Reptile Communities of Agasthyamalai Hills with Emphasis on Distribution along Elevation Gradient

Thesis Submitted to the

BHARATHIAR UNIVERSITY

For the award of

DEGREE OF DOCTOR OF PHILOSOPHY
In
ZOOLOGY

By

JINS.V.J

SACON

Sålim Ali Centre for Ornithology and Natural History
Coimbatore, India

July 2017

CERTIFICATE

This is to certify that the thesis, entitled “**Reptile Communities of Agasthyamalai Hills with Emphasis on Distribution along Elevation Gradient**” submitted to the Bharathiar University, in partial fulfillment of the requirements for the award of the Degree of Doctor of Philosophy in Zoology is a record of original work done by **Mr. Jins. V.J** during the period of September 2012–July 2017 of his research in the Department of Zoology at Sálim Ali Centre for Ornithology and Natural History (SACON), under my supervision and guidance and the thesis has not formed the basis for the award of any Degree /Diploma /Associateship /Fellowship or other similar title to any candidate of any University.

Signature of the Guide

Head of the Department /
Director

DECLARATION

I, **Jins V.J** hereby declare that the thesis, entitled "**Reptile Communities of Agasthyamalai Hills with Emphasis on Distribution along Elevation Gradient**" submitted to the Bharathiar University, in partial fulfillment of the requirements for the award of the Degree of Doctor of Philosophy in Zoology is a record of original and independent research work done by me during the period of September 2012–July 2017 under the supervision and guidance of **Dr. Arun P.R**, Principal Scientist at Sålim Ali Centre for Ornithology and Natural History (SACON) and it has not formed the basis for the award of any Degree /Diploma /Associateship /Fellowship or other similar title to any candidate of any University.

Jins V.J

CERTIFICATE OF GENUINENESS OF THE PUBLICATION

This is to certify that Ph.D. candidate **Mr. JINS.V.J** working under my supervision has published a research article in the standard refereed/**SCI** journal named **Current Science** with Vol. No. **110** Page Nos. **908-912** and year of publication **2016** published by **Indian Academy of Science (IAS)**. The contents of the publication incorporate part of the results presented in his thesis.

Countersigned   Research Supervisor

Principal / Head of the Dept. / Director
(Institute)

CERTIFICATE OF GENUINENESS OF THE PUBLICATION

This is to certify that Ph.D. candidate **Mr. JINS.V.J** working under my supervision has published a research article in the standard refereed/SCI journal named **Herpetology Notes** with Vol. No. **7** Page Nos. **555-557** and year of publication **2014** published by Societas Europaea Herpetologica (SEH) . The contents of the publication incorporate part of the results presented in his thesis.

Countersigned   Research Supervisor

Principal / Head of the Dept. / Director
(Institute)

Acknowledgements

My thesis work was an offshoot of the research project entitled 'Patterns of distribution of selected faunal groups in Agasthyamalai Hills, Western Ghats, India'. This project was conceived and initiated by late Dr. S. Bhupathy. I am immensely grateful to him for introducing me to the field of herpetology and giving this great opportunity to explore the patterns in nature through reptiles. His enthusiasm for this topic was a continuous source of inspiration throughout my Ph.D work, even now.

I am immensely thankful to my Ph.D. supervisor, Dr. Arun P.R for his guidance and support provided in various ways. I am grateful to him for all the encouraging words and advice he has given me during this period. His critical comments, friendly approach and timely advice helped a lot in the writing stage.

I express my sincere gratitude to Dr. Rajah Jaypal, Principal Scientist, SACON for his guidance and encouragement, especially in the final stage of my field work (Agasthyamalai Project) and also during my thesis writing. I would like to thank him for the invaluable help in data analysis and comments on my drafts of the thesis.

I thank Department of Biotechnology (DBT), Govt. of India for the funding and especially Dr. Omkar Nath Tiwari, Scientist, DBT for all the support throughout the study period. I acknowledge the institutional support extended by Sålim Ali Centre for Ornithology and Natural History (SACON) in all stages of this study. I am thankful to Dr. K. Sankar, Director of SACON for his continuous support and inspiring words especially in the final stages my thesis. I acknowledge Dr. P. A. Azeez, former Director, for his support and advice throughout my work and also for being my supervisor for a short period after the sudden demise of Dr.S. Bhupathy.

I greatly appreciate Dr. S. Babu, Scientist, SACON for his invaluable suggestions and support throughout my work. His help in Ecological Niche Modeling and other GIS work were commendable. I thank Dr. Karunakaran, Principal Scientist, SACON for the help in vegetation sampling. His energy and support were highly motivating for me during the field work. I am grateful to Dr. Balusubramanian, Research co-ordinator, SACON for all the help provided regarding my Ph.D. thesis and doctoral committees. I would like to thank all scientists of SACON especially Dr.Goldin, Dr.R.P.Singh and Dr.H.N Kumara for the moral support and advice at various stages of my thesis. I greatly acknowledge the help of all supporting staff from administration, finance, library and other housekeeping staff at SACON.

I express my gratitude to Kerala Forest Department for the permissions and logistic support for this study. I would like to thank Shri. V.Gopinathan, IFS, former PCCF (wildlife); Shri.G.Harikumar, IFS, PCCF (Wildlife); Shri. J.K.Sharma, former Wildlife Warden, and Shri.Ratheesh, Wildlife Warden, of Neyyar and Peppara Wildlife Sanctuaries for their extensive support. I am particularly thankful to DFO, Range Officers and staff of Neyyar and Peppara Wildlife Sanctuaries. Special thanks to

Shri.Sivaprasad, former Range Officer (RO),Shri.Saju, former Deputy RO, Shri.Selin, Deputy RO, Agasthyavanam Biological Park for providing base camp and other logistics at Kapukadu. I thank all the officers, watchers and other staff at Kapukadu Forest Office and Elephant Rehabilitation Centre (ERC) for their help during our stay at the base camp. I also thank Wildlife Warden, Shenduruney for support from the inception of the study.

I would like to express my thanks to Jeep drivers in the field, Mr.Shyju, and Mr.Ratheesh; and our field assistants from Podium, Kapukadu, and Bonacaudu for their help in fieldwork. Special thanks to Mathan Kani and Maathiyan Kani from Podium; Chandhu and Suresh from Aamoodu settlements. Thanks to Forest Dept. watchers Vinu, Shaji, Pachan, Sukumaran and Chellappan. I thank Eco-Development Committees (EDC) of Kapukadu and Podium, especially Shri. Vinod, Smt. Shobhana, Shri.Surendran and family for their support and hospitality during the fieldwork. I also thank all elephant caretakers of ERC, Kapukadu for their love and support.

Very special thanks to my colleague Ms. Madhumita Panigrahi who gave me a great company and encouragement throughout my fieldwork. I deeply acknowledge her support at various levels which helped me for the successful completion of this work.

I am thankful to my senior colleagues and friends especially Mr. Sony R.K, Rajan Pilakandy and A.P. Zaibin for their immense help, encouragement and critical comments. It helped me a lot during the course of my work. I thank Mohd Ibrahim, Riyas and Binisha for GIS help. Special thanks to my dear hostel mates Zeeshan, Anoop, Arijit, and Nambirajan, who gave me memorable moments of friendship in SACON. I am grateful to all my friends and colleagues at SACON especially Aditi, Aakriti, Akshaya, Anoop Raj, Avadhoot, Divya, Parthasarathy, Nivedita, Joydeep, Kiruba, Gayathri, Manikandan, Nishad, Chandran, Ramesh Kumar, Shanthakumar, Prakash and many others who are not listed here. I also thank my friends Sandeep Das and Rajkumar from Kerala Forest Research Institute (KFRI) for their help and valuable discussions in the field.

Special thanks to Dr. David Gower, Natural History Museum (NHM), London for his help in identification of Uropeltid snakes and his continuing support for my herpetology research. I thank SCCS, Cambridge, and Internship programme 2016 for giving me great opportunity to present my Ph.D. work and get valuable suggestions and inputs to my thesis. I thank Drs. Indraniel Das, Aaron Bauer, John. J. Wiens and Kanto Nishikawa for their help and support at various levels.

I thank my beloved parents and sister for their unconditional support, care and encouragement. I express my deep gratitude to them for being there for me at every stage of my studies. I express my sincere thanks to Joice Mariyam for her love and support throughout this period which helped me to overcome many difficult situations during my research career. Thank you all...!

Contents

Tables

Figures

Plates

Appendices

1 General Introduction

1.1 Background

Unravelling the mechanisms behind the spatial distribution of species has been a challenging endeavour for ecologists (Lomolino & Brown, 2004). Many attempts have been made to study the spatial gradients in species richness (Darwin, 1859; Wallace, 1876; Whittaker, 1960; Brown, 1971; Rahbek, 1995) which were carried out mainly to explore the underlying mechanisms of species distributions across different geographical zones. These explorations have indicated the importance of evolutionary, geographical and environmental factors in determining species distributions. Consequently, understanding species distribution patterns became a central theme in community ecology, and a prerequisite for conservation planning (Vetaas & Grytnes, 2002).

The latitudinal variations in species richness is a well known distribution pattern where more species tend to occur in the tropics than in temperate zones (Brown, 1995). Comparable patterns have been found along mountain ranges as well, where the species richness tends to decrease with increasing elevations. These patterns were initially explained as a phenomenon that happens in response to the extreme climatic conditions in higher elevations similar to that in temperate zones (Stevens, 1992). In addition, patterns such as mid-elevation peaks in species richness along elevation gradients have also been reported for various taxa.

A unimodal (hump-shaped) pattern in species richness is reportedly the commonest pattern, though species richness may increase or decrease in response to the primary productivity of an area (Waide *et al.*, 1999; Mittelbach *et al.*, 2001). It has been proposed that factors such as area availability, geometrical constraints, climate, and historical events could explain these patterns (Rahbek, 1995). In most cases, the surface area of mountains tends to decrease towards higher elevations. Hence, the number of species possibly decline in accordance with area availability (Rahbek, 1995). The species-temperature hypothesis predicts that diversity is a positive function of temperature, though it has been shown to vary between taxa and latitudes (Pianka, 1966b; Hawkins *et al.*, 2003). While most of the studies explaining the species richness patterns in relation to climatic factors, few researchers highlighted the importance of historical events such as speciation, extinction and biogeographical dispersal (Wiens *et al.*, 2007). Recent advancements in the phylogeography suggest that ecology and historical biogeography has a significant role in determining patterns of species richness (Wiens & Donoghue, 2004). On the other hand, geometric constraints hypothesis (Mid-domain effect) predicts that the patterns of species richness are influenced mainly by distinct geographical boundaries irrespective of the environmental factors (Colwell & Lees, 2000). However, the major driving factors underlying these patterns in various taxa are poorly understood.

Although the number of species may follow some linear patterns, the species turnover changes drastically across the elevation. The elevational range of a species is largely determined by multiple factors including its tolerance to changing weather conditions (Stevens, 1992). The association of species with the specific climatic conditions and habitat variables might influence the species compositions in various elevation zones. Since the turnover patterns along elevation reveal associations in specific zones, it can help in prioritizing elevation zones for conservation planning. Studies elsewhere highlighted that turnover rate is highly associated with range sizes of species where narrow ranged taxa like amphibians exhibit higher turnover rates across the globe (Buckley & Jetz, 2008). The range size of a species indicates the level of tolerance to various environmental gradients along altitudinal gradients. Rapoport's elevational rule suggest that higher elevation species tend to have larger range size considering their adaptation to accommodate extreme weather conditions as in temperate zones (Stevens, 1992).

Along with these macro-ecological patterns in species richness, understanding the 'patterns within communities' such as the niche relationships, coexistence, and inter-specific competitions have also been the focus of community ecology (Pianka, 1973). The patterns within communities can be inferred by studying different ecological aspects of constituent species such as habitat and microhabitat associations, niche breadths and guild structure. The habitat and microhabitat associations play a major role in determining the distribution of a species in a given geographical space. The habitat in combination with various environmental factors forms the ecological niche of an organism (Whittaker *et al.*, 1973). Understanding the niche breadth of an organism could provide insights on the resource use patterns and competitions within the communities. The niche dimensions and competitions in communities have been the focus of many studies. Niche breadth and overlap among different species within communities can help us to understand the biological process behind the resource use patterns of populations (Griffiths, 1987). Competition, predation, and physiology are the major factors that influence the patterns in resource partitioning by organisms (Toft, 1985). Reptiles are considered to be the suitable model organisms to study the community structure and competition (Pianka, 1975) owing to their strong microhabitat associations and morphological diversity.

The ecological niche has a significant role in determining the potential distribution of a species (Pulliam, 2000). The spatial distribution patterns and ecological niche requirements of different species have been explored recently using various geospatial tools and are widely used in conservation practices (Peterson, 2001; Guisan *et al.*, 2013). Ecological Niche Modeling (ENM) is one of such modeling tools that predicts the probable distribution ranges of a species based on their fundamental niche requirements (Peterson *et al*, 1999). Basically, these models generate habitat suitability maps for the target species using the known occurrence records and associated digital environmental layers (Pearson, 2007). These digital layers include bioclimatic, topographic and vegetation parameters (which can influence the distribution of target species) and are available from open sources as raster files to use in any Geographical Information System (GIS) platform. Maximum Entropy (Maxent) is the most popular ecological niche modeling approach that uses presence only data to predict the potential distribution ranges of a species. Prediction maps can be generated from these models and these maps are widely used in future exploratory surveys as well as in conservation planning of the targeted species (Raxworthy *et al.*, 2003). Apart from studying the niche requirements of a particular species, Ecological Niche Models are also used in understanding the competitions in species' macro distributions and suitable habitats (Anderson *et al.*, 2002).

More recently, Ecological Niche Models (ENM) are widely used in conservation practices to study the ecological niche requirements of species, biogeography of landscapes, and the distribution of known and unknown populations (Raxworthy *et al.*, 2003). Although such modeling approaches are widely used across the globe, it is rarely explored in biodiversity-rich areas like the Western Ghats. In the Indian context, the niche modeling is usually applied for predicting plant species distributions and rarely used in the case of fauna. Since many of the reptiles that occur in the Western Ghats are endemic species, it's highly relevant to predict the potential distributions of these little known taxa, mainly to propose conservation measures. In this context, ENM approaches could possibly open new avenues in biodiversity explorations and conservation planning in the Western Ghats.

The macro ecological patterns of taxa have been rarely addressed in the Western Ghats of India which is a mega-biodiversity hotspot (Myers *et al.*, 2000). The rich biodiversity, topographic complexity, gradients in elevation and distinct vegetation types make the Western Ghats a suitable geographical landmark to investigate the various concepts and mechanisms that structure ecological communities. Moreover, these hill ranges are among the major global biodiversity hotspots and important areas for conservation due to its biological wealth (Myers *et al.*, 2000). These hill ranges are well-known for endemism especially in the case of herpetofauna. About 47% of the reptiles found in the Western Ghats are endemics (Srinivasulu *et al.*, 2014). Recent explorations and new descriptions of herpetofauna from the Western Ghats (Gower & Winkler, 2007; Biju & Bossuyt, 2009; Jins *et al.*, 2014; Agarwal *et al.*, 2016; Deepak *et al.*, 2016; Gower *et al.*, 2016) revealed that a significant portion of its biodiversity remains unexplored. Moreover, reptiles are often ignored in conservation planning and most of the surveys end up only in listing the species in a given area. Unlike in amphibians (in which species turnover mostly between drainages or streams), reptiles shows higher turnover along elevation gradients in the Western Ghats mountains (Ishwar *et al.*, 2001). Exploring such patterns can help in prioritizing conservation zones for reptiles along elevation gradients.

Agasthyamalai Hills in the southern Western Ghats- a part of Agasthyamalai Biosphere Reserve (ABR) is especially well known for its diversity of endemic medicinal plants. Although the floral diversity of Agasthyamalai Hills has been explored extensively in the past, the faunal components remain unexplored. The area is also frequented by tourists and pilgrims to Agasthya peak which is popularly known as Agasthyakoodam where '*Rishi'* Agasthya's shrine is situated. The pressure on the biodiversity due to ecotourism and pilgrimage raise a serious concern in the region which needs to be prioritized into zones that need immediate conservation actions. Compared to other faunal groups, herpetofauna is known for their much greater association to particular microhabitats and climatic conditions. In this aspect, studying the distribution patterns (along elevation), climatic and habitat associations, and microhabitat preferences have implications for conservation along with the community ecology perspective. The studies on altitudinal patterns in species occurrence along mountain ranges could also suggest expected impact of climate change and associated altitudinal range shifts of species or extinction risks (Colwell *et al.*, 2008; Sekercioglu *et al.*, 2008; Chen *et al.*, 2011). The variety of forest types and the wide-ranging gradients in elevation (100-1868m) in the Agasthyamalai hills provide an ideal environment for exploring the patterns of reptile distributions and the underlying mechanisms that determine them.

With the above background, the present study was carried out to address the following major objectives:

1.2 Objectives

1. Study the distribution patterns and turnover of reptiles along an elevation gradient in Agasthyamalai Hills and the role of environmental factors influencing these patterns.
2. Understand the ecological niche, microhabitat relationships, and habitat associations in reptile communities.
3. Predict the potential distribution of select endemic reptiles in the southern Western Ghats using an Ecological Niche Modeling (ENM) approach.

1.3 Organization of the thesis

The thesis consists of six chapters of which three are technical chapters addressing the the three majore objectives. A brief literature review on the specific topic is given in the respective technical chapters.

The first chapter (Introduction) provides study background, objectives, and outline of the thesis. The second chapter describes the study area and its features including the biodiversity, vegetation types, people, and conservation.

Chapter three explains the species richness patterns and turnover of reptiles along the elevation gradient in Agasthyamalai Hills. The ecological hypotheses such as Mid-domain effect and Rapoport's elevational rule were tested and the underlying mechanisms of elevational patterns in species richness of reptiles in Agasthyamalai Hills are discussed. Species turnover of reptiles across elevational zones are also discussed in the chapter.

Chapter four deals with the ecological niche of reptile communities with emphasis on the microhabitat use by different species. The niche breadth and overlap between various species in prominent groups of reptiles were analyzed in order to understand the competition and coexistence of closely related species. The major groups such as geckos, agamid lizards, skinks, and snakes were considered separately for the niche overlap analysis. Microhabitat relationships among different species are discussed. The association of reptiles with the tree species composition and forest structure was also analyzed to understand the habitat relationship of reptile communities.

Chapter five addresses the third objective, in which the spatial distribution of select endemic reptiles in the Western Ghats was predicted with geospatial tools. Two little known and endemic species namely Indian Kangaroo Lizard (*Otocryptis beddomii*) and Captain's Wood Snake (*Xylophis captaini*) were selected for applying the Ecological Niche Modeling (ENM) approach. Maximum Entropy (Maxent) model was used to predict the potential distribution of these species and to understand the influencing factors.

The last chapter summarizes the study and describing the salient findings and future directions. The list of references and appendices are given at the end.

2 Study Area

2.1 Background

The study was conducted in Agasthyamalai Hills in the western slope of the southern Western Ghats. The area has three major protected areas namely Neyyar, Peppara and Shenduruney Wildlife Sanctuaries in the Kerala part. Agasthyamalai landscape is especially well-known for its rich biodiversity and, a large number of endemic and medicinal plants. Although the floral aspects were well studied in Agasthyamalai landscape, the faunal components remain largely unexplored. Moreover, Agasthyamalai is a popular pilgrim and ecotourism centre in the south India. Annually, about 6,000-8,000 people visit the mountain peak (Agasthyarkoodam) which is in the core area of Agasthyamalai Biosphere Reserve (ABR). The increased ecotourism and pilgrimage in the core area of ABR is a threat to its rich biodiversity through associated anthropogenic activities.

2.2 The Western Ghats

The Western Ghats comprise of a series of mountains parallel to the west coast of peninsular India. It is known to be an important biogeographical refuge for a large number of endemic and unique species (Nair, 1991). The topographic complexity and climatic factors have made these hill-ranges rich in biodiversity and endemism. Western Ghats-Sri Lanka is listed as a global biodiversity hotspot and also as a UNESCO World Heritage Site (Myers *et al.*, 2000). The local endemism of the Western Ghats-Sri Lanka biodiversity hotspot has significant implications for future conservation planning (Bossuyt *et al.*, 2004). Along with the biological wealth, strong inter-linkages between ecological and socio-economic factors existing here make the Western Ghats an important priority area for conservation (Nair, 1991).

2.3 Agasthyamalai Biosphere Reserve

The southern Western Ghats has the best preserved and climax vegetation in Peninsular India (Nair, 1991). The major hill ranges in the southern Western Ghats are Nilgiris, Anamalais, Palni Hills, Highwavys and Agasthyamalai Hills. Agasthyamalai Biosphere Reserve (ABR) spread across the southernmost tip of the Western Ghats has about 3500km^2 area, out of which 1828 km^2 is in Kerala and 1672 km^2 in Tamil Nadu. ABR comprised of Neyyar, Peppara and Shendurney wildlife sanctuaries in Kerala and, Kalakad-Mundanthurai Tiger Reserve (KMTR) in Tamil Nadu. ABR was recently included in UNESCO’s World Network of Biosphere Reserves considering its rich biodiversity and cultural values.

