	X	10
14	<i>Draco drussumeri*</i>	X	X	X	X	X			X	X	X	X	X	X	X	13
15	<i>Salea anamallayana**</i>	X						X	X	X	X	X	X	X		1
<b>Skinks (Scincidae)</b>																
16	<i>Mabuya beddomii</i>	X	X	X	X	X	X	X	X	X	X	X	X	X		13
17	<i>M.carinata</i>		X		X	X	X	X	X	X	X	X	X	X		6
18	<i>Ristella guntheri**</i>	X	X		X	X		X	X	X			X		X	7
19	<i>Scincella travancoricum**</i>	X		X		X	X		X	X						6
20	<i>Scincella spb**</i>	X				X	X		X	X						1
<b>Monitor lizard (Varanidae)</b>																
21	<i>Varanus bengalensis</i>	X	X	X				X	X				X			6



Appendix 4

Leaf litter reptiles in the contiguous rainforests of KMTR  
Spearman's rho nonparametric correlations values of micro habitat variables per network  
(for details on the measurements of these habitat variables refer Appendix 1).

	no. of species	no. of reptiles	network size	altitude (m)	no. of herbs	no. of shrubs	canopy cover (%)	litter cover (%)	rock cover (%)	root cover (%)	canopy height (m)	basal area (sq. cm) of trees	no. trees >20 cm GBH	no. large logs (>10 cm radius)	decomposition rate of logs and litter	slope	air temp. (deg C)	soil temp. (deg C)	litter depth (cm)	soil pH	soil moisture (%)	no. of buttress trees	no. of snags
no. of species	1.000	.996**	.997**	-.121**	-.063	-.032	-.034	-.022	.098*	.081	-.040	.100*	-.008	.033	-.048	-.009	.045	-.044	-.034	-.069	-.035	.097*	.094*
no. of reptiles		1.000	.997**	-.114**	-.059	-.030	-.040	-.018	.101*	.086*	-.032	.094*	-.007	.035	-.045	.007	.038	.043	-.039	.066	-.032	.094*	.094*
network size			1.000	-.111**	-.062	-.032	-.036	-.023	.100*	.086*	-.039	.095*	-.004	.038	-.054	.006	.041	.042	-.042	.071	-.042	.094*	.094*
altitude (m)				1.000	.127**	.267**	.088	-.140**	-.084*	-.022	.138**	-.076	-.105*	.037	-.037	-.145**	-.245**	-.235**	.128**	-.009	-.145**	-.073	-.046
no. of herbs layer					1.000	.256**	.044	.115**	.058	.019	.262**	.034	.034	.000	.169**	.046	-.109**	.089*	.060	-.037	.079	-.001	.093*
no. of shrubs						1.000	-.033	.033	.079	.075	.134**	-.013	-.009	.005	-.076	.066	-.195**	-.093*	.135**	-.137**	-.024	.021	.028
canopy cover							1.000	-.002	-.114**	-.083*	.027	.030	.105*	.116**	-.177**	-.178**	.200**	.191**	-.225**	.287**	-.238**	.020	-.007
litter cover (%)								1.000	-.015	-.044	.034	-.008	-.026	-.055	.219**	.018	.052	.089*	.126**	-.034	-.021	-.002	-.055
rock cover (%)									1.000	.057	.028	.156**	.062	-.024	.054	.117**	.053	.152**	.176**	.008	.047	.087*	.011
root cover (%)										1.000	1.000	.062	-.032	-.032	.054	.055	.003	.021	-.043	-.094	.352**	.010	.029
canopy height (m)											1.000	.028	-.102*	-.087*	.087*	-.000	.133**	.155**	-.007	.134**	-.074	.775**	.029
basal area (sq. cm) of trees												1.000	.514**	.030	.036	-.023	.148**	.098*	-.047	.164**	-.140**	.305**	.066
no. trees >20 cm GBH													1.000	.129**	.006	-.067	.096*	.104*	-.031	.012	-.042	.015	.140**
no. large logs (>10 cm radius)														1.000	1.000	.044	.029	.133**	.255**	.031	.085	.089*	-.003
decomposition rate of logs and litter															1.000	1.000	.001	.045	.056	.044	-.027	-.006	.041
slope																1.000	.774**	.1.000	-.265**	.546**	-.350**	.105*	.071
air temp. (deg C)																	1.000	1.000	.513**	-.229**	.129**	.102*	.102*
soil temp. (deg C)																		1.000	1.000	-.257**	.083	.001	-.073
litter depth (mm)																			1.000	1.000	1.000	576	576
soil pH																				1.000	1.000	1.000	1.000
soil moisture (%)																					1.000	1.000	1.000
no. of buttress trees																					1.000	1.000	1.000
no. of snags																					1.000	1.000	1.000
no. trees (>30 cm GBH)																					1.000	1.000	1.000

\*\* Correlation is significant at the .01 level (2-tailed).  
\* Correlation is significant at the .05 level (2-tailed)

Appendix 5

Leaf litter reptiles in the rainforests fragments of Anamalai Hills.  
Spearman's rho nonparametric correlations values of micro habitat variables per network.  
(for details on the measurements of these habitat variables refer Appendix 1).

