Distribution Pattern of Amphibians in Megamalai Landscape, Western Ghats, Tamil Nadu

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DEGREE OF DOCTOR OF PHILOSOPHY

in

ZOOLOGY

by

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Coimbatore 641 108

June 2011

CERTIFICATE

This is to certify that the thesis, entitled "**Distribution Pattern of Amphibians in Megamalai Landscape, Western Ghats, Tamil Nadu**" is a record of original work done by Mr. G.Srinivas in the Division of Conservation Ecology, at Sálim Ali Centre for Ornithology and Natural History, as a full time Research Scholar during the period from July 2006 - June 2011 under my guidance and supervision for the award of Degree of Doctor of Philosophy in Zoology. I further certify that this research work has not previously formed the basis for the award of any other Degree or Diploma or Associateship or Fellowship or other similar title to this or any other candidate in any other University.

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DECLARATION

I, do hereby declare that the thesis entitled "**Distribution Pattern of Amphibians in Megamalai Landscape, Western Ghats, Tamil Nadu**" submitted to the Bharathiar University, Coimbatore, for the award of the Degree of Doctor of Philosophy in Zoology, is a record of original and independent research work done by me from July 2006 - June 2011 under the guidance and supervision of Dr. S. Bhupathy, Principal Scientist, Division of Conservation Ecology, Sálim Ali Centre for Ornithology and Natural History, Coimbatore and it has not previously formed the basis for the award of any Degree or Diploma or Associateship or Fellowship or other similar title to this or any other candidate in any other University.

Signature of the Candidate

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SUMMARY

Amphibians, in particular anurans, contribute a significant proportion of the vertebrate biomass in all the terrestrial and freshwater ecosystems. They function as important predator and prey species. However, studies focusing on ecology of these taxa in Indian subcontinent are scanty. The present study had the following objectives: (1) understand the population of amphibians in the Megamalai landscape, (2) study the distribution pattern of amphibians with respect to elevation categories and vegetation types and (3) suggest conservation measures.

The present study was carried out in Megamalai Hills of Theni Forest Division, from December 2006 to November 2008. In the present study, three belt transects *viz.*, Mavadi, Suruli and Vellimalai were laid from hilltop to the bottom stratified at 200m interval. The transects were divided into seven elevation categories (400-600m, 600-800m, 800-1000m, 1000-1200m, 1200-1400m, 1400-1600m and 1600-1800m). Total length of three transects was 21.17 km and the width of the transect was 1000m and thus the area covered for sampling was 21.17 sq.km. Transects were assessed for vegetation types using Point-Centred Quarter. Vegetation types recognized here include Dry Deciduous, Moist Deciduous, Riverine, Rocky slopes with grass, Evergreen and Shola and Grassland. Visual Encounter Survey (VES, time constrained) and Quadrat count (area constrained 10 X 10 m) methods were used for regular sampling along the transects. Apart from regular sampling, road, night and opportunistic surveys were carried out. Data were analysed using various statistical tools and computer softwares such as Microsoft Excel, SPSS and EstimateS.

VES for 3600 man-hours yielded 2131 individuals of 19 species and 1200 Quadrats had 335 individuals of 14 species, totaling 21 species and 3166 individuals. Including all the methods, 34 species of amphibians belonging to eight families and 19 genera were observed during the study. Of the 34 species, 21 species (61.76 %) were endemic to the Western Ghats. Maximum of 11 species were recorded for Rhacophoridae and minimum for Micrixalidae (single species).

Higher number of species and individuals were recorded in VES (19 species, 2131 individuals) compared to Quadrat (14 species, 335 individuals). Six species of

amphibians were recorded only in VES and two species in Quadrat method. Statistically, species richness did not vary between methods (U=168; P>0.05). However, individuals of amphibians recorded in different methods were statistically different (U=88; P<0.01). Of the 1200 Quadrats, only 162 Quadrats had amphibians. Similarly, of the 1200 (X3 man) hours of VES only 652 (total 1956 man-hours) hours (or bouts) had amphibians. Discriminant Function analysis (DFA) identified water as the best predictor for amphibian.

Among the three transects examined, species richness was highest in Mavadi (19 species) followed by Vellimalai (16 species). However, Vellimalai had the highest number of individuals (n=1179) followed by Suruli (n=1155). The transects varied significantly with respect to species richness (F=1.962; P<0.05), family richness (F=15.643; P<0.001) and number of individuals (F=3.509; P<0.001).

Of the 14 species recorded in Quadrats, richness was 11 each during dry and wet seasons, whereas VES also had equal species richness of 18 each during each seasons. In Suruli, Quadrat data did not show any variation in species richness. In Vellimalai one species was found in higher number in wet season (7 species) than dry season, whereas in Mavadi, two species were observed only during dry season (8 species) than wet season. Based on VES in Mavadi, three species were higher during dry season (16 species) than wet season. In Suruli single species was higher during dry season (15 species) than wet season (14 species). In Vellimalai between seasons, no variation in species richness was observed.

Maximum number of amphibians was observed during dry season (Quadrats n=203 and VES n=1713) and minimum during wet season (Quadrat n=132 and VES n=1118). Except family richness, VES data showed significant difference between seasons for number of individuals (F=26.454, P<0.05), and species richness (F=4.669, P<0.05). However, Quadrat data did not show any difference for number of individuals, species richness and family richness.

Non-parametric estimators such as Chao and Jackknife were used for estimating the potential species richness. These estimators did not vary much from the Empirical species richness for VES data, however differed for Quadrat method. The estimated number of species by various non-parametric estimators ranged from 19±0.03 to

21±0.0 for VES and for Quadrat from 14±0.05 to 19.19 ± 0.0. Jackknife 2 estimated highest values for species richness of Megamalai.

Maximum of *Indirana beddomii* (731, 23.09 %) was observed followed by *Sylvirana temporalis* (647, 20.44%) and *Duttaphrynus melanostictus* (431, 13.61 %). Relative abundance of *Philautus* (284, 8.97%) was low when compared to other species. In terms of abundance, among the eight families, Petropedetidae (38.85%) was the highest and Microhylidae was the lowest. The distribution of amphibian families was not even (χ^2 = 2888.85, P<0.001).

The overall density of amphibians was 27.92/ha. Dry season had higher density of amphibians 33.83/ha compared to wet season 22/ha. Among the transects, Suruli had highest density of 36.5/ha followed by Vellimalai (24.25/ha) and Mavadi (23/ha). Of the eight families observed, two of them (Microhylidae and Nyctibatrachidae) were not sighted in the Quadrat sampling. Family density analysis showed a maximum density for Petropedetidae (13.25/ha; 3 species, 159 individuals) and minimum for Micrixalidae (0.33/ha; 1 species, 4 individuals). Species level density showed *Indirana semipalmata* (7.83/ha) as the most abundant.

Sampling intensity in each altitudinal category was based on area availability. Of the 34 species observed, the highest of 16 species was recorded in 800-1000 m and lowest of 10 species in 1000-1200 m. Highest number of endemic species (13) was found between 1400 and 1600m and lowest, two species in 400-600m.

Density of amphibians was highest at 1000-1200m and lowest between 1200 and 1400 m elevation category. Encounter rate of amphibians in Megamalai was 0.786/man-hour. The encounter rate of >1.0/man-hour was recorded in three elevational categories 800-1000m, 1600-1800m, 1400-1600m. Shannon-Weiner diversity index was highest in 1400-1600 m and lowest in 1000-1200 m. Total number of amphibian families varied from six to eight among various elevations. Maximum of eight families were observed in 1200-1400 m. Distribution of families were not even among elevational categories (χ^2 = 732.80; P<0.001). The number of species (R^2=0.5566) and endemics (R^2=0.7917) showed increasing trend with elevation.

Amphibian distribution along the elevation category showed that 16 out of 34 species confined to one elevation category. Highest number of exclusive species (confined to one elevation category) was found in low elevation. Species turnover rate was low between consecutive elevational categories and high turnover was observed between 400-600 m and 1400-1600 m. Empirical S obtained using Mid-domain null model had significant relationship with Simulated S (R^2=0.317, P<0.05). However, low R^2 value showed low fit to the mid-domain model.

Both annual temperature and rainfall showed significant relationship with elevation (Temperature r=-0.956; P<0.001; n=7 and rainfall r=0.955; P<0.001; n=7). At elevational gradients, microhabitat parameters shrub cover, canopy cover and herb cover showed non-linear relationship with amphibian species richness. Also, amphibian abundance had non-linear relationship with soil humidity, soil temperature, litter cover and fallen log.

Of the 1200 Quadrats examined only 162 had amphibians. The highest of about 30% of the Quadrats had amphibians in Shola and Grassland. Of the 3600 hours of VES, during this study 1956 (54.33%) man-hours at least one individual of amphibian was encountered. Absence of amphibians was higher than 50% in two vegetation types; Dry Deciduous and Rocky slopes with grass.

The highest of 18 species was recorded from Dry Deciduous and lowest (six species) in Riverine habitat. Excluding Dry Deciduous and Riverine, rest of the forest types had high (>70%) proportion of endemics. The highest of eight amphibian families were observed in Evergreen and lowest (4) in Riverine vegetation. Bufonidae, Dicroglossidae and Petropedetidae were found in all vegetation types.

The highest abundance of amphibian was observed in Dry Deciduous vegetation and lowest in Shola and Grassland. The abundance of various amphibian families showed different patterns. All amphibian families found in dry vegetation had equal representations with respect to abundance. Amphibian abundance was not similar among various vegetation types (χ^2= 639.74; P<0.001).

Amphibian species richness with respect to vegetation types showed significant variation between seasons with VES (F=4.669; P<0.05) and number of individuals (F=26.454; P<0.001). However, it was not significant with family richness (F=2.797;

$P>0.05$). Quadrat data did not show significant variation between seasons for species richness, family richness and number of individuals.

The highest Shannon-Weiner diversity was obtained for Evergreen (H'= 2.25) and the lowest for Riverine (H'= 1.12). Habitats Shola and Grassland had the highest (47.73/ha) amphibian density and Dry Deciduous had the lowest (16.38/ha). At species level, the highest density was recorded for *Indirana semipalmata* followed by *Duttaphrynus melanostictus*. The density of amphibians in Evergreen forests of Megamalai was different compared to other parts of Western Ghats as well as the globe.

Encounter rate for amphibians was >1 in the three vegetation types, namely Riverine (1.340/man-hour), Shola and Grassland (1.259/man-hour) and Moist Deciduous (1.148/man-hour). Of the total 19 species recorded in VES method, *Indirana beddomii* (0.189/man-hour) was numerically dominant.

The highest similarity in terms of amphibian species was observed between Rocky slopes with grass and Evergreen forest (0.814). Similarity was low between distant vegetation types.

Principal component analysis showed that tree related factors such as canopy cover, and litter cover were positively influencing the habitat on PC I. Rock crevices, boulder and distance from water added 11.90% to the variance on PC II. Variance account by PC III were boulder, termite hill and tree hole. Distance from water had highest relationship with amphibian species richness and abundance. Soil humidity and soil temperature had influenced their abundance as well.

At species level, *Indirana beddomii* and *Duttaphrynus melanostictus* were distributed in all elevational gradients and in all the vegetation types. *Philautus beddomii* and *P. griet* distributed only in higher elevation (1200-1800m) and recorded largely in Evergreen and Shola and Grassland.

In all, *Indirana beddomii* was the dominant in terms of abundance. The maximum abundance, was observed between 800-1000 m and Moist Deciduous vegetation. *Sylvirana temporalis* had higher representation in two elevational gradients (600-1000m) and the most recorded species in Riverine forest. *Fajervarya mudduraja* showed highest abundance in low elevation (400-600 m) and in Dry Deciduous. On the other hand, *Limnonectes brevipalmatus* had maximum abundance in higher elevation (1600-1800 m) and Shola and Grassland.

The highest observations of *Fajervarya mudduraja* (87.88%), *Limnonectes brevipalmatus* (91.89%) *Indirana leptodactyla* (79.63%) and *Sylvirana temporalis* (76.21%) were found in and around (5 m) water. Highest proportion of *Philautus* spp. and species *Duttaphrynus melanostictus* were recorded away from water. However, members of *Indirana* were found closer as well as away from water.

Duttaphrynus melanostictus had the highest niche breadth (5.45) with respect to elevation. *Indirana beddomii* scored the highest breath (4.78) in vegetation axis. Niche breadth in microhabitat was highest in *Sylvirana temporalis* (5.65). However, average niche breadth was higher for *Indirana beddomii* (4.78) compared to other species.

Of the 31 species recognized at species level during the present study, 15 species belonged to IUCN/SSC threatened category. Three species (*Philautus griet*, *Philautus ponmudi* and *Rhacophorus pseudomalabaricus)* are Critically Endangered (CR), five species (*Nyctibatrachus aliciae*, *Nyctibatrachus beddomii*, *Indirana leptodactyla*, *Philautus wynaadensis* and *Rhacophorus pleurostictus*) are Endangered (EN), one species (*D. microtympanum*) is Vulnerable (VU) and five species (*Ramanella montana*, *Micrixalus fuscus*, *Clinotarsus curtipes*, *Sylvirana temporalis* and *Philautus beddomii*) as Near Threatened (NT). One species (*Limnonectes brevipalmatus*) was categorised under Data Deficient (DD).

Part of the area (269.11 sq.km) of this landscape, has been declared as Megamalai Wildlife Sanctuary, is an encouraging sign for conserving amphibian fauna and other wildlife in the region.

1. INTRODUCTION

1.1. BACKGROUND

The patterns of species distribution vary across taxonomic groups along elevational gradients. Richness of species along the elevation follows one of the three general patterns; mid-elevation peak, monotonic decline or increase with elevation (Rahbek, 1995). Random distribution of species ranges within a bounded domain resulting in maximum species richness in the middle of the domain. Various studies are available on the distribution pattern of species along the elevational gradients; mammals (Patterson *et al.*, 1996, 1998; Brown, 2001; Heaney, 2001; Md. Nor, 2001; Rickart, 2001; Sanchez-Cardero, 2001; Li *et al.*, 2003; McCain, 2004b, 2005, 2006), birds (Terborgh, 1977; Navarro, 1992; Blake and Loiselle, 2000; Kessler *et al.*, 2001; Latta *et al.*, 2003; Kattan and Franco, 2004; Raman *et al.*, 2005) and herpetofauna (Scott, 1976; Daniels, 1992a; Hofer *et al.*, 1999; Vasudevan *et al.*, 2006; Naniwadekar and Vasudevan, 2007; Chettri *et al.*, 2010).

The decline in species richness with increasing elevation is widely accepted as a general pattern (Begon *et al.*, 1990; Stevens, 1992; Rahbek, 1995). However, Rahbek (1995) reported that this view on the relationship of species richness with elevation is immature. Patterns of diversity are still far from understanding (Terborgh, 1977). Monotonic decline in species richness with elevation (Heatwole, 1982; Stevens, 1992; Md. Nor, *et al.*, 2001), 'Hump-shaped' curve or mid elevation bulge or peak (Rahbek, 1995, 1997; Heaney, 2001; Md. Nor 2001; Rickart, 2001, Sanchez-Cordero, 2001) increase in number with elevation (Sanders *et al.*, 2003; Naniwadekar and Vasudevan, 2007) and 'U' shaped pattern or mid-elevation depression (Raman *et al.*, 2005) in species richness have been reported. Understanding the distribution of species along elevation gradient and factors governing the same would help in conserving biodiversity (Vetaas and Grytnes, 2002). Information on species distribution is also critical to prioritize areas for conservation planning (Hunter and Yonzon, 1993).

Herpetofauna (amphibians and reptiles) have relatively been uncommon subjects of study compared to birds and mammals (Vitt, 1987). Among the world's vertebrates the highest proportion of amphibians are on the verge of extinction (Stuart *et al.*, 2004). Amphibians often contribute an important proportion of the vertebrate biomass in forest and wetland ecosystems, and are important predator and prey species as well (Burton and Likens, 1975; Gibbons *et al.*, 2006). Conservation of a taxa (species) requires a clear understanding on its habitat association (Suzuki *et al.*, 2008), especially the microhabitat requirements and partitioning among species (Doan, 2004). It is important to know the habitat changes and related impact on distribution and abundance of species for planning biodiversity conservation (Patrick *et al.*, 2006).

Data on species richness of an area is important for prioritising areas for conservation (Myres *et al.*, 2000). Attention to study the population attributes of amphibians is scanty compared to mammals and birds (Begon *et al.*, 1990; Odum, 1996; Buckley and Jetz, 2007). Information on the drivers of amphibian distribution and diversity even at broad level is lacking (Buckley and Jetz, 2007).

Amphibians are declining globally more rapidly than birds and other taxa (Stuart, *et al.*, 2004; Beebee and Griffith, 2005, Schiesari *et al.*, 2007). According to Stuart *et al.* (2004) the group of amphibian has the highest proportion of species threatened with extinction. The reported amphibian decline is not due to single factor (Halliday, 1998; Davidson *et al.*, 2001; Storfer, 2003; Collins and Storfer, 2003). Habitat loss and fragmentation (Daniels, 1991, 2003; Brooks *et al.*, 2002; Cushman, 2006), UV-B radiation (Blaustein *et al.*, 1998; Blaustein *et al.*, 2003), toxic chemicals (Blaustein *et al.*, 2003), chytrid fungus (Puschendorf *et al.*, 2006), climate change (Carey and Alexander, 2003), alien predators (Kats and Ferrer.2003) and infectious disease (Daszak *et al.*, 2003) are a few reasons to mention.

The Western Ghats, is one the 34 biodiversity hotspots of the world (Mittermeier *et al.*, 2005). About 311 species of amphibians have been described so far from India, including 157 species (136 endemics) from Western Ghats (Dinesh *et al.*, 2010). In recent years, many new amphibian species are being reported from Western Ghats (e.g. Dutta and Ray, 2000; Biju and Bossyut, 2003; Gururaja *et al.*, 2007; Dinesh *et al.*, 2008; Biju *et al.*, 2009; Joshy *et al.*, 2009).

Of the four phyto-geographical regions of the Western Ghats, Megamalai comes under Anaimalai Palani-Cardamom Hills (Subramanyam and Nayer, 1974). Megamalai landscape harbours broad elevation range with various vegetation types, which are ideal for studying distribution pattern of amphibians. The present study was carried out with following major objectives.

1.2. OBJECTIVES

1. Study aspects of population of amphibians such as richness, diversity and abundance.
2. Determine the distribution pattern of amphibians with respect to elevation and factors governing the same.
3. Study the amphibian composition in various vegetation types of the Megamalai, and
4. Suggest options for the conservation of amphibians in Western Ghats, especially Megamalai landscape.

1.3. STUDIES IN INDIA

Available information on the amphibians of India is largely based on surveys and is mainly concerning with taxonomy and distribution. The compilation by Boulenger (1890, 1920) provides salient key characters of amphibians of the Indian Subcontinent. However, even now our understanding on the taxonomy of Indian amphibians remains incomplete (Bossyut, 2002; Biju and Bossyut, 2005a). Daniel (1963a, b, 1975) and Daniel and Sekar (1989) provided field guides to the amphibians of western India covering all taxa of amphibians. Checklist and bibliography of amphibians of India is available in Dutta (1997). Information on the key characters for identification and distribution of Indian amphibians are presented in Chanda (2002) and Daniel (2002). A compilation on the natural history of amphibians based on anecdotal records and field observations are available in Daniels (2005). Ecological studies on the amphibians in India are far behind compared to other vertebrate groups (Gupta, 1998).

The Western Ghats is considered as an important amphibian hotspot, both in terms of species richness and endemism (Daniels, 1992a; Dutta, 1997; Inger, 1999; Biju, 2001; Krishnamurthy *et al.*, 2001; Biju and Bossyut, 2003), but data on their distribution pattern is scanty (Inger *et al.*, 1987; Bossyut, 2002).

A few important studies dealing with aspects of ecology of Indian amphibians are given below. Inger *et al.* (1987) studied the herpetofaunal assemblage in Ponmudi Hills, Western Ghats and described the habitat use and species assemblage including niche breadth and overlap. Dash and Mahanta (1993) provided data on the community structure of tropical amphibians of the Sambalpur district of Orissa using dominance, diversity, evenness indices, and niche and association analysis. Brown (1992) studied microhabitat relations of amphibians in South India and reported niche breadth and overlap for selected species. Vasudevan *et al.* (2001) studied amphibian communities in Kalakad-Mundanthurai Tiger Reserve and reported *Sylvirana temporalis* as predominant species there. Krishnamurthy (2003) found higher number of species in undisturbed forests in Kudremukh National Park, Western Ghats. Vijayakumar *et al.* (2006) studied herpetofaunal assemblage in Kalakad-Mundanthurai Tiger Reserve especially in the drier areas and found *Fejervarya limnocharis* as dominant one.

Vasudevan *et al.* (2006) described the species turnover of stream amphibians in two hill ranges of Western Ghats and found significant difference in their composition at both species and family level. Naniwadekar and Vasudevan (2007) studied the distribution pattern of amphibians along the elevational gradients of Kalakad-Mundanthurai Tiger Reserve, Western Ghats. A description on the diversity of anurans inhabiting rain forests of Kalakad-Mundanthurai Tiger Reserve of Western Ghats is presented in Vasudevan *et al.* (2008).

Globally, amphibian species discovery exceeds compared to other vertebrate groups (Glaw and Kohler, 1998). New species description of amphibians in India has increased markedly in recent years. Number of amphibian species known was 181 during 1986 (Inger and Dutta, 1986), 197 in 1992 (Dutta, 1992), 212 in 1997 (Dutta, 1997), 228 in 2001 (Daniels, 2001), 238 in 2005 (Daniels, 2005), 265 in 2006 (Das and Dutta, 2006), 284 in 2009 (Dinesh *et al.*, 2009) and 311 in 2010 (Dinesh *et al.*, 2010).

As many as 51 new species of amphibians have been described from Western Ghats from 2000 to 2010. Amphibian surveys in Western Ghats showed the presence of hundreds of species to be described (Biju, 2001; Gower *et al.*, 2004; Aravind *et al.*, 2004; 2007). New species reported in recent years include one species of Bufonidae (Biju *et al.*, 2009), seven species of Dicroglossidae (Dubois *et al.*, 2001; Kuramoto *et* *al*., 2007; Joshy *et al*., 2009), one species of Microhylidae (Dutta and Ray, 2000), five species of Nyctibatrachidae (Das and Kunte, 2005; Biju *et al*., 2007; Radhakrishnan *et al*., 2007; Dinesh *et al*., 2007, 2008), 26 species of Rhacophoridae (Vasudevan and Dutta, 2000; Bossyut, 2002; Kuramoto and Joshy, 2003; Biju and Bossyut, 2005a,b,c, 2006, 2009; Das and Dutta, 2006; Gururaja *et al*., 2007; Biju *et al*., 2008a, 2010; Joshy *et al*., 2009), one species of Sooglossidae (Biju and Bossyut, 2003), seven species of Caecilidae (Giri *et al*., 2003, 2004; Ravichandran *et al*., 2003; Bhatta and Prashanth, 2004; Bhatta and Srinivasa, 2004; Bhatta *et al*., 2007a,b), one species of Ichthyophidae (Wilkinson *et al*., 2007) and two species of Uraeotyphlidae (Gower and Wilkinson, 2007; Gower *et al*., 2008).

Studies on the distribution pattern along the elevation in India received only little attention. Raman *et al*. (2005) documented U-shaped pattern in distribution of birds in Kalakad-Mundanthuri Tiger Reserve, Western Ghats. However, the validity of this pattern needs further investigation. Daniels (1992b) reported low-medium hills are more diverse in amphibian species richness. Naniwadekar and Vasudevan (2007) studied anuran distribution along the elevation gradient of Western Ghats and reported the higher concentration of species at higher elevations. Distribution of plants along the Himalayas was reported by Oommen and Shankar (2005) and Behera and Kushwaha (2007). Chettri *et al*. (2010) studied distribution of reptiles in Teesta Valley, Eastern Himalayas and found decline in species richness with elevation.

Despite the rich diversity of amphibians in India, the data on amphibians is scanty. Relatively few studies are available concerning their ecological perspective. The present study describes the distribution pattern of amphibians along the elevation gradient and vegetation types of Megamalai landscape, Western Ghats.

1.4. ORGANIZATION OF THESIS

Chapter 1 provides the general introduction to the subject with objectives and reviews pertinent literature available on the subject.

Chapter 2 describes the environs of study area, the Megamalai landscape, Western Ghats.

Chapter 3 discusses aspects of population of amphibians in Megamalai.

Chapter 4 deals with distribution pattern of amphibians along the elevation gradient. Chapter 5 describes amphibian composition in various habitats.

Chapter 6 provides the distribution pattern of select species of amphibians, and

Chapter 7 discusses aspects related to the conservation of amphibians in the Western Ghats especially in the Megamalai landscape. The last two sections provide list of literatures cited in the dissertation and supportive data in the form of appendices.

2. STUDY AREA

The present study was conducted in Megamalai landscape, Tamil Nadu, Southern Western Ghats.

2.1. WESTERN GHATS

The Western Ghats, also known as Sahyadri Hills are a chain of mountains running parallel to the West Coast. These hills extended from river Tapti in Gujarat to Kanyakumari in Tamil Nadu, the southernmost tip of Peninsular India. This mountain range constitutes only 5% of the total land area of India, but harbors about 30% of India's biological diversity (Rodgers and Panwar, 1988). It is one of the 34 biodiversity hotspots of the World (Mittermeier *et al.*, 2005). About one-third of its area is still covered by natural vegetation, including about 20,000 sq.km of rain forests (Collins, 1990). This hill range (1600 km) starting from 8 °20'N has only one major discontinuity, the Palghat Gap. There are nine National Parks and 45 Wildlife Sanctuaries in the Western Ghats (Kothari *et al.*, 1989; Biju *et al.*, 2008b), covering a total area of 16,935 sq.km or 11% (Collins, 1990). Phytogeographicaly the Western Ghats can be divided into four regions; (1) River Tapti to Goa (2) River Kalinadi to Coorg (3) Nilgris and (4) Anamalai, Palani and Cardamom Hills (Subramanyam and Nayer, 1974). The Anamudi (2695 m) in Kerala, Doddabetta (2637m) in Tamil Nadu and Kudremukha (2071m) in Karnataka are three top peaks found in the Western Ghats.

Annual rainfall of the Western Ghats may vary from 2350 to 7450 mm along the north-south gradient and the rainfall is largely from the southwest monsoon (June - August). Unique geographic position and distinct physiographic, edaphic and climatic gradients make the Western Ghats suitable for a wide array of habitats that support unique sets of plant and animal species (Biju, 2001). Several forest operations such as Coffee, Tea and Cardamom have been started during the 19th century resulting in clearing of Semi Evergreen and Evergreen forests (Fischer, 1921).

2.2. THENI FORESTS

The Theni Forest Division (9° 31' - 10°15'N, 77 °10' - 77°42'E) comprises the forests of Periyakulam, Uthamapalayam, Bodinaickanur, Theni and Andipatti taluks. The division includes eight forest ranges namely Varusanadu, Megamalai, Chinnamanur, Theni, Bodi, Uthamapalayam, Cumbam and Gudalur (Figure 2.1 & 2.2). The division is bounded by Kodaikonal Forest Division (Palani Hills) in the North, Kerala state and the Grizzled Squirrel Wildlife Sanctuary in the South, Madurai Forest Division in the East and the Kerala state in the West and South West (Figure 2.3). The total area of this division is 863.85 sq.km consisting of 315.91 sq.km of Reserved Forests and 547.94 sq.km of Reserved Lands (Forest Working Plan, 2005). Rivers and drainages of this landscape are Vaigai and Vaipaar, which feed the dry eastern plains of the south Tamil Nadu. However, the general area is steep and has undulating mountainous terrain and many parts of the forest are uninhabited by human.

The elevation of the general area ranges from 220 to 2500 m (Figure 2.2). This region has a wide range of forests/vegetation types; Montane Shola and Grassland, Wet Evergreen, Moist Deciduous, Riverine and Dry Deciduous vegetation.

2.2.1. History

The Theni forest area has a very fascinating and long history. The region was under different dynasties during different historical periods. The tract, in which the forests of this division lie, is the heart of legendary and famous Pandya kingdom.

The forest of this area was controlled by British from 1801 and maintained only to realize the revenue from the leases of forest produce till 1854. No attempt was made to conserve the forests during this period.

In 1856, a beginning was made in the forest conservancy by prohibiting the shifting cultivation for growing plantations. In 1857, Colonel Beddome reported on the rapid denudation of the forest. In 1871, a small forest establishment consisting of two ranges one at Madurai another at Periakulam were sanctioned. In 1880, a committee was formed for the reservation of 21 Forest blocks measuring about 738.15 sq.km. With the enactment of Madras Forest Act 1882, forest conservancy got a momentum and from 1882 to 1890, most of the forests in the district was demarcated, and notified as 'Reserve Forests'.

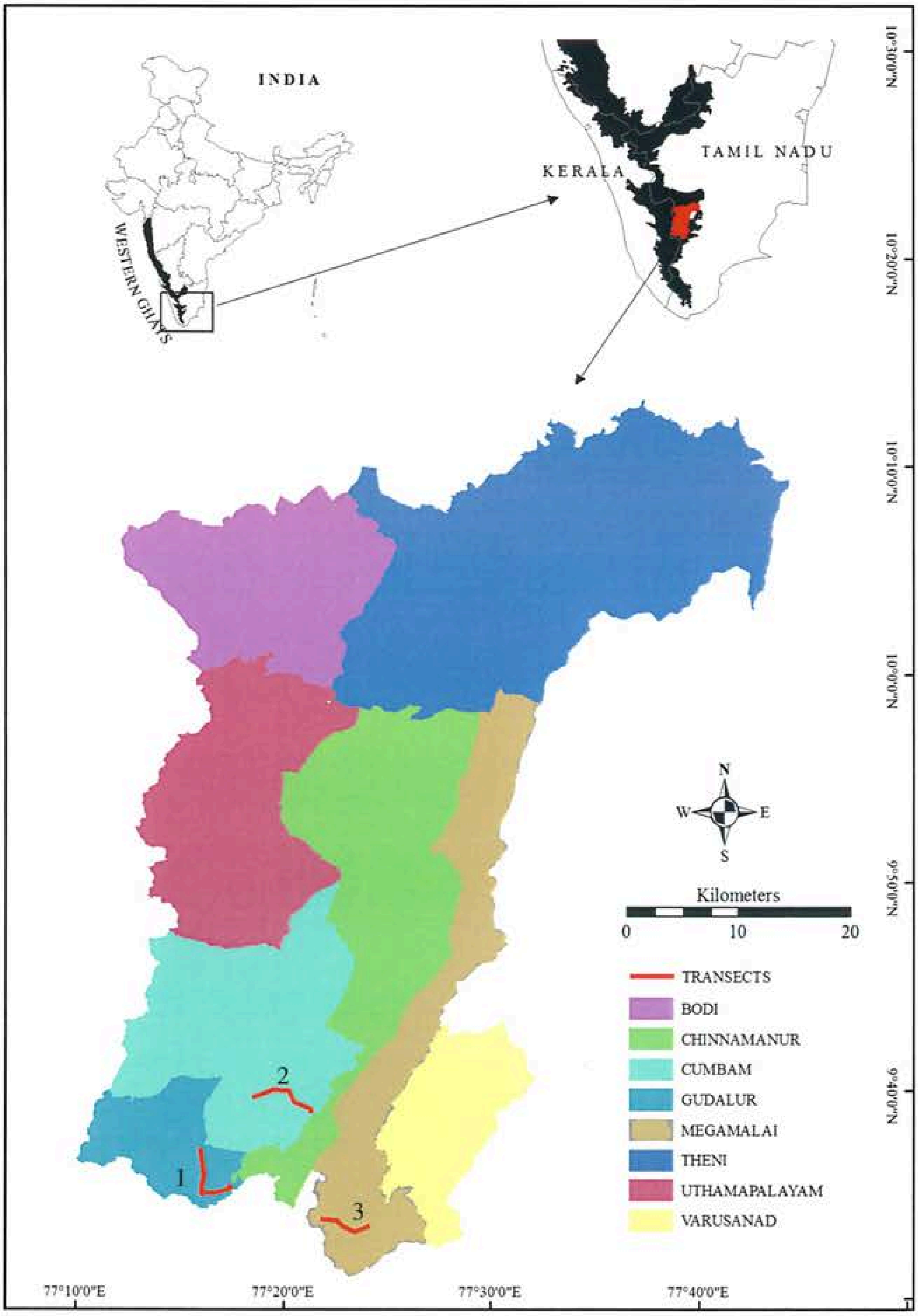


Figure 2.1. Map of the Theni Forest Division showing various Forest Ranges and transect used for sampling. The transects are 1= Mavadi; 2=Suruli; 3= Vellimalai.

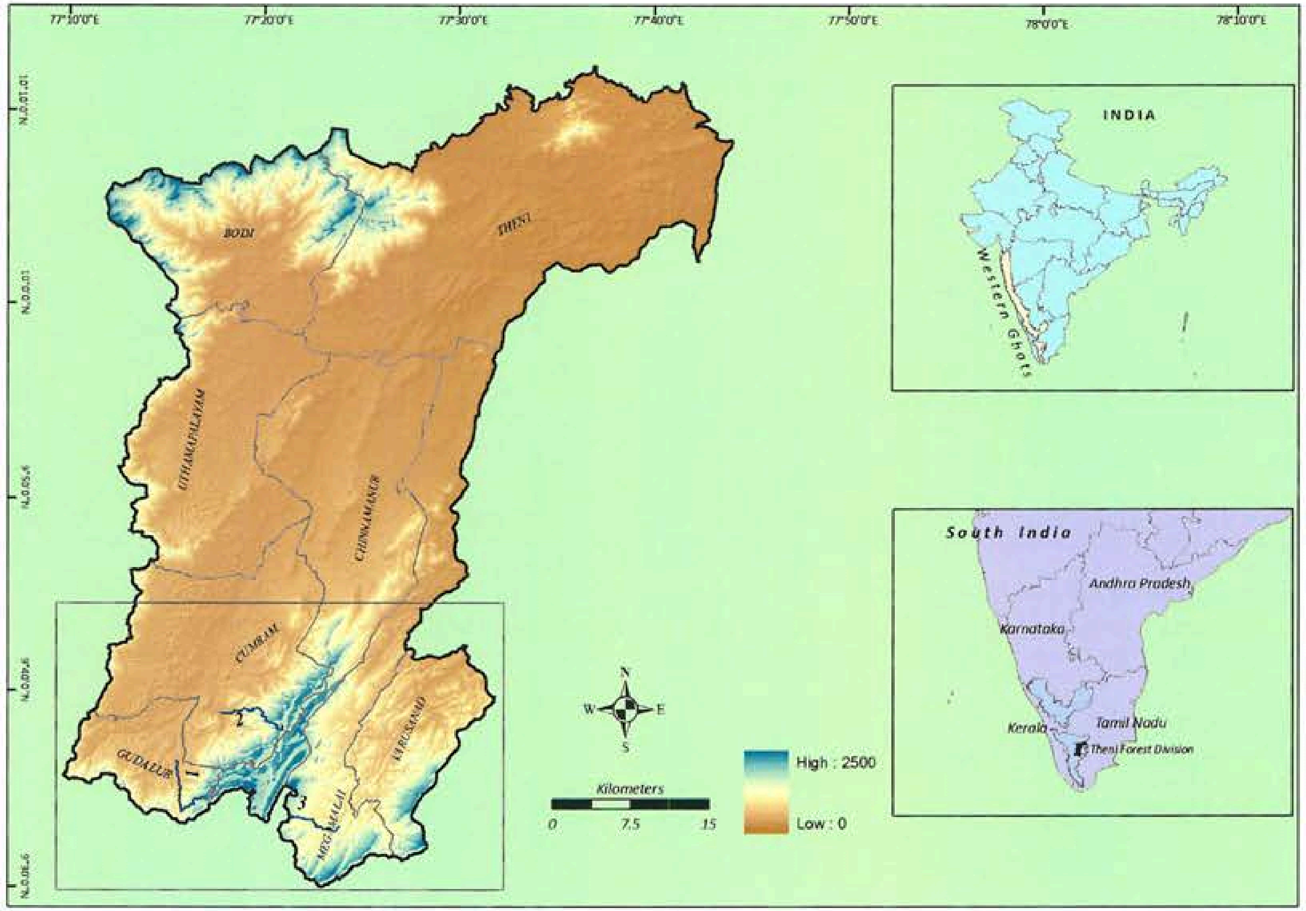


Figure 2.2. Digital elevation model of the Theni Forest Division showing the intensive study area, which is given in the box. The transects are 1= Mavadi; 2=Suruli; 3= Vellimalai.

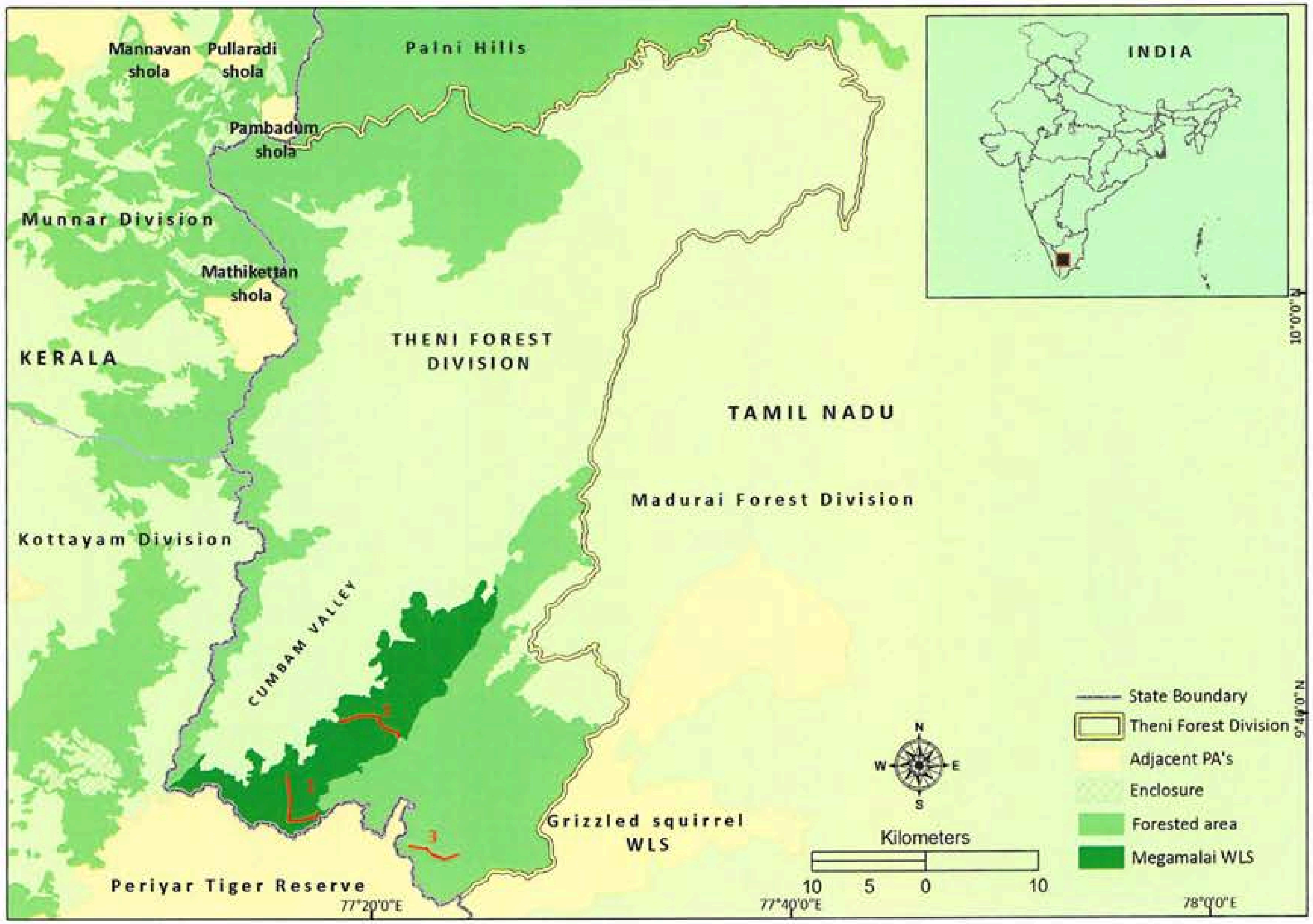


Figure 2.3. Map of the Theni Forest Division and its adjoining areas. The transects are 1= Mavadi; 2=Suruli; 3= Vellimalai.

In 1888, these forests were divided into five ranges *viz.*, Kanavaipatti, Sholavandan, Palamedu, Palani and Cumbam. Up to April 1950, the Madurai division was included as part of Tiruchirapalli district south of Cauvery. Until October 1861, all the forest with in Madurai Revenue District formed one composite division known as the Madurai Forest Division, which was bifurcated into Madurai West and Madurai East during October 1951. Madurai East division included Sivaganga and Ramnad. Again these two forest divisions were reconstituted into the Madurai North and Madurai South Divisions during 1957 and thus the Madurai South Division was formed. In 1982, the present Theni Forest Division was formed after bifurcating the Madurai Division and by adding Bodi Range from Dindigul Forest Division. Currently, a part of the area is declared as Wildlife Sanctuary by Government Order 63 dated 26th June 2009.

2.3. MEGAMALAI

Megamalai Hills are bordered by Periyar Tiger Reserve in the south west, north by Uthamapalayam and part of Chinnamanur and Megamalai Forest ranges. South eastern side is surrounded by Grizzled Squirrel Wildlife Sanctuary (Figure 2.2 & 2.3).

The Highwavy mountains are also known as the Megamalai Hills, (In Tamil: *Megha* = cloud, *Malai* = hill). The Highwavy mountains are also known as Patchakumachi, (In Tamil: *Patcha* = green, *Kumachi* = jungle). The name "Highwavy Mountains" was applied by the earlier explorers who just noted the appearance from the Cumbam Valley. The elevated plateau constitutes a spur from the Cardamom Hills oriented southwest-northwest on the south-western edge of Varusanad Hills. Megamalai Hill constitutes the western edge of the Varusanad Hills along the deep Cumbam Valley. The present study area (Megamalai) has undulating terrain and most of the area is steep.

2.3.1. Climate

The bioclimatic variables extracted from the Global Climate data (www.worldclim.org) showed variation in temperature and rainfall along the elevation. Annual mean temperature was maximum (24.10° C) in lower elevation (500 m and Dry Deciduous forest) and minimum (18° C) at higher elevation (1700 m Shola and Grassland - Appendix 1 & 2). Monthly variation of temperature showed gradual increase from January to May and decreased from July to December (Figure 2.4).