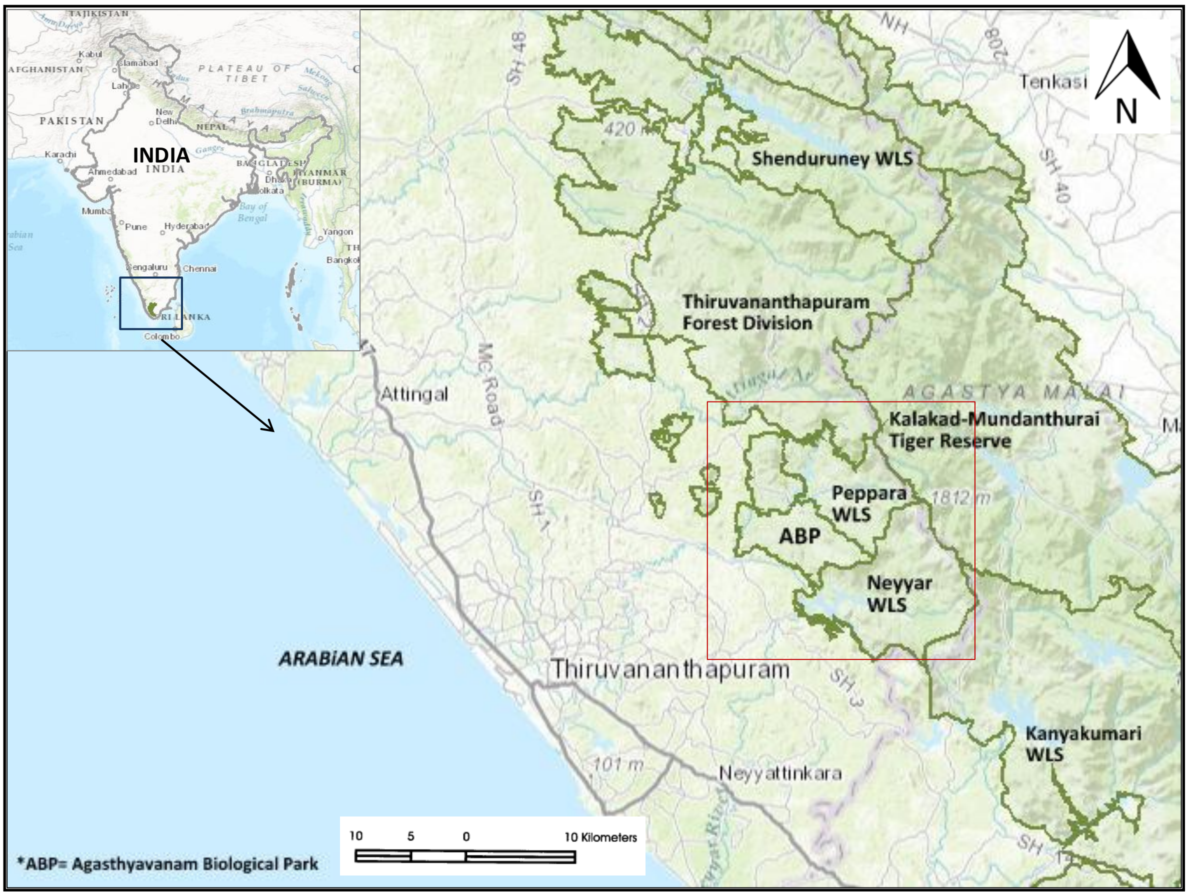


Figure 2-1 Intensive study area (inside box) and adjoining protected areas in ABR

(Base map source; www.esri.com)

2.4 Agasthyamalai Hills

The intensive study area (~250 sq.km.) is along the western slope of Agasthyamalai Hills (8°33’N- 77°6’E & 8°43’N -77°15’E, Plate 2-1) in the state of Kerala and includes the areas of Neyyar and Peppara Wildlife Sanctuaries and, the Agasthyavanam Biological Park (ABP). Both Neyyar and Peppara WLS support hydroelectric projects by having two reservoirs and power houses which supply electricity to nearby towns (Management Plan Peppara Wildlife Sanctuary 2012-2013 to 2021 to 2022, 2011; Management Plan Neyyar Wildlife Sanctuary 2012-2013 to 2021 to 2022, 2011). These reservoirs receive water from streams that originate from Agasthyamalai Hill range. The area has an elevation range of 100-1866m above mean sea level and the highest peak is 1866m. The higher elevations are marked by steep undulating terrains. The geometric constraints such as mountain summit at the top and coastline at the bottom provide an appropriate set up of a natural laboratory to test various ecological hypotheses.

2.4.1 Biodiversity

ABR is reported to have 2254 species of flowering plants belonging to 75 families; of which 475 are endemics. It is the type locality of several endemics and threatened plant species. About 600 medicinal plants and more than 100 economically important species are reported from the area. ABR is perhaps the southernmost home to stable populations of threatened and charismatic taxa like Tiger, Elephant, Lion-tailed Macaque, and Nilgiri Tahr in India. A herpetofaunal study in KMTR reported about 55 species of reptiles (Ishwar *et al.*, 2001). The total avifaunal diversity of the reserve is reported to be 337, which includes both migratory and resident species (Palni *et al.*, 2012). It also harbors unique and endangered freshwater ecosystem known as *Myristica* swamps. Though these ecosystems are naturally fragmented, there are many patches in this landscape which need immediate attention for conservation.

2.4.2 Vegetation types

The major forest types of Agasthyamalai region include Southern Hilltop Evergreen Forest, West Coast Tropical Evergreen Forest, West Coast Semi-evergreen Forest, Southern Secondary Moist Mixed Deciduous Forest and Reed brakes (Champion & Seth, 1968, Plate 2-3). Apart from these categories, mid-elevations are characterized by the presence of grasslands with isolated trees within. These are considered to be a type of tree Savanna ecosystem. The lower elevations (<600) are dominated by mixed deciduous and semi-evergreen forests, and the zone 600-1200m is characterized by tropical evergreen forest. Southern hill top evergreen forests and reed breaks occur near and above 1200m elevations (Varghese & Balasubramanyan, 1999). The evergreen forests of this region are dominated by *Cullenia-Mesua-Palaquium* species compositions (Champion & Seth, 1968). The floral aspects of Agasthyamalai region are well-studied compared to the faunal components. The area is known for the richness of medicinal plants and local endemism of the flora. Lady’s Slipper Orchid (*Paphiopedilum druryi*) is one of the rarest endemic orchids found at higher altitudes in these ranges.

Besides the natural vegetation, these hill ranges also have vast stretches of tea, cardamom and rubber plantations. The Bonacaud tea estate in Peppara WLS is more than 100 years old and extends over 1500 acres. Pilgrims proceeding to the famous ‘Agasthyarkoodam’ usually take the trekking route that starts from Bonacaud picket station which is at the edge of the forest where the tea plantation ends. These plantations were abandoned for many years. Much of the plantation areas have been reclaimed by the forest department, currently in different stages of regeneration. As most part of the plantation is not being managed actively, there is the luxuriant growth of multi-layered vegetation in these plantations, which support high faunal diversity augmented further by the eco-tone effect with the adjoining forest. Hence this plantation area became an important area for natural lovers and bird watchers due to its attractive scenic beauty and high bird diversity. The presence of some of the rare mammals (for eg; Nilgiri Martin) and few venomous snakes (King cobra, Spectacled cobra, Pit vipers) also reported by local people from these plantations.

2.4.3 Climate

The Western slope of Agasthyamalai Hills is one among the high rainfall zones of the Western Ghats. The area receives around 3000-5000mm rainfall annually with only two-four dry months in a year. The average temperature of the area varies from 17^{o}C to 29^{o}C. The average monthly rainfall in the area varies from 28-239mm (Figure 2-2, 2-3). The mountain top is characterized by misty and windy weather conditions.

2.4.4 People

‘Kanikaran tribes’ of ABR region is one of the oldest tribal groups of the world, living in the southern Western Ghats since the time immemorial (Plate: 2-2). There are many settlements within the limits of ABR with a total population of 3000 people. The Kanikaran tribes are known for their extensive traditional knowledge on medicinal plants. Several species of herbs currently used in Siddha and Ayurvedic medicines. For example, the local medicine, popularly known as ‘Arogyapacha’ (*Trichopus zeylanicus travancoricus*), was actually known to science by Kanikaran tribes of the area. These tribes, though earlier known as hunter-gatherers are now primarily dependent upon on agriculture, forest products, and employment by the forest department, for their livelihoods. The tribal settlements are spread over ABR in both buffer and core zones, and have resulted in increased human-wildlife conflicts in recent years (Jayson &

Christopher, 2008). Though the Kanikaran tribes are living in these hill-ranges since historical times, recent exponential growth in their population coupled with dramatic changes in their livelihood options, putting enormous pressure on the natural resources and biodiversity of the region. Currently, they also depend on monoculture rubber plantations, mixed agriculture and Non Timber Forest Products (NTFP) for livelihood.

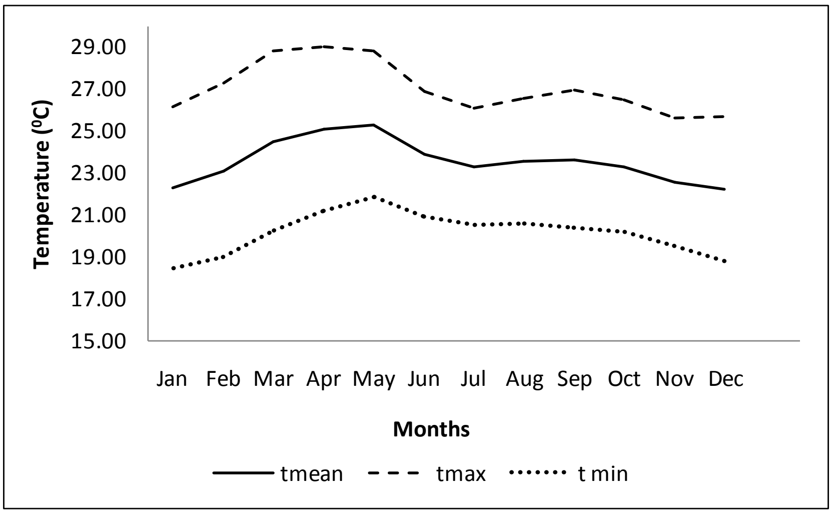


Figure 2-2: Monthly mean, maximum and minimum temperature in the study area

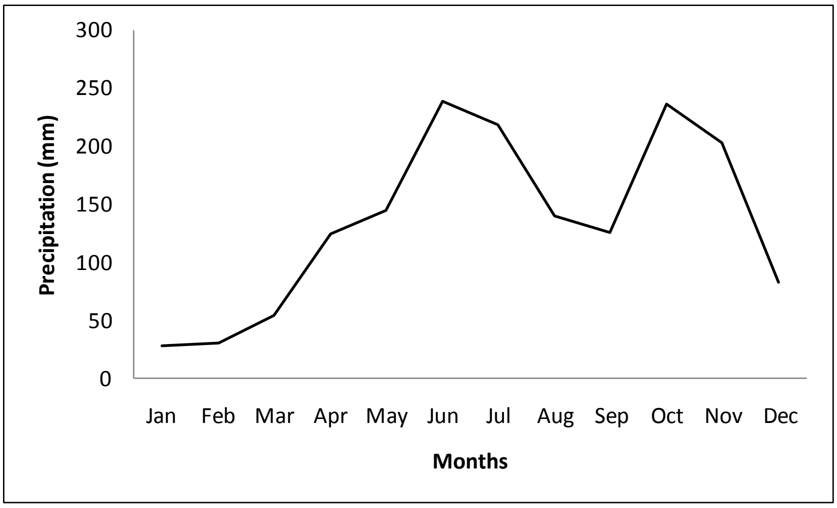


Figure 2-3: Monthly average precipitation in the study area

Source: www.worldclim.org

2.4.5 Pilgrimage and Ecotourism

The highest peak in Agasthyamalai Hills (1866m AMSL) is popularly known as ‘Agasthyarkoodam’, the shrine of Agasthyamuni, who was a sage venerated in Hindu mythology and was believed to have founded the ‘Siddha’ system of medicine. This mountain peak, therefore, is of paramount spiritual and cultural significance for people in both Tamil Nadu and Kerala. The ecotourism activities in the area are currently managed by Kerala Forest Department with the support of local people and Eco development Committees (EDC). The pressure from these pilgrims and trekkers causes widespread habitat destruction, solid waste deposition and forest fire in the tract forming a serious threat to the unique ecosystem of ABR (Kunhi & Shankar, 2002). The deforestation rate is reported to be high in the region, though much of the biodiversity rich areas is under Protected Area network (Ramesh *et al.*, 1997). The increased pressure from pilgrimage and the fast changing resource use patterns by tribal populations in Agasthyamalai region is raising a serious concern about the biodiversity conservation of the area. Hence, this landscape needs a long-term conservation plan that takes into account both the biodiversity value of the Biosphere Reserve and socio-economic considerations of local communities.

2.4.6 Conservation importance

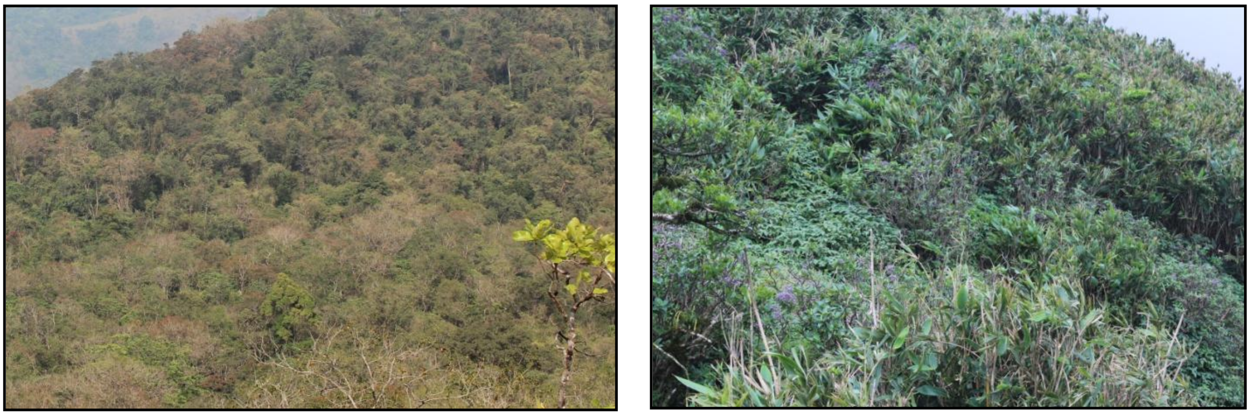
Considering the high pressure of ecotourism and associated activities in the area, a customized approach is crucial for the conservation planning. Tourism activities need to be controlled to reduce the pressure on natural habitats, especially in core areas. Solid waste disposal is a serious issue associated with the ecotourism activities. Cutting of trees and stems along the trekking path causes a lot of habitat destructions. Forest fire that happens due to the carelessness of visitors often results in loss of a large patch of forest areas in each year. The tribal settlements inside forest areas expanded drastically in recent years and the agricultural practices also changed. Monoculture plantations like rubber cultivation would change the structure and composition of natural habitats completely. This would rather affect many of the species including herpetofauna which are highly associated with the structure of the habitat and the availability of specific microhabitats. A participatory approach with the help of State Forest Department involving local communities and Eco Development Committees (EDC) in the area would be an effective way of treating the existing conservation issues of the landscape.

Plate 2-1: View of Agasthyamalai Hills

Plate 2-2: A 'Kanikaran' tribe from the Agasthyamalai region

Evergreen Forest

Hill-top Evergreen Forest



Moist Deciduous

Reed Breaks

Tree Savanna

Tea Plantation

Plate 2-3: Major vegetation types in the study area

3 Species Richness Patterns and Turnover along Elevation Gradient

3.1 Introduction

The distribution of various species on earth is influenced by many factors. Studying the large scale patterns in species richness and underlying mechanisms are important in understanding ecology, evolution and conservation needs (Pianka, 1966b; MacArthur, 1972). From the time of Darwin and Wallace, there have been many attempts to explore ecological patterns across both altitude and latitude. Elevational patterns have long been recognized as the microcosms of latitudinal patterns (Stevens, 1992). White & Bennett, (2015) highlighted that elevational patterns are important in determining extinction risk for species, but often ignored in many of the conservation prioritization schemes. As mountains possess a range of climatic zones and moisture levels within a small geographical extent, they can be natural laboratories to test various ecological hypotheses (Guo *et al.*, 2013).

The elevational patterns in species richness have got an increased attention in the recent years. In general, species richness along elevation may follow one of these three patterns: a) monotonic increase, b) monotonic decline and c) a mid-elevation peak (Rahbek, 1995). These patterns vary across different taxonomic groups and biogeographical regions. The mid-elevation (unimodal) peak is reported to be the common pattern (Rahbek, 2005) of species richness in most of the taxa: small mammals (Heaney, 2001; Li *et al.*, 2003; McCain, 2004), birds (Rahbek, 1997; Kessler *et al.*, 2001; Kattan & Franco, 2004; Ding *et al.*, 2005), invertebrates (Sanders *et al.*, 2003) and plants (Cardelús *et al.*, 2006). The monotonic decline of species richness with elevation has been reported for herpetofauna (Heatwole, 1982; Cadle & Patton, 1988; Woinarski & Gambold, 1992; Hofer *et al.*, 1999).

For instance, the reptile richness in Eastern Himalayas followed a monotonic declining pattern and temperature explained much of the variation in species richness along the elevation gradient (Chettri *et al.*, 2010). A mid-elevation peak of diversity was observed in frogs and, in lizards and snakes in Hengduan Mountains (Fu *et al.*, 2006, 2007). The hump shaped pattern was also reported in reptiles at Mt.Hermon (Nathan & Werner, 1999). A study on anurans in the Western Ghats found that species richness increased linearly with elevation and abiotic factors such as soil temperature and moisture explained much of the variation (Naniwadekar & Vasudevan, 2007). Irrespective of several studies on elevational patterns in species richness across the globe, no common pattern has been derived so far. Several studies on elevational patterns in species richness highlighted the influence of spatial, climatic or historical factors. Spatial factors influencing species distribution mainly include the species-area constraints and the geographical boundaries like mountain top or coastline that could potentially restrict further dispersal. However, it is necessary to consider multiple mechanisms that possibly contribute to these patterns (Sanders *et al.*, 2003).

The species richness along an elevational gradient are reportedly limited by productivity (Rosenzweig, 1968; Mittelbach *et al.*, 2001) phylogeny, speciation (Cadle & Patton, 1988; Patterson *et al.*, 1998), climate, historic events (Brown, 1971; Lomolino, 2001), species-area effect (Sanders *et al.*, 2003; Kattan & Franco, 2004), ecotone effect (Rahbek, 1997; Hofer *et al.*, 1999; Sánchez-González & López-Mata, 2005), and isolation (Scott, 1976). The geometric constraints hypothesis or mid-domain effect have been considered as one of the most appropriate null models to explain elevational gradients in species richness (Colwell & Lees, 2000; Jetz & Rahbek, 2001). Basically, Mid-domain effect (MDE) is the higher number of species towards the centre of the domain due to increased overlap of species ranges brought by spatial constraints in lower (forest edges or coastline) and higher (mountain top) elevations (Colwell & Hurtt, 1994; Colwell & Lees, 2000). However, MDE has been always a controversial and debatable model from the time of its conceptualization (Gaston, 2000; Hawkins & Diniz-Filho, 2002a; Zapata *et al.*, 2003; Colwell *et al.*, 2004) and reported to have several limitations in explaining species richness patterns (Zapata *et al.*, 2005) across latitude and altitude. Hence, it was suggested that MDE should only be considered as one of the possible mechanisms contributing to richness patterns along with other factors (Colwell *et al.*, 2005).

A Global analysis of bats and reptiles showed that temperature and other climatic factors as the key drivers of elevational patterns (McCain, 2007b, 2010). Although the Eastern Himalayan birds exhibited a mid-elevation peak, it didn't show a fit of Mid-domain null model and much of the variation in species richness was explained by primary productivity and habitat associations (Acharya *et al.*, 2011b). The influence of area on elevational patterns in species richness has been rarely considered (Rahbek, 1997). Few of the studies highlighted that the area availability at each zone is an important factor that contributes to elevational patterns in species richness and at the same time, local richness could be influenced by regional species pools (Rahbek, 1997; Brown, 2001; Lomolino, 2001).

It is reported that Rapoport's rule (the latitudinal gradient in geographical range size of species) could be also applied to elevational ranges to explain species richness patterns (Stevens, 1992). According to this, the species in higher elevation may have higher range sizes and those in lower elevation will have smaller range sizes in response to their climatic tolerance levels (Stevens, 1989) and it possibly leads to a monotonic decline pattern in species richness (Rahbek, 1997). Unlike the mid-domain hypothesis, Rapoport's rule explains the species elevational ranges as a result of climatic factors existing in mountain ranges (Kendall & Haedrich, 2006).

In India, elevational patterns in species richness have been explored in various taxa including birds, amphibians, reptiles and tree species across different biogeographical zones. Species richness of reptiles in Eastern Himalayan gradient showed a declining pattern and much of the variation was explained by temperature (Chettri *et al.*, 2010). Species richness in anurans of the southern Western Ghats showed an increasing pattern along elevation (Naniwadekar & Vasudevan, 2007) in which the abiotic factors such as soil temperature and moisture were the major factors contributed to the distribution patterns. The tree species richness was studied in the Western Himalayas and found that multiple mechanisms influence the elevational patterns in tree species richness (Oommen & Shanker, 2005). Tree species richness in the Eastern Himalayas (300-4500m ASL) exhibited a unimodal pattern peaked at 1500m and are influenced by the combined effect of energy, productivity and precipitation (Acharya *et al.*, 2011a). However, the bird species diversity along the same gradient showed that species richness is highest at the mid elevations where the primary productivity along with habitat correlates contributed to much of the variation (Acharya *et al.*, 2011b). A study on birds from the Western Ghats showed a declining pattern in species richness with elevation, although it was not statistically significant (Raman *et al.*, 2005).

Unlike amphibians (which exhibits high species turnover across drainages), reptiles are showing maximum turnover across altitudinal zones in the Western Ghats (Ishwar *et al.*, 2001). Hence, it is necessary to address the species turnover patterns along elevation gradient as it helps to plan conservation actions in the protected area networks of the Western Ghats. With this background, the present study was initiated to understand the species richness and turnover patterns of reptiles along an elevation gradient in Agasthyamalai Hills and to determine the factors influencing them. The study also tested some of the important ecological hypotheses with respect to species richness patterns and range size across altitude, which includes: mid-domain hypothesis and Rapoport's elevational rule. Being an exploratory survey in the hill ranges of the Western Ghats, the study also reported few rare reptiles and addressed some of the important ecological questions on the determinants of species richness patterns along an elevation gradient in Agasthyamalai Hills, a biodiversity-rich mountain ecosystem in the southern Western Ghats.

3.2 Methods

3.2.1 Reptile survey

Field surveys were conducted during April 2012 to December 2014 in the intensive study area. The total study area was categorized in to 100m elevation zones and belt transects of 1-2 km length and variable width was laid in each elevation zone based on the available area and accessibility of sampling localities. Time constrained visual encounter surveys (VES) were conducted for sampling reptile communities in all zones. VES was formalized as a time-constrained technique by Campbell & Christman, (1982) and Heyer *et al.*, (1994). This method includes surveying an area or habitat for a prescribed time and systematically searching for animals in all possible microhabitats (Campbell & Christman, 1982). Total time is expressed as the number of man-hours of searching (Crump & Scott, 1994). VES is an appropriate method for both species inventorying and monitoring, and hence is suitable for studies examining landscape level patterns. VES has been widely used to determine composition, richness and relative abundance of herpetofauna. It is also known for higher detection rate of rare species (Heyer *et al.*, 2014) and successfully applied in some of the studies conducted in the Western Ghats (Mukherjee, 2007; Bhupathy & Nixon, 2011).