no. of species	no. of reptiles	network size	altitude (m)	no. of herbs	no. of shrubs	canopy cover (%)	litter cover (%)	rock cover (%)	root cover (%)	canopy height (m)	no. of saplings (<20 cm radius)	no. of cut trees (>20 cm GBH)	basal area (sq cm) of cut trees	decomposition rate of logs and litter	slope	air temp. (deg C)	soil temp. (deg C)	litter depth (cm)	soil pH	soil moisture (%)	no. of buttress trees	no. of snags	size classes of fragments	
1.000	.993**	.995**	-.070	-.065	-.108*	-.002	-.027	.103*	.044	.033	.094*	.125**	.121**	-.008	.050	.065	.036	.022	-.107*	-.024	.121**	.024	.023	
	1.000	.996**	-.062	-.061	-.107*	-.003	-.021	.107*	.040	.035	.094*	.133**	.130**	-.007	.046	.060	.033	.024	-.102	-.031	.115*	.022	.022	
		1.000	1.000	.339**	-.107*	-.004	-.022	.111*	.039	.035	.090	.134**	.131**	-.008	.042	.070	.041	.020	-.096	-.033	.117*	.026	.023	
			1.000	1.000	500**	.144**	.045	.043	.123**	.083	.013	-.023	-.036	.021	-.026	-.493**	-.485**	.075	-.095	.099	.023	-.039	-.039	
					1.000	.104*	-.015	-.011	.007	-.078	.042	.012	.017	-.016	.063	-.244**	-.207**	.159**	-.229**	.132*	.103*	.020	-.323**	
						1.000	.034	.164**	-.063	.312**	-.016	-.096*	-.109*	-.131**	-.057	-.276**	-.282**	.090	-.178**	.025	.036	.048	-.016	-.203**
							1.000	-.042	1.000	.056	.023	.057	.062	-.043	-.044	.138**	.102*	-.019	-.239**	.062	.048	-.095*	-.284**	
								1.000	1.000	.218**	.048	.053	.063	.066	.049	-.007	-.021	.075	-.008	.186**	-.010	.011	-.117*	
									1.000	1.000	1.000	1.000	1.000	1.000	1.000	-.072	-.032	.097*	-.126*	.026	.042	.004	-.017	
											1.000	.073	.038	.015	.025	.066	.069	.102*	-.246**	.235**	.131**	-.078	-.283**	
												1.000	.981**	-.007	.051	.160**	.165**	.021	-.036	-.136*	-.031	-.020	-.156**	
													1.000	1.000	.044	.158**	.159**	.031	-.009	-.032	-.014	-.044	-.216**	
														1.000	.027	-.098*	-.087	.007	.009	-.004	-.006	.058	.203**	
															1.000	1.000	.877**	-.033	-.063	-.062	-.109*	-.070		
																1.000	1.000	.147**	.280**	.168**	-.008	-.070		
																	1.000	1.000	.314**	-.201**	-.100*	.055	.487**	
																		1.000	.034	-.201**	.016	.055	.487**	
																		1.000	1.000	-.346**	-.044	.079	.226**	
																		1.000	1.000	1.000	-.009	.027	-.235**	
																		1.000	1.000	1.000	1.000	.108*	-.035	
																		1.000	1.000	1.000	1.000	1.000	.006	
																		1.000	1.000	1.000	1.000	1.000	1.000	

\*\* Correlation is significant at the .01 level (2-tailed).  
\* Correlation is significant at the .05 level (2-tailed).

Appendix 6

Arboreal reptiles in the contiguous rainforests of KMTR  
 Spearman's rho nonparametric correlations values of micro habitat variables per plot  
 (for details on the measurements of these habitat variables refer Appendix 1).

	no. of reptiles	canopy height (m)	canopy cover (%)	altitude (m)	leaf litter depth (cm)	no. of trees (> 20 cm GBH)	no. of buttress trees	no. of herbs	no. of shrubs	rock cover (%)	root cover (%)	leaf litter cover (%)	soil temp. (deg C)	air temp. (deg C)	soil moisture (%)	soil pH	no. of woody climbers	no. of tree holes	no. of rattan	no. of burrows	no. of snags	no. of large logs (> 10 cm radius)	
no. of reptiles	1.000																						
canopy height (m)		1.000																					
canopy cover (%)			1.000																				
altitude (m)				1.000																			
leaf litter depth (cm)					1.000																		
no. of trees (> 20 cm GBH)						1.000																	
no. of buttress trees							1.000																
no. of herbs								1.000															
no. of shrubs									1.000														
rock cover (%)										1.000													
root cover (%)											1.000												
leaf litter cover (%)												1.000											
soil temp. (deg C)													1.000										
air temp. (deg C)														1.000									
soil moisture (%)															1.000								
soil pH																1.000							
no. of woody climbers																	1.000						
no. of tree holes																		1.000					
no. of rattan																			1.000				
no. of burrows																				1.000			
no. of snags																					1.000		
no. of large logs (> 10 cm radius)																						1.000	
basal area (sq cm) of trees																							1.000

\*\* . Correlation is significant at the .01 level (2-tailed).

\* . Correlation is significant at the .05 level (2-tailed).