Mean maximum temperature was highest (30.6° C) during February at low elevation and during April and May was lowest (24° C) at high elevation. Minimum temperature reached highest during May at both high elevation (21.8° C) and low elevation (16.1° C). Annual precipitation was higher (2161 mm) at higher elevation (1700 m) and low (1550 mm) in the lower elevation (500 m, Appendix 2). Annual rainfall data showed minimum rainfall was recorded during January both in high elevation and low elevation. Maximum rainfall was observed during July at low and high elevations (Figure 2.5).

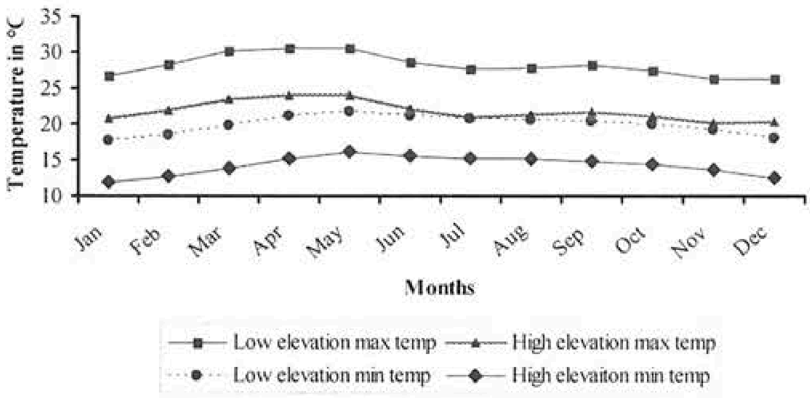


Figure 2.4. Mean monthly temperature of lower and higher elevation of Megamalai landscape based on global climate data (www.worldclim.org). Each point is a mean of 50 years data.

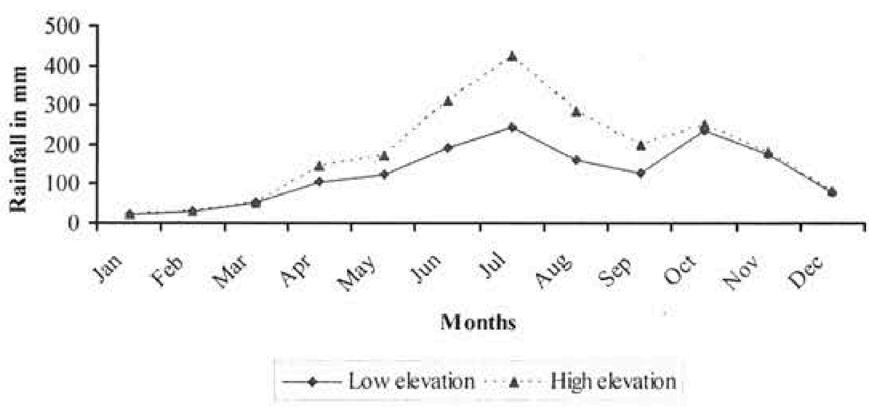


Figure 2.5. Monthly mean rainfall pattern in lower and higher elevation of Megamalai landscape based on global climate data (www.worldclim.org). Each point is a mean of 50 years data.

2.3.2. Vegetation

A total of 157 tree species with endemics (27.39%) were along the transects recorded during the present study (Figure 2.6).

Dry Deciduous

Most of the lower elevation of the area is covered by Dry Deciduous. This vegetation type was found between 400 and 1200 m. *Pterocarpus marsupium, Anogeissus latifolia, Bridelia crenulata, Randia brandisii, Wrightia tinctoria, Grewia tiliifolia, Premna tomentosa, Strychnus potatorum, Morinda tinctoria, Streblus asper, Atlantia monophylla* and *Chloroxylon swietenia* are a few common species recorded from Dry Deciduous vegetation.

Moist Deciduous

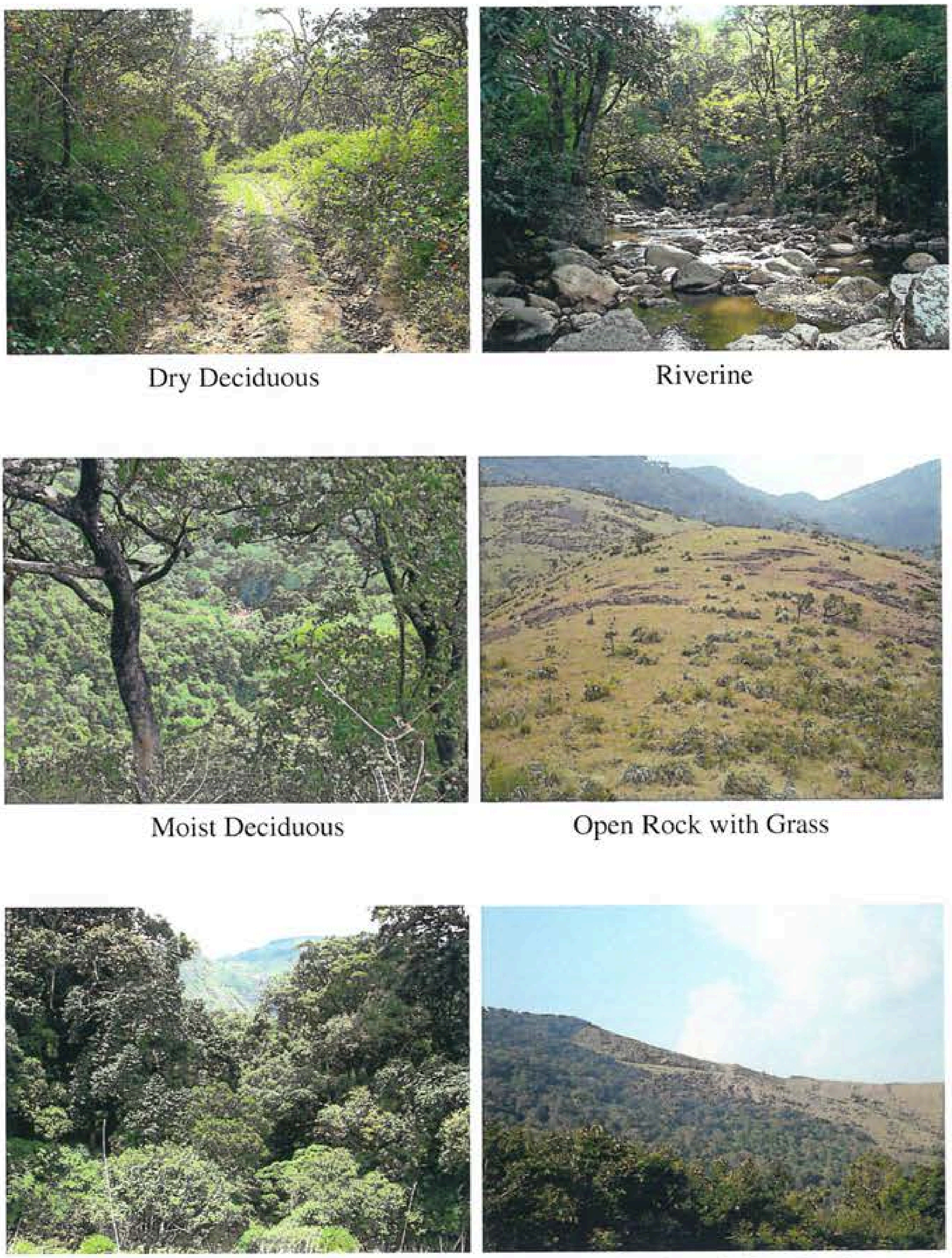
Moist Deciduous vegetations have patchy distribution in Megamalai area. This vegetation type was found between 600 and 1200 m elevation. Important tree species of this vegetation are *Erythrina stricta, Celtis wightii, Actinodaphne malabarica, Bischofia javanica, Celtis timorensis, Schleichera oleosa, Vernonia monosis, Mallotus philippensis, Oleo dioicea* and *Maesa perrottiana.*

Riverine

Riverine vegetations are found near rivers and streams. In Megamalai, this vegetation type was found from 600 to 1000 m elevation. *Vitex altissima, Syzygium zeylanica, Eugenia bracteata, Zyzygium zeylanicum, Ficus racemosa, Ficus microcarpa, Maesua ferrea, Sterosperum personatum, Albizia odoratissima, Filicium decipens, Syzygium cumini, Pongamia pinnata* and *Trichilia connaroides* are few tree species observed in the Riverine vegetation type.

Rocky slopes with Grass

Most of the middle and high elevations (1000-1600 m) of the study area have open rocky slopes with grass. These areas are covered by species such as *Tripogon bromoides, Fimbristylis spp. Chrysopogon asper, Heteropogon contortus, Themeda triandra, Themeda cymbaria, Cymbopogon flexrosus, Cymbopogon citratus* and *Zenkaria elegans.* Trees were not found in this habitat.



Dry Deciduous — Riverine

Moist Deciduous — Open Rock with Grass

Evergreen — Shola and Grassland

Figure 2.6. Study area showing various vegetation types.

Evergreen

The Evergreen vegetation is restricted between 1200 m and 1800 m elevation in Megamalai area. The important tree species are *Myristica dactyloides, Hydrocarpus pentandra, Actinodaphae malabarica, Phobe lanceolata, Nothopegia beddomei, Vernonia monosis, Acronychia pedunculata, Elaeocarpus tectorius, Mallotus albus,* and *Cinnamomum malabathrum.*

Shola and Grassland

Shola and Grassland is a characteristic association of stunted evergreen vegetation in the valleys and extensive grassland on the hill slope (Narendran *et al.*, 2001; Sukumar *et al.*, 1992). Shola vegetations are restricted to higher elevation (1400-1800 m). The area is covered by stunted growth evergreen and rolling grasslands. *Cinnamomum sulpharatum, Syzygium bentathamianum, Syzygium wightianum, Bhesa indica, Crytocarpa lawsonii, Turpinia nepalensis, Litsea tomentosa, Actinodaphne bournei, Isonandra perrottetiana, llex denticulate, Elaeocarpus munroni, Aglaia bourdillonii, Michelia nilagirica* and *Symplocus macrocarpa* are the important plant species found in this vegetation.

2.3.3. Wildlife

The Megamalai landscape is rich in biodiversity and exhaustive studies on them are scanty. During the present study, apart from collecting data on amphibians, inventory on other taxa such as mammals, birds, reptiles, fishes, butterflies and trees were made. Checklists include species found during this study and those given in literatures. A total of 106 species of butterflies, 18 species of fishes, 34 species of amphibians, 87 species of reptiles, 211 species of birds and 62 species of mammals were recorded. This includes several endemic species to the Western Ghats (Table 2.1).

Table 2.1 Species richness of different wildlife taxa in Megamalai landscape, Western Ghats.

Taxon	Species richness	Endemic	References
Butterfly	106	8	Bhupathy *et al.*, 2009
Fish	18	10	Silas, 1951; Pramod *et al.* 1999; Arunachalam *et al.* 2004
Amphibian	34	21	Bhupathy *et al.*, 2009
Reptile	87	27	Bhupathy *et al.*, 2009; Hutton, 1949a
Bird	211	11	Bhupathy *et al.*, 2009; Nichols 1944a,b; 1945; Pramod *et al.* 1999
Mammal	62	14	Bhupathy *et al.*, 2009; Hutton, 1949b

2.3.4. Earlier studies in the Megamalai landscape

Reports available on the Megamalai are based on short surveys. Palanivelu *et al.* (1998) studied the geology and geomorphology of Cumbam Valley and Varusanadu Hills using remote sensing and GIS techniques. Murugan *et al.* (2009) studied the rainfall changes in the mountain region and found reduction in summer monsoon in Venniyar and increase in rainfall during winter in Highwavy mountains.

Several short surveys are available on the flora and fauna prior to independence of India. Blatter and Hallberg (1917) published preliminary notes on botanical tour in Highwavy mountains. A description on the moss flora of Highwavy mountains is available in Blatter (1929). A new grass variety *Dimeria balakrishnaniana* was discovered by Ravikumar *et al.* (1990). Ravikumar (1999) reported seven new flora from Highwavy mountains.

Boulenger (1891a,b) described *Lygosoma subcaeruleum* and *Ixalus* (=*Philautus*) *travancoricus* from this forest division (Bodi). Hutton (1949 a) described the snake fauna of the area including a new species of snake *Trimeresurus* (=*Tropidolameous*) *huttoni.* Smith, (1949a,b) also provided information on *Trimeresurus* (=*Tropidolameous*) *huttoni,* and Blue-bellied Skink *Dasia subcaeruleum.* Hutton and David (2008) reported 39 snakes. Recently, Bhupathy *et al.* (2009) reported 72 reptiles from this hill range. Srinivas *et al.* (2008) recorded *Salea anamallayana* from Highwavy mountain. Srinivas and Bhupathy (2009) provided some information on the spatial use of *Sylvirana temporalis* and Sathishkumar and Bhupathy (2009) described the distribution of agamid lizards from this hill range. A study on the herpetofaunal mortality in the region is also available (Bhupathy *et al.*, 2011).

Biddulph (1956) reported the Red-faced Malkoha, *Phoenicophaeus pyrrhocephalus* in this mountain range. However, Hoffmann (1996) argued that the bird is endemic to Sri Lanka. Subramanian *et al.* (2006) studied the microhabitat use by Grey Jungle fowl (*Gallus sonneratii*) in Theni forests division. Anthropogenic pressure on the Grey Jungle fowl (*Gallus sonneratii*) habitats in Gudalur range in the same mountain was provided by Ramesh and Sathyanarayana (2009).

Wronghton (1921) reported mammals from the collection made by Prater during 1917 from the foothill of Highwavy mountain *viz.*, Cumbam. Hutton (1949 b) reported mammals of Highwavy mountains. Thonglongya (1972) described a new genus and new species, Sálim Ali Fruit Bat, *Latidens salimali* from the collections of Hutton's made during 1948. Muni (1994) rediscovered this species after 45 years. Singaravelan and Marimuthu (2003a, b) reported capture of bats and also reported a day roost for the species. Kumara *et al.* (2009, 2011) provided updated information on the population of primates. Pramod *et al.* (1999) have conducted a biodiversity assessment in this region.

2.3.5. Transects

Three transects namely Mavadi, Suruli and Vellimalai were laid from bottom to hilltop during the study and the same were monitored during this study.

Mavadi

Mavadi transect had elevational range from 400 to 1600 m. It had four vegetation types namely Dry Deciduous, Moist Deciduous, Rocky slopes with Grass and Evergreen. The length of this transect is 8.0 km (Figure 2.1, 2.2 & 2.3; Transect 1).

Suruli

Elevational range of this transect was 400 - 1600 m and it was 6.86 km. Dry Deciduous, Rocky slopes with Grass, Evergreen and Shola and Grassland are the vegetation types in this transect (Figure 2.1, 2.2 & 2.3; Transect 2).

Vellimalai

The length of this transect was 6.31 km. This transects has 600 to 1800 m elevation. Riverine, Dry Deciduous, Rocky slopes with Grass, Evergreen and Shola and Grassland are the different vegetation types available in this transect (Figure 2.1, 2.2 & 2.3; Transect 3).

3. POPULATION ECOLOGY

3.1. INTRODUCTION

Population ecology deals with group or groups of taxonomically or functionally related organisms (Rockwood, 2006). Population is defined as a group of individuals of the same species, which live together in one geographical area at the same time (Begon *et al.*, 1990; Odum, 1996). It is considered as a small unit of evolution (Yoblokov, 1986). Important aspects of population are natality, mortality, relative abundance, density, sex ratio and size structure.

Species richness (number of species) is the simplest expression of diversity of a given area (Magurran, 1988). Species richness of an area is determined by physical (geographic location, productivity and climate) and biological (predation and competition) factors. The counts of species are adequate for studying some pattern of species diversity and provide information regarding changes in the environment (MacArthur, 1965). Species richness is a fundamental measurement of community and regional diversity (Gotelli and Colwell, 2001). Estimation of species richness of a habitat/area is important to propose strategies for biodiversity conservation (Raxworthy and Nussbaum, 1994; Southwood and Henderson, 2000). However, accurate measure of species richness especially for 'hyperdiverse' terrestrial groups in tropics is seldom possible (Colwell and Coddington, 1994). Hence, samples can be taken as representative and various estimators could be used to assess total number of species present in the area. Non-parametric estimators such as Chao and Jackknife are useful to figure out completeness of the sampling.

Diversity refers to the combination number of species (richness) and abundance. The different diversity indices (e.g. Shannon-Weiner, Hills, and Simpson) are used to compare diversity in various ecosystems. Such measures are expected to provide several potential applications as tools for forest management and planning in general (Lexerød and Eid, 2006).

In view of amphibian global population decline, factors that influence their densities at the landscape level and at the regional level are important for planning conservation

(Vasudevan *et al.*, 2008). Studies on the herpetofauna are urgently needed, as our knowledge of vertebrate population ecology is largely based on fish, birds and mammals (Turner, 1960). According to Vasudevan *et al.* (2008) mechanisms which govern amphibian species richness at the landscape level are not well documented. Prior to 1980 amphibian studies in India were largely based on anecdotal observations and collections.

Aspects of ecology of the amphibians of India are to be studied in detail (Gupta, 1998; Vasudevan and Dutta, 2000; Vasudevan *et al.*, 2001). It is generally believed that amphibians have numerically decreased in recent years due to deforestation and fragmentation (Daniels, 1991; 1992; 1999; Gupta, 1998; Molur and Walker, 1998). Aspects of population of amphibians are available for Ponmudi Hills (Inger *et al.*, 1987). Structure and composition of amphibian communities in contiguous rainforests of Kalakad-Mundanthurai Tiger Reserve were investigated by Vasudevan *et al.* (2001). Vijayakumar *et al.* (2006) studied herpetofaunal assemblage in dry forests of Kalakad-Mundanthurai Tiger Reserve during dry season. Vasudevan *et al.* (2006) compared species turnover between two hill ranges namely Ashambu and Anamalai Hills. Vasudevan *et al.* (2008) reported the density and diversity of anurans in southern Western Ghats. Krishnamurthy (2003) recorded amphibian assemblages in disturbed and undisturbed areas of Kudremukh National Park.

Megamalai landscape is suitable for different species of amphibians due to its variations in the vegetation. Furthermore, this ecosystem contains various microhabitats such as leaf litter, fallen logs, boulders and rocks, which provide opportunities for different groups of amphibians. Till date no attempt was made to assess the diversity and distribution pattern of amphibians in this ecosystem. This chapter deals with aspects of population ecology such as species richness, diversity, density and relative abundance of the amphibians of Megamalai landscape.

3.2. METHODS

Researchers face considerable sampling challenges while studying amphibians as many of them are small in size, cryptic in colour, highly seasonal in activity and have sparse and patchy distribution.

Heyer *et al.* (1994) have suggested various sampling protocols for inventorying and monitoring amphibians and recommended using a combination of techniques to obtain reasonable idea on the faunal composition as single method may not detect all species as behaviour of them may differ. Complete enumeration of species richness with an extensive study area is however, generally not possible and consequently a number of different methods for estimating total species richness from a sample have been devised (Chiarucci *et al.*, 2003). Pearman *et al.* (1995) reported that suitability of these methods have not been tested and validated in tropics. Doan (2003) stressed on the importance of more than one method for sampling herpetofauna. Noon *et al.*, (2006) compared the efficiency of Adaptive Cluster Sampling and Random Sampling in Kalakad-Mundanthurai Tiger Reserve, Western Ghats. A brief description of advantages, disadvantages and limitations of different methods are discussed in the following section.

3.2.1. Time-constrained Visual Encounter Survey

Time-constrained Visual Encounter Surveys (hereafter referred as VES) involves systematic search of an area or habitat for a prescribed time (Campbell and Christman, 1982). In the present study, VES was used as formalized by Crump and Scott (1994), as intention of this study was to maximize species inventory. Trees (bark, buttress, root and holes), leaf litters, fallen logs, boulders and crevices were examined to locate amphibians. Streams and water bodies were surveyed walking along the waterline and scanned for amphibians. Among the various drawbacks of this method, not all microhabitats or strata of the forest could be sampled with equal success due to variation in visibility, differential habitat and microhabitat use by the species.

3.2.2. Quadrat Survey

This is an area constrained sampling technique, which involves laying out a series of squares (Quadrats) within a habitat and searching for target species. Each Quadrat should be placed randomly to make it an independent sample (Jaeger and Inger, 1994). All possible microhabitats present within the Quadrat should be examined. Species dwelling in forest floor could be detected more effectively by this method, and it looses its effectiveness in habitats having dense ground cover and steep terrain.

This method is ineffective for sampling fossorial and arboreal species. The Quadrat size and the number may vary depending upon the species and area. Schlaepfer and Gavin (2001) used 10X10m Quadrats for surveying lizards and frogs in tropical forest fragments of Fila Cruces, Costa Rica.

3.2.3. Road Cruising

A stretch (6 km) of metal road (NH-49) was monitored fortnightly for amphibian mortality between December 2006 and November 2007. Surveys were conducted in the morning (0600- 0800 hrs) and evening (1600-1800 hrs) hours and all freshly killed amphibians were recorded. The dead animals were removed from the road to avoid double counts in subsequent surveys. Road kill surveys were conducted fortnightly for a period of one year (24 days, 48 times were surveyed).

3.2.4. Night survey and Opportunistic Observations

Night surveys were made opportunistically using search lights. Night surveys were carried out in and around the areas of field camps.

In the present study, Visual Encounter Surveys and Quadrats were used for data quantification. Sampling of amphibians were done in three transects namely, Mavadi, Suruli and Vellimalai (see Chapter 2). On each belt transect, 100 hours (X 3 men) i.e. 300 man-hours of Visual Encounter Survey (VES) and 100 Quadrats (10 X 10m) i.e. 1 ha were sampled during each dry (December to May) and wet (June to November) seasons for two years from December 2006 to November 2008. Apart from these methods, road cruising and night surveys were done in the general environs but away from the transects.

Amphibians were identified following Boulenger (1890), Sathyamurthi (1967), Daniel (1963 a, b, 1975, 2002), Daniel and Sekar (1989), Chanda (2002) and Daniels (2005) also new species descriptions from the recent literatures were used. The finer breakage of amphibian families proposed by Frost *et al.* (2006) was used in the present work and nomenclature (species level) proposed by Das and Dutta (2006) was used.

3.2.5. Data analyses

1. Species accumulation curves were generated to assess the adequacy of sampling using EstimateS (Estimates-version 7.5, Colwell, 2005). The sample order was randomized 100 times to eliminate the arbitrariness resulted due to heterogeneity of empirical samples (Colwell and Coddington, 1994). Sample based rarefaction curve (species accumulation as a function of occurrence, with 95% confidence intervals, Colwell *et al.*, 2004) was computed to evaluate the completeness of sampling.
2. Species richness: Number of species present in the area.
3. Non-parametric estimators such as Chao and Jackknife were used to investigate the species richness of the area.
4. Density: Number of amphibians observed/ total area sampled.
5. Relative abundance of a species (%) = n_i /N X 100 where, n=Number of observations of a species and N= total observations of all species.
6. Diversity indices Shannon-Weiner, Hill's and Simpson's diversity and evenness were calculated.
7. Mann-Whitney U-test was performed to find out the difference between amphibians observed between VES and Quadrat method with respect to number of individuals (abundance) and species.
8. One-way ANOVA was used to know the difference among the transects and seasons, in terms of species richness, family richness and abundance.
9. Chi-square test was performed to find out the distribution pattern of amphibian families.
10. A step wise Discriminant Function Analysis was carried out to investigate the presence and absence of amphibians within the Quadrats. This statistical analysis builds a predictive model of group membership based on observed variables of each Quadrat. Stepwise Discriminant analysis with variables entered in a forward manner using F = 3.84 for entering, and F = 2.71 for removal. Statistical differences were considered significant where P-value <0.05. The variables which were measured as percentage were arc sin transformed to achieve normal distribution.

3.3. RESULTS

3.3.1. Species richness

Including opportunistic records, 34 species of amphibians belonging to eight families and 19 genera were observed during the study. However, no caecilians were observed. Of the 34 species, 21 species (61.76 %) were endemic to Western Ghats (Table 3.1; Figure 3.1). New locality for *Philautus griet* and extension for *Philautus ponmudi* and *Rhacophorus pseudomalabaricus* were reported. *Fejervarya mudduraja* was described in the year 2007 (Kuramoto *et al*., 2007). The identity of this species needs confirmation. Maximum of 11 (32.35%) species were recorded under the family Rhacophoridae followed by Dicroglossidae 6 species (17.65%). Family Micrixalidae represented by single species. Highest richness (26 species) of amphibians was documented during night and opportunistic surveys followed by VES, Quadrat and road kill survey which together had 34 species (Table 3.2).

Three transects namely Mavadi, Suruli and Vellimalai were sampled from December 2006 to November 2008. Seasonal sampling were done *i.e.* dry (December to May) and wet (June to November) seasons. In all, 3600 man-hours of VES and 12 ha of Quadrat sampling yielded a total of 3166 amphibians. Higher number of species and individuals were recorded in VES (2131 individuals of 19 species) compared to Quadrat (335 individuals of 14 species). Six species of amphibians were recorded in only VES and two species in Quadrat method. Even though, the effort was maximum in time constrained method (VES), the two species (*Philautus* sp.1 and *Rhacophorus pleurostictus*) were recorded only in Quadrats. However, the species richness did not vary among the methods (U=168; P>0.05). Of the 1200 Quadrats, only 162 had amphibians. Similarly of the 1200 (X 3 man) hours of VES, 652 (1956 man hours) hours encountered amphibians. The number of amphibians (individuals) recorded by the methods were statistically different (U=88; P<0.01).

Discriminant Function Analysis (DFA) was used to identify the difference between the Quadrat with amphibian and Quadrat without amphibian. The predictor variables included were elevation, vegetation, boulder, rock crevices, fallen log, number of trees, tree holes, termite hill, distance from water, ground cover, canopy cover, litter cover, herb cover and shrub cover. Discriminant Function analysis identified distance from water is the best single predictor followed by elevation and leaf litter (Wilks λ= 0.946; χ= 66.44; P<0.001) which classified 60.0% of the group cases correctly.

Table 3.1. List of amphibians observed in Megamalai landscape during December 2006 to November 2008.

S.No	Family	Common Name	Scientific Name[a]
1	Bufonidae	Ferguson's Toad	*Bufo scaber*
2		Common Indian Toad	*Duttaphrynus melanostictus*
3		Southern Hill Toad	*Duttaphrynus microtympanum*#
4	Dicroglossidae	Water Skipper or Skipper Frog	*Euphlyctis cyanophlyctis*
5		Indian Pond or Green Frog	*Euphlyctis hexadactylus*
6		Cricket Frog	*Fejervarya mudduraja*
7		Indian Bull Frog	*Hoplobatrachus tigerinus*
8		Short-webbed Frog	*Limnonectes brevipalmatus*#
9		Indian Burrowing Frog	*Sphaerotheca breviceps*
10	Microhylidae	Indian Painted Frog	*Kaloula taprobanica*
11		Ornate Narrow-mouthed Frog	*Microhyla ornata*
12		Red Narrow-mouthed Frog	*Microhyla rubra*
13		Jerdon's Narrow-mouthed Frog	*Ramanella montana*#
14		Lesser or Marbled Balloon Frog	*Uperodon systoma*
15	Micrixalidae	Dusky Torrent Frog	*Micrixalus fuscus*#
16	Nyctibatrachidae	Alice's Wrinkled Frog	*Nyctibatrachus aliciae*#
17		Beddome's Dwarf Frog	*Nyctibatrachus beddomii*#
18	Petropedetidae	Beddome's Leaping Frog	*Indirana beddomii*#
19		Thinlegged Leaping Frog	*Indirana leptodactyla*#
20		Small-handed Frog	*Indirana semipalmata*#
21		Leaping Frog	*Indirana* sp1#
22	Ranidae	Bi-coloured Frog	*Clinotarsus curtipes*#
23		Bronzed Frog	*Sylvirana temporalis*
24	Rhacophoridae	Beddome's Bushfrog	*Philautus beddomii*#
25		Griet's Bushfrog	*Philautus griet*#
26		Ponmudi Bushfrog	*Philautus ponmudi*#
27		Wynaad Bushfrog	*Philautus wynaadensis*#
28		Bushfrog	*Philautus* sp1#
29		Bushfrog	*Philautus* sp2#
30		Chunam or Common Tree Frog	*Polypedates maculatus*
31		False Hour-glass Tree Frog	*Polypedates pseudocruciger*#
32		Malabar Flying Frog	*Rhacophorus malabaricus*#
33		Malabar False Flying Frog	*Rhacophorus pseudomalabaricus*#
34		Spotted Green Tree Frog	*Rhacophorus pleurostictus*#

[a] Nomenclature following Das and Dutta (2006) & [#] Endemic to Western Ghats

Duttaphrynus melanostictus

Sphaerotheca breviceps

Kaloula taprobanica

Nyctibatrachus aliciae

Sylvirana temporalis

Rhacophorus pseudomalabaricus

Figure 3.1. Some of the amphibian species observed in Megamalai landscape.

Table 3.2. List of amphibians observed in Megamalai landscape following various methods during December 2006 to November 2008.

S.No	Species	Method used			
		VES	Quadrat	Road kill	Night and Opportunistic observations
1	*Bufo scaber*	0	0	0	1
2	*Duttaphrynus melanostictus*	1	1	1	1
3	*Duttaphrynus microtympanum*	1	1	0	1
4	*Euphlyctis cyanophlyctis*	1	0	0	1
5	*Euphlyctis hexadactylus*	0	0	0	1
6	*Fejervarya mudduraja*	1	1	0	1
7	*Hoplobatrachus tigerinus*	0	0	0	1
8	*Limnonectes brevipalmatus*	1	0	0	1
9	*Sphaerotheca breviceps*	1	1	1	1
10	*Kaloula taprobanica*	0	0	0	1
11	*Microhyla ornata*	0	0	0	1
12	*Microhyla rubra*	0	0	0	1
13	*Ramanella montana*	1	0	0	0
14	*Uperodon systoma*	0	0	0	1
15	*Micrixalus fuscus*	1	1	0	1
16	*Nyctibatrachus beddomii*	1	0	0	0
17	*Nyctibatrachus aliciae*	1	0	0	1
18	*Indirana beddomii*	1	1	0	1
19	*Indirana leptodactyla*	1	1	0	0
20	*Indirana semipalmata*	1	1	1	1
21	*Indirana* sp1	1	0	0	0
22	*Clinotarsus curtipes*	0	0	0	1
23	*Sylvirana temporalis*	1	1	1	1
24	*Philautus beddomii*	1	1	0	1
25	*Philautus griet*	1	1	0	1
26	*Philautus ponmudi*	1	0	0	0
27	*Philautus wynaadensis*	1	1	0	1
28	*Philautus* sp1	0	1	0	0
29	*Philautus* sp2	0	0	0	1
30	*Polypedates maculatus*	0	0	0	1
31	*Polypedates pseudocruciger*	0	0	1	1
32	*Rhacophorus malabaricus*	0	0	1	0
33	*Rhacophorus pseudomalabaricus*	0	0	0	1
34	*Rhacophorus pleurostictus*	0	1	0	0
	Total	19	14	6	26

between observed and estimated species richness was 2 (19-21) species. A total of 14 species were observed in Quadrats sampled. The non-parametric estimators yielded from 14±0.05 to 19.19 ± 0.0 (Table 3.5). However, the variation between number of observed species and estimated species based on Quadrat was relatively high (almost 6 species). The estimated number of species ranged between 14 and 19.99 (Table 3.5; Figure 3.3).

Table 3.5. Observed and incidence based estimates of species richness of amphibians in Megamalai landscape based on Visual Encounter Survey and Quadrat samples.

Estimator	Methods	
	VES Mean (± SD)	Quadrat Mean (± SD)
Chao1	19.5 (± 0)	18.5 (± 0)
Chao2	19.5 (± 0)	18.5 (± 0)
Jackknife1	20 (± 1)	17 (± 1.73)
Jackknife 2	21 (± 0)	19.99 (± 0)
Bootstrap	19.37 (± 0)	15.14 (± 0)
Cole rarefaction	19 (± 0.03)	14 (± 0.05)
No. of species observed	19	14
Sample intensity	1200 (hours X 3 persons)	1200 (Quadrats)

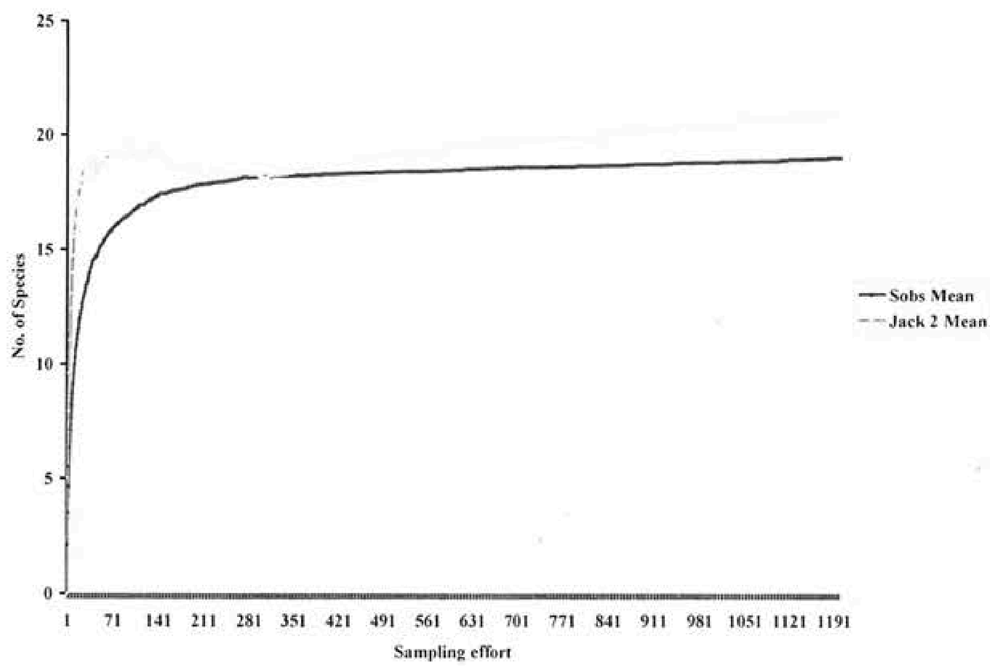


Figure 3.2. Amphibian species accumulation pattern (Jack 2) in Megamalai landscape. Data based on 1200 hours (X 3 persons) of Visual Encounter Survey.

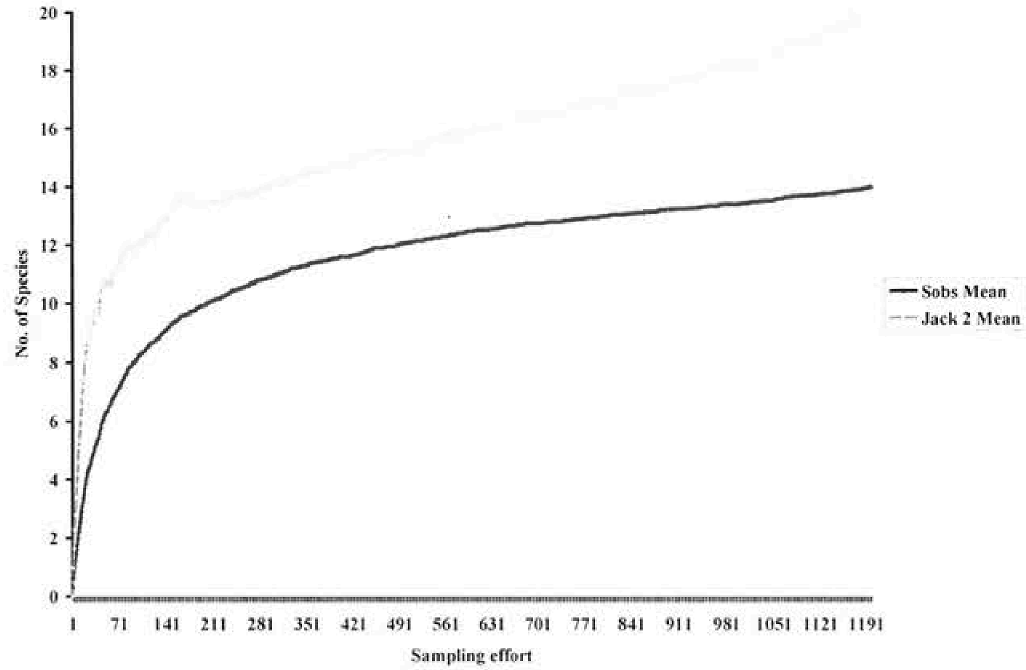


Figure 3.3. Amphibian species accumulation pattern (Jack 2) in Megamalai landscape. Data based on 1200 (10 X 10m) Quadrats.

3.3.4. Relative abundance

Totally, 21 species of amphibian species were observed in VES and Quadrat methods. (Table 3.6). Maximum of 731 (23.09%) individuals of *Indirana beddomii* was observed, which was followed by *Sylvirana temporalis* (20.44%) and *Duttaphrynus melanostictus* (13.61 %). Relative abundance of *Philautus* was low compared to other species (Table 3.6).

Four out of eight families contributed with greater than 10%, with respect to relative abundance. Petropedetidae (38.85%) was the highest recorded family followed by Ranidae (20.44%). Lowest percentage of 0.44% relative abundance was recorded by the family Microhylidae. The distribution of amphibian families was not even (χ^2 = 2888.85; P<0.001).

Table 3.6. Relative abundance of amphibians in Megamalai landscape; Numbers in parentheses are species richness and percentage abundance of those species of respective families; data based on samples.

S.No	Family	Species	Sample size	Relative abundance (%)
1	Bufonidae (2, 14.09%)	*Duttaphrynus melanostictus*	431	13.61
2		*Duttaphrynus microtympanum*	15	0.47
3	Dicroglossidae (4, 13.30%)	*Euphlyctis cyanophlyctis*	63	1.99
4		*Fejervarya mudduraja*	165	5.21
5		*Limnonectes brevipalmatus*	111	3.51
6		*Sphaerothea breviceps*	82	2.59
7	Microhylidae (1, 0.44%)	*Ramanella montana*	14	0.44
8	Micrixalidae (1, 1.96%)	*Micrixalus fuscus*	62	1.96
	Nyctibatrachidae (2, 1.96%)	*Nyctibatrachus aliciae*	49	1.55
9		*Nyctibatrachus beddomii*	13	0.41
11	Petropedetidae (4, 38.85%)	*Indirana beddomii*	731	23.09
12		*Indirana leptodactyla*	162	5.12
13		*Indirana semipalmata*	322	10.17
14		*Indirana* sp1	15	0.47
15	Ranidae (1, 20.44%)	*Silvirana temporalis*	647	20.44
16	Rhacophoridae (6, 8.97%)	*Philautus beddomii*	119	3.76
17		*Philautus griet*	130	4.11
18		*Philautus ponmudi*	1	0.03
19		*Philautus wynaadensis*	32	1.01
20		*Philautus* sp1	1	0.03
21		*Rhacophorus pleurostictus*	1	0.03
		Total	3166	100.00

3.3.5. Density

As mentioned earlier, 1200 (10 x 10m) Quadrats were examined for amphibians. In total, 335 individuals of 14 species were observed in the Quadrats. The overall density was 27.92 amphibians/ha (Table 3.7). Dry season had higher density of amphibians (33.83/ha) compared to wet season (22/ha). Among the transects studied, Suruli had highest density of 36.5/ha followed by Vellimalai (24.25/ha).

Of the eight families observed, two of them (Microhylidae and Nyctibatrachidae) were not sighted in Quadrats. Family level density analysis showed that the maximum density was Petropedetidae (13.25/ha; 3 species, 159 individuals) followed by Bufonidae (5.42/ha; 2 species, 65 individuals), Rhacophoridae (4.83/ha; 5 species, 58 individuals), Ranidae (3.17/ha; 1species, 38 individuals), Dicroglossidae (0.92/ha; 2 species, 11 individuals) and Micrixalidae (0.33/ha; 1 species, 4 individuals) (Figure 3.4). Species level density showed that *Indirana semipalmata* (7.83/ha) as the most abundant species followed by *Duttaphrynus melanostictus* (5.33/ha), *Indirana beddomii* (4.33/ha), *Sylvirana temporalis* (3.17/ha), *Philautus beddomii* (1.75/ha), *Philautus griet* (1.75/ha), *Philautus wynaadensis* (1.17/ha), *Indirana leptodactyla* (1.08/ha) and the remaining species were in very low density (Table 3.7).

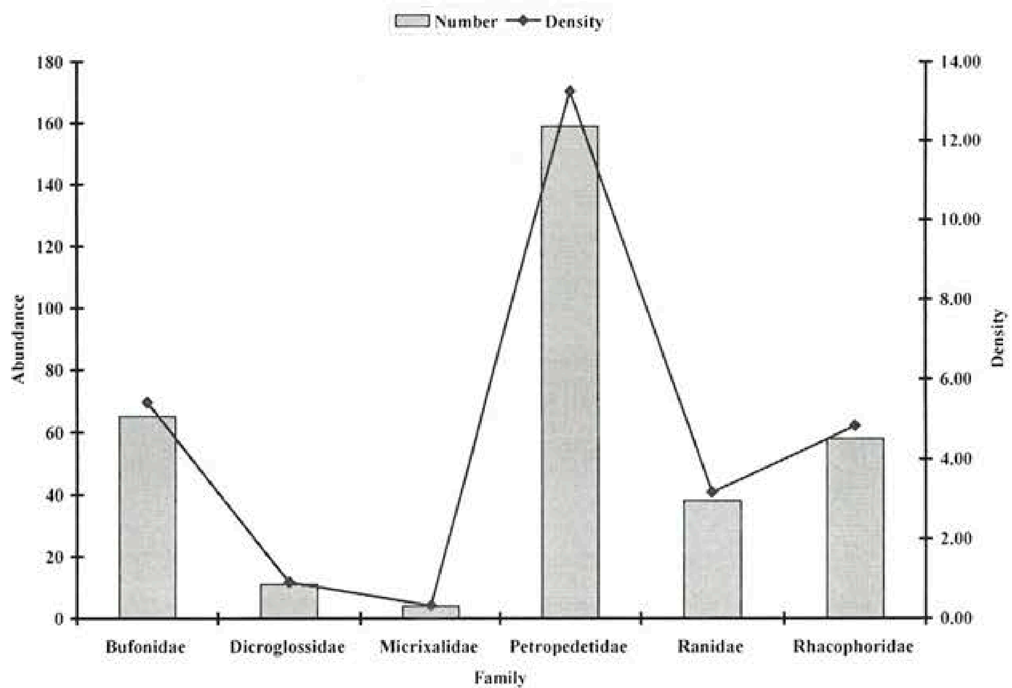


Figure 3.4. Family level abundance and density of amphibians in Megamalai landscape.