Sampling was restricted from 8.00 to 19.00 Hours (8AM to 7PM) and the search included turning stones and fallen logs, moving leaf litter, scanning the vegetation and, searching on stems and barks of trees. Each unit of VES involved systematic search by two personnel for one hour, amounting to two person-hours per search effort. Sampling effort was decided mainly based on the area availability in each elevation zone. The GPS location, habitat, weather conditions and atmospheric temperature (IR Thermo hygrometer) of the site were noted during each sampling effort. All reptiles observed were identified up to species level (except the taxonomically uncertain groups). For each observation, microhabitat and perch height were noted.

3.2.2 Habitat sampling

Vegetation plots were laid in every 250m interval along each elevational transects. Quadrat method was used to measure vegetation attributes in each sampling point (Mueller-Dombois & Ellenberg, 1974). Quadrat size of 10×10m was used to list all species of trees (height ≥3 m). At the center of this 10×10m quadrat, a 5×5m quadrat was laid for enumerating shrub species (height < 3 m) richness and density. At the four corners of the larger quadrat (10x10m), 1×1m quadrat was used to record percentage of herb cover, leaf litter, rock and boulder cover, exposed soil (recorded visually) and canopy cover (using densiometer). Heights of trees were estimated visually and a range finder was also used wherever possible.

3.2.3 Elevation and area availability

ASTER Global Digital Elevation Model (GDEM; www.gdem.aster.ersdac.or.jp/index.jsp) was used to find out area availability in each altitudinal category (Figure 3-7). The sampling effort was largely depending on area availability in each category. Elevation for each sampling point was determined with the help of an altimeter.

3.2.4 Environmental variables

Abiotic variables including annual temperature and precipitation were downloaded from WORLDCLIM data base (http://www.worldclim.org/). This database presents surface-interpolated climatic data from 1950-2000 at a spatial resolution of one kilometer or 30 seconds (Hijmans *et al.*, 2005). QGIS version 2.12 was used for extracting temperature and other environmental variables for each sampling location along the elevation range.

3.3 Data analysis

3.3.1 Status of reptiles

The opportunistic sightings of species were also included in the list for assessing the status of reptiles in the region. The conservation status was assigned based on IUCN assessment (http://www.iucnredlist.org/), numerical status was determined based on the number of sightings during the study period and the status of 'Endemism' within the Western Ghats was assessed from the available literature (Srinivasulu *et al*, 2014). The numerical abundance status assigned for each species based on the number of sightings (given in brackets) includes: common (>20), uncommon (10-20), rare (5-10) and very rare (<5).

3.3.2 Standardization of data

Species accumulation curves were obtained using Estimate S version 9.1.0 to see whether sampling was sufficient. In order to account for the inadequate sampling in different elevation zones, estimated species richness (Jackknife 2) was used for analysis. The Jackknife 2 estimator is reported to be a robust measure for estimating species richness in herpetofauna irrespective of sampling methods (Surendran & Vasudevan, 2015).

3.3.3 Mid Domain Null Model

Mid-domain hypothesis was tested using the null model predictions generated by a Monte Carlo simulation procedure (Mid-Domain Null Programme; McCain, 2003). All species observed in the sample were included for the analysis. The difference between the upper and lower range limits defined the range size of each species which were considered to be continuous, even if the species have not been recorded from the intermediate zone. Prediction curves (95%) based on 5000 simulations without replacement of empirical range sizes were used. Regression of empirical species richness with a mean value of predicted richness was performed to assess the fit of the null model (McCain, 2003, 2004). The domain limit was set to 18 signifying all elevation categories between 100-1868m. Regression analysis was performed to examine the fitness between estimated species richness and simulated curve.

3.3.4 Explanatory factors

Stepwise multiple linear regressions were used to understand the factors influencing the elevational distribution patterns of reptiles. Bioclimatic variables which are relevant to reptile distributions were selected for the analysis. Individual regressions were obtained to estimate the linear relationship between various explanatory variables including area, mean annual temperature, precipitation, tree density and mid-domain predicted richness (MDE-richness). Habitat variables such as tree diversity, canopy cover, and litter cover did not show any significant relationship; hence these variables were excluded from the regression analysis.

3.3.5 Species turnover

The presence-absence data of species in each elevation zone was considered for calculating turnover patterns. The dissimilarity or turnover between different elevation zones was estimated using the equation 1-X where X is the Sorenson's similarity index (Wolda, 1981).

3.3.6 Rapoport's rule

The elevational ranges of each species were correlated with range mid-points (Kwon *et al.*, 2014) to test whether higher elevation species has wider elevation range as described by Rapoport's elevational rule. The mid-point of each species was calculated using the midpoint between the upper and lower limits of their occurrence. All the species observed during VES were considered for analysis.

3.4 Results

3.4.1 Species richness of reptiles in Agasthyamalai hill range

Although the present study was aimed at exploring the elevational patterns in diversity, status and species richness of reptiles in the study area was also documented. About 70 species of reptiles from two orders and 14 families were recorded (including opportunistic observations) which comprises of 29 lizards, 38 snakes and 3 turtles (Appendix 1). The two major orders recorded in the study area include Squamata (lizards and snakes) and Testudines (Turtles and tortoises). A total of 1304 person hours of VES were conducted across the elevational gradient in Agasthyamalai hill range and only 47 species were found during the sampling. Many species are rare and found only once during the period.

The observation of Beddome's coral snake, *Calliophis beddomei* (Plate 3-1) from the study area was the first record of the species from the southern Western Ghats (Jins *et al.*, 2014). It was the fourth locality record of the species with a range extension of 320 km (straight line across the Palghat gap) from the closest observation. Moreover, it was an addition to the faunal list of Kerala state.

3.4.2 Conservation status, endemism, and relative abundance

Out of total 70 species, five could be only identified up to genus level and were considered as un-identified. Some other species were identified with closest described species and mentioned as 'to be compared with (*cf*)' particular species. Among the remaining 67 species, there were 11 'data deficient', 23 'least concern', five 'near threatened', two 'vulnerable' and four 'endangered' species coming under IUCN categories of red-listed species (Figure 3-1). However, the conservation status of about 20 species was not assessed by IUCN. The endangered species were *Otocryptis beddomii, Eutropis clivicola, Cnemaspis cf wynadensis* and *Vijayachelys silvatica.* The *Cnemaspis* species mentioned here was morphologically very similar to the description of *C.wynadensis* but the identity need to be examined in detail with morphological and genetic characteristics. The observation of Cochin forest cane turtle, *Vijayachelys silvatica* (two individuals) were noted as rare finding

The relative abundance and encounter rate was estimated for all the species observed during sampling. A total of 1554 individuals of reptiles observed during the sampling which comprises of 47 species. Out of the total, the skink species *Eutropis macularia* was the most abundant species represented by 549 individuals. The skink *Eutropis macularia* showed highest value for relative abundance (35.33%) followed by *Sphenomorphus dussumieri* (12.36%) which are non-endemic skinkid lizards. Among the endemics, *Otocryptis beddomii* (6.77%) and *Cnemaspis cf australis* (5.34%) showed higher value of relative abundance and followed by *Calotes ellioti* (5.27%). From all reptiles, 18 species were common, 10 were uncommon and 10 were rare categories according to the number of observations, but 31 species were categorized as very rare as they were observed less than five times during the whole study period (Figure 3-2). Among the 70 reptiles (including opportunistic observations), 30 (42.8 %) species are endemics in the Western. Out of 29 reptiles, 15 (51.7%) and, in case of snakes, out of 38 species, 13 (34.2%) were endemic to the Western Ghats (Figure 3-3).

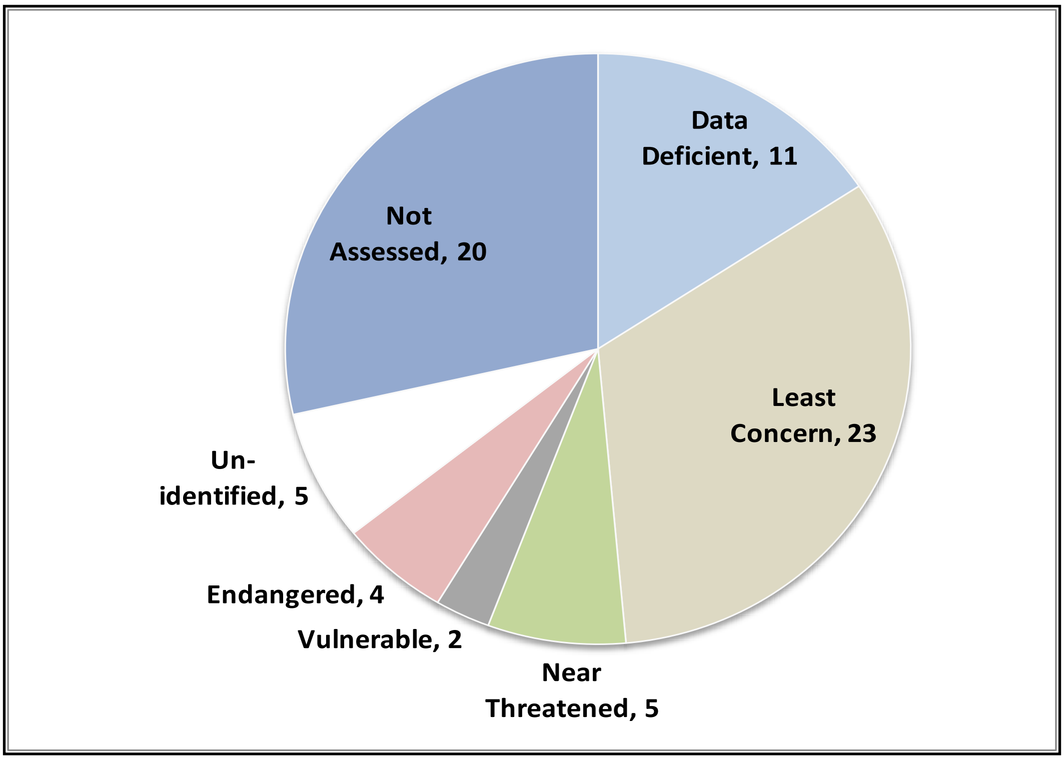


Figure 3-1: Conservation status (IUCN) of reptiles

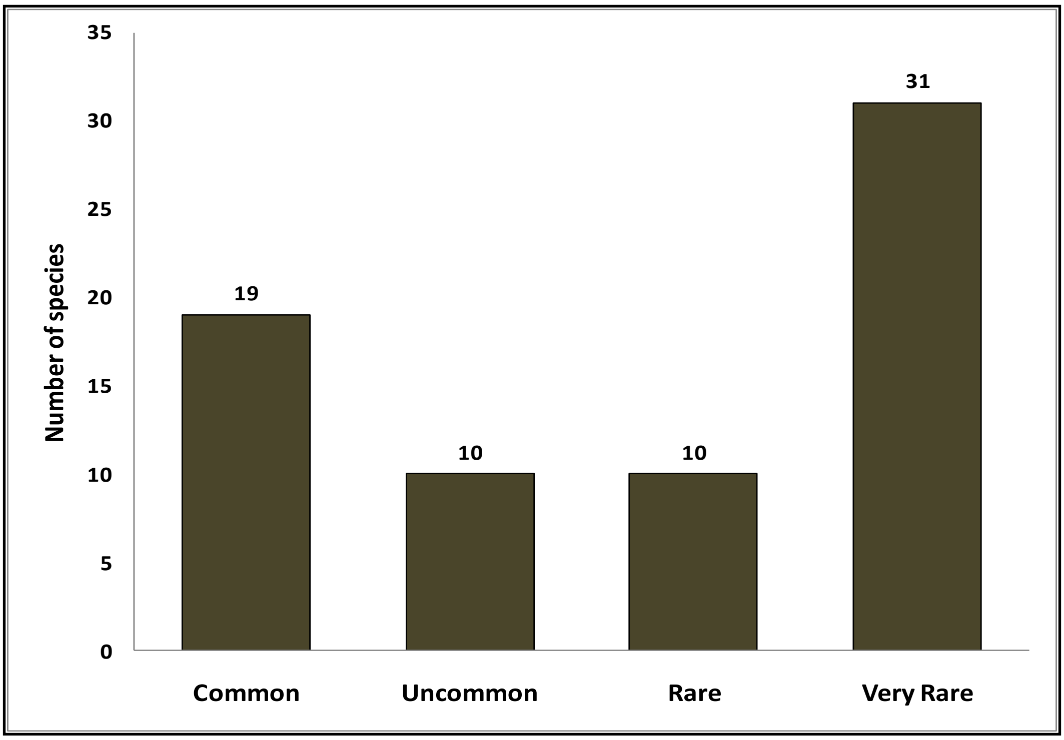


Figure 3-2: The status of reptiles in Agasthyamalai Hills based on number of sightings

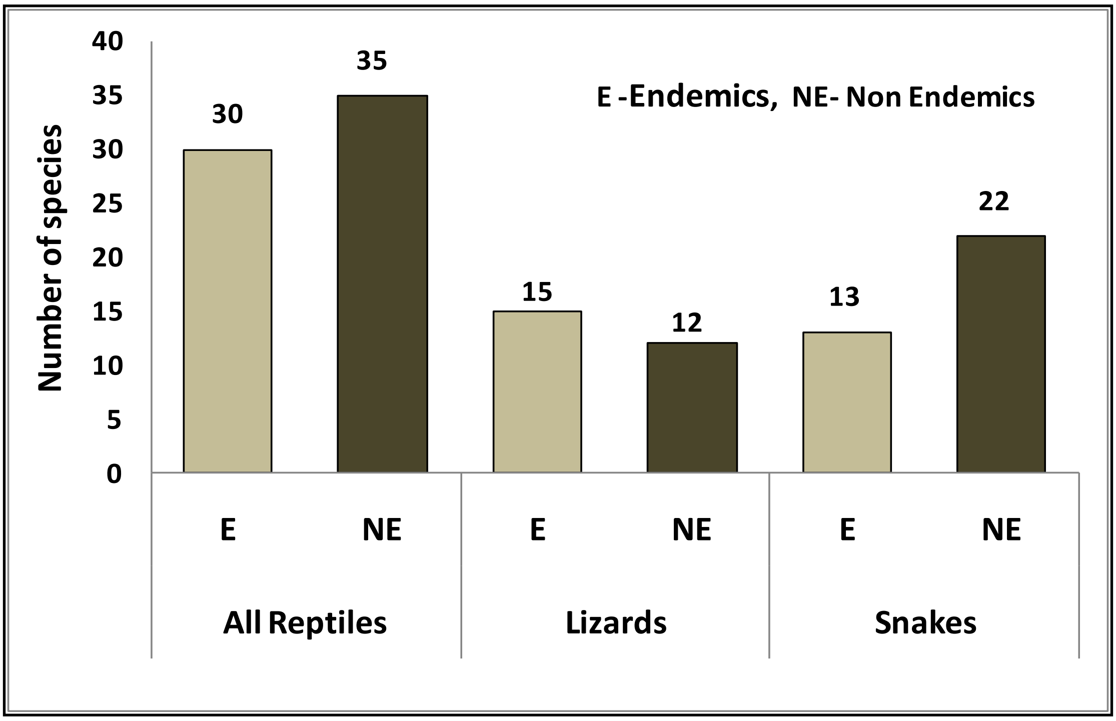


Figure 3-3: Number of endemics and non-endemics in the study area

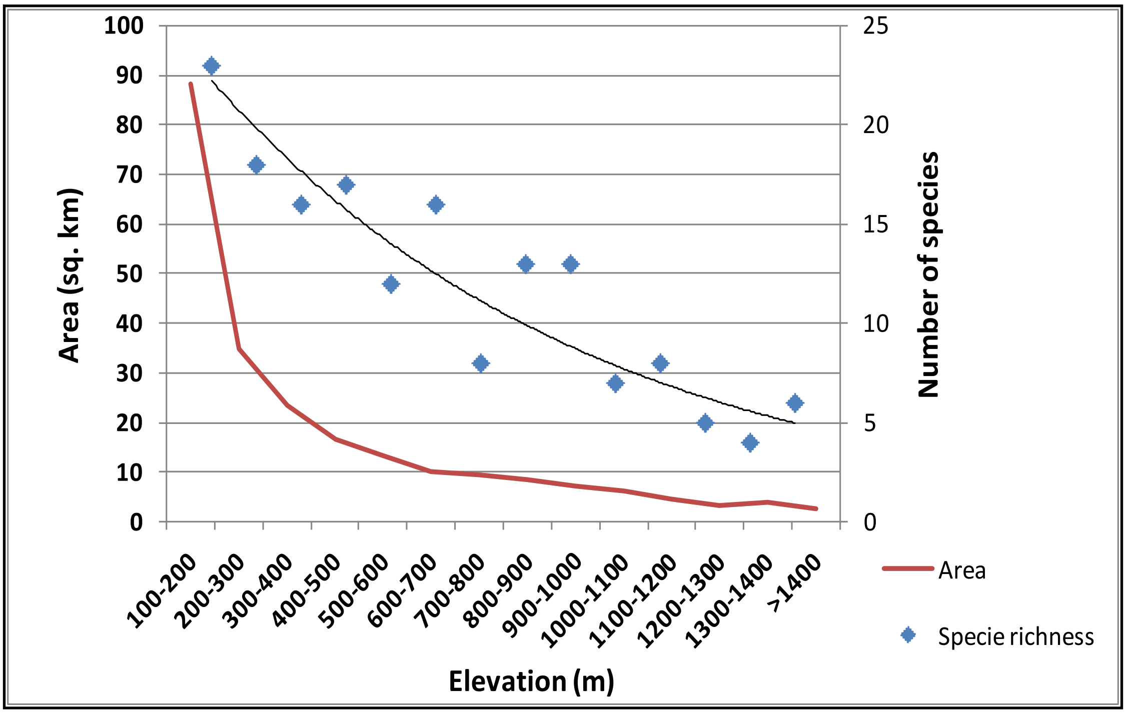
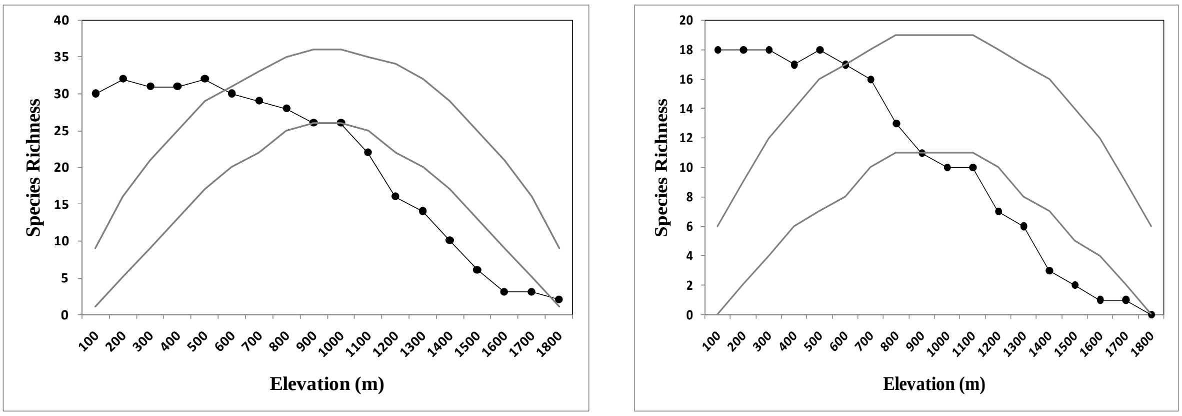


Figure 3-4: Relationship between elevation, area availability and estimated species richness of reptiles in the Agasthyamalai Hills.

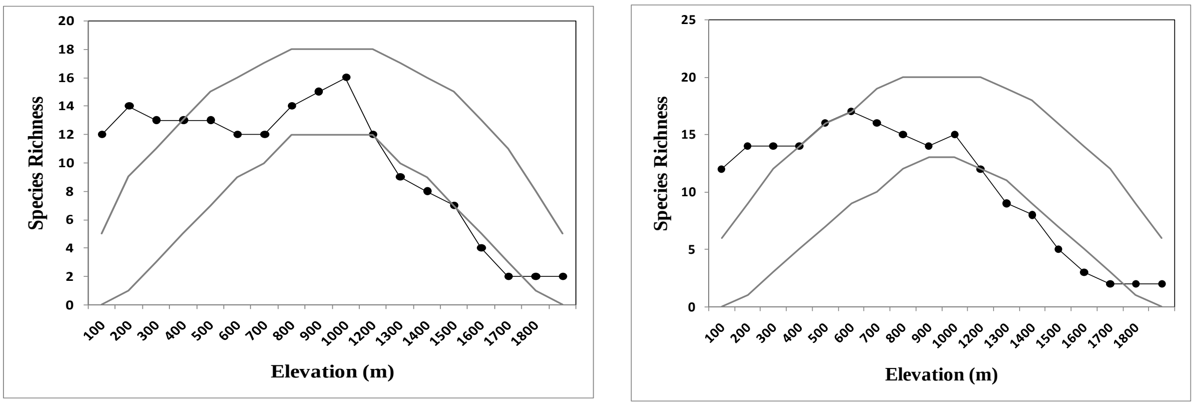
3.4.3 Species richness along elevation gradient

The species richness showed a strong correlation with area availability (r= 0.804, p=0.001). The surface area of the elevation zones decreased significantly with increasing elevation (Figure 3-4). Reptile species richness showed a monotonic decline with an increase in elevation. The Mid-Domain analysis was performed separately for lizards and snakes. In general, reptiles did not follow Mid-Domain Null model pattern. However, when analyzed separately for snakes, we found a significant but weak fit of the model (r^2=0.249, p=0.035). Endemic reptiles also showed a less significant and weak fit (r^2=0.216, p=0.052) of Mid-domain null model.



All reptiles

Lizards



Snakes

Endemic reptiles

Figure 3-5 : Distribution pattern of reptiles in Agasthyamalai Hills, Western Ghats based on observed and Mid-domain null predictions. [Species richness curve (line with squares) along the elevation bands with 95% simulation curves (lines without markers) using empirical range sizes].

3.4.4 Explanatory factors of elevational patterns

Regression analysis was performed for reptiles in general, lizards and snakes separately. Individual regressions showed significant associations with area availability, mean annual temperature and precipitation for all reptiles, lizards, and snakes (Table 3-1). The regression of lizard species richness and endemic reptiles with tree density (habitat variable) showed a significant relationship. Mid-domain richness showed a significant relationship with snakes separately (r^2=0.377, p=0.019); but not with lizards (r^2=0.215, p=0.095).

Table 3-1: Individual regression values of species richness with explanatory variables.

		Explanatory Variables	R^2
1	Reptiles	Area	0.646**
		Mean annual temperature	0.570**
		Mean annual precipitation	0.505**
		Tree density	0.123
		MDE richness	0.333*
2	Lizards	Area	0.428*
		Mean annual temperature	0.672**
		Mean annual precipitation	0.635**
		Tree density	0.376*
		MDE richness	0.215
3	Snakes	Area	0.547**
		Mean annual temperature	0.359*
		Mean annual precipitation	0.339*
		Tree density	0.002
		MDE richness	0.377*
4	Endemic Reptiles	Area	0.011
		Mean annual temperature	0.359*
		Mean annual precipitation	0.422*
		Tree density	0.641**
		MDE richness	0,049

**. Correlation is significant at the 0.01 level (2-tailed), *. Correlation is significant at the 0.05 level (2-tailed).

3.4.4.1 Stepwise multiple regressions

In stepwise regression analysis (Table 3-2), area availability was the single factor which significantly explained much of the variation in all reptile species richness (r^2=0.617, p=0.0005). However, the contributions may be also due to the sampling proportions in each elevational zone and hence the model reanalyzed by excluding the area availability variable. When the area availability variable was removed, temperature (r^2=0.534, p=0.002) was the major factor contributed to the subsequent model (Table 3-2). Similarly, temperature explained much of the variation (r^2=0.645, p=<0.001) in species richness of lizards. In case of snakes, area availability was the most significant factor which explained much of the variation (r^2=0.509, p=0.003) but, in the absence of the area factor, MDE richness significantly explained the species richness in snakes (r^2=0.325, p=0.019). Though endemic reptiles showed a fit of Mid-domain null model, tree density turned out to be the most significant factor contributed to the regression model (Table 3-2).

Table 3-2: Results of multiple stepwise regressions: influencing factors of elevational patterns.

	Model	**Variables Included**	**Model variables**	**AdjR^2± SE**	**F**	**P**
Reptiles	1	Area availability, Temperature, Precipitation, Tree density, MDE richness	Area availability*	0.617± 6.28	21.92	0.001
	2	Temperature, Precipitation, Tree density, MDE richness	Temperature	0.534± 6.93	15.89	0.002
Lizards	1	Area availability, Temperature, Precipitation, Tree density, MDE richness	Temperature	0.645± 3.42	24.59	<0.001
Snakes	1	Area availability, Temperature, Precipitation, Tree density, MDE richness	Area availability*	0.509± 3.89	14.48	0.003
	2	Temperature, Precipitation, Tree density, MDE richness	MDE richness	0.325± 4.56	7.27	0.019
Endemic reptiles	1	Area availability, Temperature, Precipitation, Tree density, MDE richness	Tree density	0.611± 2.39	21.41	0.001

*Area availability variable was removed in the next step to find out the environmental factors involved

3.4.5 Species range sizes and Rapoport's elevational rule

Out of 47 reptiles observed, 13 were found only up to 700m elevation. Only one species (*Trimeresurus macrolepis*) was specific to the high elevation (1300-1860) and most other species extended their range to mid elevations (701-1300) or low elevations (100-700m). Range width of the species varies from 100-1600m and seven species showed very narrow range sizes (≤300m). The regression of species range sizes with range mid-points showed that there is no significant increase in range sizes with elevation ($r^2=0.005$. $p=0.647$). Hence there was no strong support for the Rapoport's elevational rule, that species in higher elevation have wider ranges (Figure 3-6).

3.4.6 Species turnover

In general, higher elevation zones showed an increased turnover rates with other low elevation zones. The elevational zones 1200-1300, 1300-1400, 1400-1860m showed complete turnover compared to 200-300m zone. The zone 1200-1300m showed complete turnover compared to 600-700m. The zone 1300-1400m showed complete turn over compared to 500-600, 600-700 and 1000-1100m zones. The higher turnover (0.8) between consecutive zones was observed between 1300-1400m and zone above 1400m, followed by 0.7 between 1000-1100 and 900-1000m (Table 3-3)

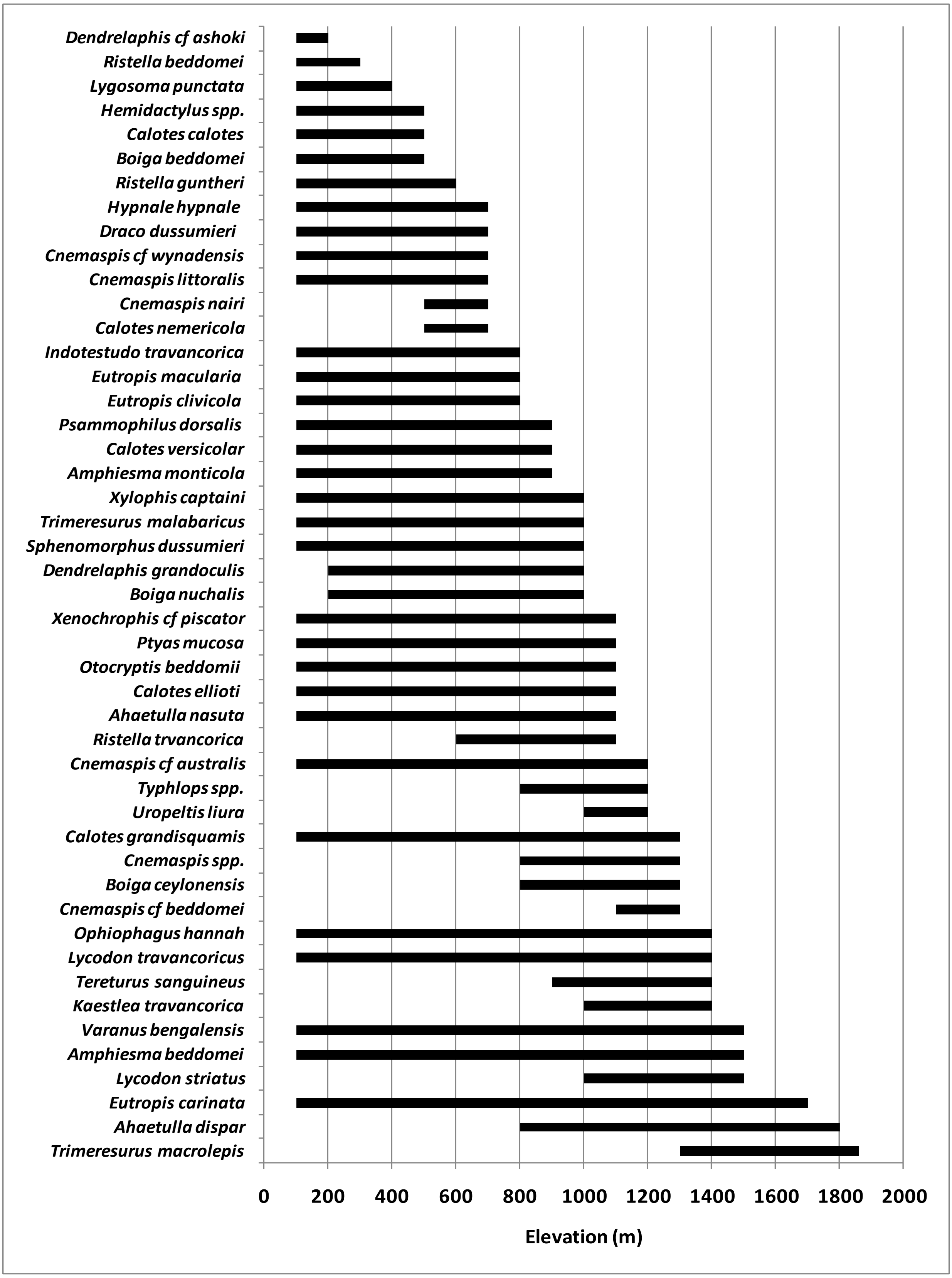


Figure 3-6: Elevational range sizes of reptiles.

Table 3-3: Species turnover (in shades) and shared species between different elevation zones.

Elevation Zones (m)	**100-200**	**200-300**	**300-400**	**400-500**	**500-600**	**600-700**	**700-800**	**800-900**	**900-1000**	**1000-1100**	**1100-1200**	**1200-1300**	**1300-1400**	**>1400**
100-200	.	0.286	0.3	0.317	0.5	0.5	0.687	0.568	0.676	0.806	0.75	0.862	0.929	0.867
200-300	15	.	0.353	0.257	0.467	0.412	0.692	0.677	0.677	0.84	0.846	1	1	1
300-400	14	11	.	0.333	0.5	0.5	0.5	0.586	0.655	0.826	0.917	0.905	0.9	0.909
400-500	14	13	11	.	0.517	0.333	0.52	0.667	0.667	0.833	0.84	0.909	0.905	0.913
500-600	9	8	7	7	.	0.429	0.5	0.44	0.52	0.789	0.7	0.882	1	0.889
600-700	10	10	8	11	8	.	0.417	0.517	0.655	0.739	0.75	1	1	0.909
700-800	5	4	6	6	5	7	.	0.429	0.429	0.6	0.875	0.846	0.833	0.857
800-900	8	5	6	5	7	7	6	.	0.385	0.7	0.619	0.778	0.882	0.789
900-1000	6	5	5	5	6	5	6	8	.	0.7	0.619	0.778	0.765	0.895
1000-1100	3	2	2	2	2	3	3	3	3	.	0.6	0.667	1	0.846
1100-1200	4	2	1	2	3	3	1	4	4	3	.	0.692	0.833	0.857
1200-1300	2	0	1	1	1	0	1	2	2	2	2	.	0.556	0.818
1300-1400	1	0	1	1	0	0	1	1	2	0	1	2	.	0.8
> 1400	2	0	1	1	1	1	1	2	1	1	1	1	1	.

3.5 Discussion

3.5.1 Elevational pattern

The species richness pattern in reptiles showed a monotonic decline pattern in Agasthyamalai Hills. Monotonic decline pattern in reptile richness was also reported elsewhere (Heatwole, 1982; Hofer *et al.*, 1999; Kryštufek *et al.*, 2008; Chettri *et al.*, 2010). The area availability (in each elevation zone) and temperature showed a strong positive correlation with species richness. Hence either of these factors or both might be contributing to the elevation patterns of reptiles. The decline in species richness with an increase in elevation may be due to low temperature (Fu *et al.*, 2007), low productivity (Mittelbach *et al.*, 2001) and low water availability (McCain, 2007a) in higher elevations. Considering the fact that reptiles are ectotherms, the temperature is reported to have a major effect on their distribution patterns (McCain, 2010). Terrestrial reptiles respond more strongly to temperature than moisture (Hofer *et al.*, 1999). Chettri *et al.*, (2010) also found a strong correlation of temperature with the monotonic decline pattern of reptile species richness.

3.5.2 Mid-domain effect

The analysis for Mid-domain effect did not show any significant fit to the Mid-Domain null model for reptiles in Agasthyamalai hills. This indicated that in general, the distribution reptiles in Agasthyamalai Hills are not governed by geometric constraints. But in the case of snakes (separately), we found a weak fit of the Mid-domain null model with notable deviations from predicted richness (r^2=0.249). However, in our regression analysis, MDE richness explained only 32.2% of the variation in snake specie richness while area availability alone explained more than 50% of the variation. Further evidence are necessary to prove that the specie richness in snakes is influenced by geometrical constraints in the study area.

The patterns of reptile species richness obtained in the present study are similar to the finding from Eastern Himalayas which also did not follow mid-domain null model (Chettri *et al.*, 2010). Though eastern Himalayas are relatively younger mountains compared to the Western Ghats, it still showed similar patterns. In another study in the southern Western Ghats on elevational patterns of anurans, also did not show mid-elevation peaks (Naniwadekar & Vasudevan, 2007). Instead, they found strong associations with abiotic factors including soil moisture and soil temperature. McCain, (2007b) reported the greater fit to MDE null model in temperate zone than either tropical or tropical-temperate transition zone.

The biological explanation and fit of the Mid-domain null model have been a long debate in explaining elevational patterns (Hawkins & Diniz-Filho, 2002b; Zapata *et al.*, 2005; Currie & Kerr, 2008). Domains or hard boundaries have less effect on small ranged species, which may be the best indicators for the influence environmental factors on species distribution (Cardelus *et al.*, 2006). Most of the reptiles in Agasthyamalai hills showed narrower elevational ranges and this could be the main reason why reptile richness did not show any significant fit of Mid-domain null model. Dunn *et al.*, (2007) also highlighted that the predictions of Mid-domain model are reliable only when range sizes and scale of analysis are large. However, the deviation from the Mid-Domain null model in the present study suggested that the reptile richness in Agasthyamalai Hills might be driven by environmental factors or other possible mechanisms including area effect.

3.5.3 Underlying mechanisms

The present study indicates that area availability along with temperature chiefly contributes to the reptile diversity patterns in Agasthyamalai Hills. The contribution of temperature to the explanatory model is expected as it is reported in earlier studies (Hofer *et al.*, 1999; Chettri *et al.*, 2010; McCain, 2010). Being ectotherms reptiles largely depend on external heat sources for energy. However, our results suggest that area availability at each elevation zones may act as an important factor along with temperature for the reptile distributions. In the case of lizards, we found that factors such as temperature, area availability and tree density played a major role in their distribution. On the contrary, for snakes area and MDE predicted richness contributed to the overall elevational pattern. Compared to other groups of reptiles, snakes are highly mobile and expected to have large ranges. This could be one reason why their distribution showed a significant influence of Mid-domain effect.

Our analysis revealed that reptile richness in Agasthyamalai hills could be mainly driven by the area effect and climatic factors like temperature. Also, the habitat heterogeneity factor such as tree density significantly contributed to species richness patterns in lizards.

Climate, spatial factors, habitat heterogeneity and length of growing season are the possible mechanism contributing to reptile diversity at the local scale (Heyer, 1967; Pianka, 1967; Fu *et al.*, 2007). Hence, multiple underlying mechanisms could be influencing complex patterns in species richness along elevation rather than a single factor (Oommen & Shanker, 2005).

3.5.4 Area effect

Area availability in each zone turned out to be an important factor contributing to the elevational pattern of reptiles. Similar results (Fu *et al.*, 2007) were found in lizard and snake species richness patterns in Hengduan Mountains, where land area explained significant variations in species richness (Fu *et al.*, 2007). Rahbek (1997), initially found a monotonic decline in Neotropical bird species richness along elevation but a hump-shaped pattern was observed after removing the effect of area. The area availability is a crucial parameter influencing distribution patterns (Rahbek, 1995; Lomolino, 2001) and in local species richness, there is an indirect area effect of the region (Romdal & Grytnes, 2007).

Since regional area and temperature are declining towards higher elevation, both variables might contribute to the monotonic declining pattern in species richness (Kluge *et al.*, 2006). The variability in a species-area relationship depends on the general elevational pattern, thus the decreasing pattern shows the strong species-area relationship (McCain, 2007a). As a surrogate of habitat heterogeneity, area availability (species-area effect) may be an important factor for reptile distributions (McCain, 2010). Moreover, it is important to consider the area effect in the Western Ghats as the available area decrease monotonically towards higher elevation in most of the mountains. Since the sampling effort was proportional to the available area, the area effect in the present study may be also due to sampling artifact. Hence, the area factor was accounted in the regression analysis for a better explanation of elevational patterns.

3.5.5 Climatic effect

The present study revealed that, climatic factor like temperature play crucial role in explaining elevational distribution pattern of reptiles. A global analysis highlighted that, reptile richness along altitude was strongly associated with temperature on wet gradients than on arid gradients (McCain, 2010). A study in Hengduan Mountains of China showed that climatic variables are strongly associated with lizard and snake species richness in which water availability was a key constraint for lizard richness whereas, the potential evapotranspiration (PET) was the strong predictor for snake species richness (Fu *et al.*, 2007). The present study showed a strong association of temperature to the reptile species richness in Agasthyamalai Hills.

3.5.6 Range size and Rapoport's rule

The analysis suggested that reptiles of Agasthyamalai hills do not follow Rapoport's elevational rule. Though a few of the high elevation species exhibited a wide elevation range, there was no significant support for the argument that higher elevation species have wider ranges. In fact, the majority of the species were distributed between 100-1400m and many having narrow ranges of elevational width. Species with narrow ranges tend to have less climatic tolerance and they may be vulnerable to extinction due to global climate change. Elevational range shifts in response to climate change are reported in many taxa (Colwell *et al.*, 2008; Sekercioglu *et al.*, 2008). Ecological specialization may be a constraint for a species to respond towards the environmental changes and it will increase their risk of extinction (Colles *et al.*, 2009). Endemics and narrow ranged species are reported to be prone to extinction (Işik, 2011). Elevational Rapoport's rule assumes that the breadth of climatic conditions experienced by species increased towards higher elevation (Stevens, 1992).

3.5.7 Species turnover

Since the herpetofauna of the Western Ghats exhibits high patchiness in their distribution (Vasudevan *et al.*, 2006), it is important to understand their turnover patterns to plan conservation actions. The reptiles in Agasthyamalai Hills showed a high rate of species turnover on a broader scale. Compared to consecutive zones distant zones showed high species turnover, implying that the change in vegetation or other bio-climatic factors may be influencing the species composition across altitude. Some of the higher elevation zones (>1200m) showed complete turn over with low elevation bands which may be due to the difference in bioclimatic conditions between the zones. The higher elevations often had very few species unique to that zone which might have resulted in a complete turnover in these zones. Our analysis showed that species turnover values are useful in identifying zones having unique species assemblages.

3.6 Conclusion

The study highlighted the importance of environmental factors and area effect along with geometrical factors in explaining the species richness patterns along elevation. Temperature was the major factor possibly contributing to elevational patterns. There was no significant influence of Mid-domain effect on specie richness in reptiles. Smaller domain and species ranges could be the probable reason for this phenomenon (Dunn *et al.*, 2007). The area availability and temperature played a major role in reptile richness in Agasthyamalai Hills. The influence of regional species pool and the ectothermic behaviour of reptiles would be the potential factors contributing to this phenomenon. As the elevational range shift has been already reported in various taxa across the globe, reptiles which are highly sensitive to atmospheric temperature, need more attention for conservation in the mountain ecosystems of the Western Ghats. The impact of climate change on species range sizes may be investigated further in these hill ranges.

Considering the topographical features of the Western Ghats, the influence of area in elevational patterns needs further investigations. The large scale patterns across different biogeographical regions would be helpful in explaining the underlying mechanisms of specie richness patterns.(Heatwole, 1982; Hofer *et al.*, 1999, 2000). Apart from the species richness patterns, it is also necessary to address the turnover patterns for a better understanding of species distributions along elevation. Moreover, studying the reptile richness patterns in other hill ranges of the Western Ghats also would be an important step for planning conservation measures for these highly ignored taxa.

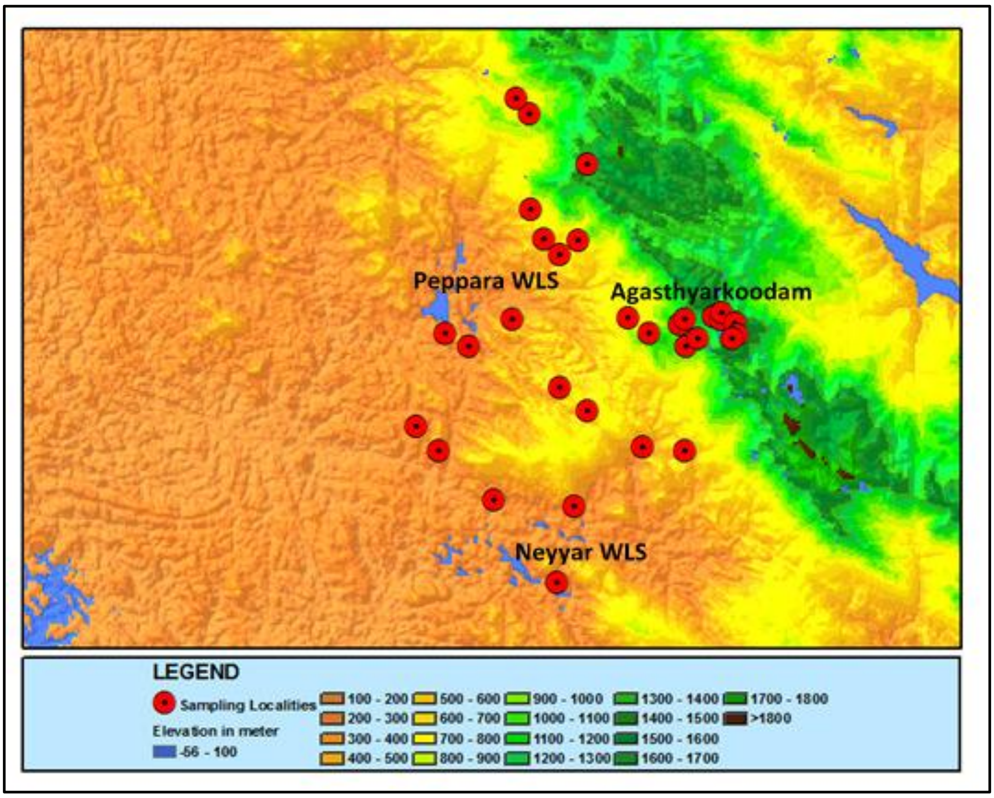


Figure 3-7: Digital Elevation Model showing elevation gradient of the study area and major sampling locations

Plate 3-1: Beddome's Coral Snake (*Calliophis beddomei*): First record from the southern Western Ghats.

Eutropis clivicola

Trimeresurus macrolepis

Calotes grandisquamis

Ophiophagus hannah

Indotestudo travancorica

Tereturus sanguineus

Plate 3-2: Some of the rare/endemic/threatened species recorded from Agasthyamalai region.

4 Ecological Niche, Microhabitat Relationships and Habitat Associations

4.1 Introduction

Ecologists have long been interested in quantifying the resource use patterns and habitat associations of organisms because of their desire to understand what determines the diversity and distribution of species (Toft, 1985). The mechanisms by which the available resources are partitioned could be the major driving factors of species diversity and community patterns (Pianka, 2000). Moreover, the ecological niche of a species is increasingly identified based on their resource use patterns. The dimensions and patterns of resource utilization would give insights into coexistence and inter-specific competitions in a community (Schoener, 1974) and it has long been used to summarize the community structure (Thompson, 1982). For instance, MacArthur's work on niche segregation and coexistence of insectivorous wood warblers of northeastern coniferous forests remains one of the classic studies in community ecology (MacArthur, 1958).