Table 3.7. Density of select amphibian species in Megamalai landscape.

S.No.	Species	Number	Density (No./ha)
1	*Duttaphrynus melanostictus*	64	5.33
2	*Duttaphrynus microtympanum*	1	0.08
3	*Fejervarya mudduraja*	4	0.33
4	*Sphaerotheca breviceps*	7	0.58
5	*Micrixalus fuscus*	4	0.33
6	*Indirana beddomii*	52	4.33
7	*Indirana leptodactyla*	13	1.08
8	*Indirana semipalmata*	94	7.83
9	*Sylvirana temporalis*	38	3.17
11	*Philautus beddomii*	21	1.75
12	*Philautus griet*	21	1.75
10	*Philautus wynaadensis*	14	1.17
13	*Philautus* sp1	1	0.08
14	*Rhacophorus pleurostictus*	1	0.08
	Total	335	27.92

3.3.6. Diversity indices

The overall (21 species of 3166 individuals) indices values were higher than that of all the transects. However, Equitability was highest in Suruli with a value of 0.78 (Table 3.8). Among the transects, numbers of species was highest in Mavadi (19) followed by Vellimalai (16) . Highest numbers of individuals were sighted in Vellimalai (1179) followed by Suruli (1155).

Table 3.8. Species richness, abundance and various diversity indices of amphibians in various transects.

Transect	Species richness	No. of individuals	Shannon-Weiner (H')	Hill's ($e^{H'}$)	Simpson's D	Equitability
Mavadi	19	832	2.18	8.83	0.84	0.74
Suruli	15	1155	2.11	8.27	0.83	0.78
Vellimalai	16	1179	1.90	6.66	0.78	0.68
Overall	21	3166	2.31	10.08	0.86	0.76

3.4. DISCUSSION

Thirty four species of amphibians were observed in three belt transects (total area of 21.17 km^2) of Megamalai. Similar to the present study, about 30-50 species of amphibians were reported elsewhere in other hill ranges of Western Ghats (Easa, 1998; Cherian *et al.*, 2000; Johnsingh, 2001; Vasudeven *et al.*, 2001, 2006; Krishnamurthy, 2003; Naniwadekar and Vasudevan, 2007). The sampled area is only a fraction compared to the Western Ghats the total area *i.e.* 1, 60,000 km^2, where a total of 157 species reported so far (Dinesh *et al.*, 2010). No limbless amphibian was recorded during the present study. This could be due to the overall dry nature of the area. Palanivelu *et al.* (1998) reported that the area as rain shadow part. Caecilians were also not observed in nearby hills as well (Ravichandren and Pillai, 1990; Malhotra and Davis, 1991).

Out of 34 species, 21 species (61.76%) were endemic to Western Ghats and the family Rhacophoridae (out of 11 species, 10 species were endemic) contributed the most. The high number of species representation of amphibians is due to sampling in various elevations (400m to 1800m) and vegetation types (Dry Deciduous to Shola and Grassland). According to Dinesh *et al.* (2010), out of 311 species of amphibians in India 136 (43.73%) are endemic to the Western Ghats. Endemism in the Western Ghats is notable (Daniels, 1992a; Inger, 1999; Biju, 2001, Biju and Bossyut, 2003). New locality of *Philautus griet* and range extension of *P. ponmudi* and *Rhacophorus pseudomalabaricus* were recorded during this study. These endemic species were recently described (Vasudevan and Dutta, 2000; Bossyut, 2002 and Biju and Bossyut 2005 c), which adds significance to Megamalai area with respect to conservation. Further, it indicates the possibility of these species having distribution throughout the southern Western Ghats.

Species accumulation pattern indicated the expected number of species from the collection of random samples and represent what was statistically expected from the area (Gotelli and Colwell, 2001). Among the incidence estimators, Jacknife 2 estimated the higher number of species than observed. Two species were more in VES and six species in Quadrat than the observed number of species. These variations in the estimated number of species could be due to behaviour and functions of these estimators such as singletons, doubletons and uniqueness of species. In the present study, the observed and estimated number of species for VES data was not very different, and this indicated the completeness of the sampling. However, the Quadrat data showed higher variation between observed and estimated values indicating incompleteness of sampling. Tropical herpetofaunal communities have a preponderance of rare species (Fauth *et al.*, 1989; Naniwadekar and Vasudevan 2007). Gotelli and Colwell (2001) stated that it is difficult to sample biological communities exhaustively hence estimation of asymptotic 'S' is mandatory.

The data obtained based on time constrained (19 species, 2831 individual) and area constrained (14 species, 335 individuals) methods differed in detecting species and encountering individuals. Doan (2003) reported that the amphibian abundance differed significantly between VES and Quadrat methods. In addition, data from these two methods differed significantly in quality and can be used for estimating species richness and assemblage study and treated independently. Allmon (1991) stated that Quadrat method sampled the entire fauna adequately. Doan (2003) proved that VES method was superior than Quadrat method which is true in the present investigation as well. Various methods were proposed by Heyer *et al.* (1994) were not tested in tropics (Pearman *et al.*, 1995). Doan (2003) explained the importance of more than one method for sampling. Vasudevan *et al.* (2001) used Adaptive Cluster Sampling and Quadrat method for studying the amphibian fauna of Kalakad-Mundanthurai Tiger Reserve, Western Ghats and concluded that the adaptive cluster sampling yielded far superior than random Quadrat method. Doan (2003) also proved more number of amphibians recorded during night time. Consistently, present study also yielded more number of species (26) during night surveys. Variation in the number of species in Quadrat and VES may be due to the behaviour of species and limitations of these methods.

According to Vasudevan *et al.* (2001) amphibians aggregate near water which they assessed from random Quadrat data of Kalakad-Mundanthurai Tiger Reserve, Western Ghats. In addition Vijayakumar *et al.* (2006) investigation using strip transect showed that the distance from water was a major feature that distinguishes amphibian presence and absence. In the present study, it is confirmed distance to water plays a major role from random Quadrats.

Studies in various hill ranges of Western Ghats showed domination (with respect to abundance) of different amphibian species (Vasudevan *et al.*, 2001; 2006; Vijayakumar *et al.*, 2006). This study reports that the *Indirana beddomii* was the most abundant species. *Sylvirana temporalis* was dominant in Kalakad-Mundanthurai Tiger Reserve (Vasudevan *et al.*, 2001, 2006), *Nyctibatrachus pygmaeus* was in Anamalai Hills (Vasudevan *et al.*, 2006) and *Fajervarya limnocharis* was in dry forests of Kalakad-Mundanthurai Tiger Reserve (Vijayakumar *et al.*, 2006). The differences in amphibian abundance could be due to different sampling methods, elevation and vegetation type.

Species richness was higher in Mavadi (n=19) than other two transects. On the other hand, the abundance was higher in Vellimalai (n=1179) than Mavadi and Suruli. High species richness in Mavadi was due to the presence Moist Deciduous vegetation in the mid elevation (800-1000m) and Evergreen vegetation (1400-1600m) at high elevation with small streams. The high abundance in the Vellimalai was due to Riverine vegetation with thick canopy in two elevational categories (600-1000m). However, the river did not influence species richness of amphibians. Suruli transect had most of the areas of Dry Deciduous and Rocky slopes with Grass.

Seasonally, species richness did not vary much in the methods and among the transects. During dry season species richness was highest in both methods in Mavadi. Suruli had equal number of species in both seasons. However, VES method had one additional species during dry season. Vellimalai had one additional species during wet season by Quadrat and there was no difference in VES.

Of the eleven families of amphibians reported from Western Ghats eight families were recorded in Megamalai. With respect to amphibian species richness the community represented by eight families, contribution of species by families varied from one to six. The community of amphibian was dominated by Rhacophoridae by 11 species. Representation of highest number of *Philautus* is not obvious since studies from different hill ranges also showing representation of more *Philautus* species. Studies from other parts of Western Ghats suggest that species richness of amphibians would be higher in high Hills (Naniwadekar and Vasudevan, 2007). Owing to maximum percentage of Dry vegetation and minimum drainage, were responsible for poor representation of endemic families like Micrixalidae and Nyctibatrachidae.

The Megamalai amphibian community was dominated by two species *Indirana beddomii* and *Sylvirana temporalis* which altogether had 43.52%. In Mavadi, the community was dominated by *Indirana beddomii* followed by *Sylvirana temporalis* and *Duttaphrynus melanostictus.* In Suruli, the abundance was dominated by *Indirana semipalmata* and *Indirana beddomii.* In Vellimalai, dominant species was *Sylvirana temporalis* (37.83). The overall community was shaped by *Indirana beddomii* and *Sylvirana temporalis* and these two species found in broad elevational gradients as well (see chapter 4). The former species had occupied in all the vegetation types and the latter one abundant in Riverine vegetation (Vellimalai) and absent in Rocky slopes with grass and Shola and Grassland. According to Vasudevan *et al.* (2001, 2006) *Sylvirana temporalis* is the dominant species also genus *Indirana* as subdominant in evergreen vegetation in Ashmabu Hills. Vijayakumar *et al.* (2006) found that the *Sylvirana temporalis* was one of the abundant species in dry vegetation of Kalakad-Mundanthurai Tiger Reserve. In the present study, high representation of taxa due to broad elevational width, various vegetation types and rainfall regimes.

Though the Quadrat method yielded few rare species, members of families Nyctibatrachidae and Microhylidae were not found in Quadrats. Former one is composed of *Nyctibatrachus aliciae* and *N.beddomii* and both species had strong affinity towards water bodies. Microhylidae (*Ramanella montana*) was recorded infrequently and found only in higher elevational regimes.

The Shannon-Weiner (H') diversity was 2.31 and Simpson's (D) was 0.76. Diversity indices of Meghamalai showed that it was comparatively higher than the Kalakad-Mundanthurai Tiger Reserve with indices of 1.6 and 0.65 respectively (Vasudevan *et al.*, 2008). Shannon-Weiner (H'), Hill's ($e^{H'}$) and Simpson's indices were maximum diversity values at Mavadi indicated the richness, abundance and contribution by species were higher comparatively than Suruli and Vellimalai. In general, equitability depends on the number of species present and size of collection. Fauth *et al.* (1989) noted that removal of single species make uneven distributions. Diversity of community also depends on quantitative equilibrium between species and the maximum equitability at Suruli showed that species were more evenly distributed than Mavadi and Vellimalai.

3.5. SUMMARY

- The Megamalai landscape was sampled for amphibians in three (belt) transects laid taking aspect, slope, plateau, nature of the terrain, various vegetation types, accessibility and the presence of valleys into consideration.
- Quadrat and VES were used from December 2006 to November 2008 for regular monitoring. road cruising, night and opportunistic surveys were also used to maximize the species richness.
- Thirty-four species of amphibians were recorded during this study. This is the first documentation of amphibians in this hill range. A total of 3166 individuals were encountered employing 3600 man hours and 1200 Quadrats. New locality for *Philautus griet* and range extension for *Philautus ponmudi* and *Rhacophorus pseudomalabaricus* were reported.
- Various non-parametric estimators with different orders of Chao and Jackknife were used for estimating the species richness for VES and Quadrat data set. These estimators did not vary much from the Empirical species richness for VES data however differed widely for Quadrat method.
- Among the 21 species recorded by regular sampling, *Indirana beddomii* was the most abundant (23.09%, n=731) and *Sylvirana temporalis* was the next abundant (20.44%, n=647). The number of individuals observed by method (VES and Quadrat) varied significantly.
- Eight families were recorded during the study period. Amphibian families did not distribute evenly. The community was dominated by Rhacophoridae with maximum of 11 species. With respect to number of individuals, Petropedetidae was the most abundant family in the amphibian community. Two species namely *Indirana beddomii* and *Sylvirana temporalis* dominated the community which altogether had 43.52% of composition.
- Shannon-Weiner (H'), Hills ($e^{H'}$), Simpson's (D) and Equitability index of amphibians were maximum at Mavadi and Suruli and minimum at Vellimalai. However, the species richness peaked in Mavadi (19 species). Density of amphibians were highest in Suruli and the number of individuals (abundance) was more in Vellimalai.

4. DISTRIBUTION PATTERN ALONG THE ELEVATION GRADIENTS

4.1. INTRODUCTION

Analysis with respect to diversity, abundance and species composition of biota along the elevation gradient can provide information on factors limiting their distribution (Navarro, 1992). As a consequence of physical heterogeneity of mountains, they harbour rich biodiversity compared to plains (Lafon, 2004). Rahbek (1997) reported that species richness pattern along the elevation gradient is poorly known. Understanding pattern of species richness along the elevation and identifying factors governing the same is essential for conservation of biodiversity (Vetaas and Grytnes, 2002; Pimm and Brown, 2004). In addition, this information would help prioritizing the area for conservation (Hunter and Yonzon, 1993).

Terborgh and Weske (1975) and Terborgh (1985) reported that the principal factors influencing structure of communities along the elevation are change in habitat, environmental parameters and competition. Rosenzweig (1992) and Stevens (1992) stated that distribution data for most of the taxa from any geographical region is inadequate. Variations in scale and sampling designs, small sample size, and annual effects contributed to controversial conclusions concerning patterns described so far (Fauth *et al.*, 1989).

According to Rahbek (1995) species richness along the elevation gradients in general follows any one of the three basic patterns; (i) monotonic decline with elevation (ii) increase with elevation and (iii) mid-elevation peak. Declining species richness with elevation emerged as first general pattern widely accepted (Rahbek, 1995). However, a review for a wide variety of taxa revealed that only 20% of the study supported the above view (Rahbek, 1995). As many as 49% studies showed the hump-shaped pattern with highest richness at mid-elevations and 24% reporting a plateau of high richness across lower elevations which declined with elevations (McCain, 2005). Patterns of species richness along the elevation are attributed to factors such as rainfall, temperature, productivity, competition, resource abundance and habitat complexity (Rickart *et al.*, 1991; Heaney, 2001; Lomolino 2001; McCain, 2005).

Environmental factors such as temperature, humidity and oxygen content might influence the geographical distribution of ectotherms (Krebs, 1994). Among them it is reported that temperature is particularly important (Greer, 1980; Huang *et al.*, 2006). Thermal environments change dramatically with elevation, with a mean temperature decreasing at 0.6 °C for every 100 m variation (Bouverot, 1985).

Navas (2003) reported that decline of biodiversity with elevation is well known but this may be taxa specific. Amphibian richness may be high at higher elevations (Navas, 2003; Naniwadekar and Vasudevan, 2007). Birds showed declining trend with elevation (Terborgh, 1971; 1977). According to Rahbek (1997) species richness declined with elevation when area was not considered, but hump-shaped pattern was found when area was included for analysis. Barring few studies on elevational distribution of amphibians in India (Daniels, 1992a; Naniwadekar and Vasudevan, 2007), and rest of them are on birds (Raman *et al.*, 2005; Acharya, 2007; Das, 2007), reptiles (Chettri, 2007; Chettri *et al.*, 2010) and woody plants (Oommen and Shankar, 2005).

Chettri *et al.* (2010) reported the decline of reptile species richness with elevation and found that the pattern was least governed by geographic hard boundaries. However, Naniwadekar and Vasudevan (2007) reported increasing amphibian richness with elevation and reported that the geometric constraints did not influence the pattern in the Western Ghats.

4.2. METHODS

Megamalai landscape was sampled for amphibians taking aspect, slope, plateau, forest type, presence of valley and accessibility into consideration. Sampling was restricted to three belt transects (Figure 2.1 2.2 & 2.3), namely Mavadi (Transect I), Suruli (II) and Vellimalai (III). The width of these transects was 1000 m. Each transect traversed from hill bottom to hill top and were stratified at 200 m elevation intervals. Area availability in each elevation category (200 m category) was considered to decide on the intensity of sampling (*i.e.* proportion of sampling depends on the area availability at a particular elevation). This procedure would minimize the bias, if any with respect to sampling in a particular elevation. By this way, in each transect, 100 hours of VES and 100 Quadrats were sampled. Sampling was done on seasonal basis during dry (December to May) and wet (June to November).

Visual Encounter Survey (VES) and Quadrats were used for sampling amphibians in Megamalai, Western Ghats (See Chapter 3 for description). Data/observation based on opportunistic observations were included for analysis (see Chapter 3). In each transect, at every 50 m interval, microhabitat variables *viz.*, canopy, herb, shrub, and litter cover were quantified using 2 X 2 m Quadrat. Other information such as presence of cattle dung and lopping were recorded qualitatively. In addition, availability of boulders, rocks and fallen logs were also counted. Distance to the nearest water source was measured qualitatively. Soil temperature and humidity was recorded using IR Thermometer and Humidity meter (EXTECH Instruments; RH 101).

The following points were considered for analysis.

Exclusive species- The species with restricted distribution to one elevation category is considered as exclusive species.

Range Size- The range *i.e.* the lowest and the highest elevations of the occurrence of a species assuming it to be present in all the intermediate elevations. (Patterson *et al.*, 1998; Md. Nor, 2001; McCain, 2004 b).

Species Turnover- Change in species composition from one place to another is known as Species turnover (Whittaker, 1960). Turnover or dissimilarity of species between two neiboring category *i.e.* in the present case elevation category and the same is calculated as (1-*X*), where *X* is Sorenson's similarity index (Wolda, 1981).

Mid-Domain Null Model- Mid-Domain Null model was used to test the effect of geographical hard boundaries on species distribution. The mid-domain null model is generated by randomly placing ranges or range midpoints between two hard boundaries (Colwell and Hurtt, 1994; Colwell and Lees, 2000; McCain, 2003). The species richness and range size of species compared with null predictions computed through Monte Carlo simulation procedures using the Mid-Domain Null developed by McCain (2004 a). Mid-Domain Null programme allows sampling without replacement and therefore restricts the sampling to observed species alone (McCain, 2004 b). Prediction curves (95% confidence) based on 50,000 simulations without replacement from empirical range sizes or midpoints were used to assess the species distribution geographic constrains (McCain, 2006).

4.2.1. Data analyses

1. Data collected using standard methods *i.e.* Quadrat and VES surveys were used for analysis such as estimation of density, abundance, and various diversity indices (See Chapter 3 for more details).
2. Encounter rate: Number of amphibians (individuals sighted)/total hours surveyed.
3. Linear Regression was performed to check the fitness between observed empirical species richness and simulated species richness across the elevation zones for mid-domain analysis.
4. Regression analysis was performed for species richness and abundance with annual rainfall and temperature (simulated data obtained from Website: www.worldclim.org).
5. Canopy cover, herb cover, shrub cover, litter cover, number of boulders, rocks, fallen log, distance from water, soil temperature and humidity were analysed with various curve fit procedures. The curve, which resulted in higher R^2 value was taken into account.

4.3. RESULTS

4.3.1. Area availability

Based on Digital Elevation Model, the study area has an elevation range from 326 m to 1955 m. Elevation below 400 asl is covered by human habitation and above 1800 m is having small area (<1%) and have merged as one *i.e.* 1600-1800 m elevation. Three transects namely Mavadi, Suruli and Vellimalai were studied. Mavadi and Suruli had elevation range of 400 to 1600 m. On the other hand, the Vellimalai transect, elevation ranged from 600 to 1800 m. Data on length, elevation range and area covered in each elevation category are given in the table 4.1. Total length of three transects was 21.17 km, and as the width of the transect was 1000 m and area covered for sampling was 21.17 sq.km. Lower elevation had higher representation than that of the higher elevation (Table 4.1).

4.3.2. Sampling effort

Sampling intensity in each elevational category was based on area availability. For instance, 20.5% of sampling was done in elevation band 400-600 m, whereas only 3.2% in 1600-1800 m.

Table 4.1. Area availability at various elevational categories based on three belt transects in Megamalai landscape; Transect I=Mavadi, Transect II= Suruli and Transect III Vellimalai.

Elevation Category (m)	Transect I	Transect II	Transect III	Total length (in km)	Area (%)
400 - 600	3	1.34	0	4.34	20.5
600 - 800	1.11	1.95	1.47	4.53	21.4
800 - 1000	1.31	0.52	1.53	3.36	15.9
1000 - 1200	0.98	0.83	0.68	2.49	11.8
1200 - 1400	1.04	1.84	0.98	3.86	18.2
1400 - 1600	0.56	0.38	0.97	1.91	9.0
1600 - 1800	0	0	0.68	0.68	3.2
Total	8.00	6.86	6.31	21.17	100

4.3.3. Species richness

In total, 34 species were recorded in Megamalai landscape (Figure 4.1). The highest of 16 species was recorded in 800-1000 m elevation category and lowest number of 10 species was observed in 1000-1200 m (Figure 4.1; Appendix 3). Out of 34 species, 21 species were endemic to the Western Ghats. Maximum number of 13 endemic species were found between 1400 and 1600 m elevation and minimum of two in 400-600 m elevation. Higher proportion of endemic species was found in medium to higher elevations *i.e.* over 60% of amphibian species in above 800 m elevation.

In all, 3166 amphibians were observed in 12 ha of Quadrat sample and 3600 man-hours of VES. Quadrat data was used for estimating the amphibian density. The overall density was 27.92/ha (335 individuals). Forests found in 1000-1200 m elevation category had maximum density (72.86/ha) followed by 1600-1800 m (52.50/ha). Elevation of 1200-1400 m had lowest (10.91/ha) density (Table 4.2).

VES data was used for calculating encounter rate and the 3600 man-hours of VES yielded 2831 individuals of amphibians *i.e.* 0.786/man-hour. Encounter rate was found >1.0 in three elevational categories which were 800-1000 m (1.333/man-hour), 1600-1800 m (1.308/man-hour) and 1400-1600 m (1.071/ man-hour, Table 4.2).

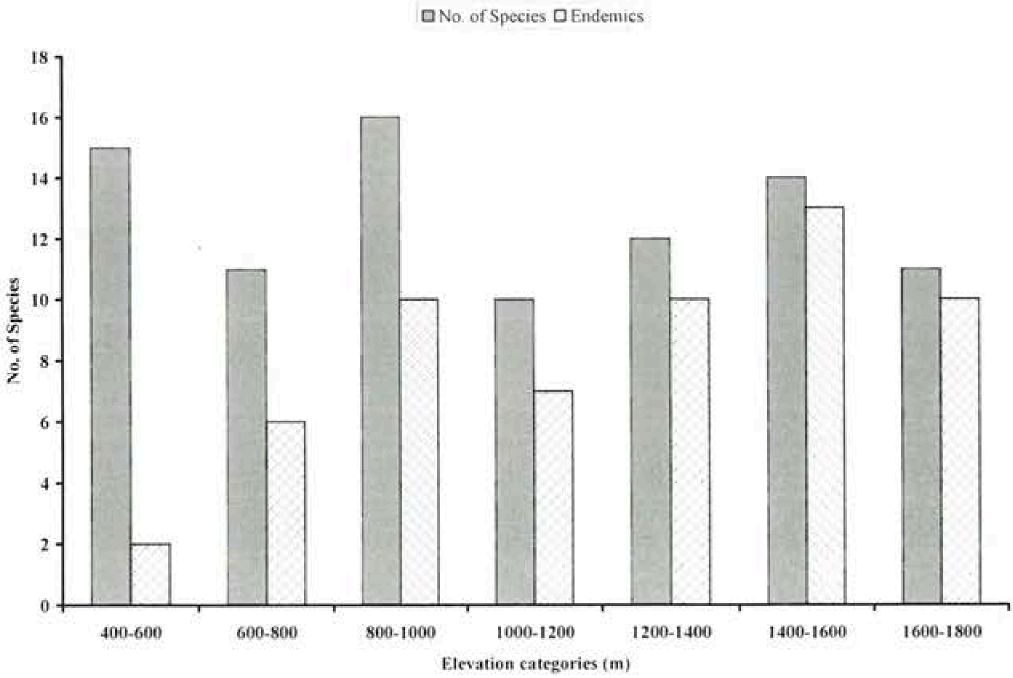


Figure 4.1. Distribution of amphibian species along elevational gradients of Megamalai landscape.

4.3.4. Diversity indices

The overall amphibian diversity (H') of the area was 2.31. The highest diversity index (H'=2.07) was observed along 1400-1600 m and the lowest (H'=1.29) in 1000-1200 m band (Table 4.2).

Table 4.2. Amphibian distribution along various elevation categories in Megamalai landscape.

Elevation category (m)	Shannon-Weiner (H')	Density (No./ha)	Encounter rate (No./hr)
400-600	1.51	18.53	0.351
600-800	1.73	17.80	0.864
800-1000	1.72	26.56	1.333
1000-1200	1.29	72.86	0.536
1200-1400	1.93	10.91	0.595
1400-1600	2.07	41.96	1.071
1600-1800	1.86	52.50	1.308
Total	2.31	27.92	0.786

Total number of amphibian families observed during this study was eight. However, along the elevational gradients it varied from six to eight. The highest of eight families were observed in elevational category 1200-1400 m and lowest of six species along 400-600 m, 600-800 m, 1000-1200 m and 1600-1800 m (Table 4.3).

Abundance of amphibian families varied in different elevations *i.e.* higher proportion of Bufonidae in 600-1000 m, Dicroglossidae in 400-800 m, Micrixalidae in 1400-1600 m, Petropedetidae in 600-1600 m, Ranidae in 600-1000 m and Rhacophoridae in 1200-1600 m (Figure 4.2). Distributions of amphibian families were not even among the elevational gradients ($\chi^2 = 732.80$; $P<0.001$).

Table 4.3. Amphibian species richness along the elevational categories at family level in Megamalai landscape.

Family	Elevation category (m)							Total
	400-600	600-800	800-1000	1000-1200	1200-1400	1400-1600	1600-1800	
Bufonidae	2	1	1	1	1	2	2	3
Dicroglossidae	5	3	3	2	1	1	1	6
Microhylidae	4	0	0	0	1	1	1	5
Micrixalidae	0	1	1	0	1	1	1	1
Nyctibatrachidae	0	0	2	1	1	1	0	2
Petropedetidae	1	3	3	3	3	4	2	4
Ranidae	1	1	2	1	1	0	0	2
Rhacophoridae	2	2	4	2	3	4	4	11
No. of species	15	11	16	10	12	14	11	34
No. of family	6	6	7	6	8	7	6	8

4.3.5. Distribution pattern

Based on the regular sampling (VES and Quadrat), the number of species of amphibians and endemics increased with elevation up to 1400-1600 m (Figure 4.3 & 4.4). The number of species increased from 400-600 m (6 species) to 1400-1600 m (14 species) with increasing elevation (R^2 =0.5566). The endemic species increased from one species at 400-600 m elevation to 12 species at 1400-1600 m (R^2=0.7917).

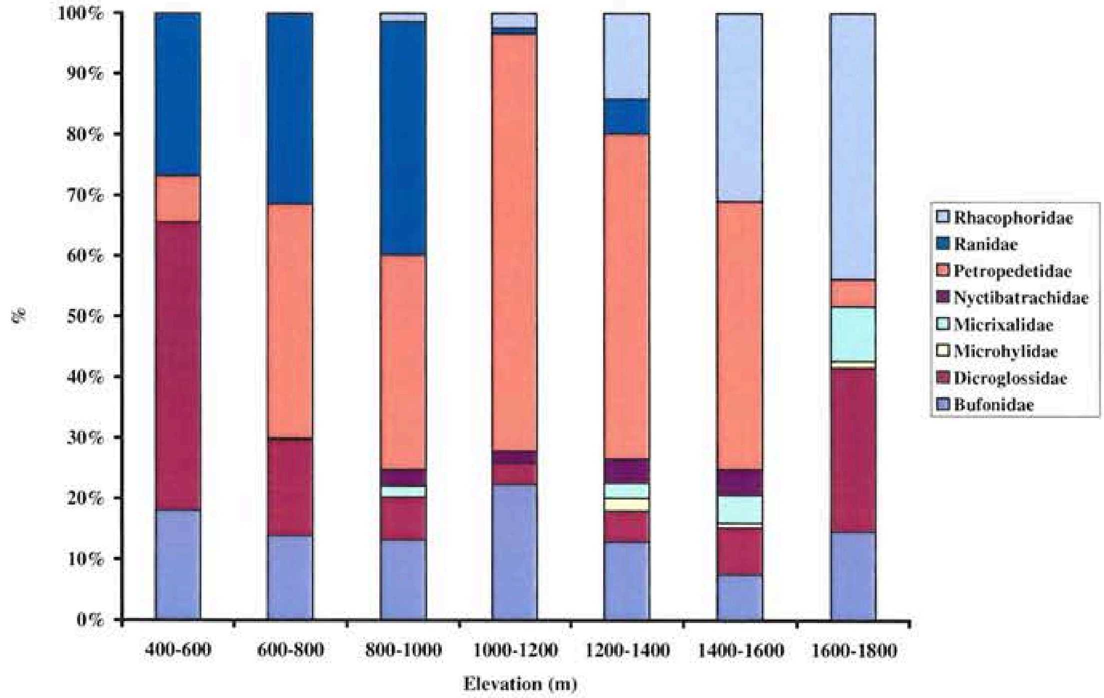


Figure 4.2. Abundance of amphibians along the elevation categories at family level in Megamalai landscape.

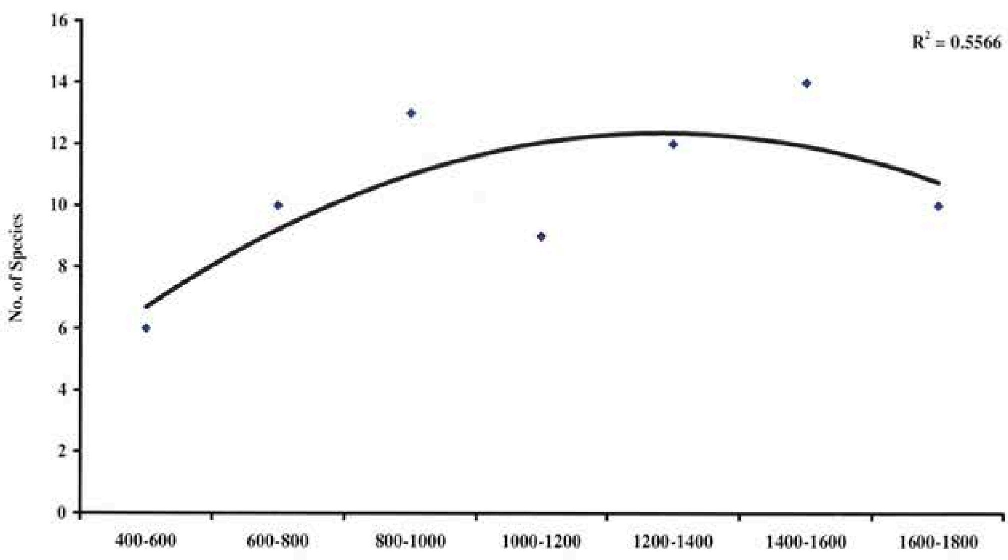


Figure 4.3. Distribution of amphibian species along the elevational gradients of Megamalai landscape. The fitted line is shown with R^2 value.

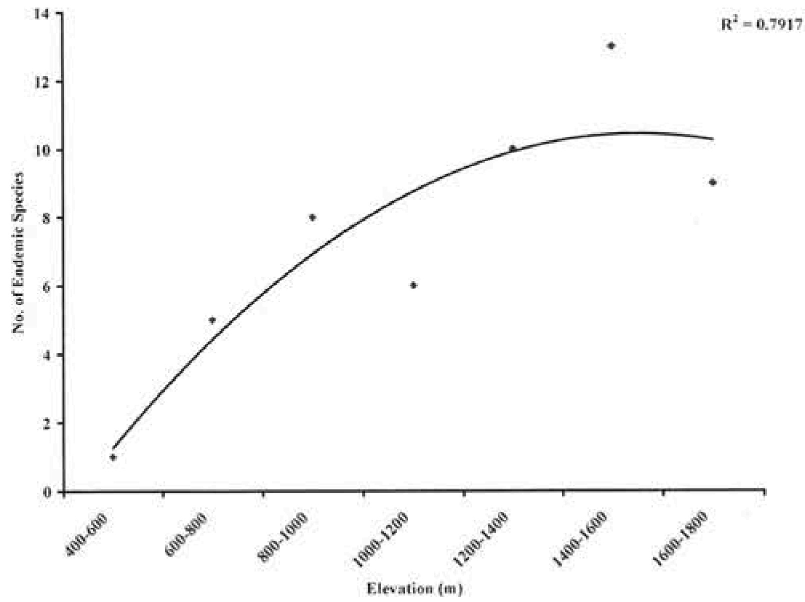


Figure 4.4. Distribution of endemic amphibian species along the elevational gradients of Megamalai landscape. The fitted line is shown with R^2 value.

4.3.6. Range size

Of the 34 species of amphibians, 16 species were observed in only one elevation category and eight species to three elevation categories. Two species were distributed in all seven elevation categories (Figure 4.5). In this study area, 24 species (70.59%) were restricted to 1 to 3 elevation categories, which indicates that amphibians are highly restricted in their distribution.

There were 16 species *viz., Bufo scaber, Euphlyctis hexadactylus, Hoplobatrchus tigerinus, Kaloula taprobanica, Microhyla ornata, Microhyla rubra, Uperodon systoma, Nyctibatrachus beddomii, Clinotarsus curtipes, Philautus ponmudi, Philautus* sp1, *Philautus* sp2, *Polypedates maculatus, Rhacophorus malabaricus, Rhacophorus pseudomalabaricus* and *Rhacophorus pleurostictus* restricted to one elevational category. Of the two widely distributed species, *Indirana beddomii* is endemic to the Western Ghats.

As many as 16 species were restricted to one elevation category. Highest number of exclusive species were found in low elevation. As elevation increased, the number of exclusive species decreased. Among the range restricted species (16), eight species were endemic and the rest (8) were non-endemics (Appendix 3).

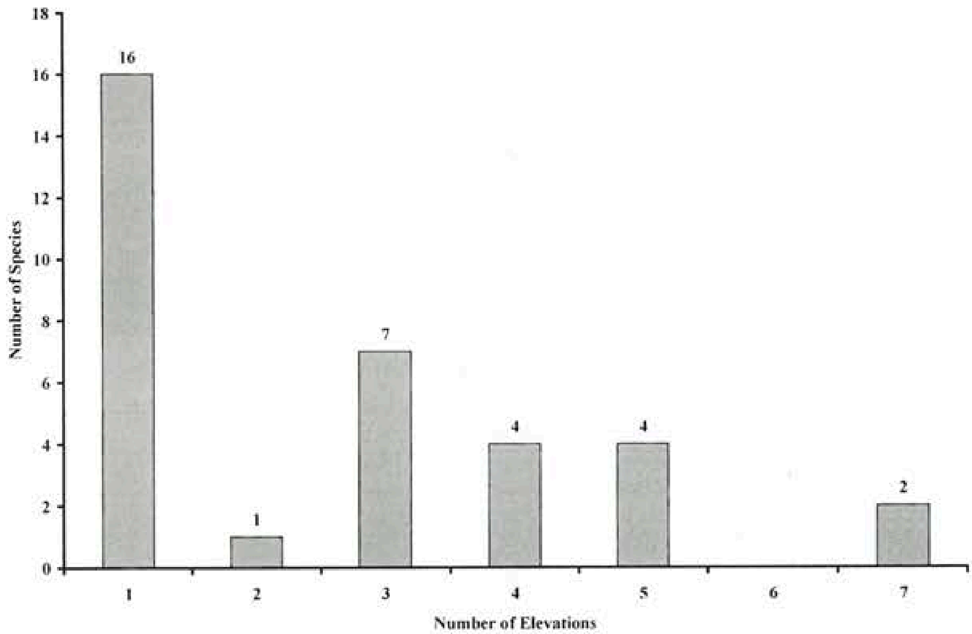


Figure 4.5. Amphibian species sharing elevation categories along the Megamalai landscape.

4.3.7. Elevational range of amphibians

Most of the species distributed in narrow elevational ranges along the elevational gradients and concentrated in higher elevations, hence species showed increasing trend with increasing elevation. *Duttaphrynus melanostictus* and *Indirana beddomii* were distributed in all elevational categories. It is observed that many species found in higher elevation extended their distribution to lower elevation. On the other hand, several species distributed in lower elevations have restricted distribution (Figure 4.6).

4.3.8. Species turnover

Species turnover was low between consecutive elevational categories compared to that of distant categories (Table 4.4). High turnover was observed between 400-600 m and 1400-1600 m (0.800). The elevation category 400-600 m had higher turnover with many elevation categories 1200-1400 m, 1400-1600 m and 1600-1800 m. Among the consecutive elevation turnover was high between 1000-1200 m and 1200-1400 m (0.334). The lowest species turnover rate was observed between 600-800 m and 800-1000 m (Table 4.4).

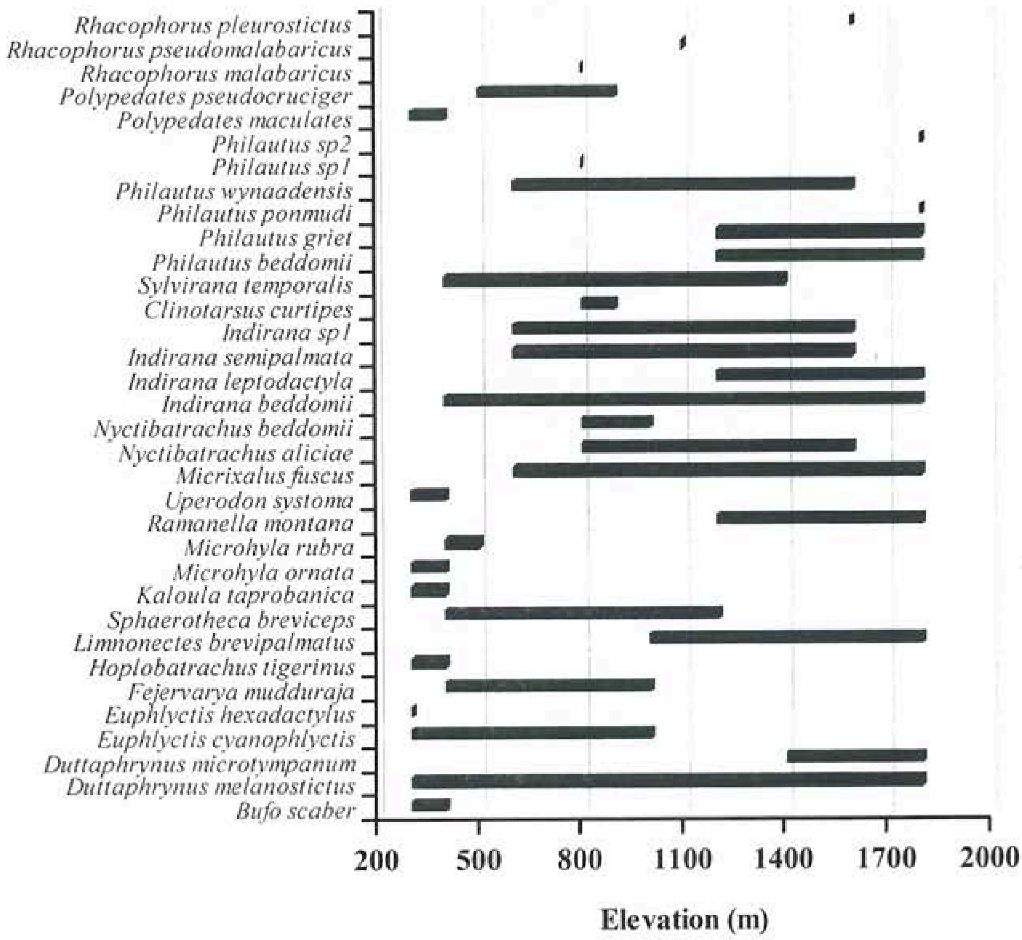


Figure 4.6. Elevational range of amphibian species observed in Megamalai landscape.

Table 4.4. Species turnover (based on Sorensen's Index) between pair of elevation categories in Megamalai landscape.

Elevation category (m)	Elevation category (m)						
	400-600	600-800	800-1000	1000-1200	1200-1400	1400-1600	1600-1800
400-600	-	0.250	0.369	0.467	0.667	0.800	0.750
600-800		-	0.131	0.264	0.455	0.500	0.700
800-1000			-	0.273	0.440	0.482	0.740
1000-1200				-	0.334	0.392	0.685
1200-1400					-	0.154	0.273
1400-1600						-	0.250
1600-1800							-

4.3.9. Mid-domain effect

A comparative analysis of empirical data with 95% prediction curve using range (width) size showed that majority of the empirical points occurred within 95% simulation prediction curves (Figure 4.7). Out of sixteen bins three (3/16) were found outside boundaries of the predicted domain. Deviations from the mid-domain boundaries were at 1000 m, 1100 m and 1800 m. Regression of empirical species richness with mean of the simulated richness across simulation per bin gives R^2 value, which acts as a tool for assessing the fit of Mid-Domain Effect (MDE) null model (McCain, 2003, 2004b). Empirical S obtained using Mid-domain null model had significant relationship with simulated S (R^2=0.31; P<0.05). However, low R^2 value showed that there is low fit to the mid-domain model.

4.3.10. Relationship with environmental parameters

Both annual temperature (r =-0.956; P<0.001; n=7) and rainfall (r =0.955; P<0.001; n=7) showed significant relationship with elevation. Amphibian species richness had negative relationship with annual mean temperature (r =-0.535; P>0.05; n=7) and positive relationship with annual rainfall (r =0.558; P>0.05; n=7). However, they were not significant. The relationship between amphibian abundance with temperature

(r =0.371; P>0.05; n=7) and rainfall (r =-0.368; P>0.05; n=7) were comparatively low and were not significant.

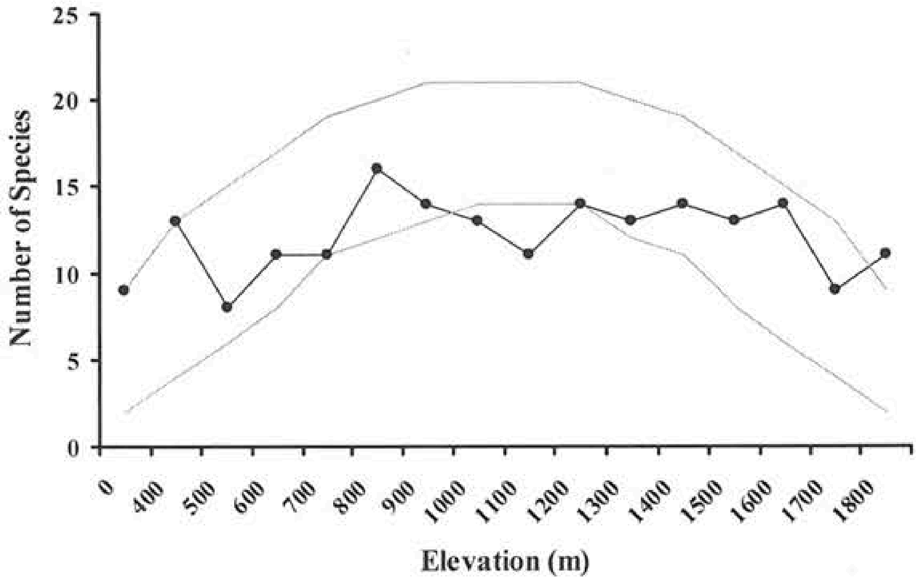


Figure 4.7. The mid-domain analysis (95% confidence limits, lines without data points) from 50,000 range size simulations using Mid-Domain Null (McCain, 2004) and empirical species richness pattern (thick line with closed circles).

4.3.11. Factors governing species distribution

Relationship of amphibian species richness and abundance with respect to various environmental factors is given in the table 4.5 and appendix 5 & 6. Amphibian species richness and abundance did not have direct relationship with respect to herb cover, shrub cover, canopy cover, litter cover, boulders, rocks, fallen log, distance from water, soil temperature and humidity. Shrub cover (R^2 = 0.6194), canopy cover (R^2 = 0.5343) and herb cover (R^2 = 0.4611) had non-linear relationship with greater R^2 values. Parameters such as soil humidity (R^2 = 0.4585), soil temperature (R^2 = 0.4544), litter cover (R^2 = 0.4048) and fallen log (R^2 = 0.4044) had moderate relationship with amphibian abundance. This indicates moderate values of these parameters influence the distribution of amphibians.

Table 4.5. Value showing relationship between environmental parameters with amphibian species richness and abundance in Megamalai landscape.

Microhabitat	Richness	Abundance
Herb cover %	0.4611	0.2447
Shrub cover %	0.6194	0.3946
Canopy cover %	0.5343	0.2938
Litter cover %	0.3709	0.4048
No. of Boulders	0.2026	0.0639
No. of Rocks	0.2810	0.1830
No. of Fallen log	0.1633	0.4044
Distance from water (m)	0.2075	0.0608
Soil temperature (C°)	0.0805	0.4544
Soil Humidity (%)	0.0744	0.4585

4.4. DISCUSSION

The Global Information System data and Digital Elevation Model showed that the elevational gradient in the study area was 326-1955 m. However, areas having elevation lower than 400 m was affected by human habitation and agriculture. The area with >1800 was too steep and the area of occupancy was < 1%. Hence, these portions were not included in the study. The percentage of maximum area available in low elevation (600-800 m) which was 21.4% and minimum in high elevation (1600-1800 m) with 3.2% (Table 4.1). This pattern is consistent with other mountains that the area decreases with increasing elevation due to the conical shape of the mountains (Körner, 2000; Lomolino, 2001).

Species richness was highest at 800-1000 m (16 species) and the lowest in 1000-1200 m elevation category (10 species), when considering the data obtained from all methods. However, by regular monitoring (*i.e.* VES and Quadrat), maximum species richness was observed at 1400-1600 m (14 species) and minimum at 400-600 m category (6 species). The pattern is similar to the observation made in amphibians of tropical Andean elevational gradients (Navas, 2003). The greater richness in high elevation is due to humid and availability of diverse water resources (Navas, 2003). The result of this study is consistent with another study in the Western Ghats (Naniwadekar and Vasudevan, 2007). Insects and herpetofaunal assemblages share some properties in their response to elevational gradients (Hofer *et al.*, 1999). Daniels (1991) stated that richness in Western Ghats was due to wide spread rainfall. Fauth *et al.* (1989) reported that species richness was positively correlated with litter depth and negatively with elevation. Broader elevational width of 400-1800 m and many vegetation types in the area could be important factors in determining amphibian species richness.

Daniels (1992) stated that higher amphibian endemism between 0 and 1000 m, which peaked at 800-1000 m. In the present investigation, endemism in amphibian species was highest in medium to high hill, above 800 m elevation category (60%) which is similar to Kalakad-Mundanthurai Tiger Reserve (Naniwadekar and Vasudevan, 2007). Globally high lands act as refuges for many endemic anurans (Campbell, 1999; Duellman, 1999). Thus, the amphibian conservation is very important in medium and high hills of Western Ghats.

Maximum of eight families were observed in elevation 1200-1400 m and minimum between 400 and 600 m. This is due to biotic and abiotic factors prevailing in high elevational regime. Naniwadekar and Vasudevan (2007) reported that anurans respond to the gradient by organizing themselves into distinct assemblages. Three families (Bufonidae, Petropedetidae and Dicroglossidae) were found across in all elevational categories it indicates that these families are not constrained by elevation and other physiological factors. Moreover, the members of a family found in lower elevation replaced by other species from the same family in the high elevation. Richness in Rhacophorids increased with elevation. This is similar to the observations made in Kalakad-Mundanthurai Tiger Reserve by Naniwadekar and Vasudevan (2007). Dicroglossidae, in contrast, which inhabited terrestrial mode of life and their abundance, increased with decreasing elevation. They require water bodies to survive and breed. Naniwadekar and Vasudevan (2007) also found decrease in terrestrial amphibians with increasing elevation in Western Ghats. The major contribution by genus *Philautus* at high hills due to availability of moisture, which would be useful in preventing water loss. According to Inger (1999), the genus *Philautus* has a terrestrial breeding habit and they dependent on atmospheric and litter moisture. Most of the high hills in Southern Western Ghats is characterized by cloud forest (Bubb *et al.*, 2004).

Amphibian density was maximum with 72.86/ha at 1000-1200 m and these areas were unoccupied by vegetation cover (bare moist rocky areas) with boulders which provided suitable place for genus *Indirana* (Petropedetids) for breeding. Minimum density was recorded at with 1200-1400 m with 10.91/ha and this elevation range was covered by Rocky slopes with grass and Evergreen forests which holded 12 species. According to Scott (1976) amphibian densities are greater in wet areas compared to dry areas. The present study also reflects the same pattern. Comparison of diversity indices at elevational gradients with other areas of Western Ghats and also for global level are lacking.

In the present study, low elevation i.e. 400-600 m had a maximum of 15 amphibian species and among them, eight were restricted to this elevation. It is due to more representation of wide spread amphibian species such as *Duttaphrynus melanostictus*, *Bufo scaber*, *Euphlyctis cyanophlyctis*, *Euphlyctis hexadactylus*, *Kaloula taprobanica*, *Hoplobatrachus tigerinus*, *Microhyla ornata*, *Microhyla rubra*, *Uperodon systoma* and *Polypedates maculatus* (Inger and Dutta, 1986). These species could not extend to high elevation due to restricted distribution and physiological constrains. According to Daniels (1992) about half of the species in Western Ghats have localized in distribution.

Duttaphrynus melanostictus and *Indirana beddomii* were distributed in all the seven elevation categories. Only one endemic species *Micrixalus fuscus* was found in all the elevation zones except the lower most elevation (400-600 m) in the study area. Extension of higher elevation species to lower elevation was recorded but not *vice-versa* (Chettri, 2007). In this study area, 24 species (70.59 %) were restricted to 1 to 3 elevation categories, which indicated that amphibians were highly restricted in their distribution.

Evaluation of Mid-domain Effect Null Model (MDE) agreed with 95% prediction limits of the simulation curve. This indicates amphibian distribution is largely driven by geographic hard boundaries. The mid-domain effect is an unavoidable consequence of bounded ranges of variable sizes (McCain, 2003). Unlike highly mobile taxa such as birds, amphibians are more likely to be constrained by geographic boundary due to their body physiology and limited movement.

McCain (2006) reported the greater fit to MDE null model in temperate zone than either tropical or tropical-temperate transition zones. Dunn *et al.* (2007) reported MDE perform better fit with large scales and larger range size. Small range size of most species indicated the influence of environmental changes, whereas large range species were more constrained by domain boundaries leading to unimodal pattern (Jetz and Rahbek, 2002; Cardelus *et al.*, 2006). The MDE null model showed fit to mid 95% prediction curve. Similar elevational study conducted in Western Ghats also reported lack of mid elevational peak (Naniwadekar and Vasudevan, 2007). The small range size and partial effect of geometric constraint opens the way for analyzing climatic and other factors rather than hard boundary as a causal factor for species distribution along the elevation in the present case.

Species turnover was high between distant elevation categories compared to consecutive ones. Due to overlapping vegetation and climatic condition, consecutive elevation categories showed low turnover rate. Among the consecutive zones, relatively high turnover rate was found between 1000-1200 m and 1200-1400 m (0.334) and low turnover was observed between 600-800 m and 800-1000 m (0.131). Vasudevan *et al.* (2006) found elevational turnover in two hill ranges also suggested that factors which cause turnover of species, should be a major consideration in any survey and conservation planning of amphibians.

Environmental variables *viz.,* annual rainfall and temperature had significant relationship with elevation. However, it was not significant with species richness and abundance. Shrub cover, canopy cover and herb cover had influenced species richness. Soil humidity, temperature, litter cover, and fallen log had influenced amphibian abundance. Allmon (1991) reported that frogs did not show any correlation with measured environmental variables *viz.*, litter moisture, litter depth, relative humidity, number of trees, palms, herbs, presence and absence of logs, soil types and slope. Naniwadekar and Vasudevan (2007) found soil moisture and soil temperature as best predictor of amphibian richness, which is similar to the findings of this study.

4.5. SUMMARY

- Distribution pattern of amphibians along the elevation gradient (400-1800 m) of Megamalai was studied. Species richness was maximum at 800-1000 m (16 species) elevation and minimum in 1000-1200 m (10 species). By regular sampling, 21 species were recorded. Maximum of 14 species in 1400-1600 m and a minimum of six species from 400-600 m was observed. Shannon-Weiner diversity (H') was maximum at 1400-1600 m and minimum in 1000-1200 m. The highest abundance of Rhacophorids was in higher elevations. The abundance of Dicroglossidae decreased with elevation.
- Range size of all the amphibian species showed lower elevation species had narrow range size and species distributed in high elevation extended to lower elevation.
- Species turnover rate was high between distant elevation categories. High turnover rate was observed between 400-600 m and 1400-1600 m.
- There is no mid-domain effect in empirical S at the alpha level. The low fit to Mid-domain Null model as indicated by low R^2 value (R^2=0.317; $P<0.05$).
- Annual temperature and rainfall showed strong significant relationship with elevation (Temperature r =-0.956; $P<0.001$; n=7 and rainfall r =0.955; $P<0.001$; n=7).
- Shrub, canopy and herb showed significant relationship with amphibian species richness. Soil humidity, soil temperature, litter cover and fallen log showed significant relationship with amphibian abundance.

5. DISTRIBUTION PATTERN IN VARIOUS VEGETATION TYPES

5.1. INTRODUCTION

Species richness of an area depends on its geographical location (Davidowitz and Rosanzweig, 1998). Distribution of vegetation directly or indirectly determines the abundance and distribution of animals (Kumara, 2005). Understanding the association of species to their environment is essential to conserve biodiversity (Greene, 1994). Loss of forest cover and area in the tropical region has been reported by several authors (*e.g.* Myres *et al.*, 2000, Brooks *et al.*, 2002, Chazdon, 2003 and Mittermeier *et al.*, 2005). An estimated 60% of the world's tropical forest is classified as degraded, including secondary forests, degraded primary forests and degraded forest land (ITTO, 2002). Identification of area of conservation importance is a primordial measures to reduce the loss of biological diversity at different levels (Soares and Brito, 2007). Understanding habitat changes and how these changes affect the distribution and abundance of species are crucial for planning biodiversity conservation and management (Patrick *et al.*, 2006).

It is thought that structure of an animal community is determined by the habitat structure of an area (Shenbrot and Krasnov, 1997). Study on the habitat utilization gives an idea of how organisms use the area, its preference and the role of the habitat in their survival and interrelations with the biotic and abiotic environments. Bharucha and Ansari (1963) considered climatic, edaphic, topographic and biotic are operative factors for habitat and the same are requisite for community characterization.

The word habitat is used extensively in ecology when describing where an organism lives (Odum, 1996; Chapman and Reiss, 1992) also refers to place occupied by community (Odum, 1996). The term habitat is widely used; the landscape, forest types and so on. Understanding the limits of ecosystem stability and resilience, particularly in relation to changes in species numbers and abundance are major challenge in ecology (Downing and Leibold, 2002). The relative importance and potential interaction of biotic and abiotic factors influence habitat use, which has important implications for possible ecological consequences of global climate change (Martin, 2001). The distribution of organisms is associated with habitat, hence identifying relationships between organisms and environmental features are vital for understanding species ecology.

Tropical amphibians are diverse vertebrate groups that are threatened by various factors. Physiology, short generation time and predominantly biphasic life make them sensitive to habitat changes. Distribution of amphibians in different vegetation types of Western Ghats is poorly known. The ecological requirements and the factors affecting the distribution of most species are poorly understood. Available studies on amphibian ecology in Western Ghats are restricted to one or two forest types (Inger *et al.*, 1987; Daniels, 1995; Vasudevan *et al.*, 2001; Vijayakumar *et al.*, 2006).

5.2. METHODS

Point-Centred Quarter (Krebs, 1989) was used for sampling tree species found along the belt transects namely Mavadi, Suruli and Vellimalai. Trees were sampled at every 50 m using point-centre quarter. Flora of Hooker (1897), Gamble (1957) and Matthew (1996, 1999) were used for tree species identification. Based on the tree species present in each quadrant, the vegetation type namely Tropical Dry Deciduous, Moist Deciduous, Riverine, Rocky slopes with Grass, Evergreen and Shola and Grassland was assigned.

In the present study, vegetation type or forest type is considered as habitat in the broader sense. Amphibians were sampled on seasonal basis using VES and Quadrat (Heyer *et al.*, 1994) in Megamalai. In each transect, 100 Quadrat (10 X 10 m) and 100 hours of VES (X 3 personnel) were sampled for amphibians on seasonal basis. December to May was considered as Dry and June to November as Wet seasons. Description of the sampling protocol is available in Chapter 3.

At every 50 m along each transect canopy, herb, shrub, and litter cover were quantified (2 X 2m Quadrat) in all the vegetation types. Availability of boulders, rocks and fallen logs were counted. Distance to the nearest water source estimated visually. Soil temperature and soil humidity were recorded using IR Thermometer and Humidity meter (EXTECH Instruments; RH 101).

5.2.1. Data analyses

Species richness, abundance, density and diversity

Data from sample within each vegetation type were pooled for analyses. Species richness includes data from VES, Quadrat, Night survey and opportunistic observations. Data from VES and Quadrat methods were used for analysis such as richness, abundance and diversity.

Principal Component Analysis (PCA) was performed to find out the primary factor influencing the habitat. Twelve habitat parameters from 1200 Quadrats (12 ha) were analysed to extract the principal factors. Eigen value >1 were taken to explain the habitat features. Varimax rotation was followed.

Global Comparison of amphibian densities were collected from published data such as Brown and Alcala (1961), Inger (1980), Scott (1982), Allmon (1991), Heatwole and Sexton, (1966), Huang and Hou (2004), Wijesinghe and Dayawansa, (2002), Vasudevan *et al*. (2008) and compared with the data gathered from the present study.

Sorensen's similarity coefficient among vegetation categories was calculated using EstimateS, version 7.5. (Colwell, 2005) and the obtained coefficient was used for assessing the similarity between vegetation types.

Canopy cover, herb cover, shrub cover, litter cover, number of boulders, rocks, fallen log, distance from water source, soil temperature and humidity were analysed with various curve fit procedures. The curves which give highest R^2 value were taken into account.

5.3. RESULTS

5.3.1. Description of various vegetation types

Three transects namely Mavadi, Suruli and Vellimalai were assessed for vegetation types. A total of 419 Quadrants were examined for trees in 21.17 km of the belt transects. Among them 276 had trees. In all, 1104 trees were observed in the quadrants, which included 157 species. Among them 43 (27.39%) species were endemic to the Western Ghats (see chapter 3). The vegetation types recognized were Tropical Dry Deciduous, Moist Deciduous, Evergreen, Shola and Grassland, Riverine and Rocky slopes with grass. Dry Deciduous distributed in highest altitudinal width and contributed the highest proportion (43.84%) in the area. The Shola and Grassland had minimum altitudinal width (1400-1800 m), whereas the Riverine had minimum area (9.04%) all along the transects studied (Table 5.1).

Among the six vegetation types observed, tree species richness and number of individuals was maximum in Dry Deciduous and no tree species was recorded in rocky slope with grass. Of the total 43 endemics, highest number of endemic species was recorded in Shola and Grassland and lowest in Riverine (Table 5.1).

Table 5.1. Vegetation types recognized along belt transects examined in Megamalai landscape. Number in parenthesis of species richness column is endemic species richness.

Vegetation type (elevational width)	Proportion (%)	Species (Endemic)	No. of individuals
Dry Deciduous (400-1200 m)	43.84	70 (6)	610
Moist Deciduous (600-1200 m)	9.04	46 (9)	137
Riverine (600-1000 m)	8.77	35 (2)	127
Rocky slopes with grass (1000-1600 m)	18.08	0 (0)	0
Evergreen (1200-1600 m)	10.68	41 (16)	105
Shola and Grassland (1400-1800 m)	9.59	36 (25)	125

5.3.2. Detection of amphibians

In all, 1200 Quadrats were placed in all vegetation types. However, only 162 Quadrats (13.50%) had amphibians. The highest of about 30% of the Quadrats had amphibians in Shola and Grassland (Table 5.2).

Seasonal variation was recorded in the presence of amphibians within the Quadrat. Out of 162 Quadrats with amphibians 66 Quadrats had amphibians during dry season 96 Quadrats during wet seasons. However, number of individuals sighted more in dry season (203) than wet season (132).

A total of 1200 hours were spent for searching amphibians in different vegetation types by three personnel (1200 X 3=3600 man-hours). Of the 1200 bouts, 652 (54.33%) had at least one individual amphibian. More than 70% of hours yielded amphibians in three vegetation types *viz.,* Riverine, Shola and Grassland and Evergreen. Absence of amphibians was more than 50% in two vegetation types in Dry deciduous and Rocky slopes with grass (Table 5.2).

Table 5.2. Detection of amphibians in various vegetation types in Megamalai landscape. Number in parentheses are sampling efforts (%).

Vegetation type	Quadrat	VES
Dry Deciduous	9.52 (43.75)	41.75 (42.92)
Moist Deciduous	14.44 (7.50)	64.15 (8.83)
Riverine	23.68 (12.67)	82.47 (12.83)
Rocky slopes with Grass	8.08 (21.67)	44.22 (20.92)
Evergreen	22.48 (10.75)	73.64 (10.75)
Shola and Grassland	29.55 (3.67)	80.00 (3.75)
Total	13.50 (100.00)	54.33 (100.00)

5.3.3. Species richness

Including all observations, 34 species were recorded during this study (see Chapter 3). The highest of 18 species of amphibians from Dry Deciduous and lowest of six species from Riverine were recorded (Table 5.3 and Appendix 4). All vegetation types excluding Dry Deciduous and Riverine had higher (>70%) endemics. Highest percentage of endemic species was in Shola and Grassland followed by Evergreen and Moist deciduous (Table 3).

Table 5.3. Endemics and non endemic amphibians recorded in various vegetation types of Megamalai landscape.

Vegetation type	Endemics	Non endemics
Dry Deciduous	5 (27.78)	13 (72.22)
Moist Deciduous	10 (76.92)	3 (23.08)
Riverine	1 (16.67)	5 (83.33)
Rocky slopes with Grass	9 (75.00)	3 (25.00)
Evergreen	12 (80.00)	3 (20.00)
Shola and Grassland	11 (84.62)	2 (15.38)
Total	20 (58.82)	14 (41.18)

5.3.4. Family richness

Data collected in VES, Quadrat, Road kill and Night and Opportunistic surveys methods were used. Number of Amphibian families observed in various vegetation types varied from four to eight (Table 5.4). The highest of eight families were observed in Evergreen and lowest in Riverine vegetation. Bufonidae, Dicroglossidae and Petropedetidae were found across all vegetation types. The family Nyctibatrachidae was restricted to a few vegetation types. The highest number of Rhacophorid species was found in wet vegetation types compared to dry vegetation. Reverse trend was observed in the case of Dicroglossidae *i.e.* higher number of species in dry vegetation types.

Table 5.4. Amphibian species richness in various vegetation types at Family level in Megamalai landscape.

	Vegetation type [a]						
Family	DD	MD	R	RG	EG	SG	Total
Bufonidae	2	1	1	1	2	2	3
Dicroglossidae	6	1	3	2	1	1	6
Microhylidae	4	0	0	1	1	1	5
Micrixalidae	0	1	0	1	1	1	1
Nyctibatrachidae	0	2	0	1	1	1	2
Petropedetidae	2	3	1	3	4	2	4
Ranidae	1	2	1	0	1	0	2
Rhacophoridae	3	3	0	3	4	5	11
No. of species	18	13	6	12	15	10	34
No. of families	6	7	4	7	8	7	8

[a] DD= Dry Deciduous, MD= Moist Deciduous, R= Riverine, RG= Rocky slopes with Grass, EG= Evergreen, SG= Shola and Grassland

5.3.5. Abundance

The abundance was maximum in Dry Deciduous vegetation and minimum in Shola and Grassland. The abundance of various amphibian families showed different patterns. The Riverine vegetation was dominated by Ranidae, Rocky slopes with grass by Petropedetidae and Evergreen by Rhacophorids. All amphibian families found in dry vegetation had similar representations with respect to abundance (Figure 5.1). Amphibian abundance was not uniform in various vegetation types (χ^2= 639.74; P<0.001).

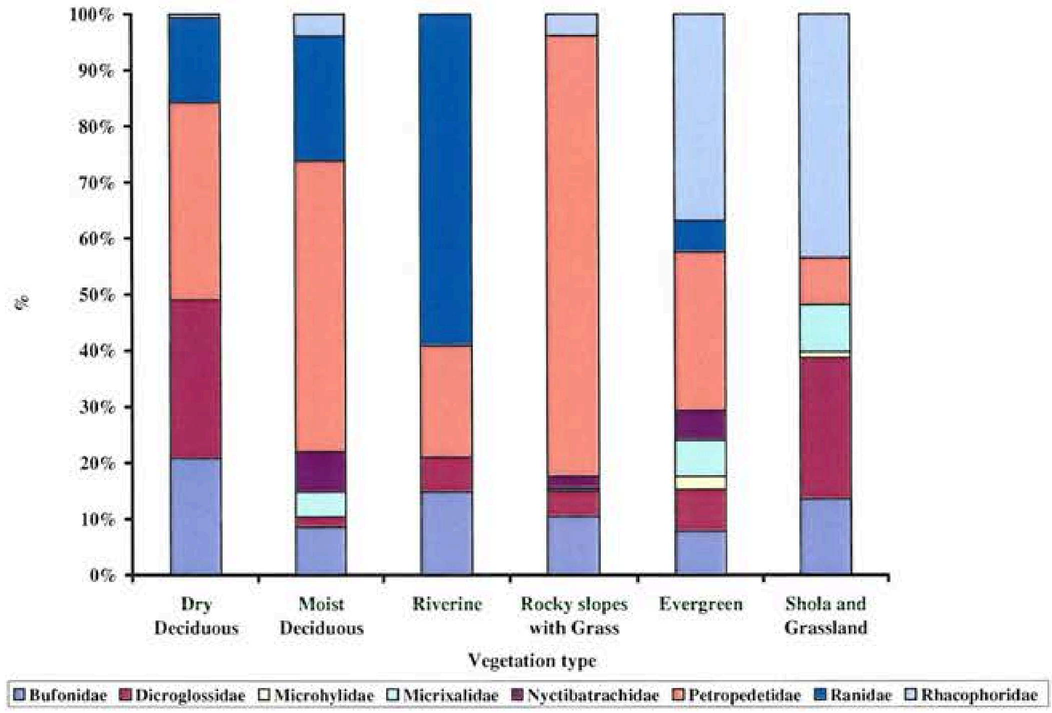


Figure 5.1. Composition of amphibian families in various vegetation types of Megamalai landscape.

5.3.6. Seasonality

The vegetation types, showed significant variation in amphibian species richness with VES subset (F=4.669; P<0.05) between seasons. However, species richness was not varied with Quadrat subset (F=2.194; P>0.05).

Family richness of the amphibians did not vary between seasons VES data set (F=2.797; P>0.05) and Quadrat data set (F=3.040; P>0.05). The number of amphibians varied significantly in VES subset (F=26.454; P<0.001). However, but it was not significant with Quadrate data (F= 2.772; P>0.05).

5.3.7. Diversity

Wet vegetation types such as Evergreen and Shola and Grassland had higher diversity of amphibians compared to dry ones (Table 5). The highest amphibian diversity was found in Evergreen (H'= 2.25) and the lowest in Riverine vegetation (H'= 1.12). The patterns of diversity, density and encounter rate followed different patterns in various vegetation types with respect to amphibians (Table 5.5).

Table 5.5. Amphibian distribution in various vegetation types of Megamalai landscape.

Vegetation type	Shannon-Weiner (H')	Density (No./ha)	Encounter rate (No./ hour)
Dry deciduous	1.91	16.38	0.557
Moist deciduous	1.70	23.33	1.148
Riverine	1.12	30.26	1.340
Rocky slopes with grass	1.70	42.69	0.576
Evergreen	2.25	38.76	0.987
Shola and Grassland	1.92	47.73	1.259
Total	2.31	27.92	0.786

5.3.8. Density

Shola and Grassland had the highest of 47.73/ha amphibian density and lowest of 16.38/ha amphibians recorded in Dry Deciduous.

Overall density of 27.92/ha was recorded in Megamalai. Among the 14 species recorded highest density was recorded for *Indirana semipalmata* followed by *Duttaphrynus melanostictus*, *Indirana beddomii* and *Sylvirana temporalis*. Minimum density was recorded for *Duttaphrynus microtympanum*, *Philautus griet* and *Philautus* sp1. Density of *Philautus wynaadensis*, *Philautus beddomii*, *Philautus griet* and *Indirana leptodactyla* reached >1/ha.

None of the species observed in all the vegetation types. Highest density of 7.78/ha of *Duttaphrynus melanostictus* and *Indirana beddomii* were recorded in Moist Deciduous. Maximum density of 7.62/ha for *Duttaphrynus melanostictus* was documented in dry deciduous. *Indirana semipalmata* had highest density in rocky slopes with grass (33.46/ha). Maximum density of *Philautus griet* (25/ha) and *Philautus beddomii* (10.08/ha) were recorded in Shola and Grassland and evergreen vegetation respectively (Table 5.6).

Highest representation of Rhacophorids was found in Evergreen (4 species). However, density of *Philautus beddomii* and *Philautus griet* were maximum in Shola and Grassland.

Table 5.6. Density (No./ha) of amphibians in various vegetation types in Megamalai landscape. Values in parenthesis is species richness.

S. No	Species	Vegetation type [a]						Mean Density
		DD (7)	MD (6)	R (3)	RG (5)	EG (10)	SG (3)	
1	*Duttaphrynus melanostictus*	7.62	7.78	5.92	2.31	1.55	0.00	5.33
2	*Duttaphrynus microtympanum*	0.00	0.00	0.00	0.00	0.78	0.00	0.08
3	*Fejervarya mudduraja*	0.76	0.00	0.00	0.00	0.00	0.00	0.33
4	*Sphaerotheca breviceps*	1.33	0.00	0.00	0.00	0.00	0.00	0.58
5	*Micrixalus fuscus*	0.00	2.22	0.00	0.00	1.55	0.00	0.33
6	*Indirana beddomii*	3.24	7.78	7.89	3.08	6.20	0.00	4.33
7	*Indirana leptodactyla*	0.00	0.00	0.00	3.46	1.55	4.55	1.08
8	*Indirana semipalmata*	1.33	0.00	0.00	33.46	0.00	0.00	7.83
9	*Sylvirana temporalis*	1.90	2.22	16.45	0.00	0.78	0.00	3.17
10	*Philauts beddomii*	0.00	0.00	0.00	0.00	10.08	18.18	1.75
11	*Philautus griet*	0.00	0.00	0.00	0.38	6.98	25.00	1.75
12	*Philautus wynaadensis*	0.19	2.22	0.00	0.00	8.53	0.00	1.17
13	*Philautus* sp1	0.00	1.11	0.00	0.00	0.00	0.00	0.08
14	*Rhacophorus pleurostictus*	0.00	0.00	0.00	0.00	0.78	0.00	0.08
	Total	16.38	23.33	30.26	42.69	38.76	47.73	27.92

[a] DD= Dry Deciduous, MD= Moist Deciduous, R= Riverine, RG= Rocky slopes with Grass, EG= Evergreen, SG= Shola and Grassland

5.3.9. Comparison anuran densities

Currently data on the density of amphibians are available for Evergreen forest from various parts of the world. A comparison is attempted with respect to the data obtained from the present study.

Anuran densities within Western Ghats differed between Megamalai (0.39/100 m^2) and KMTR (1.49/100 m^2). Except Thailand, rest of the countries had >1/100 m^2. However, considering the area of sampling (m^2) all the study sites differed. The present study shows the poor density compared to other localities (Table 5.7).

Table 5.7. Global level comparison of amphibian density observed in various evergreen forest.

Country	Study site	Mean annual rain fall (mm)	Elev ation (m)	Area sampled (m^2)	Density (100 m^2)	Source
South Asia India	Western Ghats, Megamalai	800-2000	800-1800	12900	0.39	Present study
South Asia India	Western Ghats, KMTR	2500-3500	900-1200	29,550	1.49	Vasudevan *et al.*, 2008
South East Asia Thailand	Sakaerat	1200-1500	100-250	27,812	0.12	Inger, 1980
South East Asia Borneo	Nanga Tekalit	>6000	800-1200	23,342	1.31	Inger, 1980
East Asia Taiwan	Nanjenshan Nature Reserve	3500	10-460	450	6.85	Huang and Hou, 2004
South Asia Philippines	Cuernos de Negros	2500	800-1850	4,326	8.85	Brown and Alcala, 1961
South Asia Sri Lanka	Sinharaja Forest	4000	400	2,880	12.5	Wijesinghe and Dayawansa, 2002
Africa Cameroon	Douala-Ede'aGame Reserve	4000	50	870	9.4	Scott, 1982
Central America Costa Rica	La Selva, Costa Rica	3600-4000	800-2500	2,266	13.15	Inger, 1980
Central America Panama	Silugandi	>2000	50-200	235	29.8	Heatwole and Sexton,1966
South America Brazil	INPA-WWF Reserve	2000-2500	150	12,525	4.76	Allmon, 1991

5.3.10. Encounter rate

Encounter rate was >1 in three vegetation types Riverine (1.340/man-hour), Shola and Grassland (1.259/man-hour) and Moist Deciduous (1.148/man-hour) (Table 5.8).

Of the total 19 species recorded by VES method, *Indirana beddomii* (0.189/man-hour) was the numerically dominant species. *Duttaphrynus melanostictus*, (0.102/man-hour) was frequently encountered in Dry Deciduous. Highest encounter rate of *Indirana beddomii* was recorded in Moist deciduous (0.531/man-hour), Evergreen (0.214/man-hour) and Rocky slopes with grass (0.193/man-hour). *Sylvirana temporalis* (0.797/man-hour) was the frequently sighted in Riverine. *Limnonectes brevipalmatus* (0.356/man-hour) was recorded in Shola and Grassland (Table 5.8).

5.3.11. Similarity between vegetation types

The highest similarity in amphibian species was observed between Rocky slopes with and Evergreen vegetation (0.814). Riverine vegetation had low similarity with other vegetation types. Similarity was less between distant vegetation types. Equal of five pairs had 20-40% and 40-60% similarity. Four pairs had 60-80% similarity and >80% similarity recorded in only one pair (Table 5.9).

Reduction in the similarity was observed on dry to wet vegetation gradients. The similarity of amphibian between pairs of vegetation types was lower compared to the similarity pairs. This indicated that the vegetation types play higher role in influencing formation of distinct amphibian communities in the Megamalai landscape (Table 5.9).

Table 5.8. Species wise Encounter rate of amphibians in Megamalai Landscape. Number in parenthesis is number of species.

S. No	Species	Vegetation type [a]						Mean ER (19)
		DD (9)	MD (10)	R (5)	RG (12)	EG (12)	SG (10)	
1	*Duttaphrynus melanostictus*	0.102	0.082	0.195	0.068	0.080	0.089	0.1019
2	*Duttaphrynus microtympanum*	0.000	0.000	0.000	0.000	0.000	0.104	0.0039
3	*Euphlyctis cyanophlyctis*	0.021	0.000	0.065	0.000	0.000	0.000	0.0175
4	*Fejervarya mudduraja*	0.093	0.022	0.024	0.000	0.000	0.000	0.0447
5	*Limnonectes brevipalmatus*	0.005	0.000	0.000	0.032	0.083	0.356	0.0308
6	*Sphaerotheca breviceps*	0.048	0.000	0.000	0.001	0.000	0.000	0.0208
7	*Ramanella montana*	0.000	0.000	0.000	0.003	0.026	0.015	0.0039
8	*Micrixalus fuscus*	0.000	0.047	0.000	0.001	0.067	0.119	0.0161
9	*Nyctibatrachus aliciae*	0.000	0.047	0.000	0.015	0.059	0.000	0.0136
10	*Nyctibatrachus beddomii*	0.000	0.041	0.000	0.000	0.000	0.000	0.0036
11	*Indirana beddomii*	0.099	0.531	0.260	0.193	0.214	0.067	0.1886
12	*Indirana leptodactyla*	0.000	0.000	0.000	0.161	0.059	0.037	0.0414
13	*Indirana semipalmata*	0.100	0.041	0.000	0.077	0.005	0.000	0.0633
14	*Indirana* sp1	0.000	0.035	0.000	0.000	0.010	0.000	0.0042
15	*Sylvirana temporalis*	0.087	0.264	0.797	0.000	0.059	0.000	0.1692
16	*Philautus beddomii*	0.000	0.000	0.000	0.016	0.127	0.274	0.0272
17	*Philautus griet*	0.000	0.000	0.000	0.009	0.196	0.193	0.0303
18	*Philautus ponmudi*	0.000	0.000	0.000	0.000	0.000	0.007	0.0003
19	*Philautus wynaadensis*	0.003	0.038	0.000	0.001	0.000	0.000	0.0050
	Total	0.557	1.148	1.340	0.576	0.987	1.259	0.786

[a] DD= Dry Deciduous, MD= Moist Deciduous, R= Riverine, RG= Rocky slopes with Grass, EG= Evergreen, SG= Shola and Grassland

ER=Encounter rate

Table 5.9. Amphibian similarity in various vegetation types of Meghamalai landscape.

Vegetation Type	Vegetation type [a]					
	DD	MD	R	RG	EG	SG
DD	-	0.600	0.714	0.571	0.500	0.315
MD		-	0.500	0.521	0.615	0.285
R			-	0.235	0.300	0.266
RG				-	0.814	0.727
EG					-	0.720
SG						-

[a] DD= Dry Deciduous, MD= Moist Deciduous, R= Riverine, RG= Rocky slopes with Grass, EG= Evergreen, SG= Shola and Grassland

5.3.12. Habitat Characteristics

Principal Component Analysis (PCA) was performed to describe habitat characteristics. Twelve habitat parameters were analyzed to quantify the habitat parameters from 1200 Quadrats. Components with eigen value >1 were taken to explain the factors explaining the habitat characteristics. PCA I, PCA II and PCA III were extracted, which accounted only for 49.53% variance in the data. PC I account for 28.99 % variance and the dominant factors were canopy cover, litter cover, and trees. PC II added another 11.90% of variance which was strongly influenced by rock crevices, boulder and distance from water and only 8.63% of variance account by PC III the dominant factors were boulder, termite hill and ground cover (Table 5.10).

Table 5.10. Principal Component Analysis (Varimax Rotation) explaining habitat characteristics. Three dominant variables of the components were underlined.

Variables	PC1	PC2	PC3
No. of Boulder	-0.011	0.642	-0.332
No. of Fallen log	0.514	-0.334	-0.177
No. of Rock crevices	0.010	0.680	0.073
No. of Tree	0.713	0.061	0.177
No. of Tree hole	0.413	0.213	0.438
No. of Termite hill	-0.005	0.075	0.487
Distance from water (m)	-0.345	0.438	0.162
Ground cover (%)	0.045	0.348	-0.643
Litter cover (%)	0.864	-0.154	0.136
Herb cover (%)	-0.742	-0.201	0.078
Shrub cover (%)	0.482	-0.149	-0.114
Canopy cover (%)	0.894	-0.123	0.116
Eigen values	3.479	1.428	1.036
% of Variance	28.990	11.904	8.637
% Cumulative variance	28.990	40.893	49.530

5.3.13. Factors governing species distribution

Amphibian species richness had influenced by distance to water followed by canopy cover and boulder, soil temperature and humidity. However, amphibian species abundance had relation with distance to water, humidity, soil temperature, shrub cover, litter cover, herb cover, boulders and rocks (Table 5.11).

Table 5. 11. Value showing relationship between environmental parameters with amphibian species richness and abundance in Megamalai landscape.

Microhabitat	Richness	Abundance
Herb cover %	0.0395	0.5346
Shrub cover %	0.367	0.6083
Canopy cover %	0.6166	0.4411
Litter cover %	0.2034	0.5691
No. of Boulders	0.6094	0.5006
No. of Rocks	0.0508	0.5005
No. of Fallen log	0.0509	0.2214
Distance to water (m)	0.8994	0.7938
Soil temperature (C °)	0.4449	0.7340
Humidity (%)	0.4262	0.7726

5.4. DISCUSSION

Vegetation analysis using Point-Centred Quarter method (Krebs, 1989) in intensive study area (21.17 km^2) reveals the occurrence of 157 tree species, which included 43 endemic tree species of Western Ghats. Data on herb (including grass) shrub and orchid diversity of these vegetation types is poorly known, and intensive vegetation studies may yield more species as well.

Of the 1200 Quadrats examined, the detection of amphibians was only 13.50% (162/1200). Allmon (1991) encountered amphibians in 50% of the Quadrats in Brazil. Irrespective of vegetation types absence of amphibians in Quadrat was 70% and above. Occurrences of amphibian were more in wet habitats Shola and Grassland, Evergreen and Riverine vegetation types.

Success of searching by employing VES of 3600 man hours (at least one individual) was 54.33%. Detection of amphibians was greater than 70% (per man-hour) in Riverine, Shola and Grassland and Evergreen. Less than 45% of searching was successful in Dry Deciduous and Rocky slopes with Grass. Though, this method yielded more number of species and individuals compared to Quadrat method during night. This result is consistent with the study by Doan (2003). However, VES method appears to have more daily variation (Doan, 2003).

The presence of amphibians in Quadrat as well as VES were more in wet season contradictorily the abundance was more in dry season than wet season. It indicated due to the presence of moisture everywhere during wet season the amphibian movement in the forest floor increased away from water bodies considerably and during dry season water shrinkage reduced amphibian movement.

A total of 34 species of amphibians were recorded in Megamalai and its enviorns. Species richness ranged between 6 and 18 using regular monitoring protocols. Among the different vegetation types highest number of species was recorded in Dry Deciduous (18 species) and lowest in Riverine vegetation (6 species). However, endemic species were highest in Evergreen (12 species). The high endemism in wet vegetation types indicated the conservation of wet vegetations for conserving amphibian diversity. Differences in species richness at different vegetations imply that frogs respond strongly and differentially to the degree of habitat transformation.

Amphibian families observed in different vegetation types varied from four to eight. Highest of eight families were represented in Evergreen and four families in Riverine vegetation. Family Rhacophoridae and Dicroglossidae showed contradictory trend in distribution. Rhacophoridae was found in highest number in wet vegetation types and Dicroglossidae in dry vegetation types. Inger and Colwell (1977) found most diverse and distinct amphibians in Evergreen forests in Thailand. Daniels (1992) stated that wide spread rainfall was the predominant factor in determining species diversity and Daniels (1995) observed maximum species richness of amphibians in Evergreen vegetation.

Shannon-Weiner diversity was highest in Evergreen vegetation (H'=2.25). According to Fauth *et al.* (1989) sites with high densities have high species richness. However in the present study the result is inconsistent because it depends on the samples. Species diversity is central to all conservation issues and as high diversity areas capture more attention than that with low diversity (Magurran, 1988). It is generally assumed that high species diversity is associated with habitat complexity (Das and De Silva, 1988).

Over all the density of amphibians in Megamalai was 27.92/ha. Density in Shola and Grassland had maximum of 47.73/ha and minimum of 16.38/ha in Dry Deciduous. The average density in Evergreen forests of Kalakad Mundanthurai Tiger Reserve, Western Ghats was 148/ha (Vasudevan *et al.*, 2001). It showed that the density of amphibians comparatively less in Megamalai although all the vegetation types were covered.

The present study revealed density of 0.39/100 m^2 in the study area. The density of anurans was 1.49/100 m^2 in rain forest floor in Kalakad-Mundanthurai Tiger Reserve (Vasudevan *et al.*, 2008). Analysis of density at global level showed that the density of Megamalai (0.39/100 $m^{2)}$ was slightly higher than that of Thailand (0.20/100 m^2). According to Allmon (1991) diversity and abundance of amphibians differ considerably among neotropics, Africa and Southeast Asia which has been attributed due to differences in litter fall rates, mast fruiting, heterogeneity within regions, breeding habitat constraints, and geological history (Allmon, 1991). The differences in density of anurans in the present study were due to elevational width, annual rainfall, vegetation type, sampling methods and sampling effort.

Species wise density and encounter rate of amphibians in various vegetation type followed different pattern. However, there was no comparable data in this regard.

On the basis of VES search (3600 man-hour) encounter rate was higher in three vegetation types *viz.*, Riverine (1.340/man-hour) and Shola and Grassland (1.259/man-hour) and Moist Deciduous (1.148/man-hour). There was no comparable data related to encounter rate available in India. Lack of thick canopy cover created more open area in dry vegetation zones. However, thick canopy was observed in wet vegetation types facilitated greater encounter rate in wet vegetation zones.