Niche represents the functional space of an organism and it has been used in so many different ways (Pianka, 2000). The concept of the niche was originally coined by Joseph Grinnell who viewed "niche as the functional role and position of an organism in its community" (Grinnell, 1917). The ecological niche is defined as "the sum total of all the adaptations of an organism" to survive in their environment (Pianka, 2000). The idea of 'niche' has been a subject of debate since its conceptualization (Whittaker *et al.*, 1973; Pianka & Pianka, 1976; Kearney, 2006; Holt, 2009; McInerny & Etienne, 2012). It was Hutchinson (1957) who made a distinction between the 'fundamental niche' and the 'realized niche' of an organism. According to him, the fundamental niche includes the entire set of optimal conditions in the environment of an organism. In the other hand, the realized niche only takes into account the actual set of conditions including the forces of competition and predation (Hutchinson, 1957). Though the niche concept is widely used in various aspects of community ecology, the ecological niche of an organism remains poorly understood. According to Pianka, (1973), space, time and food are the important dimensions of ecological niche of an organism. However, exploring all dimensions of the fundamental niche of an organism is challenging for community ecologists.

The enormous diversity within the taxa and, the differences in morphology and life history make reptiles as the best model organisms for various experiments in community ecology including niche dynamics and coexistence (Toft, 1985). Moreover, studies focusing on niche dimensions and habitat associations in reptiles are scarce. Resource utilization patterns and partitioning in reptiles have been addressed by many researchers elsewhere (Pianka, 1976; Toft, 1985; Chettri, 2007; Mukherjee, 2007). Being the functional space of an organism, habitat has a greater role in the distribution and survival of each species. The availability of specific microhabitats is also associated with the broad habitat types of an area. Microhabitat often acts as an important resource dimension that is partitioned between the ecologically and genetically similar species (Schoener, 1974; Toft, 1985; Vitt & Zani, 1996; Whitfield & Pierce, 2005). Microhabitat availability and preferences can provide indirect evidence for resource limitations (Abrams, 1980). Due to narrow ranges of distributions and niche requirements, reptiles are reported to be more susceptible to threats due to habitat degradations compared to birds and mammals (Gibbon *et al.*, 2000). Hence, the study on habitat requirements and species-habitat associations would definitely help in conservation planning (Michael *et al.*, 2015).

Niche breadth and niche overlaps are two important measures of the ‘ecological niche’ by which we can assess the coexistence and competition in a community (Pianka, 1981). Some species have smaller niches than others which indicate specialization and generalization of a species in their environment. Niche breadth is defined as the total variety of different resources exploited by an organism (Pianka, 1981). In other words, niche breadth is the measure of evenness in resource utilization by a species along different dimensions (Levins, 1968). The niche breadth of an organism helps us to understand whether it is a specialist or generalist with respect to the use of a particular resource (Pianka, 2000). The species having lower niche breadth values are reported to be specialists and others are known to be generalists. In fact, this information can be used in further conservation planning and habitat protection of different species.

In general, many species share the same niches and there may be overlap in resource use patterns at various levels. ‘Niche overlap’ is the measure of co-utilization of resources along one or more dimension by two organisms (Noon, 1981). Complete overlap occurs when a pair of species has similar resource requirements and there will be no overlap if the requirements are completely different. In natural conditions, the partial overlap is common since many species share their resources. However, certain dimensions of these resources are exclusive to each species (Pianka, 2000). High niche overlap may lead to competition (Hutchinson, 1957). Hence the measure of niche overlap is often used for understanding the nature of competition between the species in a community (Abrams, 1980). But, the overlap of niches does not necessarily lead to competition, if the resources are unlimited.

Physical characteristics of a species' habitat have been considered as an important ecological factor- in structuring the community- nearly as often as competition (Belll *et al.*, 2012). Habitat structure (also a part of fundamental niche) is an important component in every ecological study. As reptiles show a higher rate of specialization with respect to their microhabitats, the structural complexity of the habitat would play an important role their distributions. The importance of forest structure *versus* vegetation composition to reptile assemblages remains poorly understood and it has both ecological and conservation importance. A study in Australia revealed that habitat structure is more important than vegetation composition in determining the reptile assemblages in urban forest fragments (Garden *et al.*, 2007). Similar studies are available in other taxa including birds revealing that any of these components or both can equally contribute to the species assemblages (Rotenberry, 1985; Jayapal *et al.*, 2009).

In natural conditions, communities may be structured into clusters with all species having similar ecology, forming the ecological guilds (Wiens, 1992). Species within the same guild strongly interact among themselves for the use of specific resources but having only weak interaction with individuals of other guilds (Pianka, 1980; Blaum *et al.*, 2011). The term 'guild' was coined by Root (1967), to indicate functionally similar species in a community. Guild classification would help us to understand major groups in the community based on their resource use patterns. This will be highly useful in planning management actions focusing on specific dimensions of the resources. Being narrow ranged and less mobile taxa, reptiles are highly associated with their microhabitats and climatic conditions. A guild analysis with microhabitat as a resource dimension would reveal the major groups of reptiles associated with specific microhabitats to design a customized conservation approach.

Although there have been some exploratory surveys on herpetofauna in the Western Ghats since the colonial period (eg: Ferguson, 1895; Inger *et al.*, 1984, 1987), studies pertaining to niche segregation and microhabitat preferences of reptiles are scarce. The microhabitat use patterns of herpetofauna from Ponmudi Hills, in the southern Western Ghats, are available (Inger *et al.*, 1987). A recent re-investigation on the herpetofauna of the southern Western Ghats also included Ponmudi Hills (Chandramouli & Ganesh, 2010) but not covered the community ecology aspect of the taxa. Bhupathy & Kannan, (1997) studied the habitat and microhabitat use of Agamid lizards in the Western Ghats. There are only a few studies from the Western Ghats of India dealing with microhabitat associations of herpetofauna. The distribution of the endemic agamid, *Salea anamallayana* was reported to be highly associated with the structural aspects of the habitats (Deepak & Vasudevan, 2008). Microhabitat preferences of the endangered agamid, *Otocryptis beddomii* were studied and leaf litter was reported to be the most preferred microhabitat of the species (Chandramouli, 2009). The resource utilization patterns in reptile communities were also explored in Anaikatty Hills, in the Western Ghats (Mukherjee, 2007). The niche breadth, overlap and resource partitioning in Eastern Himalayan reptiles were also studied and they exhibited niche segregation at various levels (Chettri, 2007).

Altogether, it is important to study the ecological niche of different species to understand the competition and coexistence within the community. The associations of organisms with their macro and micro-habitats are also important factors determining their diversity and distributions. Moreover, studying the habitat relationship of a species is a prerequisite for planning long term conservation strategies (Sutton *et al.*, 2010). Most of the community studies on reptiles are limited to arid zones and in man-made habitats (Pianka, 1966a, 1973, 1980, Michael *et al.*, 2008, 2015). The ecological niches and community structure of reptiles are poorly documented in the Western Ghats. The present study examined the microhabitat preferences, niche breadth and overlap in reptile communities of Agasthyamalai Hills along with the microhabitat guild structure and habitat associations.

4.2 Methods

4.2.1 Data Collection

Field surveys were carried out during April 2012 to December 2015 in Agasthyamalai Hills. As this study was primarily designed for examining the elevational patterns, the intensive study area (100-1860m AMSL) was categorized into 100m elevation zones. Belt transects of 1-2 km length and variable width was laid in each elevation zone based on the extent and the accessibility of the zones. Time constrained visual encounter surveys (VES) were conducted for sampling reptile communities in all zones. VES was formalized as a time-constrained technique (Campbell & Christman, 1982; Heyer *et al.*, 1994) which includes surveying an area or habitat for a prescribed time and systematically searching for animals in all possible microhabitats. Total time is expressed as the number of man-hours of searching (Crump & Scott, 1994). The VES is an appropriate method for both species inventorying and monitoring and hence is suitable for studies examining landscape level patterns. VES has been widely used to determine composition, richness and relative abundance of herpetofauna. It is also known for a higher detection rate of rare species (Heyer *et al.*, 1994) and had successfully been applied in few studies conducted in the Western Ghats (Mukherjee, 2007; Bhupathy & Nixon, 2011) and in the Eastern Himalayas (Chettri *et al.*, 2010).

Sampling was restricted from 8.00 to 19.00 hours and the search includes turning stones and fallen logs, moving leaf litter, scanning the vegetation and, searching on stems and barks of trees. Each unit of VES involved systematic search by two personnel for one hour, amounting to two person-hours per search effort. The GPS location, habitat, weather conditions and atmospheric temperature (IR Thermo hygrometer) of the site were noted for each effort. All reptiles (except few of the taxonomically uncertain groups) were identified up to species level and the un-identified species were accounted as a distinct unknown species of the genus. For each observation, the variables such as microhabitat, perch height, and habitat types were recorded.

To account the forest structure (the structural complexity of the habitat) and tree species composition, vegetation sampling was carried out in each sampling sites. Habitat parameters relevant to reptile distributions were quantified in each plot. The detailed methodology adopted for habitat sampling is described in Chapter 3. Major microhabitat categories were identified and classified based on the available literature (for eg; Chettri, 2007; Michael *et al.*, 2015) and field observations.

4.2.2 Data analysis

All reptile observations were assigned to 15 microhabitat categories following the literature (Michael *et al.*, 2015) and considering the available microhabitats in the intensive study area. The niche breadth and overlap of each species were calculated based on their occurrence in different microhabitats. Niche breadth (β) for each species was calculated using Simpson's diversity index ($\beta = 1/\ \Sigma\ Pi^2$). We classified species with β <1.8 as habitat specialists and species with >1.8 as habitat generalists based on the median niche value. Niche overlap (Pianka's overlap index) between closely related species among a different group of reptiles was calculated. EcoSim Version7 was used for niche overlap analysis (Gotelli & Entsminger, 2000). Niche overlap analysis was carried out for different groups such as agamid lizards, skinks, geckos, and snakes separately to see the overlap patterns within the group.

Hierarchical cluster analysis using Bray-Curtis distance matrix was performed to explore the microhabitat guild structure of reptiles (following Michael *et al.*, 2015). The number of observations of a species in each microhabitat category was used for the analysis. Single linkage' method (nearest neighbor clustering) which will plot the cluster based on the minimum distance between the species lineages (following Pianka, 1980; Mukherjee, 2007). The R statistical program, Version 3.3.1(R Core team, 2016) was used for the hierarchical cluster analysis. The relative abundance of each species in different microhabitat category was used for the analysis.

Mantel's test was performed with reptile species composition, tree species composition and forest structure (Jayapal *et al.,* 2009). 'PAST software (version 3) was used for this analysis. Relative abundance of reptiles and tree species richness in each zone were used for Mantel test. The structural attributes of habitat include tree height diversity, mean GBH, canopy cover, slope, number of trees, number of fallen logs, number of ground holes, herb cover, leaf litter cover, exposed ground, rock and boulders and exposed roots. Three dissimilarity indices were calculated: 1) Simpson index for reptile composition, 2) Bray-Curtis index for vegetation composition and 3) Gower index for habitat structure. Since the forest structure and tree species compositions were highly correlated, a partial Mantel's test was performed for analyzing the relationship of reptile species assemblage with forest structure vs. tree species composition by removing the effect of one. This analysis was performed separately for all reptiles together as well as lizards and snakes separately.

4.3 Results

4.3.1 Microhabitat breakups

Forty seven species of reptiles from 12 families were recorded from in 1554 sightings, of which nearly 48% sightings comprised of only two skink species namely *Eutropis macularia (*n=549, 35.33%) and *Sphenomorphus dussumieri* (n=192, 12.36%). About 10 species were singletons (i.e. observed only once in the sampling).

The fifteen distinct microhabitats were identified from all observations such as 1) Buttress of trees (BT), 2) Rock crevices (CR), 3) Ground with grass/herb cover (GG), 4) tree hole (HT), 5) Inside water (IW), 6) Leaf-litter (LL), 7) Open ground (OG), 8) On log (OL), 9) On rock (OR), 10) On stem (of shrubs) (OS), 11) Tree trunk (TT), 12) Under tree bark (UB), 13) Under soil surface (UG), 14) Under log (UL), 15) Under surface rock (UR). These categories were used for calculating the niche breadth of each species based on their occurrence records in each microhabitat types.

Out of all microhabitat categories, leaf-litter was the most recorded microhabitat of reptiles (46.6% of total observations; Figure 4-1) where a single species very prominently dominated (506 sightings). Nevertheless, 20 species preferred leaf-litter which makes this microhabitat most preferred and important component for these species to occur. Rock surfaces and bark of large trees formed the other preferred microhabitats (Figure 4-1). Boulders, tree trunk, stems, rock surfaces and open ground are the other important microhabitats where more than 15 species were observed (Figure.4-2).

4.3.2 Niche breadth

Niche breadth was calculated for all species, except for singletons, to determine habitat specialists and habitat generalists. Of the total 47 species, 10 species were singletons. The median niche breadth, i.e. 1.8, was considered as cut off value for classifying habitat specialists and generalists. A total of 15 species (40.5%) were thus classified as habitat specialists (having niche breadth <1.8) while 22 species (59.5%) were categorized as habitat generalists (having niche breadth >1.8; Table 4-1).

Though a single species, i.e. Bronze Grass skink *Eutropis macularia* occurred in maximum number of microhabitats (n=8), its niche breadth was rather narrow (1.17) as it was mostly observed in same leaf-litter microhabitat. Two species of Day Geckos

(*Cnemaspis cf australis, Cnemapis spp.*) and one species of skink (*Sphenomorphus dussumieri*) occupied eight microhabitat categories which had higher niche breadths ranging 2.67 to 4.39.

Family Geckonidae exhibited the highest average niche breadth (2.80), followed by Scincidae (2.49) and Agamidae (2.30). Though Family *Xenodermatidae* showed relatively high niche breadth (2.67), it was represented by a single species, *Xylophis captaini* (Table 4-1).

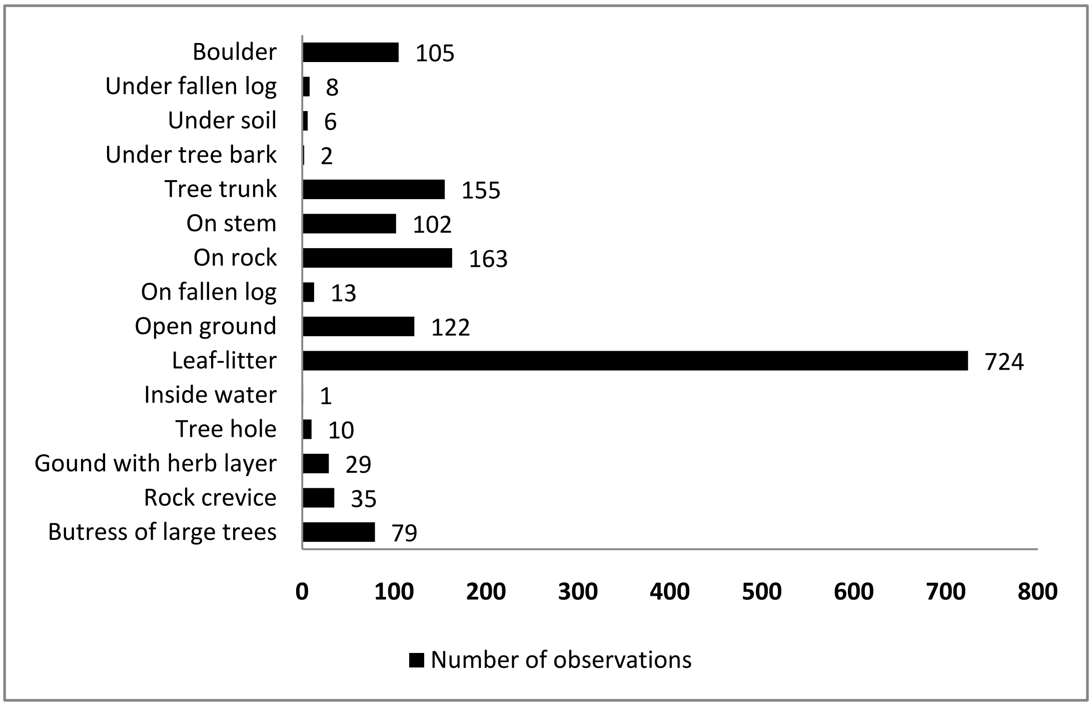


Figure 4-1: Microhabitat break-up of reptile observations

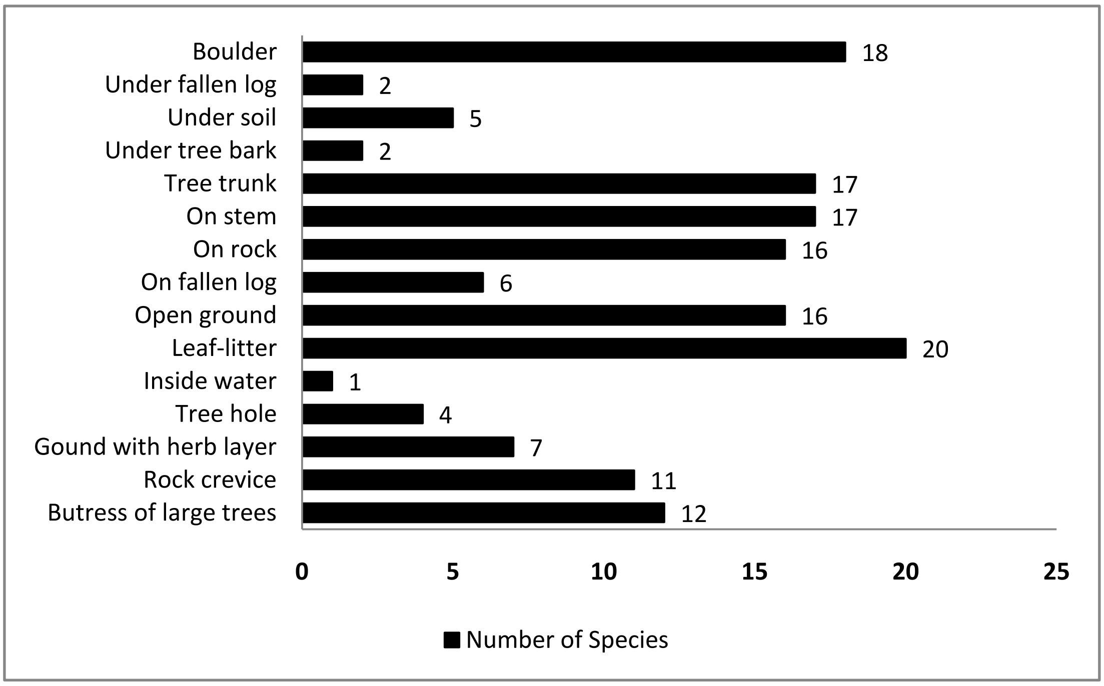


Figure 4-2: Number of species recorded from different microhabitats

Table 4-1. Niche breadth and recorded microhabitats of reptiles

Sl.	Scientific name	Common name	N#.	β	Recorded microhabitats*
	Order: SQUAMATA				
	Family: GECKONIDAE				
1	*Cnemaspis cf australis*	Southern Day Gecko	83	4.39	BT, CR, HT, LL, OG, OR, TT, UR
2	*Cnemaspis littoralis*	Coastal Day Gecko	52	1.27	BT, LL, OS, TT
3	*Cnemaspis nairi*	Ponmudi Day Gecko	18	4.38	BT, CR, HT, LL, OR, TT, UR
4	*Cnemaspis cf beddomei*	Beddome’s Day Gecko	3	1.00	UR
5	*Cnemaspis spp.*	Day gecko spp.	50	2.67	BT, CR, OL, OR, TT, UB, UL, UR
6	*Cnemaspis cf wynadenis*	Wynad Day Gecko	34	3.01	BT, CR, HT, LL, OL, TT, UR
7	*Hemidactylus spp.*	House Geck spp.	17	2.86	BT, HT, OL, TT, UB, UR
	Family:AGAMIDAE				
8	*Calotes calotes*	Common Green Forest Lizard	18	3.06	GG, LL, OG, OS, TT
9	*Calotes ellioti*	Ellioti's Forest Lizard	82	2.87	BT, CR, LL, OG, OL, OR, OS
10	*Calotes grandisquamis*	Large Scaled Forest Lizard	3	3.00	TT, OS, OR
11	*Calotes nemericola*	Nilgiri Forest Lizard	2	2.00	OS, TT
12	*Calotes versicolar*	Indian Garden Lizard	55	3.50	BT, GG, LL, OG, OR, OS, TT
13	*Draco dussumieri*	South Indian Flying Lizard	22	1.00	TT
14	*Otocryptis beddomii*	Indian Kangaroo Lizard	105	1.76	LL, OG, OR
15	*Psammophilus dorsalis*	South Indian Rock Agama	78	1.20	CR, GG, OR, UR
	Family:SCINCIDAE				
16	*Eutropis carinata*	Common Keeled Skink	33	4.44	BT, CR, GG, LL, OG, OR, TT
17	*Eutropis clivicola*	Mountain Skink	3	1.80	OG, LL
18	*Eutropis macularia*	Bronze Grass Skink	549	1.17	BT, CR, GG, LL, OG, OR, OS, TT, UR
19	*Kaestlea travancoricus*	Travancore Cat Skink	4	2.67	GG, LL, OR
20	*Lygosoma punctata*	Spotted Supple Skink	2	1.00	UR
21	*Ristella guntheri*	Günther’s Cat Skink	13	2.77	CR, LL, OG, UG, UR
22	*Ristella trvancorica*	Travancore Cat Skink	35	2.45	LL, UL, UR
23	*Sphenomorphus dussumieri*	Dussumier's Litter Skink	192	3.59	BT, CR, LL, OG, OL, OR, OS, TT
	Family:VARANIDAE				
24	*Varanus bengalensis*	Bengal Monitor	1	1.00	OR
	Family:TYPHLOPIDAE				
25	*Typhlops sp.*	Worm Snake spp.	2	2.00	UG,UR

	Family:UROPELTIDAE				
26	*Teretrurus sanguineus*	Western Shieldtail	11	1.42	UG,UR
27	*Uropeltis liura*	Ashambu Shieldtail	2	2.00	UR, UG
	Family:COLUBRIDAE				
28	*Ahaetulla dispar*	Gunther's Vine Snake	8	1.58	GG, OS
29	*Ahaetulla nasuta*	Common Vine Snake	13	1.00	OS
30	*Boiga beddomei*	Beddome's Cat Snake	2	2.00	OS, TT
31	*Boiga ceylonensis*	Ceylon Cat Snake	4	2.67	CR, OR, OS
32	*Boiga nuchalis*	Collared Cat Snake	1	1.00	OS
33	*Boiga trigonata*	Common Cat Snake	1	1.00	UR
34	*Dendrelaphis grandoculis*	Large-eyed Bronzeback Tree Snake	2	1.00	OS
35	*Dendrelaphis cf ashoki*	Ashok’s Bronzeback Tree Snake	1	1.00	TT
36	*Lycodon striatus*	Barred Wolf Snake	1	1.00	UR
37	*Lycodon travancoricus*	Travancore Wolf Snake	1	1.00	UR
38	*Ptyas mucosa*	Indian Rat Snake	8	1.28	OG, OS
	Family:XENODERMATIDAE				
39	*Xylophis captaini*	Captain’s Wood Snake	4	2.67	LL, UG, UR
	Family:NATRICIDAE				
40	*Xenochrophis cf piscator*	Checkered Keelback	1	1.00	IW
41	*Amphiesma beddomei*	Beddome's Keelback	7	2.88	LL, OG, OR
42	*Amphiesma monticola*	Montane Keelback	1	1.00	OG
	Family:ELAPHIDAE				
43	*Ophiophagus hannah*	King Cobra	1	1.00	OG
	Family:VIPERIDAE				
44	*Hypnale hypnale*	Hump-nosed Pit Viper	6	1.80	LL, OG
45	*Trimeresurus macrolepis*	Large-scaled Green Pit Viper	1	1.00	OS
46	*Trimeresurus malabaricus*	Malabar Pit Viper	20	2.78	BT, LL, OG, OL, OR, OS
	Order:TESTUDINES				
	Family:TESTUDINIDAE				
47	*Indotestudo travancorica*	Travancore Tortoise	2	1.00	LL

- *Micro habitat codes are explained in results (4.3.1)**,** **#** Number of observations**,** **β=** Niche breadth

4.3.3 Niche overlap

Niche overlaps between different species within the major groups of lizards, namely, geckos, agamids, and skinks were analyzed separately since each of these groups are distinct in their morphological and resource use patterns. Niche overlaps between different species of snakes were also separately analyzed.

Almost all agamid lizards exhibited some extent of niche overlap among the species within the group (Table 4-2). The maximum niche overlap in agamids was observed between *Calotes ellioti* and *Calotes nemericola* (94%) followed by *Calotes ellioti* and *Calotes calotes* (89%). Expectedly, the terrestrial species *Otocryptis beddomii* and *Psammophilus dorsalis* did not show any overlap with two semi-arboreal species such *Calotes nemericola* and *Draco dussumieri* considering their segregation in microhabitats.

Geckonid lizards exhibited 0-95% overlaps in their microhabitat niches. *Cnemaspis spp.* showed 95% overlap with *Cnemaspis beddomei* and *Cnemaspis cf wynadensis*. while *Cnemaspis cf wynadensis* and *Cnemaspis beddomei* showed 91% niche overlap. The arboreal species *Hemidactylus sp.* and *Cnemaspis littoralis* also showed similar overlap. Unlike other groups, only one pair (*Cnemaspis littoralis* and *Cnemaspis beddomei*) showed no overlap in their microhabitat niches (Table 4-3).

Among the skinks, high niche overlap was observed between following species pairs: *Ristella guentheri* and *Ristella travancorica* (92%); *Sphenomorphus dussumieri* and *Eutropis carinata* (90%); *Eutropis macularia* and *Sphenomorphus dussumieri* (83%). All other skinks showed less than 80% niche overlap between the species pairs (Table 4-4).

The burrowing snakes *Uropeltis liura* and the *Typhlops spp*. showed complete niche overlap (100%). Moreover, all the burrowing snakes (*Uropeltis liura*, *Typhlops spp*., *Xylophis captaini*) showed niche overlaps among them, but not with any other species (Table 4-5). Among all the colubrid snakes, the high niche overlap was observed between some of the semi-arboreal colubrids. *Ahaetulla dispar* and *Ahaetulla nasuta* showed 95% overlap in their microhabitat niche. Also, *Dendrelaphis grandoculis* showed high niche overlap (95%) with *Ahaetulla dispar*.

Table 4-2: Niche overlap in Agamid lizards

Species	***Cc***	***Ce***	***Cg***	***Cm***	***Cv***	***Dd***	***Ob***	***Pd***
Calotes calotes (Cc)		0.89	0.62	0.76	0.35	0.19	0.32	0.002
Calotes ellioti (Ce)			0.78	0.94	0.48	0.45	0.09	0.02
Calotes grandisquamis (Cg)				0.82	0.57	0.58	0.02	0.58
Calotes nemericola (Cn)					0.63	0.71	0	0
Calotes versicolar (Cv)						0.78	0.1	0.12
Draco dussumieri (Dd)							0	0
Otocryptis beddomei (Ob)								0.04
Psammophilus dorsalis (Pd)								

Table 4-3: Niche overlap in Geckonid lizards

Species	***Cn1***	***Ca***	***Cl***	***Cn***	***Cb***	***Cw***	***Hem***
Cnemaspis spp. (Cne)		0.55	0.052	0.45	0.95	0.95	0.17
Cnemaspis cf australis (Ca)			0.4	0.61	0.35	0.63	0.45
Cnemaspis littoralis (Cl)				0.37	0	0.27	0.9
Cnemaspis cf nairi (Cn)					0.35	0.63	0.42
Cnemaspis beddomei (Cb)						0.91	0.09
Cnemaspis cf wynadensis (Cw)							0.37
Hemidactylus spp. (Hem)							

Table 4-4: Niche overlap in Skinks

Species	***Ec***	***Ecl***	***Em***	***Kt***	***Lp***	***Rg***	***Rt***	***Sd***
Eutropis carinata (Ec)		0.8	0.67	0.7	0	0.65	0.49	0.9
Eutropis clevicola (Ecl)			0.47	0.18	0	0.52	0.34	0.68
Eutropis macularia (Em)				0.44	0	0.9	0.76	0.83
Kaestlea travancorica (Kt)					0	0.37	0.31	0.71
Lygosoma punctata (Lp)						0.38	0.63	0
Ristella guntheri (Rg)							0.92	0.77
Ristella travancorica (Rt)								0.61
Sphenomorphus dussumieri (Sd)								

Table 4-5 Niche overlap in snakes

Species	***Ad***	***An***	***Ab***	***Bb***	***Bc***	***Dg***	***Hh***	***Pm***	***Ty***	***Ts***	***Tm***	***Ul***	***Xc***
Ahaetulla dispar (Ad)		0.95	0	0.67	0.77	0.95	0	0.13	0	0	0.87	0	0
Ahaetulla nasuta (An)			0	0.71	0.82	1	0	0.14	0	0	0.92	0	0
Amphiesma beddomei (Ab)				0	0.19	0	0.87	0.48	0	0	0.26	0	0.29
Boiga beddomei (Bb)					0.58	0.71	0	0.1	0	0	0.64	0	0
Boiga ceylonensis (Bc)						0.82	0	0.12	0	0	0.78	0	0
Dendrolaphis grandoculis (Dg)							0	0.14	0	0	0.92	0	0
Hypnale hypnale (Hh)								0.44	0	0	0.22	0	0.37
Ptyas mucosa (Pm)									0	0	0.46	0	0
Typlops spp. (Ty)										0.84	0	1	0.87
Tereturus sanguineus (Ts)											0	0.84	0.89
Trimeresurus malabaricus (Tm)												0	0.03
Uropeltis liura (Ul)													0.87
Xylophis captaini (Xc)													

4.3.4 Microhabitat relationships

Hierarchical cluster analysis of reptiles, based on frequency of occurrence of each species in each microhabitat categories (Fig.4-3) delineated five prominent guilds namely 1) saxicolous (boulder or outcrop-dwelling) 2) ground-dwelling (open ground& leaf-litter), 3) cryptozoic (surface rock-dwelling) 4) semi-arboreal and 5) arboreal.

The open ground guild formed the largest group with 18 species. It consisted of subgroups which inhabit leaf-litter, open ground and surface soil. Ground-dwelling guild included eight species of skinks (*Eutropis clivicola, Eutropis macularia, Kaestlea travancorica, Eutropis carinata, Sphenomorphus dussumier, Ristella guentheri, Ristella travancorica, Lygosoma punctata*) and seven snakes (*Ptyas mucosa, Amphiesma beddomei, Hypnale hypnale, Tereturus sanguineus, Xylophis captaini, Typhlops sp and Uropeltis liura).* Other than skinks and snakes, this guild consisted of a species of day gecko (*Cnemaspis cf. beddomei*) and a litter-dwelling lizard *(Otocyptis beddomii),* and one species of tortoise (*Indotestudo travancorica*). Some of these snakes such as *Tereturus sanguineus, Xylophis captaini, Typhlops sp and Uropeltis liura* are known to be fossorial in nature. However, in the present study, there was no method used which involve digging and they were often observed in surface soil or under stones and turned out to be a ground-dwelling group in the analysis.

Semi-arboreal guild consisted of 10 species including six snakes and four agamid lizards. Most of the snakes were Colubrids (*Ahaetulla nasuta, Ahaetulla disapar, Dendrelaphis gradoculis, Boiga ceylonensis, Boiga beddomei)* and one species of viper (*Trimeresurus malabaricus*). The agamid lizards in the semi-arboreal group are *Calotes calotes, Calotes grandisquamis, Calotes ellioti,* and *Calotes nemericola.* All these semi- arboreal species were mostly observed on stems of small trees or shrubs.

Arboreal guild included only four species which are mainly found on tree trunks. Species like *Draco dussumieri, Cnemaspis littoralis* were mostly found on tree bark going higher on branches. However, species like *Calotes versiocolar* and *Hemidactylus sp.* were having lower perch height compared to other species in this guild. The outcrop-dwelling (saxicolous) species consisted of four species of day geckos (*Cnemaspis spp., Cnemaspis cf. wynadensis, Cnemaspis cf. australis and Cnemaspis cf. nairi*). There was only one species, *Psammophilus dorsalis* in rock-dwelling guild (cryptozoic) which exclusively found associated with rock surfaces.

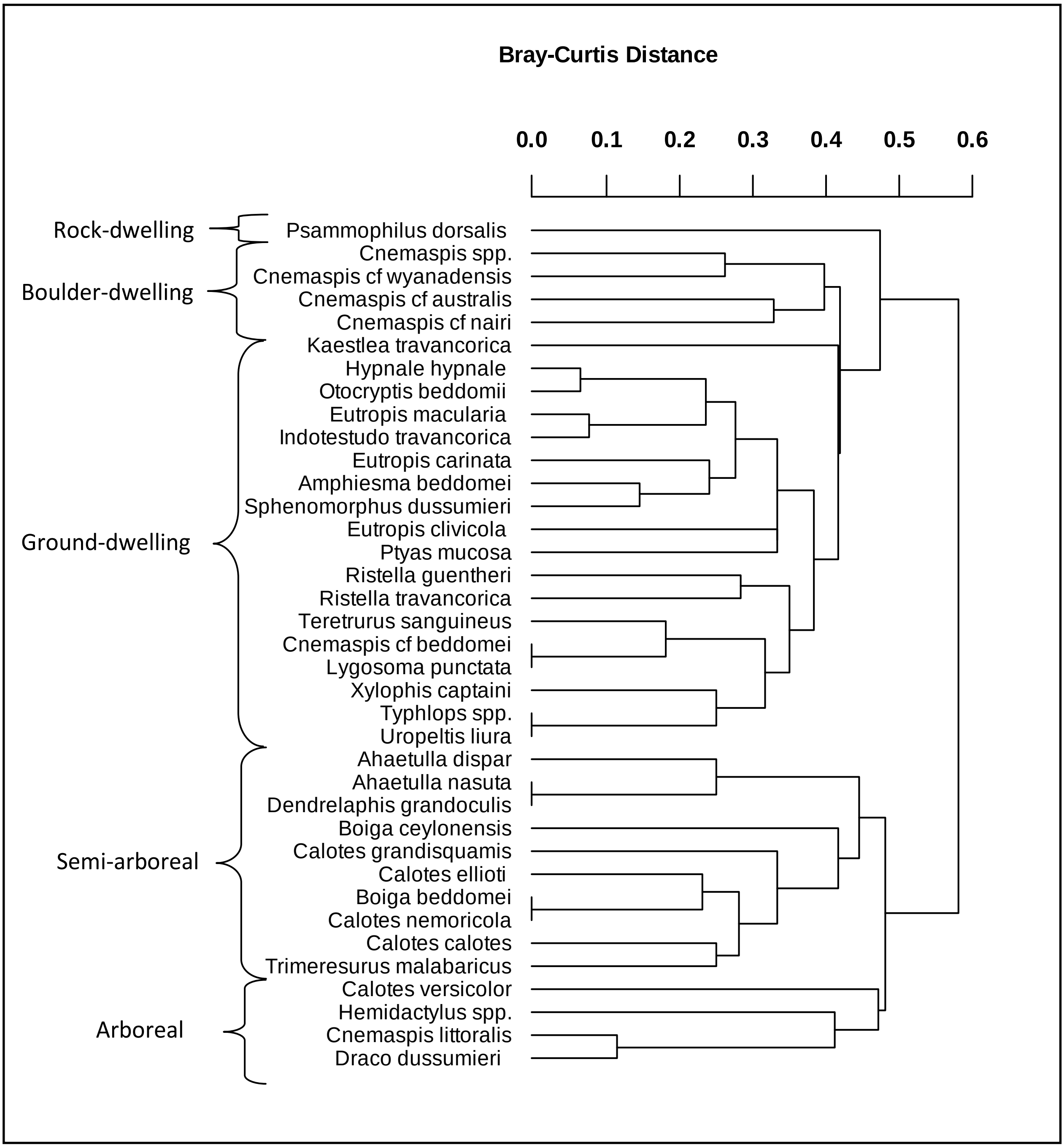


Figure 4-3.The microhabitat relationships of reptiles in Agasthyamalai Hills

4.3.5 Role of forest structure and tree species composition

The Mantel's test was performed to examine the relative effects of tree species composition and forest structure in determining reptile assemblages as a whole as well as lizards and snakes separately. The analysis revealed that species composition of reptiles was significantly influenced by forest structure than the tree species composition (Table 4-6). However, lizards showed a significant association with tree species composition. In contrary, snake assemblages were significantly associated with forest structure.

Table 4-6: Mantel's test showing association of reptile assemblage with forest structure *vs*. tree species composition.

SL.	Group	Variable 1	Variable 2 (Partial)	R - value	P -value
1	Reptiles	Forest Structure	Tree species composition	0.4594	0.024
2	Reptiles	Tree species composition	Forest Structure	0.3598	0.008
3	Lizards	Forest Structure	Tree species composition	0.2931	0.101
4	Lizards	Tree species composition	Forest Structure	0.4027	0.001
5	Snakes	Forest Structure	Tree species composition	0.4056	0.020
6	Snakes	Tree species composition	Forest Structure	0.3628	0.378

4.4 Discussion

4.4.1 Microhabitat association

The present study found that leaf-litter is a major microhabitat for the reptile communities in Agasthyamalai Hills. Other microhabitats like tree trunks, rock surfaces and boulders also act as an important substratum for many species. Numerous studies noted the relationship between leaf-litter and abundances of amphibians and reptiles (Heyer & Berven, 1973; Scott Jr, 1976; Sima Lieberman, 1986; Fauth *et al.*, 1989; Heinen, 1992). For many species of reptiles, leaf-litter acts as an important feeding substratum. Some of the threatened species (out of six recorded in the study) found in Agasthyamalai landscape such as *Otocryptis beddomii*, *Indotestudo travancorica* and *Vijayachelys silvatica* are largely depending on leaf-litter as their major microhabitat (Jose *et al.*, 2007; Ramesh, 2008; Chandramouli, 2009; Vasudevan *et al.*, 2010; Kanagavel & Raghavan, 2012). Additionally, most of the skink species largely depend on leaf-litter habitats. The removal of leaf-litter from the forest areas during fire-lining was reported in the literature

(Jose *et al.*, 2007; Chandramouli, 2009). Although in lower quantity, litter-removal can affect many species of reptiles and amphibians. Considering these important microhabitats, forest fire could be a major and potential threat for many reptiles in Agasthyamalai Hills. Activities such as ecotourism and pilgrimage which exerts much pressure on the leaf-litter habitats may be managed for protecting the microhabitats of reptiles, especially for the threatened species in the area.

4.4.2 The ecological niche

Niche breadth analysis along microhabitat dimension indicated that many species have narrow niche ranges that make them habitat specialists. In the present study, more than 40% of the population was identified as habitat specialists based on their niche breadth analyses. These specialists are susceptible to threats from habitat degradation and human influences, compared to generalists (Michael *et al.*, 2015). Out of 70 species of reptiles observed (including opportunistic sightings) during the study, only 47 species were recorded during the sampling, of which ten species were singletons. This indicates the rarity of many species in the area and the need for more survey efforts and long term studies. Detailed field observations are crucial in understanding the ecological specializations of all species in the area.

Niche overlap indices have been used as potential estimators to understand competitions in the communities (Pianka, 1973). In the present study, the niche overlap was measured among different groups such as snakes, geckos, skinks and agamid lizards to understand the resource partitioning and co-existence of species. Snakes were much diversified group represented by an array of species having fossorial to arboreal habits, sharing a wide variety of microhabitats. Fossorial and arboreal species of snakes were very evidently mutually exclusive in their niches.

On the other hand, a remarkable complete overlap in niches was observed between two fossorial snakes namely *Uropeltis liura* and *Typhlops sp*. Many of the Colubrid snakes also showed high degree of niche overlaps. In the case of lizards, the high niche over lap (>80%) between some of the agamid lizards of the genus *Calotes* and Geckonid lizards of the genus *Cnemaspis* is an indication of probable interspecific competition for the resources. This implies the need for niche analyses at different taxonomic categories (e.g. Family level) which could provide insights in to understanding resource partitioning. Examining other aspects of niches such as altitude may give further insights into competitive interactions among groups like lizards and snakes. For instance, two species skinks of the genus *Ristella* exhibited clear altitudinal segregation: *Ristella travancorica* was observed predominantly in 800-1100m elevation, while *R.guentheri* was mostly found in lower elevations (200-600). Hence, the altitudinal segregation in these skink species may be one of the possible mechanisms that reduce interspecific competition. Altitudinal segregation contributing to competitive exclusion of some taxa has been noted in the literature (Noon, 1981; Vrezec & Tome, 2004; Jankowski *et al.*, 2010).

4.4.3 The microhabitat guilds

Microhabitat guilds delineated using hierarchical cluster analysis as in this study could provide a broader classification of reptiles based on their resource space. These ecological guilds can give an idea how a particular resource dimension (microhabitat in the present study) is distributed among different species within a community. The present study indicated that forest floor (both open ground and leaf-litter) habitats form the major substratum for a large number of reptiles. As the microhabitat availability is a limiting factor for most of the herpetofauna, these clusters could possibly reveal the community structure and patterns. This will potentially help to identify species which are vulnerable to habitat alterations and human influences in a microhabitat perspective (Michael *et al.*, 2015). The habitat and microhabitat profiles of reptile species as done in the current study (e.g. importance of leaf litter for foraging and open ground for basking substratum for many species of reptiles) help us to identify major guilds within the community and in planning effective management strategies for their habitats (Opdam *et al.*, 2001). Functional guild responses in taxa have been used in conservation practices of regional landscapes elsewhere (Bishop & Myers, 2005). The ecological guilds may reveal the life-history characteristics shaped by ecological and evolutionary factors which make them co-exist in the community (Bonsall *et al.*, 2004). Moreover, identification of ecologically similar groups (For eg; in the present study, the similar microhabitat users) would always help in the conservation planning of a group rather than a single species. Such strategies are adapted in identifying the causal factors for population decline in herpetofauna elsewhere and noted that similarity in ecological characteristics made some of the guilds more susceptible to local extinctions (Williams & Hero, 1998). The cluster analysis revealed that forest floor and associated microhabitats are the most important substratum that needs to be considered in planning conservation actions in the study area.

4.4.4 Forest structure *vs.* tree species composition

Forest structure rather than tree species composition contributed to the occurrence and distribution of reptiles in Agasthyamalai Hills. Garden *et al.* (2007) noted a similar effect of habitat structure on reptile distribution in the urban landscapes of Australia. Snakes followed a similar trend as other reptiles, whereas lizards were influenced by tree species composition. Being chiefly insectivorous, lizard distributions might be depending on the availability of food resources such as insects that are associated with different tree species and it could be the possible factor governing the association of lizards with the vegetation composition. However, the structural characteristics turned out to be the major influencing factors in reptile assemblages in Agasthyamalai Hills considering the fact that animal species diversity is positively correlated with habitat structural complexity (MacArthur & MacArthur, 1961; Sanders, 1968; Karr & Roth, 1971; Dean & Connell, 1987). Habitat structure is known to influence the foraging dynamics in a wide variety of animal communities including lizards (Losos *et al.*, 1997), birds (MacArthur & MacArthur, 1961; Parrish, 1995) and mammals (Price, 1978; Ziv *et al.*, 1995). An experimental study on Geckonid lizards also showed that the habitat structure is a major influencing factor for competition intensity and invasion success (Petren & Case, 1998). The present study indicated that human influence in the study area could possible change the structural characteristics of habitats and can negatively affect many species of reptiles in Agasthyamalai landscape. Hence, a customized approach to manage ecotourism and other destructive activities would be a major step towards the conservation of many reptiles in the area.

4.5 Conclusion

The preferences of microhabitats such as leaf litter, tree trunk and stems, which are closely associated with habitat types, indicated the importance of habitat protection for the conservation of many threatened species of reptiles in the study area. Reptiles are highly sensitive to habitat alterations and consequently succumb to population decline at global level (Gibbon *et al.*, 2000). The study highlighted that more than 40% species are microhabitat specialists which imply that the preservation of structural complexity of their macro habitats is crucial for their survival. The niche overlap analysis indicated that lizard species exhibit a higher rate of overlap in their niches, especially with congeners. A detailed study analyzing various dimensions of their niche could reveal the niche segregation and coexistence of these species. Studies focusing on resource partitioning in these taxa are essential to understand their ecological requirements, interactions and overall role in forest communities. The habitat association analysis showed that structural complexity is more important than vegetation composition in determining the reptile assemblages of the area, highlighting the need for conservation measures to preserve their habitats as intact as possible.