Similarity was observed to be high between Rocky slopes with grass and Evergreen (0.814). Riverine had low similarity with all the vegetation types. Vegetation types played significant role in the formation of distinct amphibian communities. Similarity in adjacent vegetation types was due to low fluctuation in temperature and rainfall which triggers the amphibian movement in the adjacent zones.

Principle Component Analysis (PCA) extracted three principal components which account for 49.53% variance in the data. Among the variables canopy cover, litter cover, trees, rock crevices, boulder, distance to water, termite hill and tree hole were influenced the habitat characteristics.

Distance to water had highest relationship with both number of species and abundance than all the other factors analysed. Amphibian abundance had highest relation with soil humidity, soil temperature and shrub cover. Amphibian richness and abundance had moderate relationship with canopy cover, boulder, soil temperature, soil humidity, litter cover and herb cover. Inconsistently, Allmon (1991) reported frogs did not show any correlation with measured environmental variables *viz.*, litter moisture, litter depth, relative humidity, number of trees, palms, herbs, presence and absence of logs, soil types and slope. Consistently, Naniwadekar and Vasudevan (2007) found soil moisture and soil temperature as best predictor of amphibian richness. Also, Vasudevan *et al.* (2001) and Vijaykumar *et al.* (2006) proved water plays major role in amphibian abundance.

5.5. SUMMARY

- In the present study, six vegetation types *viz.*, Dry deciduous, Moist deciduous, Riverine, Rocky slopes with grass and Shola and Grassland were identified using Point-Centred Quarter method.
- Totally, 3600 hours of VES and 1200 Quadrats were used to survey amphibians in all the habitats. Detection of amphibians was 13.50% (162/1200) in Quadrats. Success of searching by employing VES of 3600 man-hours was 54.33%.
- Highest number of species was recorded in Dry Deciduous (18 species) considering all the methods (VES, Quadrat, Road kill survey and Night and opportunistic observations). However, by regular monitoring maximum species richness observed in Evergreen (15 species) and minimum in Riverine (5 species). Evergreen forest obtained highest Diversity index (Shannon-Weiner H' and Hills $e^{H'}$).
- Amphibian encounter rate was the highest in Riverine (1.340/man-hour) and lowest in Dry Deciduous (0.557/ man-hour) vegetation. Density in Shola and Grassland had maximum of 47.73/ha and minimum of 16.38/ha in Dry Deciduous.

- Maximum similarity (0.814) was found between Rocky slopes with grass and Evergreen forests.
- Principal Component Analysis (PCA) explained 49.53% of variance in the habitat characteristics.
- Distance from water had highest relationship with amphibian species richness and abundance. Soil humidity and soil temperature had influenced with abundance of amphibians.

6. DISTRIBUTION PATTERN OF SELECT SPECIES

6.1. INTRODUCTION

Understanding species distribution is undoubtedly one of the major goals in ecology (Gaston, 2000). Begon *et al.* (1996) stated that the life history of an organism depends upon the habitat it occupies. Without understanding the habitat requirements of amphibians, it will not be possible to deal with the problems associated with the decline of anurans in India and in particular Western Ghats (Daniels, 1992b). Hence, elucidating the spatial distribution of amphibian in highly threatened landscapes such as Western Ghats is important to initiate conservation action. Despite the high richness with about 311 species in India (Dinesh *et al.*, 2010), their ecology is poorly known (Krishnamurthy, 2003), and studies on this taxa are far behind compared to other vertebrate groups (Gupta, 1998). Understanding the relationship of species to their environment is essential to conserve biodiversity (Greene, 1994). Among the vertebrates, amphibians are probably more choosy about habitats and microhabitats (Daniels, 1992b) and studies in this regard are scanty.

The concept of ecological niche is an important aspect with respect to resource utilization patterns among various communities (Grinnell, 1928). It is the functional role and position of an organism in the community. Elton (1927) defined niche as its place in the biotic environment. Hutchinson (1957) considered niche as the total range of environmental variables to which a species must be adapted (Physical, chemical and biotic) and under which a species population lives and replaces itself. The concept of niche as an "N-dimensional hyper volume" has proved useful as a theoretical tool, especially in relation to competition and competitive exclusion (Green, 1971). Niche utilization may be based on the distribution of organisms within a set of resource states. Niche breadth may be defined as the sum total of the variety of different resources exploited by a species population (Pianka, 1988). In the present chapter, an attempt has been made to analyze various spatial use patterns of select species of amphibians in various elevational gradients, vegetation types and microhabitats in Megamalai landscape.

6.2. METHODS

As described earlier, sampling was restricted to three belt transects, namely Mavadi, Suruli and Vellimalai (see chapter 2). Sampling was done between 400 and 1800 m covering six vegetation types. Point-Centred Quarter (Krebs, 1989) along the transects was used for sampling tree species (see chapter 5). Amphibians were surveyed using Visual Encounter Survey (VES), Quadrat, Road cruising and Night survey and Opportunistic observations (see chapter 3).

On detection of an individual, data on the microhabitat were recorded. Microhabitat data were taken descriptively and then grouped into ten categories (Table 6.1). For each sighting, the distance from water was also measured. Species with greater than 100 observations were included in the analysis.

Table 6.1. Categorization of microhabitat in the present study

Habit*	Microhabitat	Description
Terrestrial	Litter	fallen leaves
	Log	fallen logs (live or dead, under or above)
	On stone	above movable stones
	Under stone	under the movable stones
	On rock	rock surface (fixed rocks)
	Floor	open ground
	Grass	forest floor with grass
Arboreal	Tree	tree holes, bark, branch
Aquatic	Edge of water	on the water line of puddle, streams, check dam etc.
	Water	In water

*includes seven microhabitat related to terrestrial habit (1-7), one to arboreal (8), and two aquatic (9-10)

Niche breadth may be defined as a unit of resource utilisation of an organism. The narrower the niche breadth, the species is more specialized and vice-versa in resource use. Niche breadth value (β) varies from 1 (exclusive use of one resource) to n (using all resource categories considered).

6.2.1. Data analyses

1. One-way ANOVA was used to know the difference among the microhabitat use by select amphibian species.

2. Chi-square test was performed to find out the distribution of amphibian species with respect to water.

3. Niche breadth (β) at elevation, vegetation and microhabitat leaves were calculated using Simpson's diversity index.

$\beta = 1/\sum pi^2$

Where, *pi* is the proportion of individuals in i^{th} category

Niche breadth of all the species for each resource level was calculated and average niche breadth was computed using data from all resource dimensions (Pianka, 1973).

6.3. RESULTS

A total of 34 species of amphibians were recorded in Megamalai landscape (Appendix 3&4). Among the 21 species were encountered during regular sampling (3600 man-hours of VES and 1200 Quadrats).

Of these 21 species, nine of them *viz., Duttaphrynus melanostictus, Fajervarya mudduraja, Limnonectes brevipalmatus, Indirana beddomii, Indirana leptodactyla, Indirana semipalmata, Sylvirana temporalis, Philautus beddomii* and *Philautus griet* were observed over 100 times.

6.3.1. *Duttaphrynus melanostictus*

Among the two Bufonids observed, *Duttaphrynus melanostictus* had 431 sightings. This species was found from 400-1800 m elevation with a mean of 1100 m (Figure 6.11). It was distributed all over, from hill bottom to plateau. Highest number (25.06%) of them were observed in 800-1000 m elevation category followed by 600-800 m. Higher elevation (1600-1800 m) had only fewer individuals (Figure 6.1). Among the different vegetation types, Dry Deciduous had highest number of individuals (45.71%) and Shola and Grassland had the lowest frequency of this species (Figure 6.2).

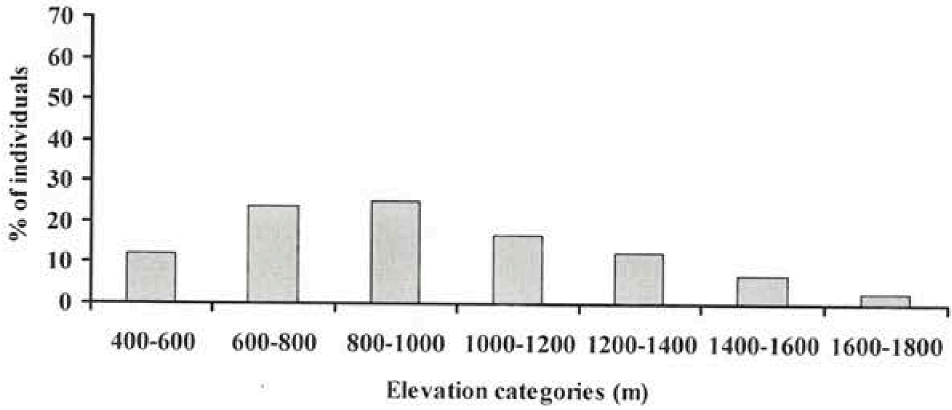


Figure 6.1. Distribution of *Duttaphrynus melanostictus* along the elevational gradients of Megamalai landscape.

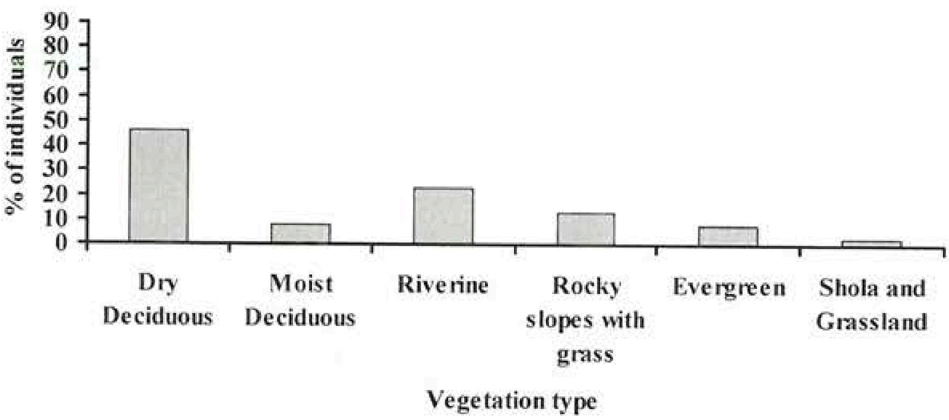


Figure 6.2. Distribution of *Duttaphrynus melanostictus* in various vegetation types of Megamalai landscape.

Six species of Dicroglossidae were observed in Megamalai landscape. Among them, only two species (*Fajervarya mudduraja* and *Limnonectes brevipalmatus*) with >100 observations.

6.3.2. *Fajervarya mudduraja*

A total of 165 individuals of *Fajervarya mudduraja* were observed. This species had restricted distribution between 400 and 1000 m (mean 700 m, Figure 6.11). The number of individuals observed decreased with elevation. The highest number (63.03%) were found in low elevation (400-600 m) and only 12.12% of them were observed in elevational category 800 - 1000 m (Figure 6.3). This species had distribution in Dry Deciduous (89.09%), Riverine (6.67%) and Moist Deciduous (4.24%, Figure 6.2.1).

6.3.3. *Limnonectes brevipalmatus*

Totally 111 individuals of *Limnonectes brevipalmatus* were observed. Among them, higher number (43.24%) was observed at high elevation (1600-1800 m) and lowest (9.91%) between the range of 1000-1200 m (Figure 6.3). Mean elevation range for the species was 1400 m (Figure 6.11). It was not recorded in areas below 1000 m. The highest number of individuals were observed in Shola and Grassland (43.24%) followed by Evergreen (28.83%, Figure 6.4).

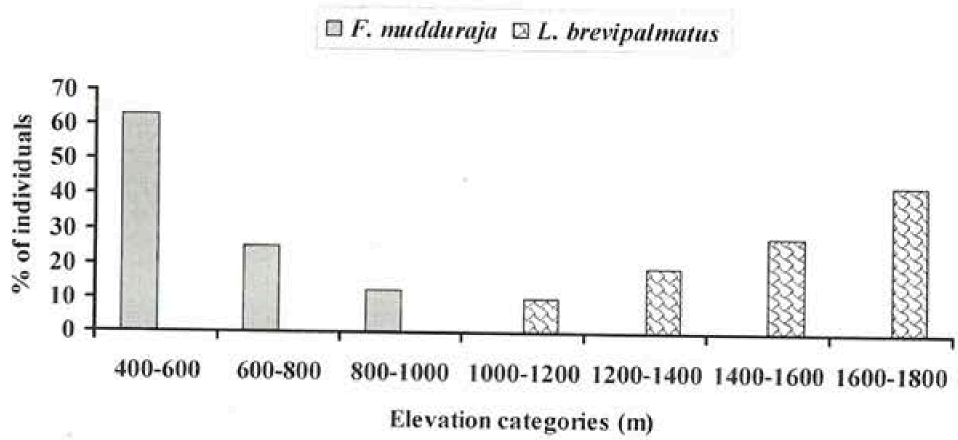


Figure 6.3. Distribution of *Fajervarya mudduraja* and *Limnonectes brevipalmatus* along the elevational gradients of Megamalai landscape.

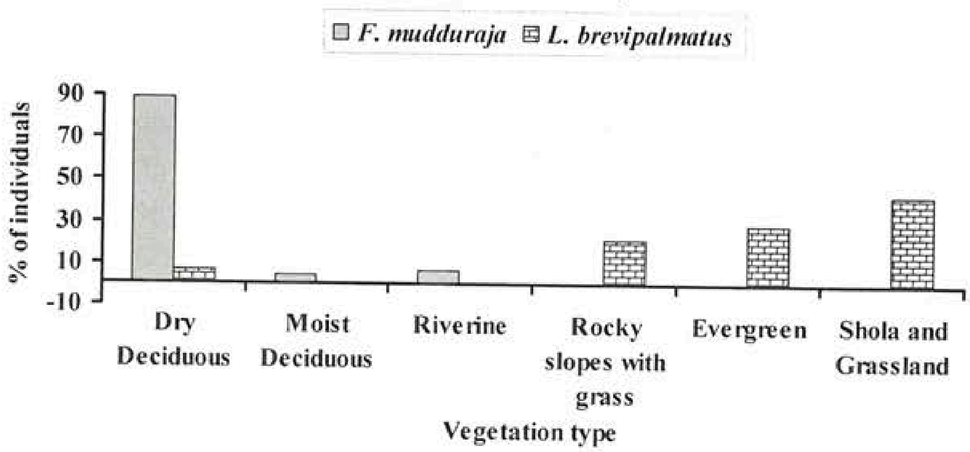


Figure 6.4. Distribution of *Fajervarya mudduraja* and *Limnonectes brevipalmatus* in various vegetation types of Megamalai landscape.

It is found that both species of Dicroglossids differ in the distribution at elevation and forest types in almost mutually exclusive manner.

Four species of Petropedetidae were recorded in Megamalai landscape. Of these, three species (*Indirana beddomii*, *Indirana leptodactyla* and *Indirana semipalmata* had >100 observations.

6.4.4. *Indirana beddomii*

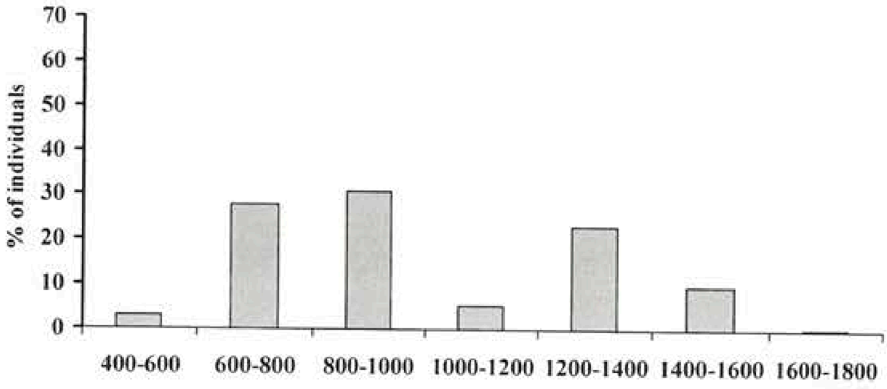
Indirana beddomii was the most common (n= 731) among all *Indirana* species of the present study area and it had distributed in all the elevations and vegetation types. Number of individuals observed were highest (30.78%) at 800-1000 m and lowest (0.27%) at 1600-1800 m (Figure 6.5a). Mean elevation range of this species was 1100 m (Figure 6.11). Highest number of individuals (24.08 %) were observed in Moist Deciduous and lowest number (1.23%) Shola and Grassland (Figure 6.6a).

6.5.5. *Indirana leptodactyla*

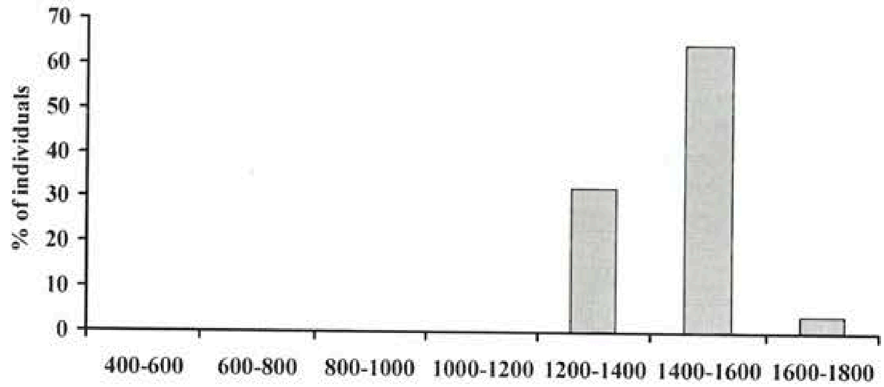
This species had restricted distribution in higher elevations (1200-1800 m). Of the total 162 individuals observed, highest of them (64.20%) was observed at 1400-1600 m and lowest (3.70%) between 1600-1800 m (Figure 6.5b). Mean elevation range of this species was 1500 m (Figure 6.11). Nearly 80.25% of individuals were observed in Rocky slopes with grass followed by Evergreen (15.43%) and Shola and Grassland (4.32%, Figure 6.6b).

6.3.6. *Indirana semipalmata*

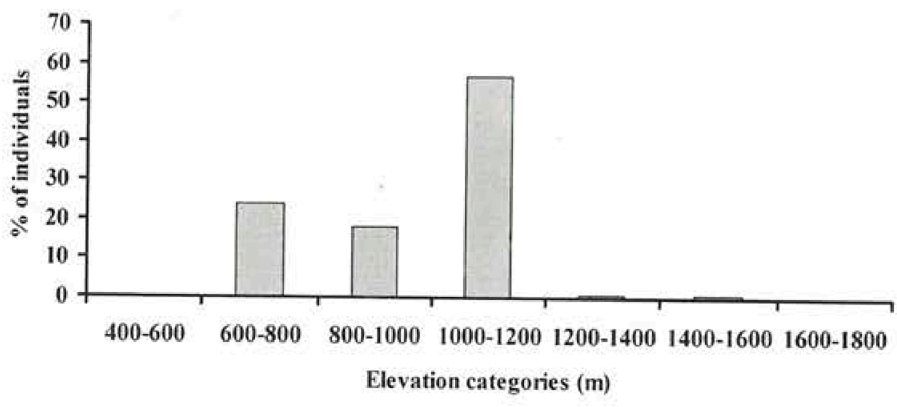
This species had distribution within 600-1600 m elevations. However, the number of individuals encountered was highest (56.83%) in 1000-1200 m elevation category (Figure 6.5c) and only two individuals were sighted in two elevational categories 1200-1400 m and 1400-1600 m. Mean elevation range of this species was 1100 m (Figure 6.11). Dry Deciduous had more than 50% of individuals followed by Rocky slopes with grass (45.03%) rest of the forest types had less than 5% (Figure 6.6c).



a. *Indirana beddomii*

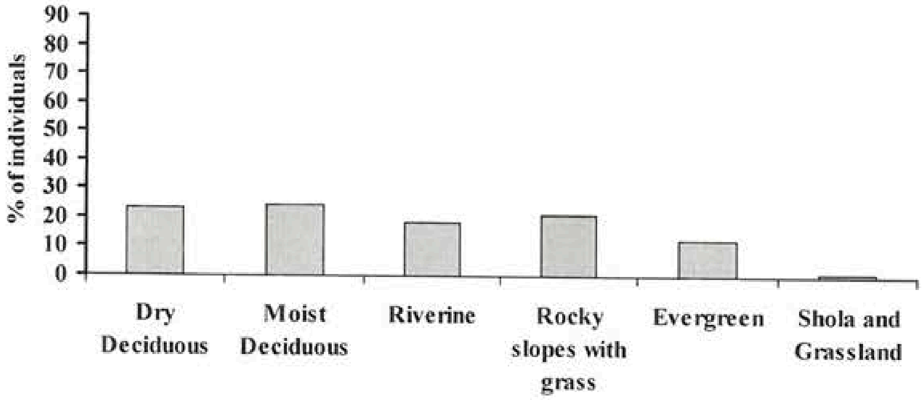


b. *Indirana leptodactyla*

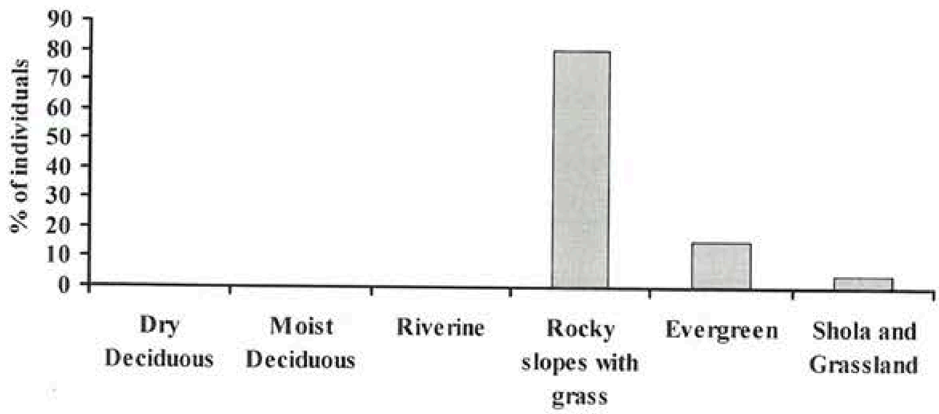


c. *Indirana semipalmata*

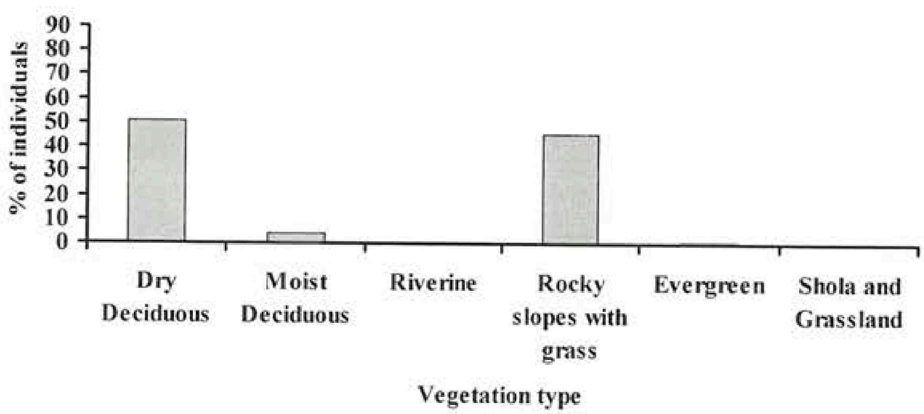
Figure 6.5. Distribution of *Indirana* spp. in various elevational gradients of Megamalai landscape.



a. *Indirana beddomii*



b. *Indirana leptodactyla*



c. *Indirana semipalmata*

Figure 6.6. Distribution of *Indirana* spp. in various vegetation types of Megamalai landscape.

Mean elevational distribution of *Indirana beddomii* and *Indirana semipalmata* was 1100 m. But it was 1500 m in the case of *Indirana leptodactyla. Indirana leptodactyla* and *Indirana semipalmata* separate them selves in elevation and vegetation. It appears that *Indirana beddomii* is versatile in the use of various elevational categories and forest types.

6.3.7. *Sylvirana temporalis*

This species was observed within 400-1400 m elevation range in the study area. Higher number of individuals were observed in two elevational gradients (600-800 m and 800-1000 m, Figure 6.7). Mean elevation range for the species was 900 m (Figure 6.11). Of the 647 individuals observed, the highest of 60.74% were found in Riverine vegetation followed by Dry Deciduous (22.26%). This shows *Sylvirana temporalis* is highly associated with Riverine vegetation (Figure 6.8).

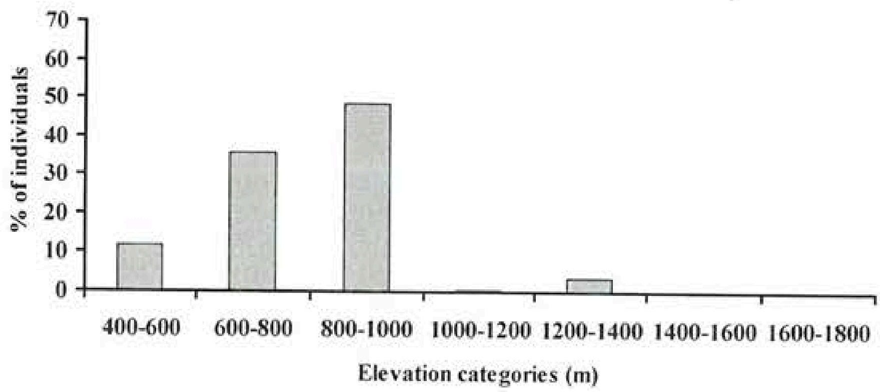


Figure 6.7. Distribution pattern of *Sylvirana temporalis* along the elevational gradients of Megamalai landscape.

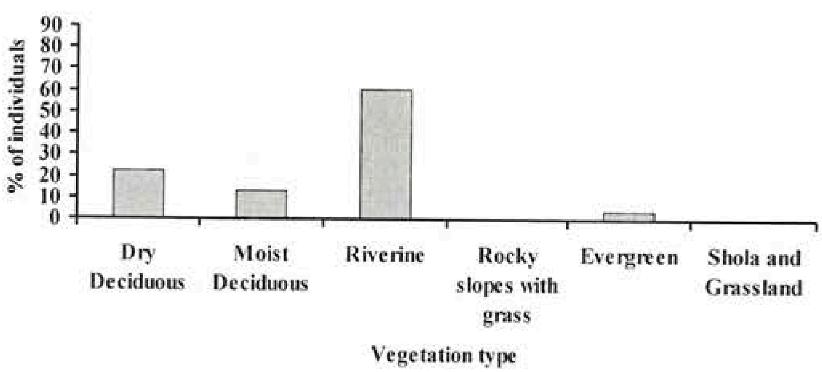


Figure 6.8. Distribution pattern of *Sylvirana temporalis* in various vegetation types of Megamalai landscape.

Elevan species of *Philautus* were recorded during the study. Among them, *Philautus beddomii* and *Philautus griet* were recorded over 100 individuals.

6.3.8. *Philautus beddomii*

A total of 119 individuals were observed in Megamalai landscape. Number of individuals was higher in 1400-1600 m (54.62%, Figure 6.9) followed by 1600-1800 m (34.45%) and 1200-1400 m (10.92%). Mean elevation range of this species was 1500 m (Figure 6.11). This species was observed only in three vegetation types (Figure 6.10) *viz.*, Rocky slopes with grass (10.08%), Evergreen (52.10%) and Shola and Grassland (37.82%).

6.3.9. *Philautus griet*

A total of 130 individuals were observed. Highest percentage (42.31%) of individuals were seen between 1400-1600 m, followed by 1200-1400 m (30.00%) and 1600-1800 m (27.69%, Figure 6.9). Eighty-five individuals (65.38%) were observed in Evergreen followed by Shola and Grassland (28.46%) and Rocky slopes with grass (6.15%, Figure 6.10).

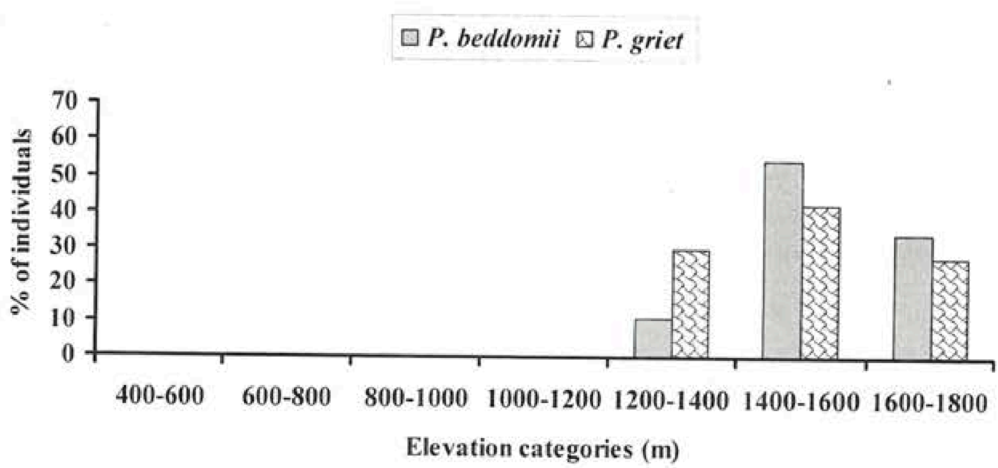


Figure 6.9. Distribution of *Philautus beddomii* and *Philautus griet* along the elevational gradients of Megamalai landscape.

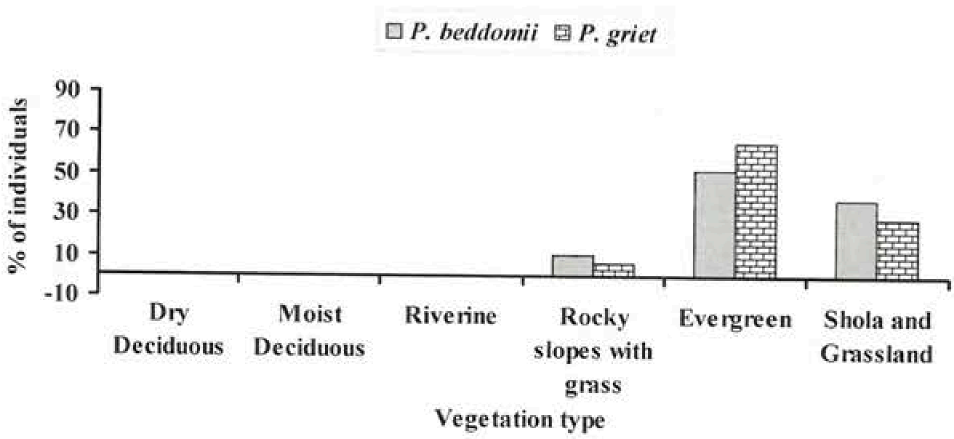


Figure 6.10. Distribution of *Philautus beddomii* and *Philautus griet* in various vegetation types of Megamalai landscape.

Both species showed similar pattern with respect to their distribution along the elevation and forest types. They were restricted to 1200-1800 m with a mean elevation of 1500 m (Figure 6.11). Of the select species, mean elevational range of *Fajervarya mudduraja* was alone below 800 m (*i.e.* Low elevation) whereas rest of the species had above 800 m (Figure 6.11).

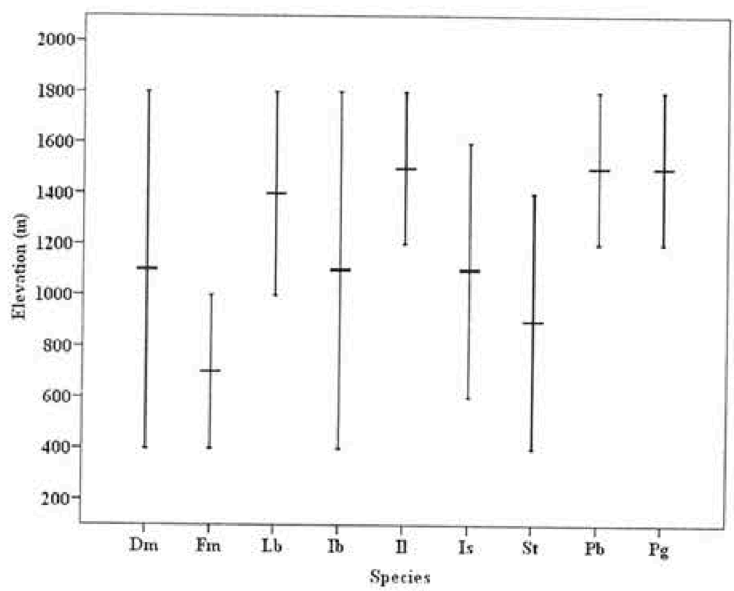


Figure 6.11. Overall mean elevation range of select species in Megamalai landscape.

[a] = Dm= *Duttaphrynus melanostictus*, Fm= *Fajervarya mudduraja*, Lm= *Limnonectes brevipalmatus*, Ib= *Indirana beddomii*, Il= *Indirana leptodactyla*, Is= *Indirana semipalmata*, St= *Sylvirana temporalis*, Pb= *Philautus beddomii*, Pg= *Philautus griet*

6.3.10. Microhabitat use

Descriptive records of microhabitats of amphibians were categorized in to ten types as seven terrestrial, one arboreal and two aquatic. The toad *Duttaphrynus melanostictus* used all the ten microhabitats. However, majority of them were found on the floor (29.70%), in the grass (27.15%) and in the litter (21.81%, Table 6.2, Figure 6.12). Majority of the toads were observed in terrestrial microhabitats (96.06%). Only a few of them were found in water aquatic or above ground.

Dicroglossids (*Fajervarya mudduraja.* and *Limnonectes brevipalmatus*) used eight microhabitats and majority of them were recorded in and around water. Higher number (70.27%) of *Limnonectes brevipalmatus* were observed in aquatic microhabitats, but only 52.73% of *Fajervarya mudduraja* were found in water and edge of water. Above ground (arboreal) microhabitats was not used by Dicroglossids.

Among the members of genus *Indirana*, *Indirana beddomii* used ten microhabitats and *Indirana leptodactyla* and *Indirana semipalmata* were found in nine microhabitats. Majority of the observations of genus *Indirana* were found to be terrestrial microhabitats (*Indirana beddomii* 83.86%, *Indirana leptodactyla* 96.91% and *Indirana semipalmata* 87.27%). Litter (33.38%) was the most used microhabitat by *Indirana beddomii* and Grass by *Indirana leptodactyla* (29.01%) and *Indirana semipalmata* (39.71%).

Sylvirana temporalis was found in all microhabitat categories. About 65% of frogs were recorded in terrestrial microhabitats followed by aquatic 34.78%. However, highest number of individuals were observed in the edge of water (26.74%) followed by litter (24.73%, Table 6.2).

Genus *Philautus* (*Philautus beddomii* and *Philautus griet*) was found in all the eight non-aquatic microhabitats. Both the species were frequently observed in litter (*Philautus beddomii* 42.02% and *Philautus griet* 44.62%).

In all, amphibians of Megamalai were largely terrestrial (79.52%) and only few of them used arboreal microhabitats (Table 6.3). All the species used terrestrial microhabitat. Among the terrestrial microhabitat litter was the most used microhabitat (23.85%). Four species *viz.*, *Indirana beddomii*, *Indirana semipalmata*, *Sylvirana* *temporalis* and *Philautus beddomii* were observed in arboreal microhabitats. No *Philautus* species was found in water.

Overall microhabitat use by amphibians showed that the highest percentage of amphibians used litter followed by grass, floor, on rock, edge of water and water (Figure 6.12). The microhabitat use by select amphibians varied significantly (F=3.012; P<0.001).

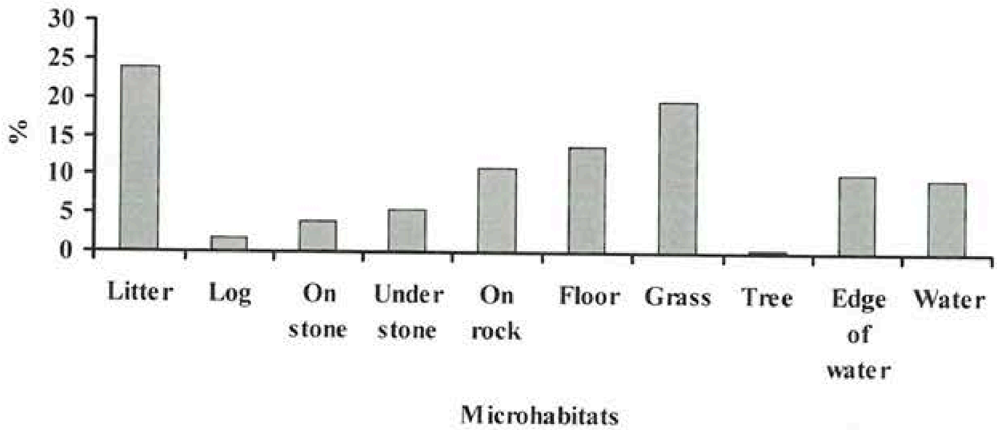


Figure 6.12. Overall microhabitat use by amphibians in Megamalai landscape.

6.3.11. Distribution with respect to water

In all, 59.76% of amphibians observed in Megamalai landscape were distributed in and around (5 m) of water (Table 6.4, Figure 6.13). Only, 20.65% of toads (*Duttaphrynus melanostictus*) were found with in 5 m of water. *Fajervarya mudduraja* (87.88%) and *Limnonectes brevipalmatus* (91.89%) were found 0-5 m of water. Among the all the species *Limnonectes brevipalmatus* highest percentage of 82.88% individuals were found within water. It indicates Dicroglossids showed more depend on water. More than 55% all the species of *Indirana* were found within 5 m radius of water. However, *Indirana leptodactyla* was found 79.63% in and around 5 m of water. Nearly, 76% of *Sylvirana temporalis* was distributed in and around 5 m radius of water. Greater than 70% of genus *Philautus* were distributed away from water bodies *i.e.* >10 m (Table 6.4). Distribution of select amphibians with water were not even (χ^2 =4167.78; P<0.001).

Table 6.2. Microhabitat use (%) by select amphibians in Megamalai landscape.

Species[a]	Dm	Fm	Lb	Ib	Il	Is	St	Pb	Pg	Overall
Litter	21.81	18.79	4.50	33.38	4.94	6.83	24.73	42.02	44.62	23.85
Log	3.02	0.61	0.00	1.37	0.62	0.31	1.24	5.88	8.46	1.85
On stone	3.02	0.00	4.50	3.69	1.85	0.93	8.04	2.52	2.31	3.87
Under stone	6.50	0.61	1.80	3.15	26.54	2.48	0.46	10.08	27.69	5.54
On rock	4.87	7.27	2.70	11.08	27.78	20.50	11.90	1.68	0.77	10.93
Floor	29.70	11.52	5.41	11.76	6.17	16.46	11.44	9.24	3.08	13.88
Grass	27.15	8.48	10.81	19.43	29.01	39.75	6.96	26.89	12.31	19.62
Tree	0.93	0.00	0.00	0.27	0.00	0.93	0.46	1.68	0.77	0.53
Edge of water	1.62	18.79	16.22	8.21	0.62	0.00	26.74	0.00	0.00	10.29
Water	1.39	33.94	54.05	7.66	2.47	11.80	8.04	0.00	0.00	9.65
N	431	165	111	731	162	322	647	119	130	2818

Table 6.3. Habits of select amphibians (%) of Megamalai landscape

Habits	Dm	Fm	Lb	Ib	Il	Is	St	Pb	Pg	Overall
Terrestrial	96.06	47.27	29.73	83.86	96.91	87.27	64.76	98.32	99.23	79.52
Arboreal	0.93	0.00	0.00	0.27	0.00	0.93	0.46	1.68	0.77	0.53
Aquatic	3.02	52.73	70.27	15.87	3.09	11.80	34.78	0.00	0.00	19.94
N	431	165	111	731	162	322	647	119	130	2818

[a] = Dm= *Duttaphrynus melanostictus*, Fm= *Fajervarya mudduraja*, Lm= *Limnonectes brevipalmatus*, Ib= *Indirana beddomii*, Il= *Indirana leptodactyla*, Is= *Indirana semipalmata*, St= *Sylvirana temporalis*, Pb= *Philautus beddomii*, Pg= *Philautus griet*

Table 6.4. Distribution of amphibians with respect to water in Megamalai landscape.

Distance from water	Dm	Fm	Lb	Ib	Il	Is	St	Pb	Pg	overall
	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)
0	17(3.94)	106(64.24)	92(82.88)	231(31.60)	101(62.35)	151(46.89)	233(36.01)	23(19.33)	6(4.62)	960(34.07)
1-5	72(16.71)	39(23.64)	10(9.01)	239(32.69)	28(17.28)	30(9.32)	273(42.19)	11(9.24)	22(16.92)	724(25.69)
6-10	42(9.74)	4(2.42)	2(1.80)	57(7.80)	10(6.17)	2(0.62)	54(8.35)	14(11.76)	15(11.54)	200(7.10)
11-15	18(4.18)	0(0.00)	0(0.00)	8(1.09)	1(0.62)	0(0.00)	16(2.47)	3(2.52)	2(1.54)	48(1.70)
16-20	22(5.10)	4(2.42)	3(2.70)	17(2.33)	3(1.85)	3(0.93)	14(2.16)	5(4.20)	2(1.54)	73(2.59)
21-25	30(6.96)	0(0.00)	0(0.00)	24(3.28)	1(0.62)	2(0.62)	2(0.31)	2(1.68)	1(0.77)	62(2.20)
26-30	11(2.55)	2(1.21)	1(0.90)	10(1.37)	0(0.00)	2(0.62)	5(0.77)	1(0.84)	0(0.00)	32(1.14)
31-35	1(0.23)	0(0.00)	0(0.00)	0(0.00)	0(0.00)	0(0.00)	0(0.00)	0(0.00)	0(0.00)	1(0.04)
36-40	20(4.64)	0(0.00)	1(0.90)	10(1.37)	0(0.00)	1(0.31)	0(0.00)	1(0.84)	0(0.00)	33(1.17)
>40	198(45.94)	10(6.06)	2(1.80)	135(18.47)	18(11.11)	131(40.68)	50(7.73)	59(49.58)	82(63.08)	685(24.31)
Total	431(100)	165(100)	111(100)	731 (100)	162(100)	322(100)	647(100)	119(100)	130(100)	2818(100)

[a] = Dm= *Duttaphrynus melanostictus*, Fm= *Fajervarya mudduraja*, Lm= *Limnonectes brevipalmatus*, Ib= *Indirana beddomii*, Il= *Indirana leptodactyla*, Is= *Indirana semipalmata*, St= *Sylvirana temporalis*, Pb= *Philautus beddomii*, Pg= *Philautus griet*

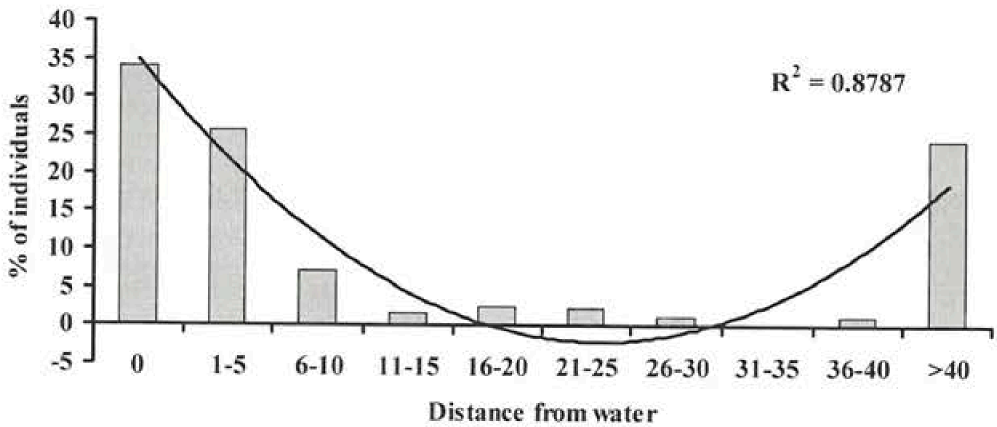


Figure 6.13. Overall distribution of select species of amphibians with respect to water in Megamalai landscape. The fitted line is shown with R^2 value.

6.3.12. Niche breadth

Niche breadth of select species in elevation ranged from β=1.94 to 5.45. In vegetation it was β=1.25-4.90 and in microhabitat it ranged between β= 2.96 and β=5.62. Average niche breadth of select amphibian species ranged from β=2.54-4.78 (Table 6.5).

Elevation-wise niche breadth of *Duttaphrynus melanostictus* (β=5.45) was highest than rest of the eight species analysed. The average niche breadth was β =4.49. Among the Dicroglossids, *Limnonectes brevipalmatus* had highest niche breadth at elevation and vegetation. But the microhabitat niche breadth was highest in *Fajervarya mudduraja*. However, average niche breadth was highest in *Limnonectes brevipalmatus*. Among the genus *Indirana*, *Indirana beddomii* had highest niche breadth value at elevation, vegetation, and microhabitat. Moreover, vegetation niche breadth and also the average niche breadth values were higher than rest of the eight species. Average niche breadth of *Sylvirana temporalis* was β=3.52. Microhabitat niche breadth (β=5.62) was higher than all the other species. Elevation and vegetation niche breadth was β=2.66 and β=2.29 respectively. Only little variation in the average niche breadth values of genus *Philautus*. *Philautus beddomii* had highest niche breadth value at vegetation and microhabitat. But *Philautus griet* had highest value at elevation.

At elevation maximum niche breadth was in *Duttaphrynus melanostictus* (β=5.45) and minimum in *Indirana leptodactyla* (β=1.94). At vegetation level niche breadth was highest in *Indirana beddomii* (β=4.90) and lowest in *Fajervarya mudduraja* (β=1.25). At microhabitat dimension *Indirana beddomii* (β=5.25) showed maximum niche breadth value and minimum was *Limnonectes brevipalmatus*. On an average *Duttaphrynus melanostictus* reached maximum of β=4.49 and minimum was *Indirana leptodactyla* (β=2.54).

Table 6.5. Niche Breadth (β) of select amphibians in Megamalai landscape.

S.No	Species[a]	No of individuals	Elevation (7)	Vegetation (6)	Microhabitat (10)	Average niche breadth (8)
1	Dm	431	5.45	3.43	4.58	4.49
2	Fm	165	2.11	1.25	4.73	2.70
3	Lb	111	3.22	3.12	2.96	3.10
4	Ib	731	4.19	4.90	5.25	4.78
5	Il	162	1.94	1.49	4.18	2.54
6	Is	322	2.42	2.19	4.06	2.89
7	St	647	2.66	2.29	5.62	3.52
8	Pb	119	2.33	2.36	3.67	2.79
9	Pg	130	2.89	1.95	3.34	2.73

[a] = Dm= *Duttaphrynus melanostictus*, Fm= *Fajervarya mudduraja*, Lm= *Limnonectes brevipalmatus*, Ib= *Indirana beddomii*, Il= *Indirana leptodactyla*, Is= *Indirana semipalmata*, St= *Sylvirana temporalis*, Pb= *Philautus beddomii*, Pg= *Philautus griet*

6.4. DISCUSSION

As mentioned earlier, 34 species of amphibians were recorded from Megamalai landscape. Nine species (*Duttaphrynus melanostictus*, *Fajervarya mudduraja*, *Limnonectes brevipalmatus*, *Indirana beddomii*, *Indirana leptodactyla*, *Indirana semipalmata*, *Sylvirana temporalis*, *Philautus beddomii* and *Philautus griet*) were observed for over 100 times, and the same was analysed in terms of distribution in relation to elevation, vegetation, microhabitat and water body.

Among the 34 species of amphibians observed in this study *Indirana beddomii* (n=731) was the most common (731) followed by *Sylvirana temporalis* and *Duttaphrynus melanostictus*. *Duttaphrynus melanostictus* and *Indirana beddomii* are widely distributed across all the elevation gradients and vegetation types indicating their tolerance to environmental gradients. Daniels (1992) reported *Duttaphrynus melanostictus* distributed from 0 to 2600 m and *Indirana beddomii* till 1400 m. Vijayakumar *et al.* (2006) reported the species *Indirana beddomii* as one of the dominant species in Dry forests of Kalakad-Mundanthurai Tiger Reserve, Western Ghats.

Fajervarya mudduraja was distributed from 400-1000 m with a mean elevation of 700 m. On the other hand, *Limnonectes brevipalmatus* was distributed from 1000-1800 m with its mean elevation range being 1400 m. Both the species belongs to the family Dicroglossidae. Abundance of *Fajervarya mudduraja* (63.03%) was highest between 400-600 m elevation, whereas the maximum abundance of *Limnonectes brevipalmatus* (43.24%) was between 1600-1800 m. While the abundance of *Fajervarya mudduraja* was highest in Dry Deciduous vegetation type, that of *Limnonectes brevipalmatus* was in Shola and Grassland. There is no comparable data available on abundance level for *Limnonectes brevipalmatus* and *Fajervarya mudduraja*. Distribution pattern of *Fajervarya mudduraja* and *Limnonectes brevipalmatus* was inverse to each other the difference in the distribution pattern at elevation and at vegetation clearly indicates that *Fajervarya mudduraja* and *Limnonectes brevipalmatus* almost mutually exclusive species in Megamalai landscape. *Fajervarya mudduraja* is a recently described species by Kuramoto *et al.*, 2007. Earlier the species was considered as *Fajervarya limnocharis*, which was later separated into four species.

The species under the genera *Indirana*, *Indirana leptodactyla* and *Indirana semipalmata* were distributed in three (1200-1800 m) and five elevational gradients (600-1600 m) respectively. However, *Indirana beddomii* was distributed through all the elevational gradients and in all the vegetation types. Vasudevan *et al.* (2001) and Vijayakumar *et al.* (2006) showed the abundance of genus *Indirana* was low in Kalakad-Mundanthurai Tiger Reserve, Western Ghats. However, the present study shows greater abundance of genus *Indirana* in Rocky slopes with grass (35.23%) and

Dry Deciduous (27.33). Moreover, the sampling was carried out from hill bottom to top covering all the vegetation types and the effort was 3600 man-hours and 1200 Quadrat searches. This may be due to variation in the elevational gradients, various vegetation types and other bioclimatic regimes.

Sylvirana temporalis the second abundant species in Megamalai had the mean elevational range of 900 m, and it had distribution in five elevational gradients (400-1400 m). Abundance was highest between 600-1000 m and highest representation in Riverine vegetation. This species showed discontinuous distribution (0-1200 m and 1800 to 2000 m) in the Western Ghats (Daniels, 1992). However, in the present study this species was distributed from 400 m to 1400 m. Also, Vasudevan *et al.* (2001) reported *Sylvirana temporalis* is the dominant species in Kalakad-Mundanthurai Tiger Reserve of Western Ghats. It is one of the dominant (third dominant) species in Dry forests of Kalakad-Mundanthurai Tiger Reserve (Vijayakumar *et al.*, 2006) and in Evergreen forests of Ponmudi hills (Inger *et al.*, 1987). Presence of streams in all the above sites could be one of the reasons for the abundance of *Sylvirana temporalis*. The dependency of *Sylvirana temporalis* to water has already been reported by (Daniels, 2005; Srinivas and Bhupathy, 2009).

Though the representation of genus *Philautus* was higher in terms of species richness (6 species), but only two species *viz., Philautus beddomii* and *Philautus griet* recorded more than 100 individuals. These two species were distributed only above 1200 m and had a mean elevation range of 1500 m. Both the species had maximum abundance in Evergreen and Shola and Grassland. Inger *et al.*, (1987) stated that several species of *Philautus* are confined to high elevation. According to Daniels (1992) species preferring the moist evergreen vegetation tend to have patchy distributions.

Of the 2818 observations of select species of amphibians, 79.52% observations were in terrestrial microhabitats and the rest in aquatic microhabitats 19.94% and 0.53% in arboreal microhabitats. Statistically, significant difference was calculated in microhabitats. It showed the different species differ in usage of microhabitat. Dependence on an aquatic and nonaquatic microhabitat to complete their life cycle by amphibians is well known (Duellman, 1989). According to Inger *et al.* (1987) usage of microhabitats by amphibians reflects the nature of area rather than behaviour of individuals. Poor representation *Philautus* in above ground microhabitats showed their terrestrial habits rather than arboreal. Also, the genus *Philautus* inhabits direct development they do not require water to complete their life cycle (Bossyut and Dubois, 2001). Litter was the single and most (23.85%) used microhabitat by amphibians. According to Daniels (1991) litter is an important day time refuge for amphibians and also highlighted the problem of leaf litter removal in Western Ghats. Two species of *Indirana* (*Indirana leptodactyla* and *Indirana semipalmata*) used grass as major microhabitat. Other microhabitats were largely absent in the habitat of these species.

Fajervarya mudduraja and *Limnonectes brevipalmatus* showed narrow distribution because they are restricted to aquatic microhabitats. Higher representation of *Philautus beddomii* and *Philautus griet* in litter, which may prevent loss of water due to evapotranspiration. Also these species occurred only in high elevations (1200-1800 m). Naniwadekar and Vasudevan (2007) stated arboreal species richness increased in higher elevations in Western Ghats.

Indirana beddomii, Sylvirana temporalis and *Duttaphrynus melanostictus* found in all the microhabitats, and also encountered frequently *i.e.* more than 400 observations. This indicates that common/abundant species are generalist in microhabitat use. However, *Sylvirana temporalis* seen more on the edge (bank) of water with leaf around litter. Similar to the present observation, Inger *et al.* (1987) reported *Sylvirana temporalis* species is a widely distributed species in the forest floor of Ponmudi. *Indirana beddomii* was frequently seen in the litter (33.38%) and *Duttaphrynus melanostictus* was frequently observed in floor (29.70%). This is because their greater physiological tolerance and thus found in all the elevation and vegetation types.

Highest proportion of species *Fajervarya mudduraja* (87.88%), *Limnonectes brevipalmatus* (91.89%), *Indirana leptodactyla* (79.63%) and *Sylvirana temporalis* (76.21%) were distributed in and around 5 m of water. It showed these species have strong affinity to water. Though genus *Indirana* were found closer to water (55%) but showed much wider distribution with distance from water. The highest proportion of the members of *Philautus* and *Duttaphrynus melanostictus* were recorded away from water. Bossyut and Dubois (2001) stated genus *Philautus* exhibit direct development and they do not require water for breeding. Also *Duttaphrynus melanostictus* (Toad) need water for breeding however tolerant to wide environmental gradients.

Statistically, distribution of amphibians was not even in relation to water. It shows difference in behaviour of different species in relation to water.

In the present study *Duttaphrynus melanostictus* and *Indirana beddomii* was found in all the elevation gradients, vegetation types and also microhabitats. The average niche breadth was β=4.49 and β=4.78 respectively. It indicates these two species are wide tolerance to environmental gradients and wide habitat requirements and classified as habitat generalists. Among the Dicroglossids, *Limnonectes brevipalmatus* had highest niche breadth at elevation and vegetation. But the microhabitat niche breadth was highest in *Fajervarya mudduraja*. Average niche breadth of *Sylvirana temporalis* was only β=3.52. However, niche breadth with respect to microhabitat was highest (β=5.62) compared to all the other species. It shows that this species use variety of microhabitat. Only little variation in the average niche breadth values of genus *Philautus*. *Philautus beddomii* had highest niche breadth value at vegetation and microhabitat. But *Philautus griet* had highest value at elevation. According to Schoener (1974) and Toft (1985) habitat is the most important dimension partitioned in amphibians. It has to be noted that species occurring in litter in low elevation and high elevation vary also at different vegetation type.

6.5. SUMMARY

- *Indirana beddomii* and *Duttaphrynus melanostictus* were distributed in all the elevational gradients and in all the vegetation types. *Philautus beddomii* and *Philautus griet* were distributed only in higher elevation (1200-1800 m) and recorded more in Evergreen and Shola and Grassland.
- Among the selected species *Indirana beddomii* is the dominant in terms of abundance. The maximum abundance of *Indirana beddomii* was observed between 800-1000 m and Moist Deciduous vegetation. *Sylvirana temporalis* the subdominant species had its higher representation in two elevational gradients (600-1000 m) and the most recorded species in Riverine it shows association with Riverine vegetation.
- Distribution pattern of *Fajervarya mudduraja* and *Limnonectes brevipalmatus* was inverse to each other. *Fajervarya mudduraja* showed highest abundance in low elevation (400-600 m) and in Dry Deciduous, while *Limnonectes*

brevipalmatus had maximum in Shola and Grassland at the elevation between 1600 and1800 m.

- Amphibians of Megamalai were largely terrestrial (79.52) followed by aquatic (19.94) and only 0.53% were arboreal.

- Highest proportion of species *Fajervarya mudduraja* (87.88%), *Limnonectes brevipalmatus* (91.89%), *Indirana leptodactyla* (79.63%) and *Sylvirana temporalis* (76.21%) were distributed in and around 5 m of water. Members of genus *Philautus* (56.63%) and *Duttaphrynus melanostictus* (45.94%) were recorded away from >40 m.

- Niche breadth with respect to elevation was highest in *Duttaphrynus melanostictus* (β=5.45). *Indirana beddomii* had the highest (β=4.78) niche breadth in vegetation types. *Sylvirana temporalis* obtained the highest niche breadth β=5.65 along the microhabitat categories. Average niche breadth was higher in *Indirana beddomii* β=4.78. *Duttaphrynus melanostictus* and *Indirana beddomii* was found in all the elevation gradients, vegetation types and also microhabitats. It indicates that these two species are habitat generalists.

7. CONSERVATION OF AMPHIBIANS

7.1. INTRODUCTION

Amphibians are ancient vertebrate group evolved about 350 million years ago (Duellman and Trueb, 1994). Currently, 6638 amphibian species are reported and the same are placed in three orders namely Anura (frogs and toads), Caudata (salamanders) and Gymnophiona (caecilians) (Frost, 2010). Amphibians comprised significant portion of vertebrate biomass (Burton and Likens, 1975; Gibbons *et al.*, 2006).

7.2. GLOBAL SCENARIO

Among the world's vertebrate populations amphibians have the highest proportion of species under verge of extinction (Stuart *et al.*, 2004), and their decline rate has increased over the past 25 years (Beebee and Griffith, 2005). Numerous factors contribute to these decline (Blaustein *et al.*, 2003); habitat destruction (Daniels, 1991, 2003; Brooks *et al.*, 2002), infectious diseases (Daszak *et al.*, 2003; Puschendorf *et al.*, 2006) introduced exotic species (Kats and Ferrer, 2003), ultraviolet radiation (Blaustein *et al.*, 1998, 2003; Kiesecker *et al.*, 2001), pollution including pesticides (Davidson *et al.*, 2001; Blaustein *et al.*, 2003; Daniels, 2003; Relyea, 2006; Schiesari *et al.*, 2007), specimen collection (Daniels, 1991), human consumption (Abdulali, 1985) and climate change (Donnelly, 1998; Alexander and Elecheid, 2001; Caray and Alexander, 2003). These factors may act alone or in combinations. Cooper *et al.* (2008) reported that body size and fecundity only affect extinction risk indirectly through their effect on geographical range size. Amphibians are of particular conservation concern because many species have restricted geographical ranges and occur only in localized microhabitats that may be vulnerable to developmental activities (Semlitsch, 2000). The IUCN's Global Amphibian Assessment indicates that as many as a third of amphibian species have undergone severe decline or extinction (Stuart *et al.*, 2004).

The current rate of species extinction is 1000-10,000 times higher than the background rate of 10^{-7}species/species which inferred from fossil record also the rate of extinction is two to five species from tropical forests alone (Singh, 2002). The magnitude of species loss has drawn worldwide attention, fueling attempts to rapidly assess the current status and to conserve amphibian diversity. Increase in species extinction rates caused by anthropogenic pressure has been reported by Ehrlich and Wilson (1991). Global assessment reported that of the world amphibians, 8% of amphibians are critically endangered, 13% endangered and about 23% are data deficient (Stuart *et al.*, 2008).

Among the various threats, habitat loss and fragmentation are the major ones to amphibian population (Beebee and Griffith, 2005; Cushman, 2006). The tropics have some of the fastest rates of degradation of natural land cover (Myres *et al.*, 2000; Mittermeier *et al.*, 2005). Habitat fragmentation alters population viability mainly through the concomitant processes of decrease in habitat availability and increase in isolation of each remaining patch (Joly *et al.*, 2003). Amphibians are sensitive to environmental change and so widely advocated as 'biological indicator' or sensitive indicators of environmental health. The highly permeable nature of skin makes them especially sensitive to pollutants from various sources. Higher number of species and as well as declines are reported from tropical regions. However, eco-toxicological research focusing on this line is meager in tropics (Schiesari *et al.*, 2007).

Climate change is thought to have contributed to the observed decline, and extinction of many amphibian species throughout the world, but the mechanisms as how it happens remain unclear (Reading, 2007). Climate variability also responsible for amphibian decline (Alexander and Eicheid, 2001). Increased temperature, increased length of dry season, decreased soil moisture and increased inter-annual rainfall variability would affect the breeding periodicity and availability of prey (Donnelly, 1998).

Many recent amphibian declines are reportedly associated with Chytridiomycosis (Sánchez *et al.*, 2008). However, these fungi may coexist with some species without causing their decline as well (Sánchez *et al.*, 2008). Chytridiomycosis fungus has not been reported from Indian region so far.

7.3. WESTERN GHATS

IUCN (2009) reported the assessment of 272 amphibian species including 66 % are endemic to the country. Indian amphibians were categorized as least concern 37%, data deficient 35%, endangered 11%, vulnerable 8%, near threatened 4%, critically endangered 5% and extinct 0.5% (Figure 7.1).

The Western Ghats is one of the 34 biodiversity hotspots in India (Mittermeier *et al.*, 2005). The Southern Western Ghats is biologically and topographically more diverse (Pillay, 2009). The Western Ghats possess one of the richest assemblages of amphibian species (157 species) in tropical Asia (Dinesh *et al.*, 2010). Global Amphibian Assessment (GAA) showed that of the 131 species assessed, about 0.7% of the amphibians are extinct and 7.6% are critically endangered (Biju *et al.*, 2008b).

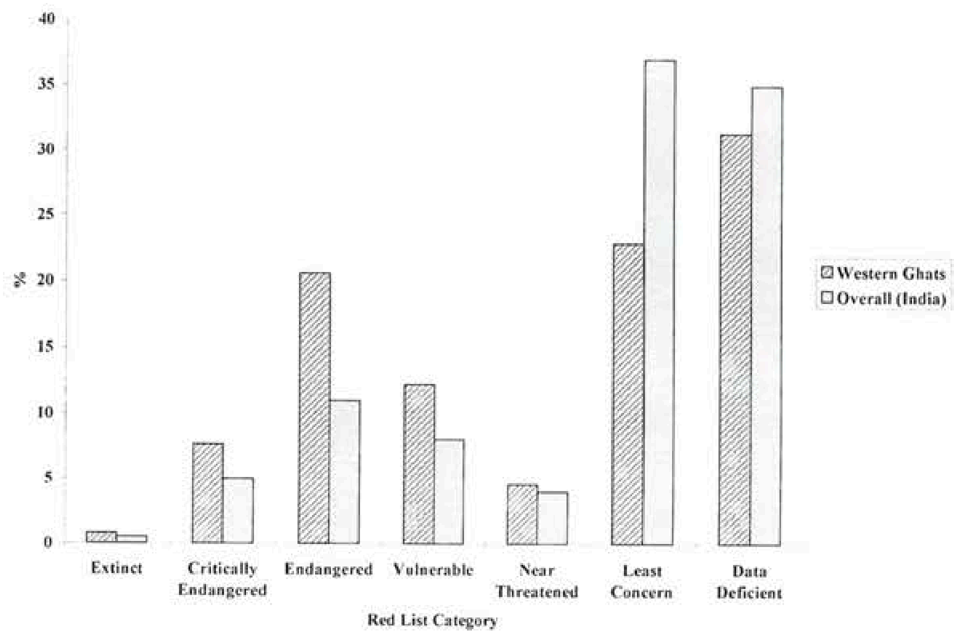


Figure 7.1. Bar diagram showing the status of amphibians (India, Western Ghats) based on assessments.

Several factors are reportedly causing considerable damage to amphibian fauna of the Western Ghats. 1) Habitat destruction (Daniels, 1991; Humraskar and Velho, 2007), 2) Pollution by Tea (*Camellia sinensis*), Coffee (*Coffea arabica*) and Rubber (*Havea brasiliensis*) estates (Daniels, 1991), 3) Draining and diversion (altering natural flow) of water for irrigation and factory use (Daniels, 1991, 2003), 4) Construction of dams (Dutta *et al.*, 2004), 5) Specimen collection for dissection and research (Daniels, 1991), 6) Introduced Mosquito fish *Gambusia affinis* (IUCN, 2009), 7) Road kills due to vehicular traffic (Vijayakumar *et al*., 2001; Seshadri *et al*., 2009; Baskaran and Boominathan 2010; Bhupathy *et al*., 2011), 8) Removal of tree species (Parthasarathy, 2001) and 9) deforestation (Menon and Bawa, 1997). It is reported that over 70 years, 40% of the original natural vegetation were lost or converted to plantations, reservoirs and cultivated lands in Western Ghats (Menon and Bawa, 1997).

7.4. MEGAMALAI

A total of 34 species of amphibians were recorded, which include 21 (61.76%) endemics to the Western Ghats. The highest richness of 16 species of amphibians was observed between 800 and 1000 m elevation category. Among the vegetation types, Dry Deciduous had highest of 18 species. Status category of 31 species is given in Figure 7.2 (IUCN, 2010). *Philautus griet*, *Philautus ponmudi* and *Rhacophorus pseudomalabaricus* comes under Critically Endangered (CR). *Nyctibatrachus aliciae*, *Nyctibatrachus beddomii*, *Indirana leptodactyla*, *Philautus wynaadensis* and *Rhacophorus pleurostictus* listed as Endangered (EN). Only one species *Duttaphrynus microtympanum* comes under Vulnerable (VU). Near Threatened (NT) includes five species *viz.*, *Ramanella montana*, *Micrixalus fuscus*, *Clinotarsus curtipes*, *Sylvirana temporalis* and *Philautus beddomii*. One species (*Limnonectes brevipalmatus*) was categorised under Data Deficient (DD). Nearly, 16 species comes under Least Concern (LC).

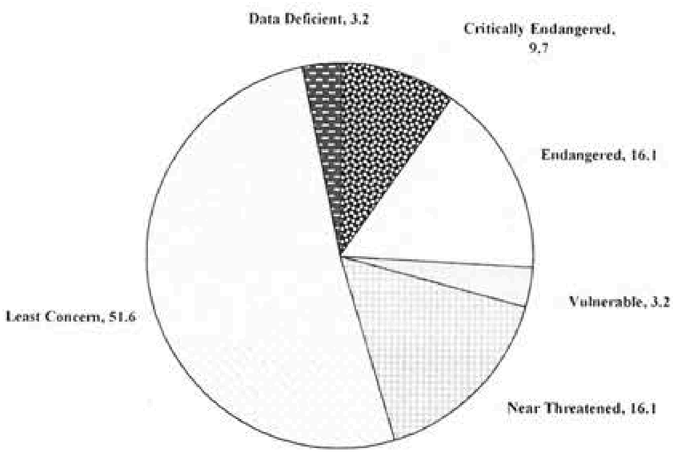


Figure 7.2. Pie diagram showing the status of Western Ghats amphibians based on IUCN Red List.

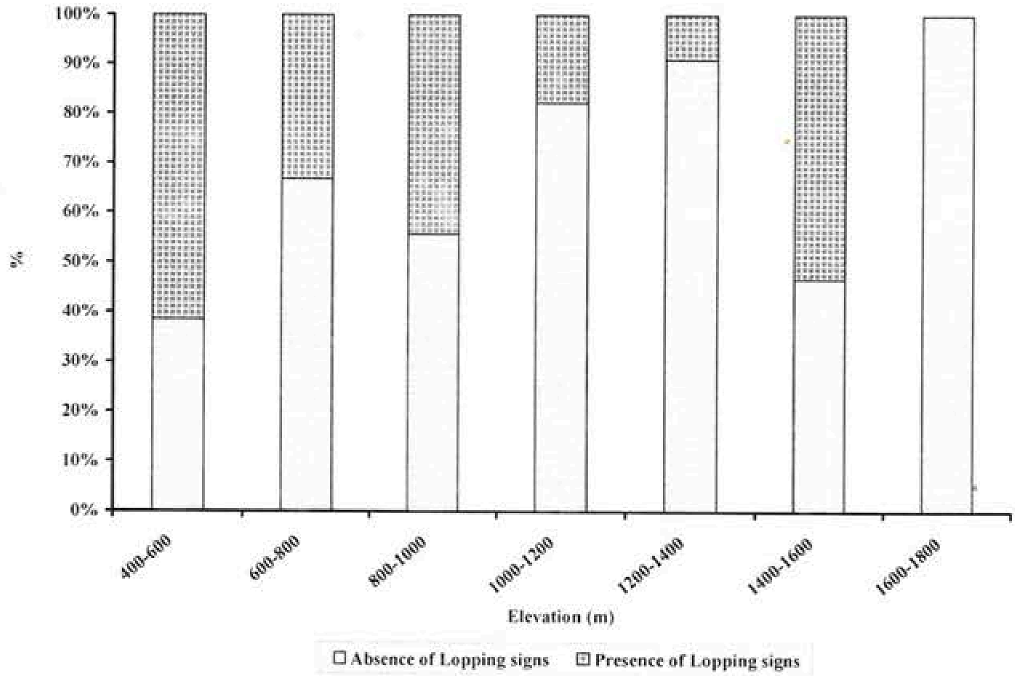
The following detrimental factors were observed in Megamalai area with respect to the potential threats to the survival of amphibians (see Chapter 4).

(1) Habitat analysis showed that lopping signs on trees were found in 35% of 220 samples (Figure 7.3a). The lopping of tree was done by villagers and estate workers for fire wood and fodder for their live stock. Lopping would change the canopy cover of any given area, and changes in canopy cover would certainly affect the amphibian community of an area (Daniels, 1991) due to changes in temperature and moisture content of the soil. Lopping should be carefully monitored and controlled by the Forest Department.

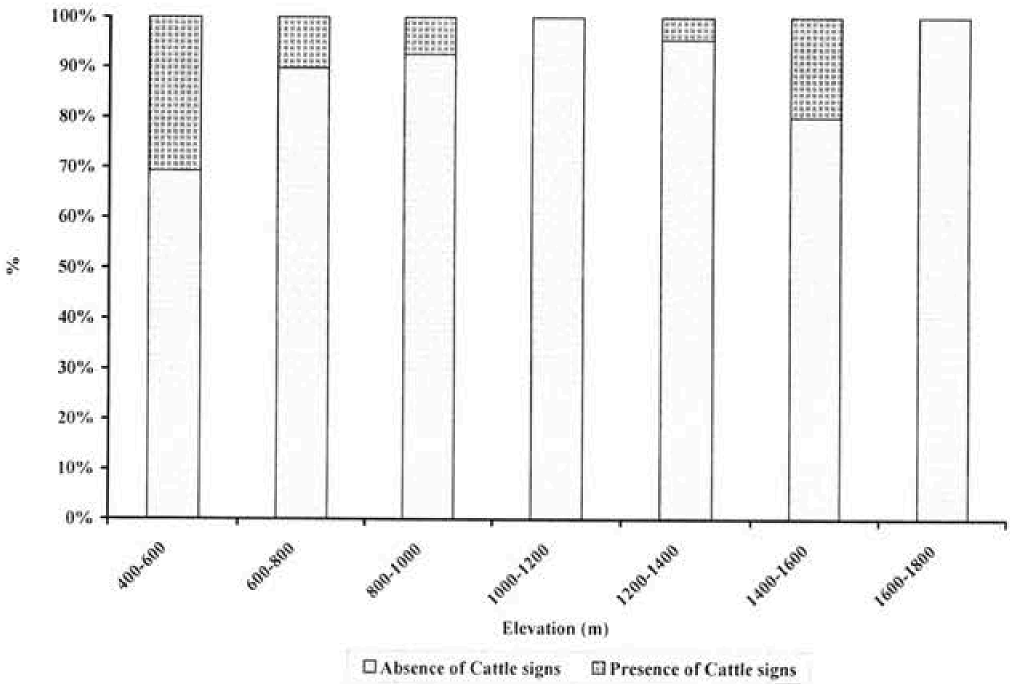
(2) Domestic live stock dung piles were found in 11.81% of 220 samples analysed (Figure 7.3 b). Lopping and cattle dung piles were relatively high in the lower elevation (400-1000 m) and it was low in mid elevation (1000-1400 m). This is due to the presence of villages and settlements in these elevation bands (Bhupathy *et al.*, 2009). Excess of grazing by livestock would affect the regeneration of vegetation in an area (Adams, 1975). Presence of several estates (plantations) in the area caused considerable disturbance, as labors largely depend on forests for firewood. LPG gas replacing firewood and stall feeding of the cattles may solve the problem to a greater extent, which is very much possible with the participation of estate management who are dealing with plantation activities.

(3) The people settled in hill tracts and estate (plantation) workers solely depend on forests for fire wood collection and Non Timber Forest Produce (NTFP). These practices have to be minimized by giving them alternative livelihood options and periodic nature education programmes.

(4) Tea, coffee and cardamom estates such as Highwavy, Megamalai, Venniyar, Manalar, Eravangalar and Kardana cause substantial damage to the forest ecosystem in the region by polluting the water and soil with fertilizers, pesticides and factory wastes (Urea, Dicofol, Quinalphos, Copper oxychloride etc.). In a few occasions natural flow of streams have been diverted for irrigating the plantations. Currently we do not have data on the status pollution levels in the area. Involving the plantation people in conservation and education programme would minimize the above problems.



a. Lopping



b. Cattle dung

Figure 7.3. Intensity of anthropogenic disturbance in the forests of Megamalai landscape

(5) There are three major dams (Megamalai, Highwavy and Maharajamettu) are constructed for holding and for power generation in close vicinity to Megamalai. The present status (water holding capacity, flow) and impact of these (dams/ reservoirs/ embankments) should be reviewed.

(6) Presently, only one road, Chinnamanur to Eravangalar through Highwavys is operational in the Megamalai area, and the same is maintained by estates. A study conducted near by area in Cumbum-Kumuly road showed the mortality of 3.5 amphibians/ 10km. This study found six amphibian taxa were affected (*Duttaphrynus melanostictus, Sylvirana temporalis, Indirana leptodactyla, Polypedates pseudocruciger* and *Rhacophorus malabaricus*). New road proposal in the area should be carefully reviewed considering mortality of wild animals and loss of forest cover.

A portion of the forests of this area have been declared as Wildlife Sanctuary Government Order: G.O. (D) No. 63, Environment and Forest (FR V), dated 26 June 2009, declaring a part (269.11 Sq.km) as Megamalai Wildlife Sanctuary, which was a long pending (Rodgers and Panwar 1988) . This is an encouraging sign with respect to amphibian and other wildlife conservation in the area.

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Appendix 1. Bioclimatic variables extracted from Global climate data with respect to different vegetation types of Megamalai landscape (www.worldclim.org).

Bioclimatic variables	Vegetation type					
	Dry Deciduous	Riverine	Moist Deciduous	Rocky slopes with Grass	Evergreen	Shola and Grassland
Annual Mean Temperature (°C)	24.10	23.10	22.90	21.60	19.80	18.00
Mean Diurnal Range (Mean of monthly (max temp – min temp))	8.30	8.20	8.00	8.10	7.80	7.60
Isothermality (P2/P7) (* 100)	64.00	64.00	64.00	63.00	62.00	63.00
Temperature Seasonality (standard deviation *100)	12.33	12.76	11.98	12.21	11.90	11.09
Max Temperature of Warmest Month	30.60	29.50	29.10	28.00	25.90	24.00
Min Temperature of Coldest Month	17.70	16.70	16.60	15.30	13.50	12.00
Temperature Annual Range (P5-P6)	12.90	12.80	12.50	12.70	12.40	12.00
Mean Temperature of Wettest Quarter	24.40	23.50	23.20	22.00	20.20	18.30
Mean Temperature of Driest Quarter	23.40	22.40	22.30	20.90	19.10	17.40
Mean Temperature of Warmest Quarter	25.60	24.60	24.40	23.20	21.30	19.40
Mean Temperature of Coldest Quarter	22.40	21.30	21.20	20.00	18.10	16.50
Annual Precipitation	1550.00	1544.00	1775.00	1804.00	2018.00	2161.00
Precipitation of Wettest Month	246.00	243.00	314.00	331.00	395.00	425.00
Precipitation of Driest Month	23.00	24.00	24.00	23.00	22.00	22.00
Precipitation Seasonality (Coefficient of Variation)	56.00	55.00	60.00	61.00	65.00	66.00
Precipitation of Wettest Quarter	598.00	594.00	763.00	800.00	951.00	1025.00
Precipitation of Driest Quarter	103.00	102.00	107.00	101.00	101.00	106.00
Precipitation of Warmest Quarter	282.00	419.00	311.00	512.00	585.00	632.00
Precipitation of Coldest Quarter	276.00	283.00	282.00	276.00	275.00	283.00

Appendix 2. Bioclimatic variables extracted with respect to different elevations extracted from Global climate data in various elevations of Megamalai landscape (www.worldclim.org).

Bioclimatic variables	Elevations (m)						
	500	700	900	1100	1300	1500	1700
Annual Mean Temperature	24.10	23.10	21.60	21.60	21.60	19.30	18.00
Mean Diurnal Range (Mean of monthly (max temp - min temp))	8.30	8.20	8.10	8.10	8.10	7.80	7.60
Isothermality (P2/P7) (* 100)	64.00	63.00	63.00	63.00	63.00	62.00	63.00
Temperature Seasonality (standard deviation *100)	12.33	12.39	12.29	12.29	12.21	11.68	11.09
Max Temperature of Warmest Month	30.60	29.50	27.90	27.90	28.00	25.50	24.00
Min Temperature of Coldest Month	17.70	16.60	15.20	15.20	15.30	13.10	12.00
Temperature Annual Range (P5-P6)	12.90	12.90	12.70	12.70	12.70	12.40	12.00
Mean Temperature of Wettest Quarter	24.40	23.50	22.00	22.00	22.00	19.70	18.30
Mean Temperature of Driest Quarter	23.40	22.40	20.90	20.90	20.90	18.70	17.40
Mean Temperature of Warmest Quarter	25.60	24.60	23.20	23.20	23.20	20.80	19.40
Mean Temperature of Coldest Quarter	22.40	21.30	19.90	19.90	20.00	17.70	16.50
Annual Precipitation	1550.00	1636.00	1810.00	1810.00	1804.00	2068.00	2161.00
Precipitation of Wettest Month	246.00	277.00	333.00	333.00	331.00	409.00	425.00
Precipitation of Driest Month	23.00	23.00	23.00	23.00	23.00	22.00	22.00
Precipitation Seasonality (Coefficient of Variation)	56.00	58.00	62.00	62.00	61.00	66.00	66.00
Precipitation of Wettest Quarter	598.00	672.00	805.00	805.00	800.00	985.00	1025.00
Precipitation of Driest Quarter	103.00	101.00	101.00	101.00	101.00	102.00	106.00
Precipitation of Warmest Quarter	282.00	454.00	514.00	514.00	512.00	601.00	632.00
Precipitation of Coldest Quarter	276.00	276.00	276.00	276.00	276.00	275.00	283.00

Appendix 3. Distribution of amphibians in various elevation categories of Megamalai landscape.

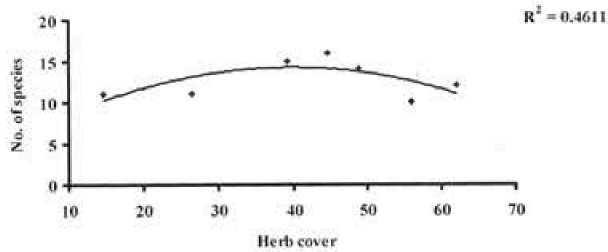
S.no	Species	Elevations (m)						
		400-600	600-800	800-1000	1000-1200	1200-1400	1400-1600	1600-1800
1	*Bufo scaber*	1	0	0	0	0	0	0
2	*Duttaphrynus melanostictus*	1	1	1	1	1	1	1
3	*Duttaphrynus microtympanum#*	0	0	0	0	0	1	1
4	*Euphlyctis cyanophlyctis*	1	1	1	0	0	0	0
5	*Euphlyctis hexadactylus*	1	0	0	0	0	0	0
6	*Fejervarya mudduraja*	1	1	1	0	0	0	0
7	*Hoplobatrachus tigerinus*	1	0	0	0	0	0	0
8	*Limnonectes brevipalmatus#*	0	0	0	1	1	1	1
9	*Sphaerotheca breviceps*	1	1	1	1	0	0	0
10	*Kaloula taprobanica*	1	0	0	0	0	0	0
11	*Microhyla ornata*	1	0	0	0	0	0	0
12	*Microhyla rubra*	1	0	0	0	0	0	0
13	*Ramanella montana#*	0	0	0	0	1	1	1
14	*Uperodon systoma*	1	0	0	0	0	0	0
15	*Micrixalus fuscus#*	0	1	1	0	1	1	1
16	*Nyctibatrachus aliciae#*	0	0	1	1	1	1	0
17	*Nyctibatrachus beddomii#*	0	0	1	0	0	0	0
18	*Indirana beddomii#*	1	1	1	1	1	1	1
19	*Indirana leptodactyla#*	0	0	0	0	1	1	1
20	*Indirana semipalmata#*	0	1	1	1	0	1	0
21	*Indirana* sp1#	0	1	1	1	1	1	0
22	*Clinotarsus curtipes#*	0	0	1	0	0	0	0
23	*Sylvirana temporalis*	1	1	1	1	1	0	0
24	*Philautus beddomii#*	0	0	0	0	1	1	1
25	*Philautus griet#*	0	0	0	0	1	1	1
26	*Philautus ponmudi#*	0	0	0	0	0	0	1
27	*Philautus wynaadensis#*	0	1	1	1	1	1	0
28	*Philautus* sp1#	0	0	1	0	0	0	0
29	*Philautus* sp2#	0	0	0	0	0	0	1
30	*Polypedates maculatus*	1	0	0	0	0	0	0
31	*Polypedates pseudocruciger#*	1	1	1	0	0	0	0
32	*Rhacophorus malabaricus#*	0	0	1	0	0	0	0
33	*Rhacophorus pseudomalabaricus#*	0	0	0	1	0	0	0
34	*Rhacophorus pleurostictus#*	0	0	0	0	0	1	0
	Total	15	11	16	10	12	14	11
	Endemics	2	6	10	7	10	13	10

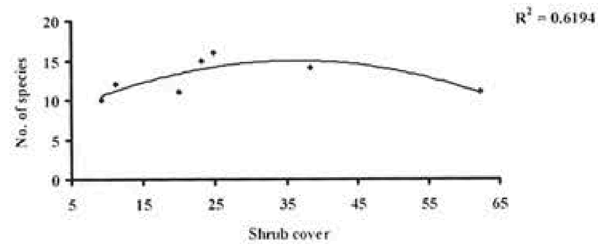
Appendix 4. Distribution of amphibians in various vegetation types of Megmalai landscape.