Forest fragmentation is reported to cause physical and biological changes in the environment (Laurance, 1990; Tabarelli *et al.*, 1999; Laurance *et al.*, 2000). Similarly, habitat degradations in the study area can pose threat to the existing reptile communities where the pressure due to ecotourism and pilgrimage is at higher level. The changes in microhabitat availability caused by habitat destructions could potentially affect the reptile communities in Agasthyamalai Hills. It is reported that even slight modifications in the habitats have impacts on reptile communities (Theisinger & Ratianarivo, 2015). The findings of the present study have conservation implications with respect to the habitat protection of reptiles in Agasthyamalai Hills. Detailed ecological studies pertaining habitat associations and niche relationships will be crucial in planning conservation strategies of reptiles in biodiversity-rich areas like the Western Ghats.

5 Ecological Niche Modeling of Two Endemics

5.1 Introduction

The distribution data of a species and the factors influencing them are used as powerful tools in conservation biology (Urbina-Cardona & Flores-Villela, 2010). The geographical distributions of species are now been largely characterized with the help of new algorithms and geospatial tools (Pearson *et al.*, 2007). The known occurrence records and associated environmental factors are used for predicting the potential distribution and the suitable habitats of the target species. These distribution models are widely used in conservation planning and biogeographical analyses of various species including the cryptic ones (Graham *et al.*, 2004; Rissler & Apodaca, 2007; Rutishauser *et al.*, 2012). Studies elsewhere highlighted that these prediction maps are potential tools that could guide field surveys to explore unknown populations and undiscovered species (Raxworthy *et al.*, 2003; Bourg *et al.*, 2005).

Ecological Niche Model (ENM) predicts the ‘fundamental niches’ of a species (Soberon & Peterson, 2005) which is basically the set of environmental conditions that make the long term survival of a species possible (Hutchinson, 1957) excluding the effect of biotic interactions and human influences. These mathematical models are produced by analyzing the environmental datasets of the sites of occurrences of the study species (Aguilar & Lado, 2012). ENMs are widely used to understand the impacts of changing the environment on ecosystems and species’ distributions (Guisan *et al.*, 2006). More recently, ENM combined with climatic factors (climate envelope models) are widely used in predicting the effect of global climate change on future distributions of target species (Peterson *et al.*, 2002; Pearson & Dawson, 2003; Hijmans & Graham, 2006).

Globally, ecological niche models are applied to various taxa including amphibians (Graham *et al.*, 2004; Groff *et al.*, 2014) and reptiles (Pearson *et al.*, 2007; Raxworthy *et al.*, 2007). The Western Ghats, a global biodiversity hotspot (Myers *et al.*, 2000) is well-known for its high endemism, especially for the herpetofauna. About 47.13% of all reptiles found in the Western Ghats are endemic to these hill ranges (Srinivasulu *et al.*, 2014) and are often ignored in conservation planning. Many of them are little known and a good percentage of their population remains unexplored. Understanding their ecological niche requirements and suitable habitats are crucial for designing conservation measures for these threatened taxa in the Western Ghats. Hence, Ecological Niche Modeling (ENM) could be an effective tool for predicting the potential distribution ranges of these endemics in this landscape.

In the Indian context, modeling approaches were mainly applied for plants. For example, the Ecological Niche Modeling (ENM) has been applied to find out the distribution of the endemic and threatened plant *Aglaia bourdillonii* in the southern Western Ghats (Irfan-Ullah *et al.*, 2007). The study on a critically endangered tree species, *Gymonocladus assamicus* from north-eastern India revealed that niche modeling is an excellent tool to locate new populations of endemic and rare species (Menon *et al.*, 2010). In a recent study in the Western Ghats, Ecological Niche Modeling (ENM) was used to assess the potential distribution and conservation status of a Coenophidian snake, *Xylophis captaini* (Bhupathy *et al.*, 2016). The study also highlighted the importance of such modeling approaches to plan conservation strategies for endemics and other little known species in the Western Ghats.

There are many algorithms to model geographical distribution of species: BIOCLIM (Busby, 1991), DOMAIN (Carpenter *et al.*, 1993), Genetic Algorithm for Rule-Set Prediction, GARP, (Stockwell, 1999) Ecological Niche Factor Analysis, ENFA (Hirzel *et al.*, 2002) and Maximum Entropy, Maxent (Phillips *et al.*, 2006) are the widely used ENM approaches. Each algorithm has its own merits and limitations in predicting the potential distribution of a species. However, 'Maxent' is the most popular ENM algorithm which is a presence-only modeling method; reportedly efficient compared to other presence-only models like GARP (Phillips *et al.*, 2006).

Maxent is considered as one of the simplest and precise mathematical formulations for species distribution modeling. It is a general purpose method in which the prediction is done from incomplete information on the target species. The idea of Maxent is to estimate a species' 'target probability distribution by finding the probability distribution of maximum entropy (i.e., most spread out, or closest to uniform), subject to a set of constraints that represent our incomplete information about the target distribution' (Phillips *et al.*, 2006). In most of the cases, the actual absence data of a species is unavailable. In Maxent, the environmental requirements of the study species will be formulated from a set of presence records together with a set of environmental variables which can influence the suitability of the environment for the species. The presence-only records are simply latitude-longitude data of their occurrence site collected randomly from the known geographical ranges of the target species. The environmental layers are openly available from various web data resources (for eg; WorldClim, SRTM, MODIS) in digital format which can be easily used in any GIS platform and are partitioned into grid of pixels (~1Km^2). The Maxent model will produce resulting files showing the probable distribution of the species with probability values between zero and one for each pixel. The available distributional area for the study species can be either calculated for a set threshold or under various threshold intervals based on the goal of the study.

Maxent is reported to be a reliable prediction model even with a small number of occurrence records and it can be successfully applied in cryptic taxa like lizards (Pearson *et al.*, 2007). For instance, the Maxent niche modeling approaches have been effectively used for prioritizing conservation-area networks for the Mexican herpetofauna (Urbina-Cardona & Flores-Villela, 2010).

5.1.1 Study species

In the present study, two endemics (including one 'endangered' species) were taken as focal species to apply ENM approach. Both of these species are found in the southern Western Ghats; only south of Palghat Gap (a major biogeographical barrier for many taxa). Moreover, these species are reported to have a narrow extent of distribution compared to other endemic reptiles in the Western Ghats. One of them is an agamid called Indian Kangaroo Lizard (*Otocryptis beddomii*), an 'Endangered' species under IUCN redlist and the other species is a burrowing snake called Captain's Wood Snake (*Xylophis captaini*), currently a 'Least Concern' species under IUCN.

5.1.1.1 *Otocryptis beddomii* (Indian Kangaroo Lizard):

Otocryptis beddomii Boulenger 1885 is a ground dwelling agamid lizard in the Western Ghats (Figure 5-1). Leaf-litter in evergreen and semi-evergreen forests are the preferred microhabitats of this species (Chandramouli, 2009). This lizard species is also reported from Myristica Swamps in Kulathupuzha, which is a threatened fresh water ecosystem in the southern Western Ghats (Jose *et al.*, 2007). It is the only species of the genus (*Otocryptis*) found in India and other two species of *Otocryptis* are endemic to Sri Lanka. Interestingly, the major distribution range of *O.beddomii* is largely south of Shencottah gap; mostly within Agasthyamalai Biosphere Reserve. Though it appears to be locally common in their natural habitats, the area of occurrence is reported to be very small for this endemic lizard. Moreover, forest degradation, litter removal, and forest fire are reported to be the major threat for this species. As this lizard species shows highly patchy distribution and microhabitat specialization (leaf litter), it is important to identify their key habitats for conservation planning.

Type locality of *O.beddomii* is reported as Sivagiri Ghats which is north of Shencottah gap (Smith, 1935). Further to the type description, there are no precise locality records or published information from the same landscape. Moreover, there is a single record of this species from Kodaikanal (at ~2000m elevation) in the Palni Hills (Murthy, 1980) which is reported to be an inconsistent record and it is far north of its confirmed distribution range (Chandramouli, 2009). Hence, the predictive approach like Maxent using presence records will be an appropriate tool to explore the potential distribution ranges and validating the locality records (including the inconsistent ones) of the species in future surveys.

5.1.1.2 *Xylophis captaini* (Captain's Wood Snake):

The coenophidian snake genus *Xylophis*, Beddome 1878 has only three nominate species namely *Xylophis perroteti*, *Xylophis stenorhynchus* and *Xylophis captaini*. All the three species are endemic to the Western Ghats of India. The snake *Xylophis captaini* (Figure 5-2) is a subterranean, poorly known snake found only in the southern part of the Western Ghats (Gower & Winkler, 2007). They are found in loose soil in different habitats such as shady plantations and other disturbed or secondary habitats. They are also reported from an evergreen plantation in Ponmudi Hills (Inger *et al.*, 1984). So far, there are no serious threats reported for this species and is locally common, inhabiting variety of habitats (Gower & Winkler, 2007). But changing land use patterns and agricultural practices may be a threat to their population in disturbed or secondary habitats. From available data, most of its locality records are outside protected areas. As it is also reported from natural forests, there is a need for intensive field surveys in protected area networks to explore unknown or intact populations of the species.

Xylophis captaini is reported to be similar in its appearance but morphologically distinct from *X.stenorhynchus* (Gower & Winkler, 2007). However, *X.perroteti* is larger in size compared to other two known species in the genus. Including the museum record of *X.indicus* (BMNH 78.8.2.1) - a junior synonym of *X. stenorhynchus*, is represented by only a few precise and authentic locality records, i.e., forests of Cumbam Valley (~1,200 m ASL, Theni District) and Valparai (1,200 m ASL, Coimbatore District) of Tamil Nadu State. The available data shows that distribution range of *X.stenorhynchus* (Cumbam Valley and Valparai) may be distinct from the range of *X. captaini*. It appears that the three species of the genus *Xylophis* are spatially segregated; *X. perroteti* (higher elevation > 1,500 m, plateau, largely north of Palghat gap), *X. stenorhynchus* (1,200–1,500 m, possibly on the eastern slopes of the mountains from south of Palghat Gap) and *X. captaini* (50–1,000 m, western slope, south of Idukki District, Kerala). Further field explorations and modeling approaches would be an effective approach to validate the spatial segregation of these species. Being a little known and recently described species, the distribution and ecology of species need further investigations.

5.2 Methodology

5.2.1 Data collection

Intensive field surveys were conducted in Agasthyamalai Biosphere Reserve during the period of March 2012 to December 2014. The observations during the Visual Encounter Surveys (VES) and other opportunistic sightings were also considered for the analysis. VES involve systematic survey for the species in a prescribed time interval. The detailed VES technique is given in the previous technical chapters (Please refer Methodology section of Chapter 3).

All the occurrence locations of the species were marked using a hand-held Global Positioning System (GPS, Garmin 12 Channel). Known localities of *O.beddomii* and *X. captaini* from the present study and published literature were used for analysis. Details of the major locality records and sources are given in the Tables 5-1 & 5-3. These points were loaded into a GIS platform and a buffer with a radius of 2 km was generated around each of the occurrence localities. Where buffers of two sites overlap, one of them were removed for avoiding the pseudo-replication and the points that were not having any overlap at two kilometer radius, were alone used for model building. The locality records which are not precise and inconsistent were excluded from the analysis.

5.2.2 Environmental layers

Twenty five environmental covariates were considered for analysis (Appendix.1) and out of these, about 19 were bioclimatic variables obtained from open data sources

(WorldClim).Topographic variables such as altitude, slope and aspect , and land cover variables including MODIS tree, bare and herb cover were also utilized in Maxent prediction (Hansen *et al.*, 2003). Detailed methods involved in the surface-interpolation of the climatic data (WorldClim) are available elsewhere (Hijmans *et al.*, 2005). About 600 random points were generated across the area of interest and raster values of environmental layers were extracted for each point. The degree of auto-correlation between the variables was estimated using Pearson correlation coefficients and redundant parameters were removed from the final analysis. Eight uncorrelated variables such as altitude, slope, MODIS tree cover, isothermality, precipitation seasonality, mean diurnal temperature range, precipitation of wettest month and precipitation of driest quarter were used in the model for *Otocryptis beddomii* and *Xylophis captaini.* Considering the potential distribution and previous records, the distribution of *Otocryptis beddomii* was predicted only within the boundaries of southern Western Ghats. All the above variables were extracted covering all occurrence points of the species in southern India.

5.2.3 Maximum Entropy Modeling (Maxent)

Maximum Entropy (Maxent) algorithm was used predicting the geographic distribution of the species using presence only data (Phillips *et al.*, 2006). The Estimated probable distribution of the species will direct for the survey in the areas not covered during the survey (Phillips *et al.*, 2006). The area under the Receiver Operating Characteristic (ROC) curve value was used as a measure to determine the fit of the model (Phillips *et al.*, 2006). Higher AUC (the area under ROC curve) value is considered to be the indicator of best model performance. Hence the model with higher AUC value was selected as the reliable model to calculate the potential distribution of species and the environmental variables influencing them. The Maxent model was run with five replications with cross validation settings. The ‘10 percentile training presence’ was applied as a threshold to determine the presence and absence of the species. This threshold is reported to give ecologically significant results compared to other (Redon & Luque, 2010). However, the potential area under various threshold levels (probability values) from zero to one was calculated for helping conservation actions.

5.2.4 Prediction maps and area calculation

Predition maps showing the potential distribution of study species were developed using the output layers of Maxent Model. Quantum GIS, Version 2.10.1 was used for map preparation and calculation of available area under various threshold levels.

5.3 Results

5.3.1 *Otocryptis beddomii* (Indian Kangaroo Lizard)

It was found that about 21 locality records were one km away from each other (Table 5-1). From these points, only 14 points which are at least two kilometers distant were identified for the final model building. Most of these sightings from evergreen forests and Myristica swamps within Agasthyamalai Biosphere Reserve (ABR). The Maxent prediction for *Otocryptis beddomii* was done using eight environmental layers which could possibly influence the distribution of the species. The area under the Receiver Operating Characteristic (ROC) curve value was higher (mean=0.968); showing that the model prediction is reliable. Precipitation seasonality was the factor which contributed maximum (37.4%) to the model and followed by mean diurnal range (36.9%). Additionally, precipitation of the driest quarter contributed 20 % to the final model. Among topographic factors, altitude (1.2%) contributed maximum (Table 5-2). Mean diurnal range and precipitation seasonality has the maximum predictive gain when used in isolation, followed by precipitation of the driest quarter (Figure 5-3).

Maxent showed that major distribution of the Indian Kangaroo Lizard is only south of Sivagiri Ghats in the Cardamom hills which are reported to be the type locality of the species. However, the results also showed that Palni Hills which is far north (about 100 km) of Sivagiri Ghats likely to be a potential site for the species with less probability (<0.25). The potential distribution based on 10 percentile training presence (threshold 0.483) of the species in its occurrence range is very narrow and it is estimated to be 934 km^2. The major distribution of this species appeared to be south of Shencottah gap in Agasthyamalai Biosphere Reserve (Figure 5-2).

Table 5-1. Major locality records of *Otocryptis beddomii*

Sl.	Place	District	Altitude (m)	Source
1	Bonacord top	Thiruvanathapuram	810	Present study
2	Karamanayar	Thiruvanathapuram	635	Present study
3	Bonacord	Thiruvanathapuram	575	Present study
4	Athirumala	Thiruvanathapuram	720	Present study
5	Athirumala	Thiruvanathapuram	980	Present study
6	Karamanayar	Thiruvanathapuram	656	Present study
7	Vazhapazhanthi	Thiruvanathapuram	620	Present study
8	Unnikadavu	Thiruvanathapuram	610	Present study
9	Athirumala	Thiruvanathapuram	1134	Present study
10	Kallar	Thiruvanathapuram	366	Present study
11	Ponmudi	Thiruvanathapuram	650	Inger *et al.*, 1984
12	Rockwood	Kollam	737	Present study
13	Dharbhakulam	Kollam	540	Present study
14	Anchal forest range	Kollam	200	Jose *et al.*, 2007
15	Kulathupuzha	Kollam	200	Jose *et al.*, 2007
16	Sivagiri Ghats	Tirunelveli	1310	Smith, 1935
17	Maramalai hills	Kanyakumari	400	Daniels, 1991
18	Rosemala	Kollam	370	Present study
19	Palaruvi	Kolam	250	Kumar *et al.*, 2002
20	Kannupulimettu	Kollam	1300	Bhupathy pers. com (2013)
21	Sengaltheri-	Tirunelveli	2800	Bhupathy pers. com (2013)

Table 5-2: Relative contributions of environmental variables for *Otocryptis beddomii*.

Environmental variables	**Percentage of contribution**
BIO15 = Precipitation seasonality (Coefficient of Variation)	37.40
BIO2 = Mean diurnal range (Mean of monthly (max temp - min temp))	36.90
BIO17 = Precipitation of driest quarter	20.00
BIO13 = Precipitation of wettest month	03.00
Altitude = elevation from sea level (m)	01.20
BIO3 = Isothermality (P2/P7) (* 100)	00.80
MODIS Tree cover = Percent of tree cover	00.70
Slope = Degree of flow	00.00

5.3.2 *Xylophis captaini* (Captain's Wood Snake)

About 33 locality records were identified that are at least one km away from each other (Table 5-3). The distribution of *X. captaini* was predicted with eight environmental variables (two topographic, one vegetation type and five bio-climatic variables). The area under the Receiver Operating Characteristic (ROC) curve value was higher (mean = 0.986), indicating the random distribution of the model. As in *Otocryptis*, mean diurnal range has the highest predictive gain when used in isolation and it appears to be the most important variable for the predicted model for *Xylophis* (Figure 5-4). Mean diurnal range (27.8%) and precipitation of the driest quarter (26.1%) contributed the maximum to the model (Table 5-4). Tree cover and altitude also had a notable contribution to the predictive model. The Maxent model showed the predicted distribution of *X. captaini* to be south of Thodupuzha (09^{o}58'N, 76^{o}38' Vazhakulam, Ernakulam District) of the Kerala State (Figure.5-3). There is a high probability of its occurrence at unsampled locations in the Kanyakumari and Tirunelveli Districts in Tamil Nadu, especially in Kalakad-Mundanthurai Tiger Reserve and east of Aryankavu Pass. The estimated potential area of the species distribution based on 10 percentile training presence (threshold 0.274) is about 3690 sq km. Though the predicted area of distribution of this species is narrow, it is reported to be locally common in its suitable habitats.

Table 5-3 Major locality records of *Xylophis captaini*

Sl.	Place	District	Altitude (m)	Source
1	Vazhakulam	Ernakulam	50	Present Study
2	Peralamattayam	Idukki	40	Gower & Winkler (2007)
3	Kannam	Kottayam	110	Gower & Winkler (2007)
4	Chengalam	Kottayam	120	Gower & Winkler (2007)
5	Punalur	Kollam	110	Gower & Winkler (2007)
6	Pathanapuram	Kollam	40	Gower & Winkler (2007)
7	Mylam	Kollam	30	Gower & Winkler (2007)
8	Mottal Mood	Kollam	190	Present Study
9	Poovanathumoodu	Kollam	170	Present Study
10	Ammayambalam	Kollam	180	Present Study
11	Munnam Chal	Kollam	190	Present Study
12	Pillekode	Kollam	180	Present Study
13	Perum Pappy	Kollam	170	Present Study
14	Emponge	Kollam	180	Present Study
15	Kambaka Thottam	Kollam	210	Present Study
16	Vilakku Maram	Kollam	190	Present Study
17	Palod	Thiruvananthapuram	80	Gower & Winkler (2007)
18	Cheranikara	Thiruvananthapuram	90	Gower & Winkler (2007)
19	Mennookonom	Thiruvananthapuram	100	Gower & Winkler (2007)
20	Vanchuvam	Thiruvananthapuram	100	Gower & Winkler (2007)
21	Potukani	Thiruvananthapuram	320	Gower & Winkler (2007)
22	Chathankodu	Thiruvananthapuram	110	Gower & Winkler (2007)
23	Vithura	Thiruvananthapuram	110	Chandramouli & Ganesh (2010)
24	Athirumala	Thiruvananthapuram	980	Present study
25	Bonaccord	Thiruvananthapuram	810	Present study
26	Podium	Thiruvananthapuram	200	Present study
27	Aamala	Thiruvananthapuram	120	Present study
28	Peppara	Thiruvananthapuram	150	Present study
29	Neelikampara	Thiruvananthapuram	120	Present study
30	Chekidi Chal	Thiruvananthapuram	200	Present Study
31	Muppathi	Thiruvananthapuram	200	Present Study
32	Uthiran Chira	Thiruvananthapuram	210	Present Study
33	Aarukani*	Kanyakumari	200	Gower & Winkler (2007)

Table 5-4: Relative contributions of environmental variables for *Xylophis captaini*.

Environmental variables	**Percentage of contribution**
BIO2 = Mean diurnal range (Mean of monthly (max temp - min temp))	27.80
BIO17 = Precipitation of driest quarter	26.10
MODIS Tree cover = Percent of tree cover	23.30
Altitude = elevation from sea level (m)	14.10
BIO15 = Precipitation seasonality (Coefficient of Variation)	08.70
Slope = Degree of flow	00.10
BIO3 = Isothermality (P2/P7) (* 100)	00.00
BIO13 = Precipitation of wettest month	00.00

5.3.3 Potential Distribution ranges

The estimated area of occupancy (by IUCN) is 2500km^2, but the area of occupancy of *X.captaini* is unknown due to the lack of information. The high probability sites for the distribution of these little known species could be very narrow as predicted by the Maxent model. The distribution ranges of *O.beddomii* and *X.captaini* under various threshold levels are given in Table 5-5

Table 5-5: Potential distribution ranges (in sq.km) of two study species in southern India under different threshold levels..