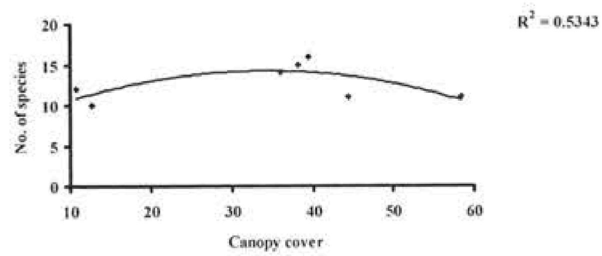
S.no	Species	Vegetation type [a]					
		DD	MD	R	RG	EG	SG
1	*Bufo scaber*	1	0	0	0	0	0
2	*Duttaphrynus melanostictus*	1	1	1	1	1	1
3	*Duttaphrynus microtympanum*#	0	0	0	0	1	1
4	*Euphlyctis cyanophlyctis*	1	0	1	0	0	0
5	*Euphlyctis hexadactylus*	1	0	0	0	0	0
6	*Fejervarya limnocharis*	1	1	1	0	0	0
7	*Hoplobatrachus tigerinus*	1	0	0	0	0	0
8	*Limnonectes brevipalmatus*#	1	0	0	1	1	1
9	*Sphaerotheca breviceps*	1	0	1	1	0	0
10	*Kaloula taprobanica*	1	0	0	0	0	0
11	*Microhyla ornata*	1	0	0	0	0	0
12	*Microhyla rubra*	1	0	0	0	0	0
13	*Ramanella montana*#	0	0	0	1	1	1
14	*Uperodon systoma*	1	0	0	0	0	0
15	*Micrixalus fuscus*#	0	1	0	1	1	1
16	*Nyctibatrachus aliciae*#	0	1	0	1	1	1
17	*Nyctibatrachus beddomii*#	0	1	0	0	0	0
18	*Indirana beddomii*#	1	1	1	1	1	1
19	*Indirana leptodactyla*#	0	0	0	1	1	1
20	*Indirana semipalmata*#	1	1	0	1	1	0
21	*Indirana* sp1#	0	1	0	0	1	0
22	*Clinotarsus curtipes*#	0	1	0	0	0	0
23	*Sylvirana temporalis*	1	1	1	0	1	0
24	*Philauts beddomii*#	0	0	0	1	1	1
25	*Philautus griet*#	0	0	0	1	1	1
26	*Philautus ponmudi*#	0	0	0	0	0	1
27	*Philautus wynaadensis*#	1	0	0	1	1	0
28	*Philautus* sp1#	0	1	0	0	0	0
29	*Philautus* sp2#	0	0	0	0	0	1
30	*Polypedates maculatus*	1	0	0	0	0	0
31	*Polypedates pseudocruciger*#	1	1	0	0	0	0
32	*Rhacophorus malabaricus*#	0	1	0	0	0	0
33	*Rhacophorus pseudomalabaricus*#	0	0	0	0	0	1
34	*Rhacophorus pleurostictus*#	0	0	0	0	1	0
	Total	18	13	6	12	15	13
	Endemics	5	10	1	9	12	11

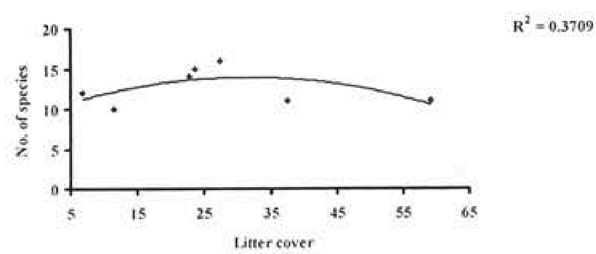
[a] DD= Dry Deciduous, MD= Moist Deciduous, R= Riverine, RG= Rocky slopes with Grass, EG= Evergreen, SG= Shola and Grassland

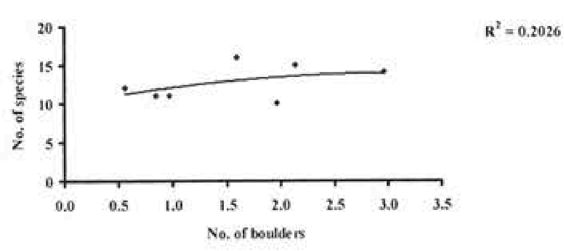
Appendix 5. Relationship of amphibian species richness with various environmental factors at elevational gradients.



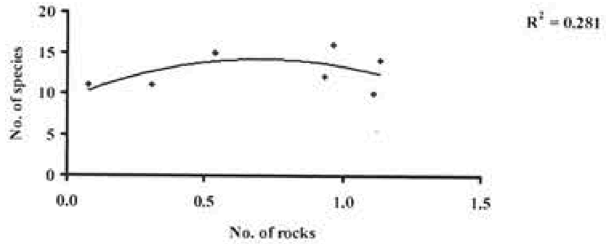


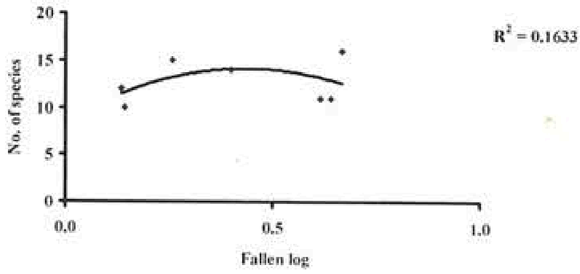


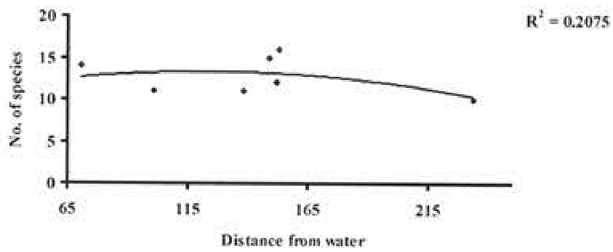


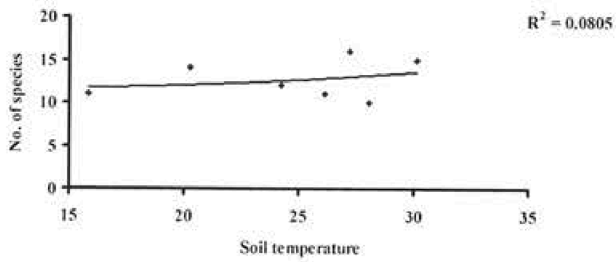


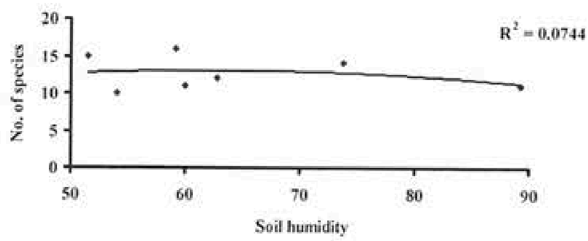
Appendix 5 cont...


R² = 0.281
No. of species
20
15
10
5
0
0.0
0.5
1.0
1.5
No. of rocks

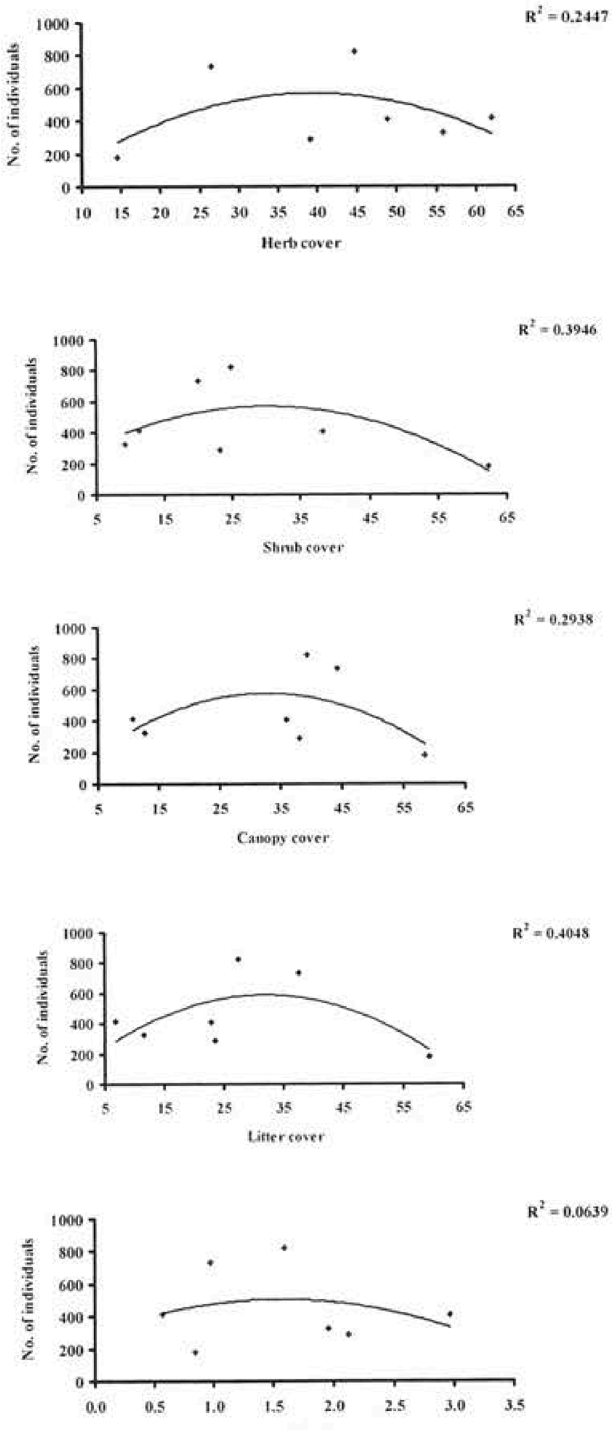

R² = 0.1633
No. of species
20
15
10
5
0
0.0
0.5
1.0
Fallen log


R² = 0.2075
No. of species
20
15
10
5
0
65
115
165
215
Distance from water

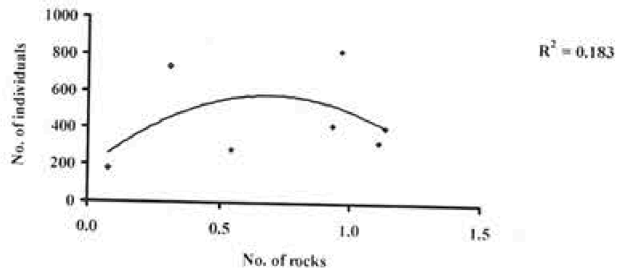

R² = 0.0805
No. of species
20
15
10
5
0
15
20
25
30
35
Soil temperature


R² = 0.0744
No. of species
20
15
10
5
0
50
60
70
80
90
Soil humidity

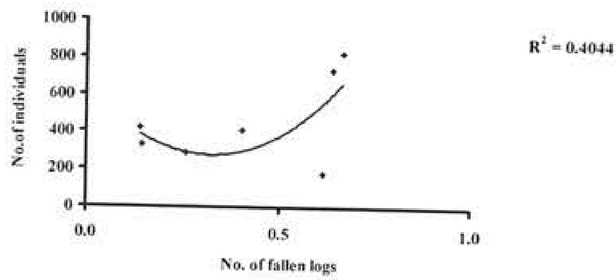
Appendix 6. Relationship of amphibian abundance with various environmental factors at elevational gradients.



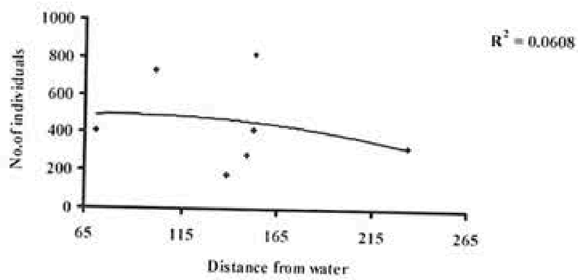
Appendix 6 cont…



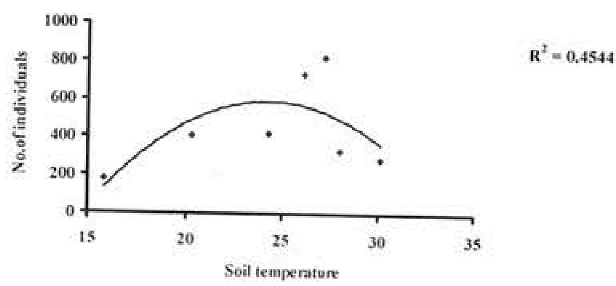
No. of individuals
1000
800
600
400
200
0
0.0
0.5
1.0
1.5
No. of rocks
R^2 = 0.183



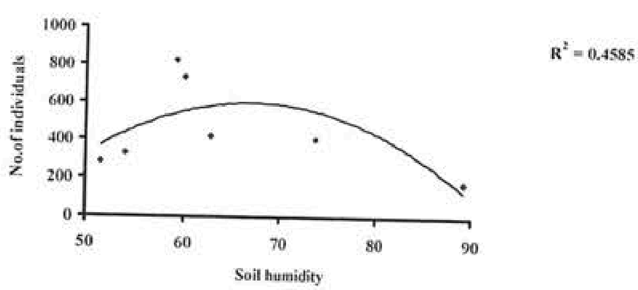
No.of individuals
1000
800
600
400
200
0
0.0
0.5
1.0
No. of fallen logs
R^2 = 0.4044



No.of individuals
1000
800
600
400
200
0
65
115
165
215
265
Distance from water
R^2 = 0.0608

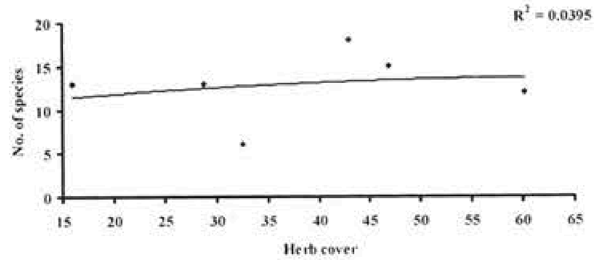


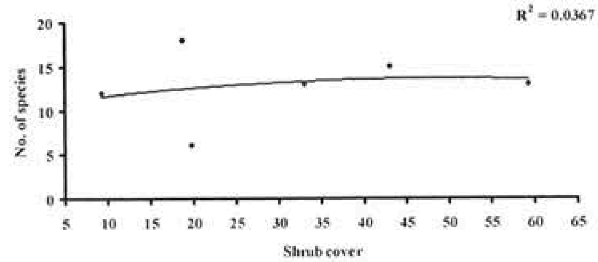
No.of individuals
1000
800
600
400
200
0
15
20
25
30
35
Soil temperature
R^2 = 0.4544

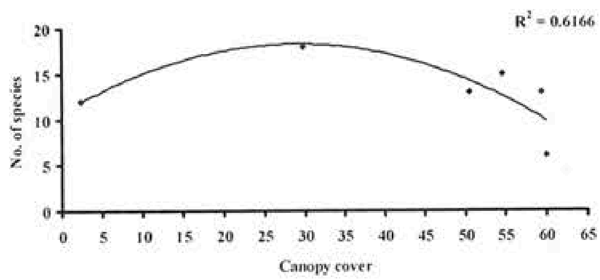


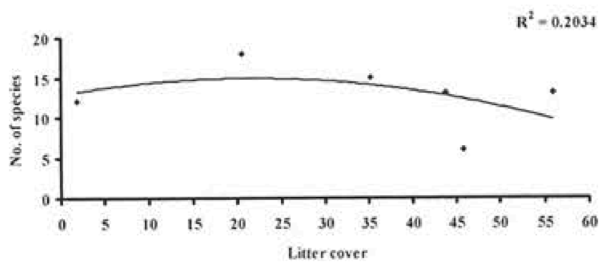
No.of individuals
1000
800
600
400
200
0
50
60
70
80
90
Soil humidity
R^2 = 0.4585

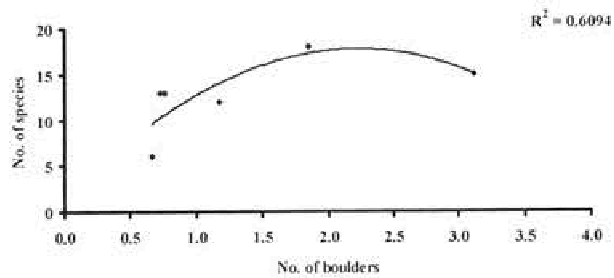
Appendix 7. Relationship of amphibian species richness with various environmental factors at vegetation level.



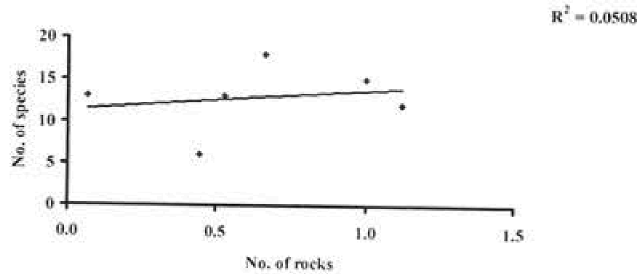


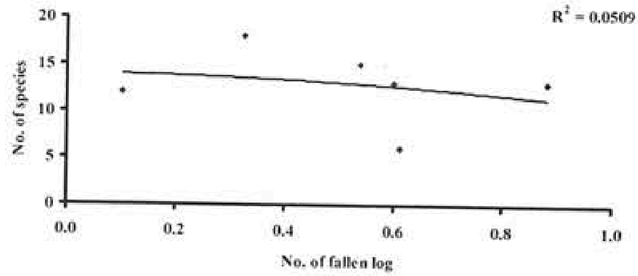


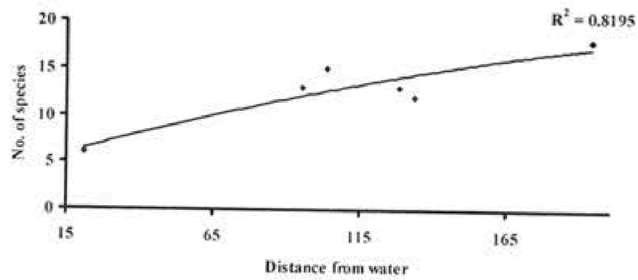


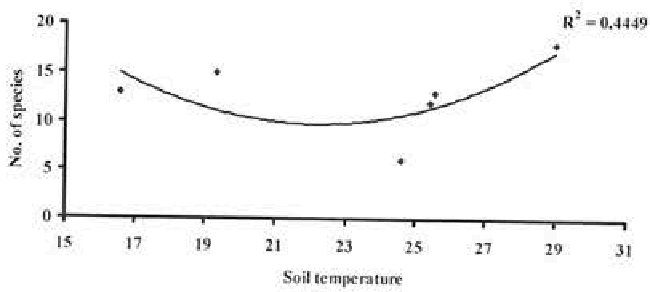


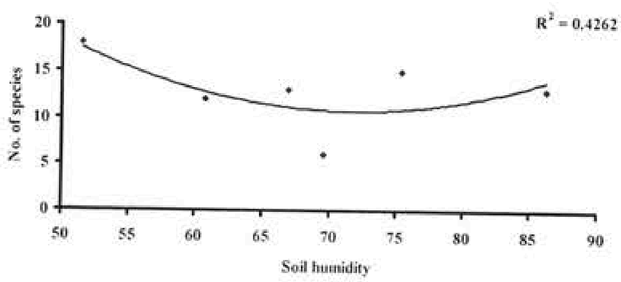
Appendix 7 cont…


R² = 0.0508
20
15
10
5
0
No. of species
0.0
0.5
1.0
1.5
No. of rocks

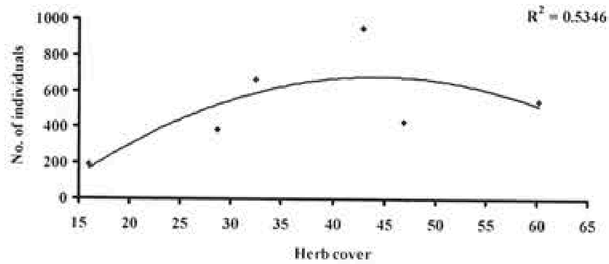

R² = 0.0509
20
15
10
5
0
No. of species
0.0
0.2
0.4
0.6
0.8
1.0
No. of fallen log

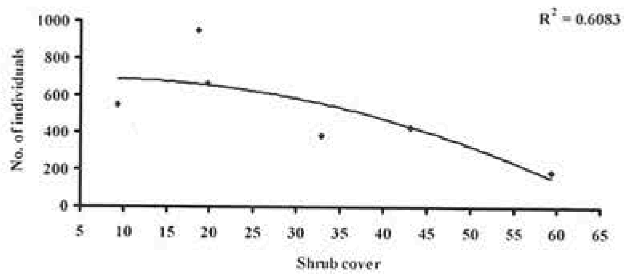

R² = 0.8195
20
15
10
5
0
No. of species
15
65
115
165
Distance from water

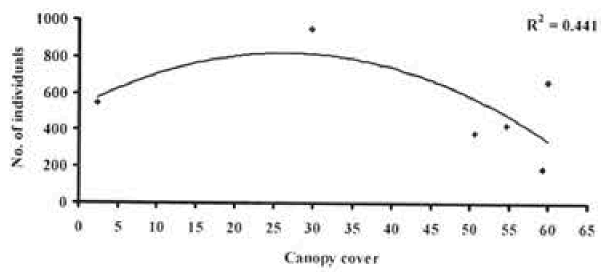

R² = 0.4449
20
15
10
5
0
No. of species
15
17
19
21
23
25
27
29
31
Soil temperature

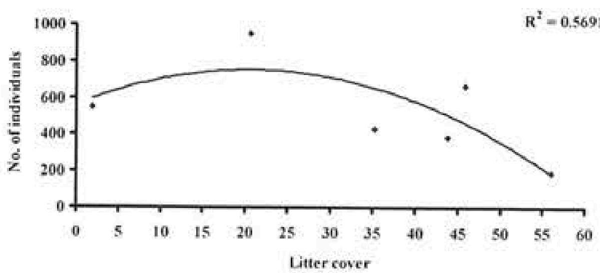

R² = 0.4262
20
15
10
5
0
No. of species
50
55
60
65
70
75
80
85
90
Soil humidity

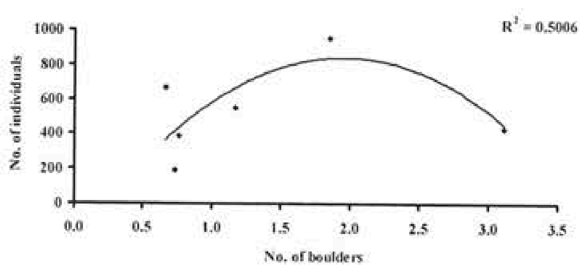
Appendix 8. Relationship of amphibian abundance with various environmental factors at vegetation level.



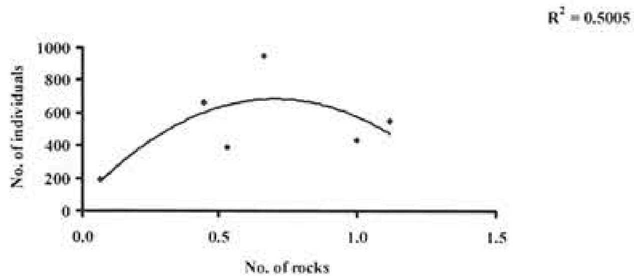


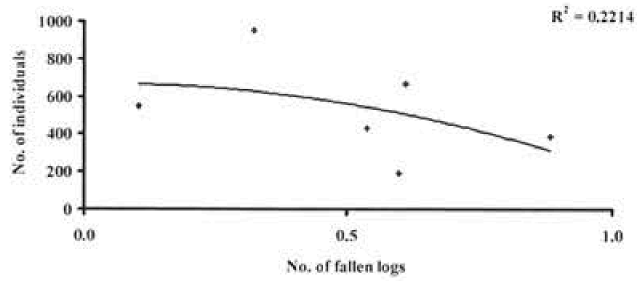






Appendix 8 cont…


R² = 0.5005
No. of individuals
1000
800
600
400
200
0
0.0
0.5
1.0
1.5
No. of rocks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No. of individuals
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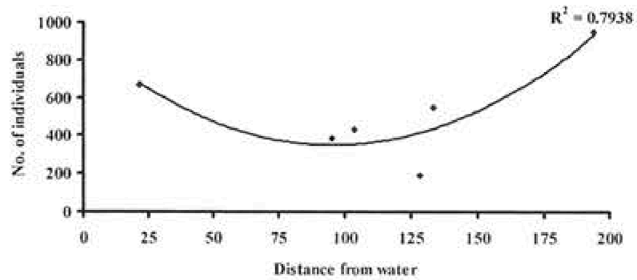
800
600
400
200
0
0.0
0.5
1.0
No. of fallen logs


R² = 0.7938
No. of individuals
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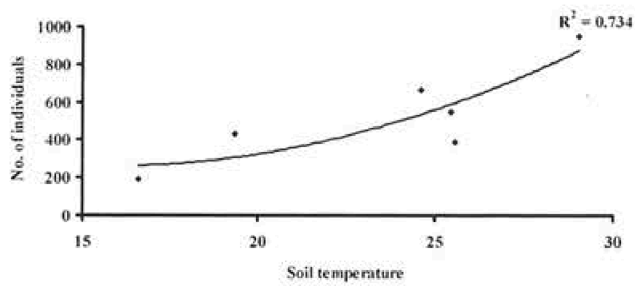
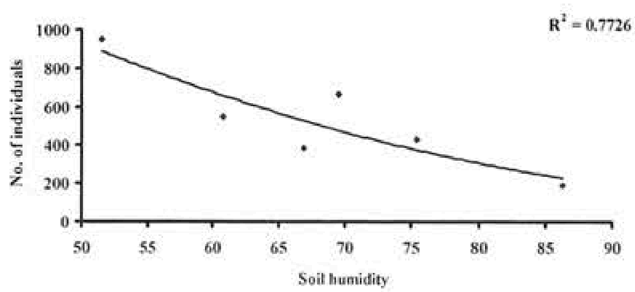
800
600
400
200
0
0
25
50
75
100
125
150
175
200
Distance from water


R² = 0.734
No. of individuals
1000
800
600
400
200
0
15
20
25
30
Soil temperature


R² = 0.7726
No. of individuals
1000
800
600
400
200
0
50
55
60
65
70
75
80
85
90
Soil humidity

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HERPETOFAUNAL MORTALITY DUE TO VEHICULAR TRAFFIC IN THE WESTERN GHATS, INDIA: A CASE STUDY

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Abstract: We monitored the mortality of herpetofauna on a fortnightly basis along National Highway 220, which cuts across the Western Ghats, India, during December 2006- November 2007. In all, 101 amphibians (3.5 amphibians/ 10km) belonging to six taxa and 78 reptiles (2.7 reptiles/ 10 km) of 23 taxa were found dead in 48 surveys. The mortality of amphibians during day and night was significantly different ($Z= 3.12$, $n1= 24$, $n2= 24$, $P<0.01$), whereas this was not so with respect to reptiles. The difference in the mortality of amphibians between seasons was not significant, but it was significant with respect to reptiles ($Z= -1.188$, $n1= 24$, $n2= 24$, $p< 0.05$). Overall, the road kills of amphibians were significantly correlated with that occurring in nearby forests ($r = 0.67$, $n= 12$, $P< 0.01$), but reptiles had no such relationship. The number of road kills of amphibians and reptiles on a monthly basis was not correlated with the intensity of vehicle plying on the road.

Keywords: Biodiversity hotspot, Asia, amphibians, reptiles, road kills.

Resumen: S. Bhupathy, G. Srinivas, N.S. Kumar, T. Karthik y A. Madhivanan. "Mortalidad de herpetofauna debido a tráfico vehicular en los Western Ghats, India: un caso de estudio". Monitoreamos la mortalidad de herpetofauna sobre una base bi-semanal a lo largo de la Autopista Nacional 220 que atraviesa los Western Ghats, India, durante diciembre 2006- noviembre 2007. En total, 101 anfibios (3.5 anfibios/ 10km) pertenecientes a seis taxones, y 78 reptiles (2.7 reptiles/ 10 km) de 23 taxones fueron encontrados muertos en 48 muestreos. La mortalidad de los anfibios durante el día y la noche fue significativamente diferente ($Z= 3.12$, $n1= 24$, $n2= 24$, $P<0.01$), mientras que esto no fue así con respecto a los reptiles ($Z= -1.188$, $n1= 24$, $n2= 24$, $p< 0.05$). En total, las muertes por arrollamiento en anfibios tuvo una correlación significativa con aquella que ocurre en bosques cercanos ($r = 0.67$, $n= 12$, $P< 0.01$), pero los reptiles no tuvieron tal relación. El número de anfibios y reptiles atropellados en la carretera sobre una base mensual no estuvo correlacionados con la intensidad de vehiculos en la carretera.

Palabras clave: "Hotspot" de biodiversidad, Asia, anfibios, reptiles, muertes por arrollamiento.

INTRODUCTION

Globally, transportation of materials and people, especially by road, has become one of the major modes of travel. Roads fragment habitats; and with the growing networks, animals are increasingly forced to cross roads during their daily activities and hence are often killed by vehicles (Hourdequin 2000). Roads cause direct mortality of animals during construction and vehicular movement, changes in animal behaviour, alterations in the physical and chemical environment, spread of exotic species and land use pattern by humans (Trombulak and Frissell 2000 and Shepard 2008). Monitoring roads that cut across forests provides information on richness and relative abundance of species occurring in the area (Heyer *et al.* 1994). Based on regular road cruising, Klauber (1939) prepared an inventory of nocturnally active snakes.

Reports on the mortality of fauna due to vehicular traffic are available for various taxa; macro invertebrate soil fauna (Haskell 2000), herpetofauna (Rodsan and Lowe 1994, Fehrig *et al.* 1995, Gibbs and Shriver 2002, Andrews and Gibbons 2005, Glista *et al.* 2008, Elzanowski *et al.* 2009 and Langen *et al.* 2009), birds (Mumme *et al.* 2000) and mammals (Laurance *et al.* 2006). However, information in this regard is scanty in India (Gokula 1997, Vijayakumar *et al.* 2001, Sundar 2004, Das *et al.* 2007, Kannan 2007 and Rao and Girish 2007), and all these studies covered only one season or a few months. It is important to quantify the magnitude and the effect of vehicular traffic on faunal groups, which would help conserve them as various infrastructure projects, including roads, are planned to cater the growing needs of the country.

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As per the National Highway Authority of India, the country has the second largest road system in the world, which covers over 3.31 million kilometers including 26,697 km passing through wildlife habitats and forests (Rajvanshi *et al.* 2007). According to Rao and Girish (2007), in India, the total length of the road and number of motorized vehicles increased by about 10 fold (0.4 to 3.4 million kilometers and 0.3 to 3.0 million vehicles) during 1951- 2004. The Western Ghats, southwestern India, is one of the 34 Biodiversity Hotspots of the World (Mittermeier *et al.* 2005). Though the Western Ghats constitutes only 5% of the total land area of India, it harbors about 30% of India's biological species (Rodgers and Panwar 1988). A total of 130 species of amphibians and 165 reptiles have been reported from this hill range (Das and Dutta 2006 and Das 1996). Several National and State Highways connect the Indian state of Kerala and Tamil Nadu cutting across the Western Ghats. However, impact of these and other proposed road networks on wildlife is poorly understood. In the present paper, we report the mortality of herpetofauna along National Highway 220, which cuts across the Western Ghats.

METHODOLOGY

The present study was conducted along a stretch of six kilometers (Fig. 1) of the National Highway (NH 220; 9°.36'N, 77°.10'E and 9°.37'N, 77°.11'E) between December 2006 and November 2007. Mountainous forests surround this road, which connects the Indian states Kerala and Tamil Nadu. It also connects Kumuly, a tourist spot and Sabarimala, a pilgrimage centre that attract a large number of visitors annually.

This stretch of road was traversed fortnightly on foot once during morning (0600- 0800 hrs, Indian Standard Time) and evening (1600-1800 hrs) hours. All freshly killed animals found during 0600-0800 hrs were assumed to have been killed during the previous night and the others have been killed during the day. The dead animals were identified to species level, wherever possible, and removed from the road to avoid repeat count. Herpetofaunal abundance in the forests found 500m on either side of the road was assessed during dry (December -May) and wet (June - November) seasons using time constrained visual encounter survey (Heyer *et al.* 1994). The road under this study was divided into six equal segments and each of them was surveyed for 40 man hours totaling 240 hours of search per season. All possible microhabitats such as leaf litter, trees, tree holes, fallen logs, boulders, crevices and water bodies were examined to locate herpetofauna. Traffic intensity was monitored around the clock counting vehicles that pass through a particular point on a monthly basis.

A Mann-Whitney U-test was performed to test the difference between the mortality and abundance of herpetofauna in the environs between seasons, and mortality during the day and night. The Pearson correlation coefficient was used to find out the relation between number of road killed animals with vehicle intensity and number of road kills with the abundance of herpetofauna observed in the adjacent forests.

RESULTS

A total of 48 (24 morning and 24 evening) surveys were conducted along the six kilometer stretch of the road from December 2006 to November 2007. In all, 101 amphibians (3.5 amphibians/ 10km) belonging to six taxa and 78 reptiles (2.7 reptiles/ 10km) of 23 taxa were found dead during the fortnightly surveys. Among the six taxa of amphibians found dead, *Indirana* sp. contributed the most (47.52%) followed by *Duttaphrynus melanostictus* (41.58%). Higher number of amphibians was killed during wet season especially those belong to *Indirana* sp. (Table 1). Twenty three taxa of reptiles were found killed on the road during the sampling. The number of snake species found dead on the road was higher than that of the lizards (Table 2). However, many snake species were represented by singletons. Among reptile species that were killed, the snake *Macropisthodon plumbicolor* constituted the highest (15.38%) followed by the lizard *Calotes calotes* (11.54%).

Of the 101 amphibians found dead, 89 (88.1%) were killed during night and the rest during day. In the case of reptiles, 50/78 mortalities occurred during night. Traffic intensity in 24 hour cycle was low during night (7147±595.58) compared to day (14630 ± 1219.17). The mortality of amphibians during day and night was significantly different ($Z= 3.12$, $n1= 24$, $n2= 24$, $P<0.01$), whereas this was not so with respect to reptiles.

TABLE 1. Mortality of amphibians during dry and wet seasons along the National Highway 220. Numbers within parentheses are relative abundances.
TABLA 1. *Mortalidad de anfibios durante las estaciones seca y lluviosa a lo largo de la Autopista Nacional 220. Números entre paréntesis son abundancias relativas.*

Amphibian Species	Dry season	Wet season	Total
Duttaphrynus melanostictus	22	20	42 (41.58)
Sylvirana temporalis	2	2	4 (3.96)
Indirana sp.	2	46	48 (47.52)
Polypedates pseudocruciger	1	0	1 (0.99)
Rhacophorus malabaricus	3	0	3 (2.97)
Sphaerotheca breviceps	0	3	3 (2.97)
Total	30	71	101

A higher proportion (70.3%, n= 101) of amphibians was killed during wet season compared to dry season. Of the six species of amphibians found dead during this study, *Sphaerotheca breviceps* was observed only during wet season and *Polypedates pseudocruciger* and *Rhacophorus malabaricus* were observed only during dry season (Table 1). Among the reptiles, a higher number (44/78) of them were killed during the dry season than during the wet season (Table 2). Of the 23 taxa found dead, 10 were observed in both the seasons, seven were restricted to the dry and six to the wet season. The difference in the mortality of amphibians between seasons was not significant, but it was significant with respect to reptiles ($Z= -1.188$, $n1= 24$, $n2= 24$, $p< 0.05$).

Among the 11 species of amphibians recorded in forests adjacent to the road, *Indirana* sp. (39.85%), *Fejervarya* sp. (29.12%) and *Duttaphrynus melanostictus* (12.64%) were common (Table 3). In both seasons, 261 amphibians (5.43/ 10 man hour effort) were observed using VES. Eight species of amphibians were common for both seasons, but number of amphibians observed varied greatly between season; 73 during dry and 188 in wet season (Table 3).

In all, 507 reptiles (10.56/ 10 man hour) belonging to 21 species were observed during both seasons in the nearby forests (Table 4). The visual encounter surveys revealed the dominance of three species (by number); *Cnemaspis mysoriensis* (40.24%), *Eutropis macularia* (27.81%) and *Psammophilus blanfordanus* (11.41%). Eleven of them were observed in both seasons; five each exclusive to dry and wet seasons.

Seasonal variations in the abundance of reptiles and amphibians observed in the forests were not significant. Overall, the road kills

TABLE 2. Seasonal variation in the mortality of reptiles along the National Highway 220. Numbers within parentheses are relative abundances.
TABLA 2. *Variación estacional en la mortalidad de reptiles a lo largo de la Autopista Nacional 220. Números entre paréntesis son abundancias relativas.*

Reptile Species	Dry season	Wet season	Total
Calotes versicolor	5	1	6 (7.7)
Calotes calotes	7	2	9 (11.5)
Psammophilus blanfordanus	0	1	1 (1.3)
Chamaeleo zeylanicus	1	1	2 (2.6)
Eutropis macularia	2	1	3 (3.9)
Varanus bengalensis	1	2	3 (3.9)
Ramphotyphlops braminus	3	3	6 (7.7)
Uropeltis sp.	0	4	4 (5.1)
Eryx conicus	1	0	1 (1.3)
Ahaetulla nasuta	1	0	1 (1.3)
Ahaetulla pulverulenta	1	0	1 (1.3)
Boiga beddomei	0	1	1 (1.3)
Coelognathus helena	6	0	6 (7.7)
Macropisthodon plumbicolor	7	5	12 (15.4)
Oligodon arnensis	0	2	2 (2.6)
Ptyas mucosa	1	0	1 (1.3)
Bungarus caeruleus	1	2	3 (3.9)
Calliophis nigrescens	0	1	1 (1.3)
Daboia russelii	0	5	5 (6.4)
Echis carinatus	1	1	2 (2.6)
Hypnale hypnale	3	2	5 (6.4)
Unidentified gecko	1	0	1 (1.3)
Unidentified snake	2	0	2 (2.6)
Total	44	34	78 (100.00)

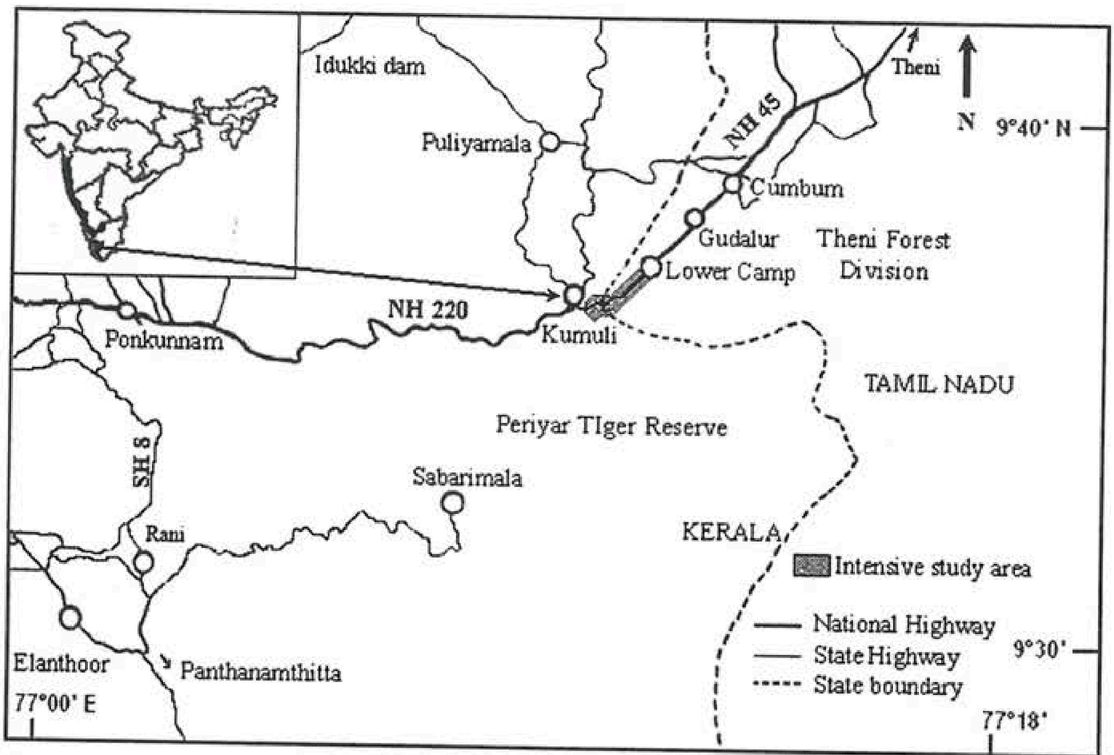

FIG. 1. Map showing the study area, National Highway 220, India.
Mapa que muestra el área de estudio, Autopista Nacional 220, India.

of amphibians had a significant correlation with those that occurred in nearby forests (r = 0.67, n= 12, P< 0.01). Reptiles had no such relation overall or seasonally. Amphibian kills were highly correlated with their abundance in the adjacent forests during wet season (r = 0.79, n= 12, P< 0.01), but it was not significant during dry season.

The mean number of vehicles traveling on the road during this study was 1814.75/ 24 hours (day). Figure 2 provides data on the mean number of vehicles passing on a monthly basis, which showed that the intensity was higher during December (2908) and May (2482), but it was the lowest during September (1449). The mean herpetofaunal mortality was 7.55/ day (n=24). Herpetofaunal daily mortality was highest during November (31) and lowest in September (4). The mortality pattern of reptiles and amphibians differed; reptiles- maximum during January and February (5.5/ 24 hours) and minimum in September (1) and amphibians- the highest mortality during October (13.5) and the lowest during April, May, August and September (1/ 24 hours). The correlation between number of vehicles traveling on the road and mortality of both amphibians and reptiles was not significant.

DISCUSSION

A total of 23 taxa of reptiles have been observed during the fortnightly sampling covering all months of the year during this study. Mukherjee (2007) reported 33 species of reptiles in a study spanning for three years in Anaikatty Hills, Western Ghats and suggested road cruising as the best way to make an inventory/monitor reptiles compared to other methods such as visual encounter survey, quadrat and transect. Road kills may indicate herpetofaunal diversity of the area (Hels and Buchwald 2001). However, the mortality of animals may depend on season, traffic density and behaviour of species involved. The edge of the road may support a greater variety of food items for some reptiles. Spellerberg (2002) reported higher abundance of a few species of spiders and insect along the edges of the road. Presence of breeding habitat and open patches near the road may enhance the herpetofaunal mortality especially in amphibians and lizards (Andrews and Gibbons 2005).

In all, 3.5 amphibians/ 10km and 2.7 reptiles/ 10km were found dead during the present study. Mortality of herpetofauna reported from other parts of the Western Ghats are as follows: Anamalai (amphibians: 20/ 10km, reptiles: 4.3/ 10km; Vijayakumar et al. 2001; Study period: May-June 1998), Mudumalai (amphibians: 19/ 10km; reptiles: 8.3/ 10km; Boominathan 1999; December 1998- March 1999) and Anaikatti Hills (3.49 reptiles/ 10km; Mukherjee 2007; January 2003- December 2004). The present study augments the view of Sundar (2004) that amphibians are more susceptible to vehicular traffic. Amphibians constituted higher number of road kills compared to reptiles in the present study, which is similar to the earlier studies undertaken in the Western Ghats (see above).

A higher number of amphibians and reptiles were killed during night despite relatively low vehicular traffic density. This could be related to higher nocturnal activity of many species of herpetofauna. For instance, species such as *Bungarus caeruleus* were killed only during night confirming their restricted activity during night (Whitaker and Captain 2004). Insects may be attracted to the light post and or head lamps of the vehicles plying on the road, which may in turn attract insectivorous species of herpetofauna. Dodd *et al.* (1989) hypothesized that reptiles and amphibians are attracted to road to elevate their body temperature on cool nights following the sunny days, because the road surface remain warmer than the surroundings. Species that move frequently, especially snakes, are at the highest risk of mortality (Bonnet *et al.* 1999 and Roe *et al.* 2006) as their movement in relatively smoother surface may be difficult. Even though only fewer species of lizards were killed on the road compared to snakes, their number was higher. Higher number of openings in the canopy near the road might have enhanced the activity of lizards near roads.

A higher number (72%) of amphibians was recorded during wet season, which could be due to the increased activity associated with breeding such as aggregation nearby puddles and dispersal of froglets. The present result augments the findings of Hels and Buchwald (2001) and Mazerolle (2004). However, mortality of reptiles was high during dry season, which may be due to their enhanced activity during this season as most of the reptiles in tropics begin reproductive activity prior to rain. However, a few taxa such as uropeltid snakes (Rajendran 1985, Kumara *et al.* 2000 and Vijayakumar *et al.* 2001) may differ from this general pattern. As in the present study, a higher proportion of road kills has been contributed by *Indirana* sp. and *Duttaphrynus melanostictus* (Vijayakumar *et al.* 2001 and Sundar 2004).

The present study found no relation between number of reptiles found dead on the road and those found in adjacent forests. However, the number of amphibian kills had significant relationship to that found in the nearby forests (collectively and during the wet season). This shows the influence of climate on the activity of amphibians. Six taxa of amphibians were found killed on the road by vehicles; among them *Indirana* sp. contributed the most (47.52%) followed by *Duttaphrynus melanostictus* (41.58%). However, forests found adjacent to the road had 11 species, and *Indirana* sp. (39.85%) *Fejervarya* sp. (29.12%) and *Duttaphrynus melanostictus* (12.64%) contributed the highest proportion of these. The discrepancy in the abundance of these species in the forests and road kill records (Table 1 and 3) could be due to variation in their activity, behaviour and spatial use. For instance, *Fejervarya* spp. are largely aquatic and their activity may be restricted around water bodies, and hence they were not found in the road kills. Similar to amphibians, several reptile species observed in the forests were not found in road kills and *vice-versa*.

Various views are available on the relationship between traffic volume and mortality of herpetofauna. Smith and Dodd (2003) found no relationship between traffic volume and monthly road kill rate, which is similar to the findings of the present study. However, positive relationship between traffic volume and mortality of herpetofauna has also been reported (Amphibians: Fehrig *et al.* 1995, Hels and Buchwald, 2001 and Mazerolle 2004; Reptiles: Szerlag and McRobert 2006).

Roads are essential for transportation of materials and people. However, in India, the impact of roads on wildlife is poorly understood, barring a few fragmentary data on select taxa. The impact of road network may be server on wildlife, especially on herpetofauna, which are relatively slow moving. Including the present study, the rate of reptile mortality ranged from 0.27/ day (this study) to 0.83/ day in Mudumalai (Boominathan 1999) in the Western Ghats (see above), and a moderate road kill rate of 0.55/ day would result in the mortality of 14700 reptiles/day in about 26697 km of National Highways that

TABLE 3. Abundance of amphibians in the forests adjacent to the National Highway 220 during dry and wet seasons as recorded by Visual Encounter Survey. Number within parentheses are relative abundances.

TABLA 3. *Abundancia de reptiles en los bosques adyacentes a la Autopista Nacional 220 durante las estaciones seca y lluviosa, según registros con el método de encuentros visuales. Números entre parentesis son abundancias relativas.*

Amphibian Species	Dry season	Wet season	Total
Duttaphrynus melanostictus	12	21	33 (12.64)
Euphlyctis cyanophlyctis	7	1	8 (3.07)
Fejervarya sp.	15	61	76 (29.12)
Sphaerotheca breviceps	--	5	5 (1.92)
Silvirana temporalis	19	5	24 (9.20)
Clinotarsus curtipes	--	1	1 (0.38)
Indirana sp.	12	92	104 (39.85)
Nyctibatrachus beddomii	5	--	5 (1.92)
Nyctibatrachus aliciae	2	--	2 (0.77)
Philautus sp.	--	2	2 (0.77)
Polypedates pseudocruciger	1	--	1 (0.38)
Total	73	188	261 (100.00)

TABLE 4. Abundance of reptiles in the forests adjacent to the National Highway 220 during dry and wet seasons, as recorded by Visual Encounter Survey. Number within parentheses are relative abundances.

TABLA 4. *Abundancia de reptiles en los bosques adyacentes a la Autopista Nacional 220 durante las estaciones seca y lluviosa, según registros con el método de encuentros visuales. Números entre parentesis son abundancias relativas.*

Reptile Species	Dry season	Wet season	Total
Cnemaspis mysoriensis	124	80	204 (40.24)
Geckoella collegalensis	1	2	3 (0.59)
Hemidactylus frenatus	13	6	19 (3.75)
Hemidactylus maculatus	0	2	2 (0.39)
Draco dussumieri	15	0	15 (2.96)
Calotes versicolor	5	1	6 (1.18)
Calotes calotes	20	5	25 (4.93)
Calotes rouxii	2	0	2 (0.39)
Psammophilus blanfordanus	47	11	58 (11.44)
Chamaeleo zeylanicus	0	1	1 (0.20)
Lygosoma punctata	2	0	2 (0.39)
Eutropis carinata	2	9	11 (2.17)
Eutropis macularia	96	45	141 (27.81)
Varanus bengalensis	5	2	7 (1.38)
Ramphotyphlops braminus	1	2	3 (0.59)
Boiga beddomei	0	1	1 (0.20)
Dendrelaphis tristis	1	0	1 (0.20)
Coelognathus helena	1	0	1 (0.20)
Oligodon arnensis	0	1	1 (0.20)
Ptyas mucosa	1	1	2 (0.39)
Hypnale hypnale	0	2	2 (0.39)
Total	336	171	507 (100.00)

pass through the forest and wildlife habitats. The mortality of wildlife due to vehicular traffic may be influenced by various factors such as status of the forest, wildlife density, behaviour of the species, climatic conditions and traffic density.

Measures such as dwarf barriers (30 cm) on either side of the road, pipe culverts and bridges in appropriate areas such as stream crossings, as well as speed controls (breakers), would help to reduce the mortality of animals, especially the herpetofauna. Installation of signage regarding wild animal movements and regulation of speed of the vehicles and traffic regulations would also help to minimize mortality (Spellerberg 2002). Studies to identify important sectors of roads (Langen *et al.* 2009), especially those cut across forests may be useful for proposing measures to reduce their impacts on biota. A data base of mortality of wildlife in various categories of existing roads in India including the State Highways and further studies on designs to minimize the impact of roads on wildlife would provide further insights with respect to wildlife conservation and infrastructure development.

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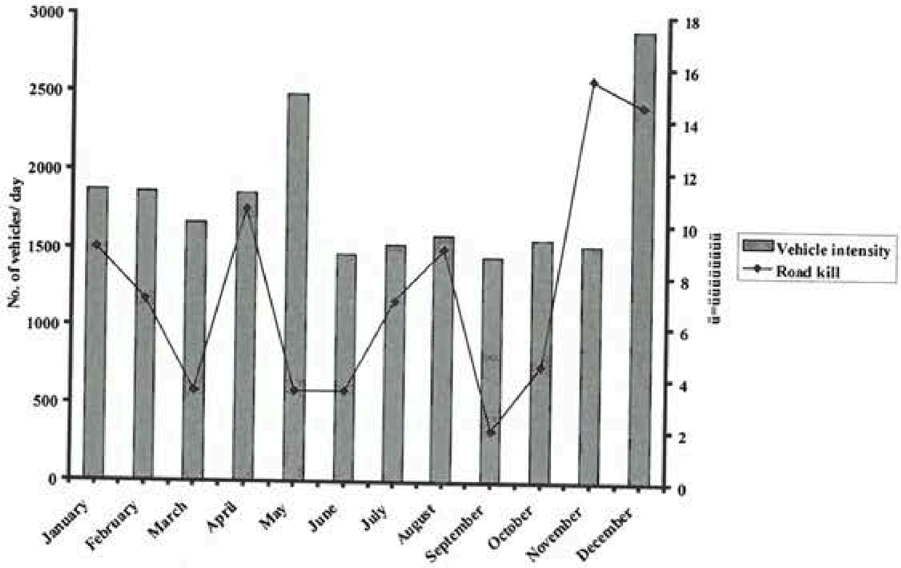

FIG. 2. Herpetofaunal mortality and Vehicle intensity in a stretch of National Highway 220, India.
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quickly mastered and easy to teach to other investigators. It did, however, rely upon skillful tracheostomy and subsequent skin suturing by the operator. No complications were noted in our study.

With our modification of the traditional technique, endotracheal intubation in rats could be safely performed with high success rate, which makes it highly suitable for basic cardiovascular research. Our intubation method requires no special equipment, needs little training to master and thus far has not been seen to be associated with any complications.

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Distribution, abundance and conservation of primates in the Highwavy Mountains of Western Ghats, Tamil Nadu, India and conservation prospects for lion-tailed macaques

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In the present study, we surveyed the primate species in the Highwavy Mountains of Tamil Nadu, India. Five primate species, including Nilgiri langur, Hanuman langur, bonnet macaque, lion-tailed macaque and slender loris were recorded in the region. Coffee and cardamom plantations in the hill system still hold the population of endangered lion-tailed macaque and Nilgiri langur. However, tea plantations act as a barrier for the movement of primate groups between the forest patches. The disturbance in the hill system and its consequence may be a reason for the increased group size of lion-tailed macaques. The inclusion of the lion-tailed macaque occurring areas to the newly declared Megamalai Wildlife Sanctuary in the Highwavy Mountains is recommended.

Keywords: Distribution, Highwavys, lion-tailed macaque, Megamalai, primates.

THE forests of the Western Ghats harbour a large number of flora and fauna. Due to its high biodiversity, the hill system has been recognized as one of the global biodiversity hotspots[1]. Nevertheless because of high human density[2] and high anthropogenic pressure, the rate of forest loss is alarming and these forests are considered to be one of the world's most endangered forests[3]. Developmental activities such as construction of dams, roads and power lines, converting the forests for commercial plantations such as coffee, tea and eucalyptus, and exploitation of trees for decades to cater to the wood industry led to a sharp decline of forest cover and resulted in fragmentation[4,5]. As a consequence of this, populations of many species have become fragmented. In addition, hunting of wild animals by humans has resulted in local extinction of some species[6,7]. Nevertheless, protected area network was created during 1972 to conserve the flora and fauna of the country (Wildlife Protection Act 1972, ref. 8). Although some parts of the Western Ghats were declared as

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protected areas, many potential forest regions were left out due to lack of baseline data. The Highwavy Mountains in the southern Western Ghats is one such area lacking baseline data on mammals except for few five decade old occurrence records. Wroughton[9] identified 25 mammals and later Hutton[10] reported 56 mammals including certain range restricted and threatened species such as lion-tailed macaque *Macaca silenus*, Nilgiri tahr *Hemitragus hylocrius*, Nilgiri langur *Semnopithecus johnii*, Salim Ali fruit bat *Latidens salimali* and Nilgiri marten *Martes gwatkinsii*. All the five species of primates known from the Western Ghats are reported in Hutton's survey of the Highwavys.

Highwavys of the southern Western Ghats have remnant evergreen forests that have been severely fragmented and overexploited to raise economic crops such as tea, coffee, cardamom, etc. Nevertheless, it forms a crucial wildlife refuge that spurs north to the Periyar Tiger Reserve (PTR) and connects the Grizzled Squirrel Wildlife Sanctuary (GSWLS) of Srivilliputhur in the east[11]. Yet, detailed data on any aspect of mammals are not available for this hill system. We present here findings from a survey of primates in the evergreen forests and adjoining dry disturbed forests in the Highwavys and discuss the conservation value of the hill system.

Highwavys (~490 sq. km) is located in Theni district of Tamil Nadu, and lies between 9°30′N to 9°50′N and

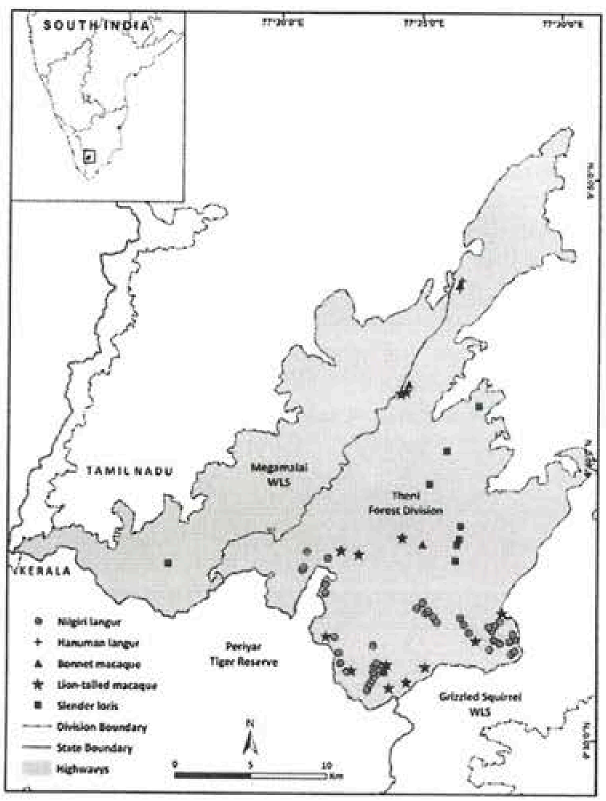

Figure 1. Map showing the sightings of primates in Highwavy Mountains.

77°10′E to 78°30′E (Figure 1). The elevation ranges from 300 to 2016 m above msl. The average rainfall ranges from 700 mm in the foothills to over 2500 mm in the higher reaches[12]. The forest types[13,14] include shola forests and grasslands at high altitude, evergreen and semi-evergreen forests at slopes and plateau (i.e. 108.44 sq. km), moist deciduous forests and its degraded stages (i.e. 103.38 sq. km) deciduous forests towards the edge on eastern side (i.e. 228.73 sq. km) and plantations and commercial croplands of tea, coffee and cardamom (i.e. 49.78 sq. km). The commercial crops that are grown in the region are coffee, tea, cardamom, clove, cashew and silk cotton.

The survey was done in the evergreen forests and its adjoining dry forests for the diurnal primates focusing mainly on the endangered lion-tailed macaque. A large proportion of the dry forests was not covered in the survey. We also surveyed the commercial plantations of coffee, tea and cardamom at higher altitude. However, all the forest types in the entire hill system were surveyed during the night for slender loris.

Laying transect lines is often not possible over much of the forested areas of the mountains. Considering the total area to be surveyed (108.44 sq. km of evergreen forests and adjoining degraded moist deciduous forests, dry forests and plantations of about 70 sq. km), the total area was divided into seven segments of about 25 sq. km. We trained forest department personnel, research students and few local people in the survey methods. The survey was conducted during 21–25 January 2009, which involved simultaneous walks in selected segments (five persons for each segment) by maintaining the inter-individual distance of 100–200 m. A total of 204 km was walked between 0600 and 1400 h on predetermined routes. During the walk, after sighting a primate group, 5–10 min were spent to obtain a proper count of individuals and coordinates were recorded. The data on group composition of all the primate species was collected for a span of 10 days.

The major goal of the survey was to assess the status of the lion-tailed macaque in the Highwavys. Previous studies have documented the home range of a single group to be about 5 sq. km (refs 15–18). Hence, we considered each group that was sighted within a range of 1.5 km radius from the other group as same, unless the two groups were sighted in a short span of time and the group identity of each was confirmed as different. The inter-group distance was extracted with GIS.

Meanwhile, the survey was also carried out between 1900 and 2400 h for slender loris. The night survey was done by walk on pre-existing trails at a speed of 0.5 km/h, and the total distance walked was 62 km. While walking, we flashed light on the sides and recorded the distance walked. Slender loris *Loris lydekkerianus* was differentiated from other animals by its orange-red reflection of eyes to the light, which is very different from the

Table 1. Encounter rate and group size of the primates in Highwavy Mountains. Effort during the day was 204 km of walk (for diurnal primates) and night was 62 km of walk (for nocturnal primates)

	Encounter rate			Group size	
Species	No. of groups sighted	Groups/km	*N*	Minimum–Maximum	Mean group size (SD)
Diurnal primates					
Nilgiri langur	61	0.30	11	3–11	6.00 (± 2.62)
Hanuman langur	2	0.01	2	10–12	11.00 (± 1.41)
Bonnet macaque	18	0.09	5	6–28	17.20 (± 8.41)
Lion-tailed macaque	15	0.07	8	7–55	33.25 (± 18.78)
Nocturnal primate					
Slender loris	8*	0.13**	–	–	–

*Number of individuals; **Number of individuals/km; *N*, Number of groups with group size data.

Table 2. Mean number of different age–sex individuals in the groups and age–sex ratios of the primate groups in Highwavy Mountains

Age, sex	Nilgiri langur	Hanuman langur	Lion-tailed macaque
Adult ♂	1.17	1.15	1.75
Sub-adult ♂	0.33	1.00	1.25
Adult ♀	2.17	3.50	7.00
Sub-adult ♀	0.66	1.00	1.00
Juvenile	1.00	2.50	6.75
Infant	1.17	1.50	2.00
Adult ♂ : Adult ♀	1 : 1.9	1 : 2.3	1 : 3.9
Adult : Immature	1 : 0.9	1 : 1.2	1 : 1.3
Adult ♀ : Infant	1 : 1.5	1 : 1.7	1 : 0.3

eye reflections of other nocturnal animals[19–21]. If there was ever any doubt regarding the identity of a species, we walked to the animal and confirmed its identity. For each sighting, number of individuals, forest type and coordinates were recorded.

The study confirms the presence of all five primates, viz. Nilgiri langur, Hanuman langur *S. priam*, bonnet macaque *M. radiata*, lion-tailed macaque and slender loris in the Highwavys. The subspecies of slender loris in the hill system was confirmed to be *L. lydekkerianus lydekkerianus*. Bonnet macaque being a habitat generalist species showed a wider distribution and was found in all the forest types. Nilgiri langur was restricted to evergreen and moist deciduous forests, lion-tailed macaques were confined to high and medium elevation evergreen forests and coffee plantations, and Hanuman langur and slender loris were confined to dry forests. Population of Nilgiri langur was discontinuous towards north and absent in certain forest patches. Further, Nilgiri langur and lion-tailed macaques were not recorded from western slopes of the hills.

Table 1 summarizes the number of groups or individuals seen, encounter rate and group sizes for each species. The encounter rate of Nilgiri langur was higher than other primates. Complete count of the group size could be obtained only for few groups for each species. Nevertheless we were able to obtain group sizes of all the lion-tailed macaque groups. Mean group sizes of Nilgiri langur, Hanuman langur, bonnet macaque and lion-tailed macaque were 6.00 ± 2.62, 11.00 ± 1.41, 17.20 ± 8.41 and 33.25 ± 18.78 respectively. The group size of lion-tailed macaque varied between 7 and 55. The slender loris is mostly solitary and all the sightings were of single individuals. The group composition and age–sex ratio of Nilgiri langur, Hanuman langur and lion-tailed macaque are summarized in Table 2. The groups of these species were multi-male and multi-female. We could not get the group composition of bonnet macaque since they did not permit proximity. The average age–sex ratio of the Nilgiri langur, Hanuman langur and lion-tailed macaque groups was 1.9, 2.3 and 3.9 adult female per adult male, 1.5, 1.7 and 0.3 infants per adult female and 0.9, 1.2 and 1.3 immature per adults respectively.

Considering the location details of each group of lion-tailed macaque and their group size during the survey, a separate effort was made for collecting the group characteristics, i.e. size and age–sex of each group. In addition to this, the data on location of groups with size, repeated counts and sightings helped to differentiate the groups from each other. Although the number of groups encountered during the survey was 15, we could establish a minimum number of groups in the hills as eight with about 266 animals (Table 3). All the groups sighted were associated or found amidst private estates.

Highwavys has a wide array of forest types due to high variation in altitude and rainfall. Drastic bioclimatic changes caused by the steep environmental cline create very restricted habitats and niches[22]. The vegetation gradient of Highwavys ranges from dry scrub forests in the foothills (low rainfall and more dry months) to montane shola at higher altitude where the rainfall is high. Although the rainfall in the Highwavys is low and the dry months are high and not typical enough to hold typical evergreen vegetation, the occult precipitation because of the massive elevation gradient is speculated to compensate it[23]. Hence, the mountains still hold the remaining fine evergreen forests (isolated amidst dry plains), especially the high elevation montane forests which is indeed the top-most endangered vegetation type in the Western Ghats[24]. The forest mosaic thus available (even after large-scale commercial conversions into non-forest

Table 3. Estimated lion-tailed macaque groups and their group size in Highwavy Mountains

Area	Coordinates	Altitude (m asl)	Group size
Vellimalai estate I	9°32′43.8″N, 77°23′45.9″E	1014	34
Vellimalai estate II	9°32′36.7″N, 77°23′45.8″E	1061	55
Engineering estate	9°36′24.6″N, 77°22′50.6″E	1263	28
Ananda estate	9°32′37.4″N, 77°22′37.4″E	1417	10
Palanikumar estate	9°31′54.7″N, 77°24′31.4″E	1180	50
Egan jaga	9°32′30.7″N, 77°22′36.3″E	1404	28
Kardana estate I	9°41′32.8″N, 77°23′48.2″E	1204	7
Kardana estate II	9°41′19.6″N, 77°24′02.6″E	1421	54
Total			266

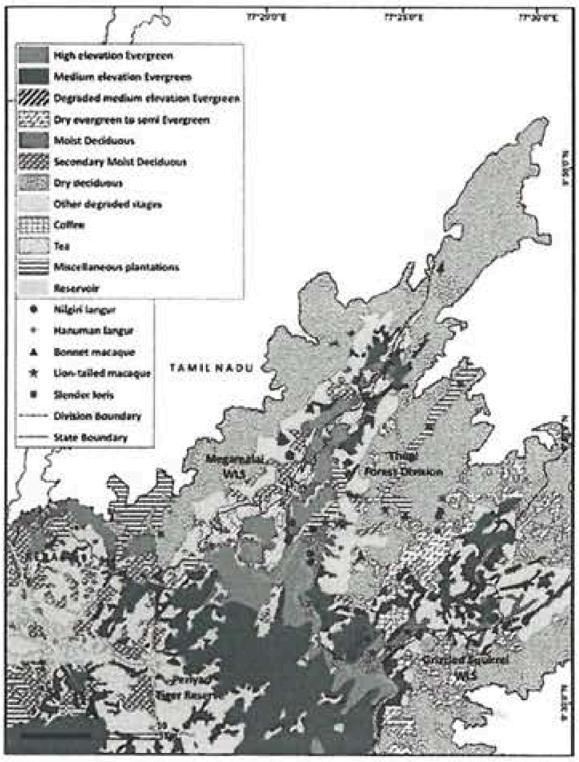

Figure 2. Vegetation map of the Highwavy Mountains and adjoining forest divisions showing the sightings of primates.

land-uses) enabled the mountain system to harbour all the primate species found in the Western Ghats. In the eastern side of the southern Western Ghats, Hanuman langur is restricted to dry forests whereas the Nilgiri langur is found in high altitude evergreen to moist deciduous or semi-evergreen forests. Lion-tailed macaque is highly restricted to evergreen forests. Although bonnet macaque is found in evergreen forests, it is largely restricted to low elevation gradients. Slender loris is found only in low elevation scrub or disturbed deciduous forests (e.g. Indira Gandhi Wildlife Sanctuary[25]). The present observation of primate distribution in Highways closely follows the same pattern.

Many anthropogenic disturbances are apparent such as the commercial plantations of tea, coffee and cardamom at the cost of rainforests and the three dams built in the hills have submerged vegetation in the valleys and plateaus that have created a gap for the animal movements. Yet, due to relative plasticity to adapt to varying habitat conditions, lion-tailed macaque, bonnet macaque and Nilgiri langur were found in the coffee and cardamom plantations. This has made the population of all the primate species continuous in the entire hill system except towards the western side where the tea plantation is predominant. The tea plantations act as a barrier to the west side deciduous forests and hence the populations of Nilgiri langur and lion-tailed macaque are restricted only to eastern parts of the hill. The Mysore slender loris is known to be found in drier forests of the plains and rain shadow forests of Western Ghats[19–21], and the present records in the Highwavys confirm this.

The evergreen forests of the Highwavys are continuous with the adjacent forest divisions (Figure 2), i.e. PTR in Kerala in the south and GSWS in Tamil Nadu on the eastern side. We presume that the populations of all primate species would be continuous including the lion-tailed macaque. Earlier we have sighted a few groups of lion-tailed macaque in both PTR and GSWS, and hence a proper survey of especially the lion-tailed macaques is necessary in these two protected areas to understand the total population status.

The mean group size and mean age–sex ratio of all primate species were close to the average calculated for many other regions except the mean group size of the lion-tailed macaque (33.25), which is much higher than all other regions, e.g. 19.6 in the Silent Valley[26], 16.3 in Anaimalai Hills[18] and 24.7 in Sirsi–Honnavara[27]. The lion-tailed macaque groups in the Highwavys are highly associated with the coffee or cardamom plantations or a portion of their home range is in the plantations. Even lion-tailed macaques in smaller fragments which were associated with the coffee plantations in Anaimalai Hills had high group size (22.83) than in the larger forest complexes (13.17)[18], and the group size of one of the smallest groups is more than 80 (ref. 28). Although it is very difficult to conclude which factor has really influenced the increased group sizes; one of the common factors in both the regions is the disturbed forests which forms a habitat mosaic with high plant diversity. However, this requires a detailed study. Although the number of groups is small (8 groups), the minimum population size of 266 individuals is very promising. Since the population is expected to be continuous with PTR and GSWS, the total population size may be much larger. However, this needs confirmation from further investigation of the status of lion-tailed macaque groups in neighbouring forests. Considering the current status of the lion-tailed macaque population in different parts of the Western Ghats (e.g. Kumara and Singh[29] and Kumara and Sinha[30] reported the decline in population size or almost local extinction of the lion-tailed macaques in different parts of the Western Ghats), the present finding of a large population therefore has high conservation value.

The population in the Highwavys needs proper attention since the habitat of the lion-tailed macaque remains outside the protected area network. Even the recently declared Megamalai Wildlife Sanctuary in the Highwavys (Figure 1) totally left out the habitats of lion-tailed macaques and Nilgiri langur. Further the large proportion of such habitat is under private holdings, and the official status of the forest is still considered as a 'reserve land', which raises need of urgent concern to retain the population through proper conservation and management strategy. In the near future it is necessary to provide a protected area status for this region.

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OBATES GRYLIO (Pig Frog). USA: TEXAS: CHAMBERS CO.: ray 124, 5 km N of High Island (29.61379°N, 94.38073°W; 84). 25 June 2008. Collected by Paul Crump. Verified by Carl nklin. University of Texas Arlington (UTADC 3691–3698). sue deposited at the MRJ Forstner Frozen Tissue Collection as State University (MF 27033).

mitted by **PAUL CRUMP** (e-mail: pcrump@houstonzoo. **RACHEL ROMMEL**, Department of Conservation and Sci- Houston Zoo, 1513 North Macgregor Way, Houston, Texas , USA (e-mail: rrommel@houstonzoo.org); and **JAIME ZALEZ**, Katy Prairie Conservancy, Katy Prairie Conservan- aller, Texas 77098, USA (e-mail: jaimegonzalez72@gmail.

OBATES PALUSTRIS (Pickerel Frog). USA: ARKANSAS: Y CO.: Off AR 14, ca. 2.2 km down Ramblewood Trail in drainage creek (UTM 15N 0536006E, 3990296N; WGS 84). rch 2009. M. B. Connior. Verified by S. E. Trauth. Arkansas University Museum of Zoology Herpetology Collection MZ 31312). Adult female caught by hand. First county re- lling a distributional gap among surrounding Stone, Marion, Newton counties (Trauth et al. 2004. The Amphibians and les of Arkansas. Univeristy of Arkansas Press, Fayetteville. p.).

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OBATES SYLVATICUS (Wood Frog). USA: TENNESSEE: BUREN CO.: Flooded pit near Piney Falls at Fall Creek Falls Park (35.67278°N, 85.375°W; datum NAD27). 06 January Matthew L. Brown and Thomas P. Solomon. Verified by oyd Scott. Twenty-two adults and egg masses located, two s photographed and catalogued at Austin Peay State Univer- Center for Field Biology (APSU 18954). First county record mond and Scott 1996. Atlas of Amphibians in Tennessee. Publ. No. 12. The Center for Field Biology, Austin Peay University, Clarksville, Tennessee. 94 pp. Internet version ://www.apsu.edu/amatlas] contains links to information ding Tennessee distribution of amphibians recorded since ; accessed 17 January 2009). Extends range from nearest mented occurrence by approximately 25 km west.

bmitted by **MATTHEW L. BROWN**, Fall Creek Falls Park, Pikeville, Tennessee, 37367, USA; e-mail: matthew. n@state.tn.us

SALAEMUS KROYERI (Kroyer's Dwarf Frog). BRAZIL: UÍ: Municipalidade de Piracuruca: Parque Nacional de Sete des (03.978°S, 41.556°W; datum SAD69; 110 m elev.). April . B. B. Annunziata, I. S. Castro, and W. M. Fontenele. February . B. B. Annunziata, M. R. A. Mendes and D. Cisne. Verified . Silvano and P. Valdujo. Herpetological Collection of Uni- dade Estadual do Piauí, Parnaíba (UESPI 0062, 0394–0404). species ranges from the northern part of the State of Minas is and from the central part of the State of Bahia, north to São do Bonfim and Mamanguape in State of Paraíba, occurring 240 m elev. (Frost 2009 Amphibian Species of the World http://research.amnh.org/herpetology/amphibia/index.php IUCN 2009 Global Amphibian Assessment). First state record, extends distribution ca. 588 SE from the city of São José do Bonfim, Paraíba state (Arzabe et al. 1998 Herpetol. J. 8:111–113), and a new elevation range of the species, up to 110 m.

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PSEUDACRIS CRUCIFER (Spring Peeper). USA: ARKANSAS: CARROLL CO.: 3.2 km S Berryville off St. Hwy 21 (36.201993°N, 93.340094°W; NAD83). 23 March 1996. H. W. Robison. Verified by S. E. Trauth. Arkansas State University Herpetological Museum (ASUMZ 31320). New county record completely filling a distributional gap in northwestern Arkansas among Benton and Boone counties (Trauth et al. 2004. Amphibians and Reptiles of Arkansas. Univ. Arkansas Press, Fayetteville. 421 pp.). This frog has now been reported from all but six counties of the state (Trauth et al. *op. cit.*).

Submitted by **CHRIS T. McALLISTER**, RapidWrite, 102 Brown Street, Hot Springs National Park, Arkansas 71913, USA (e-mail: drcmcallister@aol.com); and **HENRY W. ROBISON**, Department of Biology, Southern Arkansas University, Magnolia, Arkansas 71754, USA (e-mail: hwrobison@suddenlink.net).

RHACOPHORUS PSEUDOMALABARICUS (False Malabar Tree Frog). INDIA: KERALA STATE: WESTERN GHATS: Sakkulathumedu (9.8830556°N, 77.2330556°E), Idukki District, 1080 m elev., 10 km N of Periyar Tiger Reserve. 2100 h, 19 April 2008. G. Srinivas and Suganthan R. Sakthivel. Digital image voucher, USDZ (IMG) 1.27. Verified by Karthikeyan Vasudevan. Metamorphs observed 12 June 2008. Including type locality, currently known from two sites in Andiparai shola, 1190 m elev., Indira Gandhi National Park, Tamil Nadu, India (Vasudevan and Dutta 1998. Hamadryad 25[1]:21–28). Appears to be distributed in narrow elevational range. First report for Kerala State, 60 km S of type locality.

Submitted by **G. SRINIVAS** (e-mail: sriniherp@gmail.com), **S. BHUPATHY** (e-mail: bhupathy.s@gmail.com), Salim Ali Centre for Ornithology and Natural History, Anaikatty, Coimbatore 641 108, Tamil Nadu, India; and **SUGANTHAN R. SAKTHIVEL**, Kerala Forest Research Institute, Peechi 680 653, Kerala, India.

SPHAENORHYNCHUS PRASINUS: BRAZIL: PERNAMBUCO: MUNICIPALITY OF SÃO LOURENÇO DA MATA: Estação Ecológica do Tapacurá (08.03333°S, 35.18333°W, WGS 84, elev. 140 m). 10 January 2000. E. Maranhão dos Santos. Coleção Herpetologica da Universidade Federal Rural de Pernambuco, Unidade Acadêmica de Serra Talhada, Serra Talhada, Pernambuco, Brazil (CHUFRPE 966, adult specimen SVL 26.8 mm). Verified by M. Trefault Rodrigues. Previously known from states of Bahia (Centro de Pesquisa

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GRIMMETT R., C. INSKIPP & T. INSKIPP (1998): Birds of the Indian Subcontinent. Christopher Helm. London. Pp. 739.
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9. OCCURRENCE OF *SALEA ANAMALLAYANA* BEDDOME, 1878 IN HIGH WAVY MOUNTAINS, WESTERN GHATS, INDIA

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Two species of spiny lizards, *Salea **horsfieldii*** and *Salea anamallayana*, have been reported from the Western Ghats of south-western India. Unequal and strongly imbricate dorsal scales and compressed body distinguish these lizards from other agamids of the Western Ghats. The Anamalai Spiny Lizard, *S. anamallayana* could be distinguished from Nilgiri Spiny Lizard, *S. horsfieldii* based on the presence of a fold on the shoulder, and continuous nuchal and dorsal crest in males (Smith 1935). While *S. **horsfieldii*** is reported both from north and south of the Palghat gap, *S. anamallayana* is restricted to south of Palghat (Smith 1935). However, Bhupathy and Kannan (1997) suggested the need for further investigations to confirm the occurrence of *S. **horsfieldii*** south of Palghat.

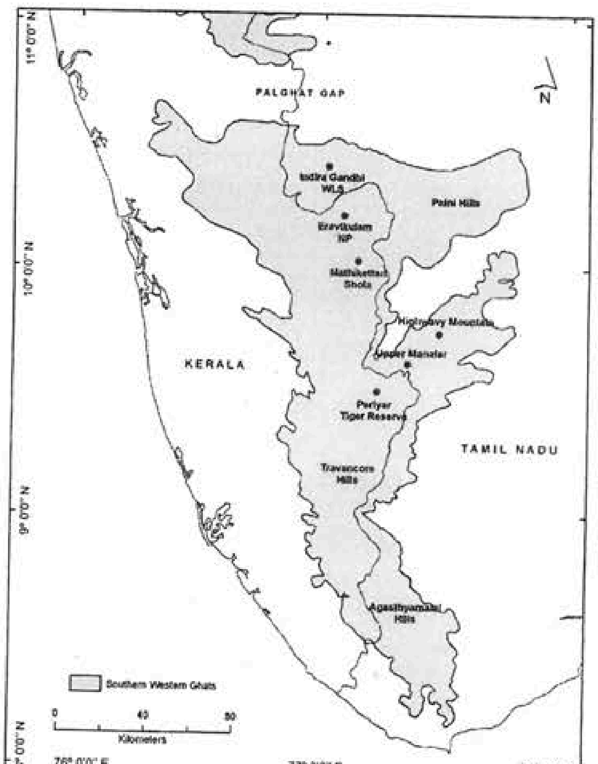

Fig. 1: Map of Southern Western Ghats, south-western India showing the locality records of *Salea anamallayana*

The Sálim Ali Centre for Ornithology and Natural History (SACON), Coimbatore is conducting ecological investigations on the herpetofauna of High Wavy Mountains, Theni Forest Division, Western Ghats since April 2006, and the following agamid lizards have been recorded; *Sitana ponticeriana*, *Calotes versicolor*, *C. calotes*, *C. grandisquamis*, *C. rouxii*, *C. elliotti* and *Psammophilus* sp. till December 2007. On April 20, 2007, while sampling in the Plateau of High Wavy Mountains, we came across an agamid lizard and it has been identified as a male *Salea anamallayana* based on the presence of unequal dorsal scales, fold on shoulder and continuous nuchal and dorsal crests. Snout-vent length and tail length of the lizard measured 40.2 mm and 60.3 mm respectively. Precise locality of this record is upper Manalar (9° 36' N; 77° 21' E), High Wavy Mountains, Western Ghats in Theni Forest Division, Tamil Nadu. This area (1,700 m above mean sea level) has remnants of evergreen forests, and is located on the border of Tamil Nadu and Kerala states. The boundary of Periyar Tiger Reserve, Kerala was in close vicinity (about 500 m) from the observation site of this agamid lizard.

It reported that *S. anamallayana* is restricted to the higher altitudes of the southern Western Ghats, especially in Anamalai, Palni (*Palani*) and Travancore Hills (Smith 1935). However, precise locality records for this species are scanty, which include Indira Gandhi Wildlife Sanctuary, Eravikulam National Park (Anamalai Hills), Mathikettan Shola and Mariyanshola in Palni Hills (Smith 1935; Bhupathy and

Kannan 1997; Bhupathy and Nixon 2004, Fig. 1). Even though, the present locality lies within the general Travancore Hills, it is perhaps, the only precise locality record available for this species south of Anamalai and Palni Hills, and is about 50 km (in straight line) from the nearest known site (i.e. Mathikettan shola). This record also indicates the possibility of the occurrence of *S. anamallayana* in Periyar Tiger Reserve, Kerala and on other hill tops such as Agasthiayamalai located further south. Further intensive surveys may yield new locality records and insights on the distribution pattern of this rare and endemic agamid species.

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10. RECORDS OF *ERYX JOHNII* (RUSSELL, 1801) (OPHIDIA: BOIDAE) AND *ECHIS CARINATUS* (SCHNEIDER, 1801) (OPHIDIA: VIPERIDAE) FROM THE THAR DESERT, RAJASTHAN, INDIA, WITH DISTRIBUTIONAL NOTES ON OTHER SNAKES

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During the course of a routine survey of the Thar Desert of Rajasthan, as a part of the assessment of impacts of the Indira Gandhi Nahar Project on biodiversity, two snakes, *Eryx johnii* and *Echis carinatus*, were encountered. Indian Sand Boa *Eryx johnii* was observed at 2245 hrs on August 15, 2000, in an agricultural field near the Desert National Park (DNP) guest house at Sudansari, Jaisalmer. The venomous Saw-scaled Viper *Echis carinatus* was observed at 2150 hrs on August 17, 2000, in a hard rocky area with sparse vegetation, *c.* 8 km towards Barmer on the road from Jaisalmer. The subspecies status of this reptile was not determined, i.e., whether the snake was *Echis carinatus carinatus* or *Echis carinatus sochureki* (some taxonomists consider the two to be distinct species – *Echis carinatus* and *Echis sochureki*).

A marked difference in behaviour was observed between the two species. The Indian Sand Boa on being disturbed was not aggressive, instead it tried to escape. The Saw-scaled Viper on the other hand, adopted a defensive posture.

Both the snake species have been reported to occur throughout the dry arid regions of India. The Thar Desert covers 13 districts of western Rajasthan. So far, a total of 20 snake species have been reported from the Thar Desert (Sharma 1996; Bhide *et al.* 2004). However, a look at their district-wise distribution reveals that they are not uniformly distributed. Maximum concentration occurs in Jodhpur district (15 species), while not a single species has been reported from Barmer, Churu, Ganganagar, Hanumangarh, Jalore and Jhunjhunu districts. In our opinion, as all the 13 districts of western Rajasthan lie within the Thar Desert and have similar environmental conditions, 60-70% of the snake species recorded in the Thar Desert may be present in all the districts. The present status of report may be due to the biased nature of earlier surveys. Thus, there exists plenty of scope in the distributional study of snakes within all 13 districts of the Thar Desert.

Previously, the Indian Sand Boa has been reported from two districts and the Saw-scaled Viper from five districts of western Rajasthan. The present report adds to the existing knowledge of distribution of snake fauna in Jaisalmer district of the Thar Desert, Rajasthan, India.

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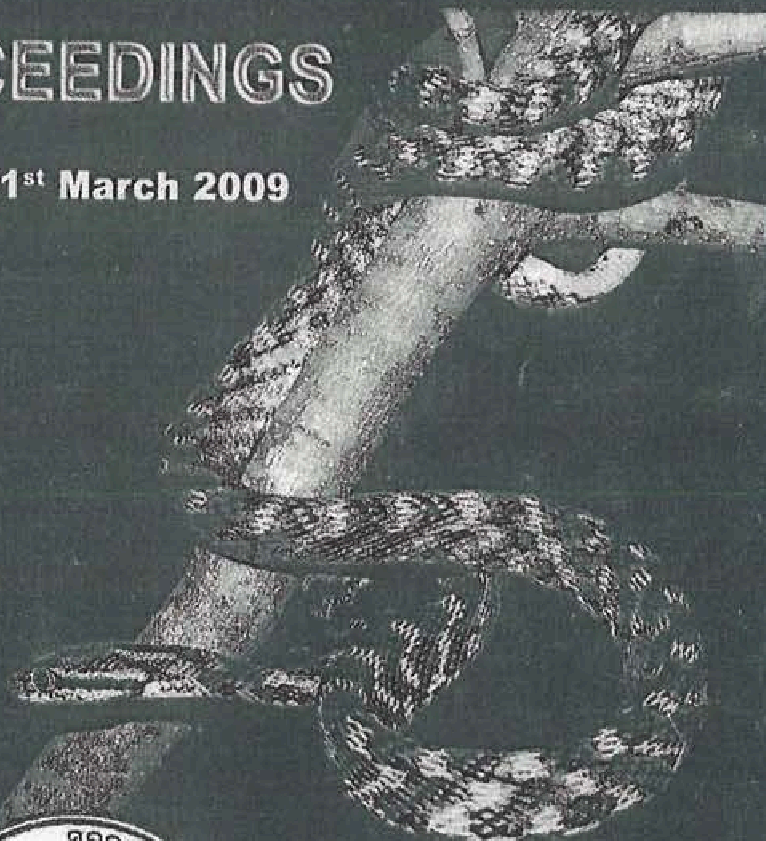

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SPATIAL USE BY *SYLVIRANA TEMPORALIS* (GUNTHER, 1864) IN THENI FORESTS, WESTERN GHATS

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In the present paper, we describe the spatial use by *S. temporalis* in Theni forests of the Western Ghats. Fieldwork was conducted between January 2007 and December 2008 in Theni Forests (9°31' - 10°15'N and 77°10' - 77°42'E) of Western Ghats, Tamil Nadu. Encounter rate and density of this species in Theni forests was evaluated, which indicates that this species is common in low and medium hills. Among various microhabitats, this species largely used edge of the water followed by litter and rock near water. This species has more affinity to water and importance of moist microhabitat in conserving this species.