Sl.	**Threshold**	***Otocryptis beddomii* (km^2)**	***Xylophis captaini* (km^2)**
1	0.001-0.0250	15361.85	162834.03
2	0.251-0.500	1053.903	2712.48
3	0.501-0.750	929.96	1334.72
4	0.751-1.000	151.0033	598.91
5	10 percentile *	934.02	3583.95

* Logistic threshold values (10 percentile training presence): *Xylophis captaini*- 0.273, *Otocryptis beddomii*-0.482

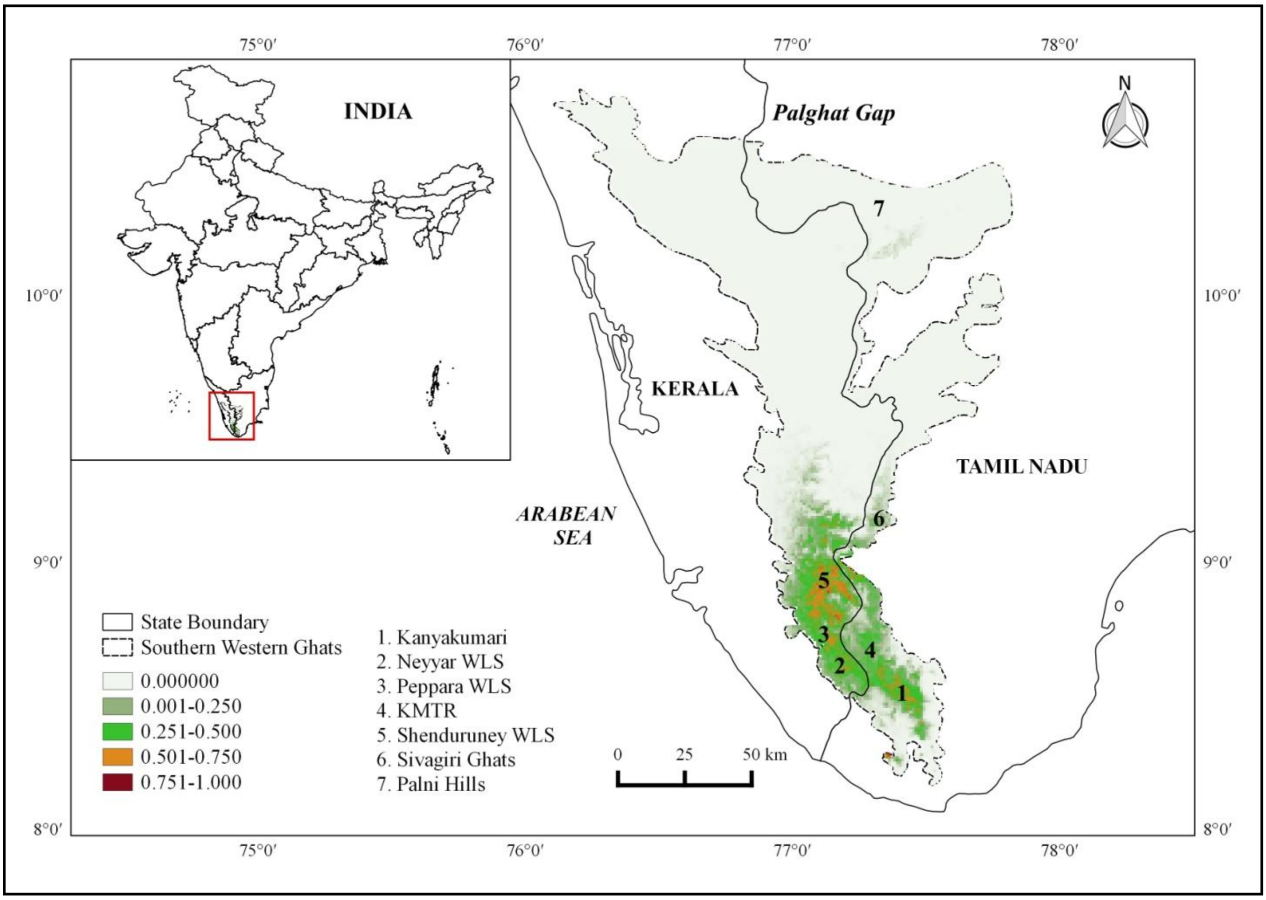


Figure 5-1: Distribution of *Otocryptis beddomii* predicted by Maxent

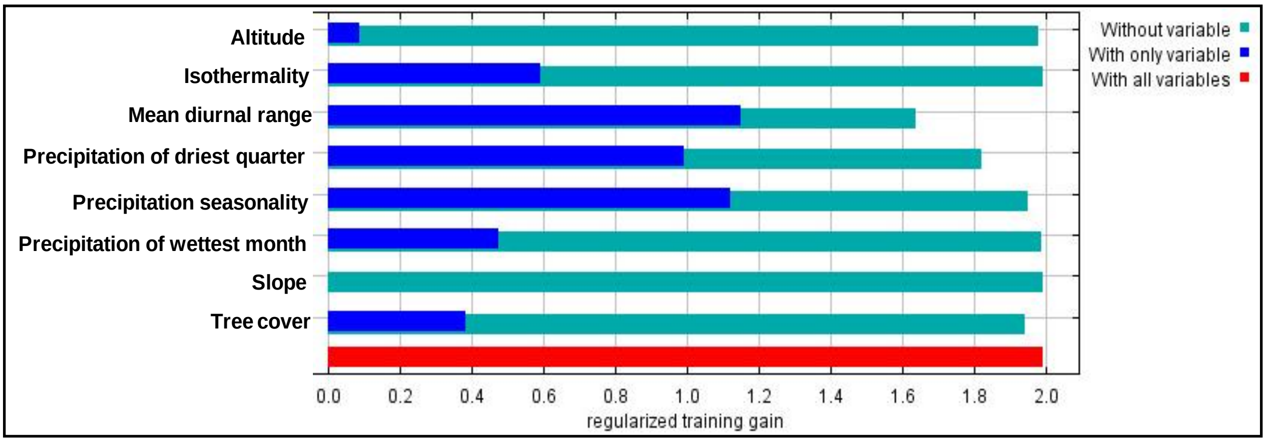


Figure 5-2: Regularized training gain of different variables (*Otocryptis beddomii*)

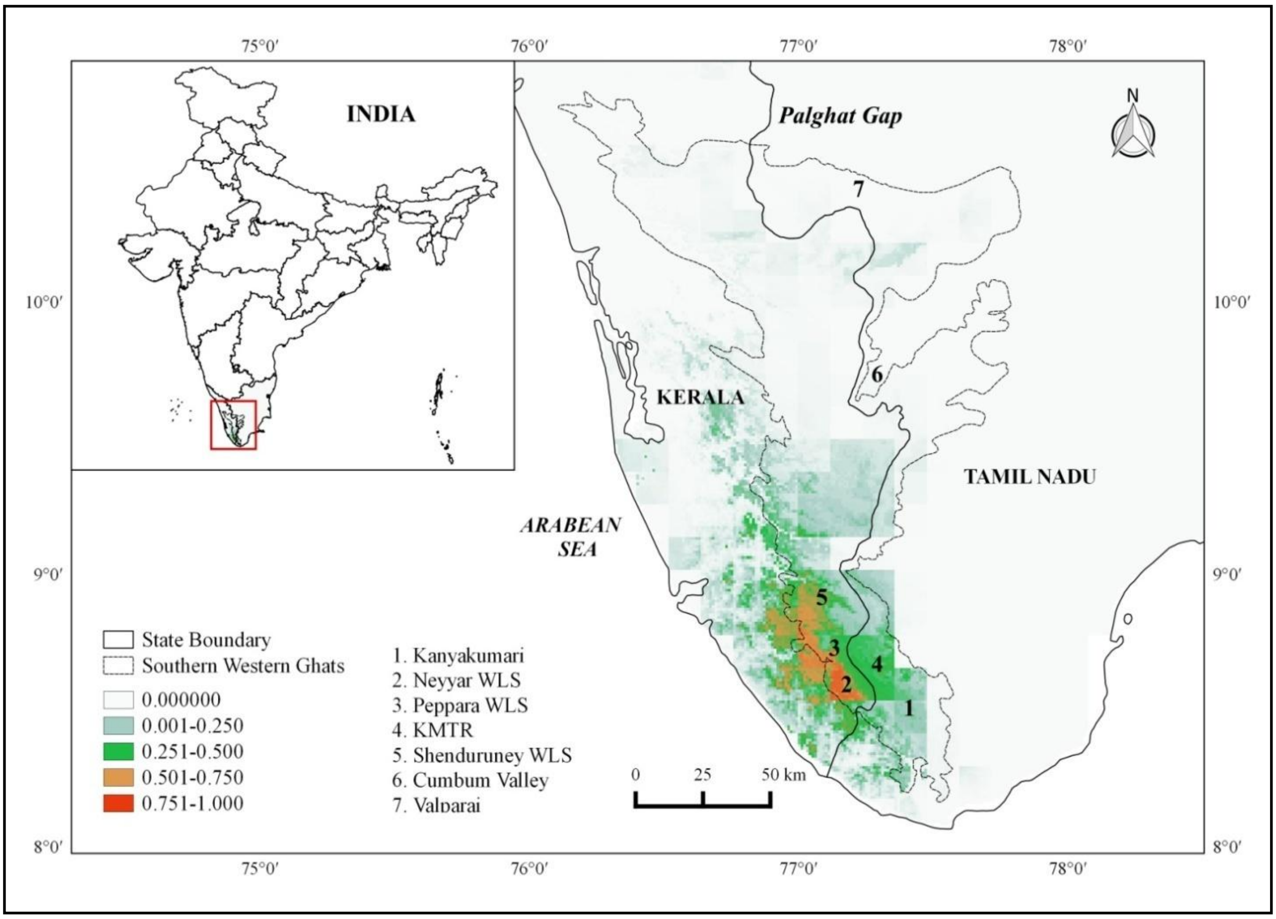


Figure 5-3 Distribution of *Xylophis captaini* predicted by Maxent

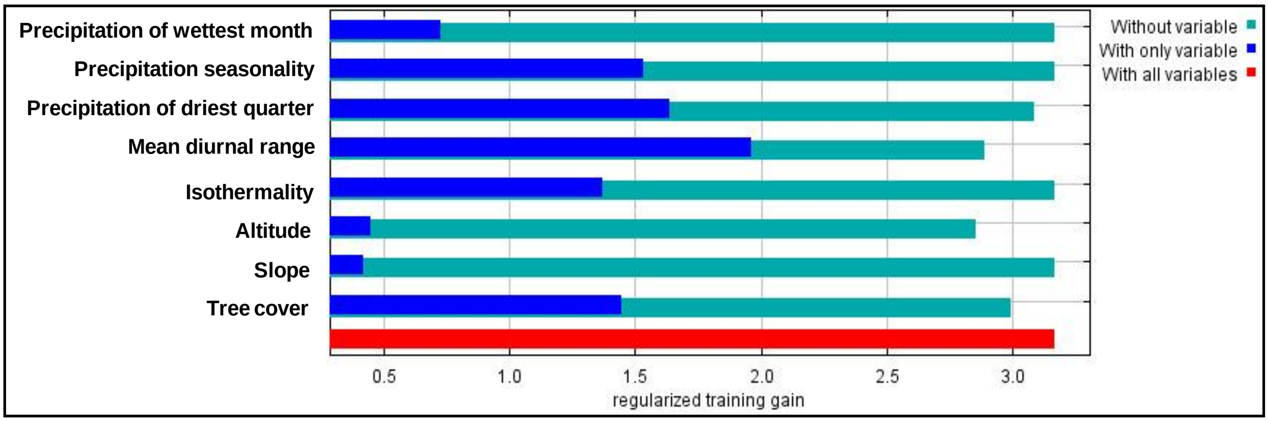


Figure 5-4: Regularized training gain of different variables (*Xylophis captaini*)

5.4 Discussion

The present study highlighted the importance of Maxent model as an effective tool in predicting distribution ranges of rare or unobtrusive species and will be useful for further targeted surveys in the Western Ghats landscape at multiple spatial scales. Among various species distribution modeling tools, Maxent model is reported to be a very useful tool in predicting potential ranges of different species including cryptic ones (Rissler & Apodaca, 2007). The study on cryptic geckos in Madagascar showed that geographical prediction of species distribution from a limited number of records also has a great value considering the fact that it may be helpful in discovering the unknown populations from potential areas (Pearson *et al*., 2007).

Of the environmental factors examined, the distributions of these two study species are chiefly governed by climatic factors like temperature (mean diurnal range) and precipitation (precipitation seasonality and precipitation of the driest quarter) indicated that temperature and rainfall patterns in the study area might be the major regulating factor for the distribution of the species. The habitat and topography variables had less contribution in the models. However, these predictions need to be tested and validated with the support of adequate field data. Being a habitat specialist, the distribution of *O.beddomii* was expected to be influenced by tree cover but it contributed very less to the model predictions. In the contrary, the lowland and habitat generalist species *X.captaini'*s distribution was influenced by tree cover (23.3 %) along with other climatic factors. In general, the diversity and distribution of reptiles are largely influenced by climatic factors including temperature and precipitation (McCain, 2010). Hence, reptiles are prone to extinction due to the global climate change and the increasing habitat alterations (Gibbon *et al.*, 2000; Bickford *et al.*, 2010). Habitat fragmentations often result in isolation of populations which make them more vulnerable to global climate change scenario (Bickford *et al.*, 2010). The prediction analysis showed that both species (especially *Otocryptis beddomii*) are possibly distributed only in the southern tip of the Western Ghats. Though the Captain's wood snake is adapted to altered habitats in including agricultural fields and plantations (Gower & Winkler, 2007; Bhupathy *et al.*, 2016), Indian kangaroo lizard is limited to natural habitats (Chandramouli, 2009). Considering this scenario, the key habitats within predicted distribution ranges of these species need to be explored further to design conservation strategies for these little known reptiles of the southern Western Ghats.

5.4.1 Conservation Implications; Prioritization of high suitable sites

The ground dwelling agamid, *Otocryptis beddomii* showed a narrow range of high suitability sites (< 1000 km^2), mainly in the Southern tip of the Western Ghats. Though the estimated area of occurrence of the species is about 2500km^2 (IUCN redlist), the high suitable area might be smaller as predicted by the model. The predicted distribution shows that the species is mostly restricted to the south of Shencottah Gap. The available dta and the present model suggested that Agatshyamalai Biosphere Reserve could be the most suitable sites for this species. Neyyar, Peppara ans Shenduruney WLS expected to have larger populations. The presence of this species was already recorded from Kalkadu Mundanthurai Tiger Reserve (KMTR), which is the eastern slope of ABR in Tamil Nadu part. Being the only ground dwelling lizard with a marked degree of habitat specialization, it needs immediate attention from conservationists and managers. As it is a litter dwelling species forest fire may be a serious threat to the species. Land clearance and habitat alterations are reported to be the major threats for this endangered lizard in the southern Western Ghats. Hence, it is crucial to assess the potential threats to the species across its' predicted distribution range in the southern Western Ghats.

Interestingly, the inconsistent locality record of the *O.beddomii* from Kodaikanal in Tamil Nadu state was shown as a potential site for the species with less probability. This is an indication for the presence of the species in the area. If the distribution of *O.beddomii* is confirmed from here, it would be the northern most population existing in its known occurrence range. Though type locality of the species was not used in the Model predictions (due to the unavailability of precise locality), the Sivagiri Ghats turned out to be one of the potential sites for the species. The status of their population in the type locality is unavailable and it needs to be assessed with field surveys.

From the available data, most of the observations of *Xylophis captaini* are from lowlands (<300m) and human modified habitats. However, these populations in altered habitats also need to be assessed considering the change in agricultural practices and land cover across the area (Gower & Winkler, 2007; Bhupathy *et al.*, 2016). Large extents of high probability sites are within the protected area network; hence the population may have a larger extent of undisturbed habitats in its distribution range. Further investigations covering protected area networks in the southern Western Ghats would give more insights on the status and distribution of this species in its predicted range.

Similar to the ENM approaches elsewhere, the results of the present study have important conservation, habitat restoration, and population management implications (Groff *et al.*, 2014). The conservation status by IUCN for *Xylophis captaini* is unavailable, though it was recommended to be considered as 'Least Concern'. In this aspect, the present study was an important step to assess the status and distribution limits of the species. Both of the study species are endemics and having relatively smaller geographic distributions. Moreover, the Indian Kangaroo Lizard is a habitat specialist found only in the leaf-litters of evergreen and semi-evergreen forests. It is reported that the models generated for specialists reported having higher predictive power than the models for generalists, and accuracy would be comparatively higher for small-ranged species (Segurado & Araujo, 2004; Elith *et al.*, 2006). Hence, a model validation to explore the predicted ranges of the species is essential to implement conservation actions at ground level. The study indicated that ABR is the major landscape where both of the species are distributed. Considering the human influence and pressure due to ecotourism in the study area, the protection of their high suitability sites would be an important step towards their conservation.

5.5 Conclusion

The Indian Kangaroo Lizard, being the only litter-dwelling agamid lizard in the Western Ghats, showed narrow distribution ranges in the southern Western Ghats. Since this is an endemic species and habitat specialist, it is also important to analyze the available habitats for the same in its predicted distribution range. Predicting the distribution limits of a species followed by field validation can help in the effective documentation of the species' range and occupancy patterns, and will greatly strengthen conservation planning (Guisan *et al.*, 2013). As some of the inconsistent locality records of the species tuned out to be the potential sites of the species in the model, these ranges need further explorations to confirm their distribution records. Being an endemic species having potential distribution ranges both inside and outside protected area networks, *Xylophis captaini* also need a customized approach for conservation actions. The Western Ghats being home for large number endemics and rare species, modern tools would be very effective in exploring species distributions compared to traditional sampling strategies. It is also recommended that Maxent modeling could be used for further analysis to estimate the probable distribution of many other rare, endemic and little known reptiles in the hill ranges of the Western Ghats- a global biodiversity hotspot.

Plate 5-1: Indian Kangaroo Lizard (*Otocryptis beddomii)*

Plate 5-2: Captain's Wood Snake (*Xylophis captaini)*

6 Summary and Conclusion

Understanding the striking patterns in species distributions and the influencing factors are among the central questions in community ecology. The Western Ghats - a series of mountains along the west coast of India are known for its high endemism with about 47% of reptiles present here are endemic to this landscape. Elevational diversity patterns in reptiles have rarely been explored in India especially in the mountain ranges of Western Ghats. It is reported that species turnover of reptiles in the Western Ghats are highly varied along the elevation gradients. Long term research programmes are crucial in understanding the landscape level patterns in species distributions, especially on herpetofaunal assemblages. The elevational patterns in species distributions have been widely used in conservation planning and understanding the impact of climate change on specie range sizes. Understanding on the community structure would be an important aspect in explaining landscape level patterns. Along with macro ecological patterns, the niche dimensions, microhabitat relationships, and habitat associations are a very important aspect of community ecology and a prerequisite for conservation planning. In fact, these components largely contribute to the community structure of reptiles in a landscape. However, these aspects are least studied in Indian context especially in the Western Ghats. Additionally, the landscape level distribution patterns of species are now being predicted by modern tools like Species Distribution Models (SDM) and are widely used in conservation planning. Ecological Niche Modeling (ENM) approaches using Maxent is one among them which can predict the probable distribution of a species from presence-only data. These resultant prediction maps can be used for further explorations and new discoveries.

In this context, the present study was aimed at studying the species richness patterns of reptiles along an elevation gradient (100-1866m AMSL) in Agasthyamalai Hills, in the Western Ghats. The total elevation range was categorized into 100m zones and reptile sampling was conducted systematically covering all elevation zones. The factors influencing the elevational patterns in species richness were analyzed to understand the underlying mechanisms of elevational diversity patterns. Additionally, the species turnover across different elevation categories was estimated. The ecological niches of reptiles in view of their microhabitats were estimated for all observed species and the niche breadth and overlaps were quantified. The relationship of reptile assemblages with habitat structure and tree species composition was also analyzed. A hierarchical cluster analysis was used for understanding the microhabitat relationship among different species of reptiles. Probable distribution of two endemic reptiles of the Western Ghats *viz*. Indian Kangaroo Lizard (*Otocryptis beddomii*) and Captain's Wood Snake (*Xylophis captaini*) was predicted using Maxent distribution model. The available areas under different threshold levels were calculated in order to address the conservation measures and policy actions.

6.1 Elevational patterns in species richness

Reptile sampling was done using Visual Encounter Surveys (VES) across the elevation gradient in the Agasthyamalai Hills. A total of 70 species of reptiles (including opportunistic sightings) from two orders and 14 families were recorded during the study which included four endangered species. Out of 70 species, 30 (42.9%) species were endemic to the Western Ghats. Many species were found to be rare and observed only once during the whole study period. About 1304 person hours of VES resulted in 47 species of reptiles. The new record of Beddome's coral snake (*Calliophis beddomei*) from Ponmudi Hills in the Agasthyamalai landscape was the first record of the species from the southern Western Ghats with a range extension of 320 km towards south across the Palghat gap. Moreover, the species was an addition to the faunal list of Kerala state, India.

Species richness showed a pattern of monotonic decline towards the mountain peak. The lower elevations had a higher number of species while higher elevation zones consisted limited number but unique set of species. Mean annual temperature turned out to be an important factor possibly influencing the reptile distributions across an elevation gradient in the study area. Being ectothermic animals, the effect of temperature on reptile distributions are well known. However the effect of the area availability needs to be examined further to address the species-area relationships in species richness patterns of reptiles in this landscape. It is also possible that the observed area effect could be a sampling artifact which needs to be addressed in the future explorations. Some of the important ecological hypotheses such as Mid-domain effect and Rapoport's elevational rule were tested in the study. The Mid-domain hypothesis predicts that the number of species will peak at the centre of the domain as a result of increased overlap of species' distribution ranges due to Geometrical constraints (For eg; mountain peak and coastline).

The Mid-domain null model analysis indicated that geometrical constraints do not have a significant role in determining reptile distributions in Agasthyamalai Hills. However, snakes and endemic reptiles showed a weak fit of Mid-domain null model when analyzed separately. Reptile distribution in Agasthyamalai hills did not follow Rapoport's elevational rule (high elevation species tend to have larger elevational range size). Species turnover increased with increasing elevation in which most of the higher elevation zones showed higher turnover compared to lower zones. The higher elevation exhibited unique species compared to other zones contributed to the higher turnover rates.

6.2 Ecological niche and microhabitat relationships

Leaf litter was the major microhabitat where the maximum number of species and maximum individuals of reptiles recorded. The niche breadth, overlap, microhabitat relationships and habitat associations were studied in order to understand the patterns within the community. It provided valuable information on microhabitat specialization and co-existence of different species. Out of 47 species recorded, 15 species were found to be habitat specialists considering the low value (<1.8) of niche breadth and the remaining 22 species were habitat generalists. To account for competition of closely related species, niche overlap was estimated for groups such as agamid lizard, geckos, skinks, and snakes separately. Cluster analysis delineated all reptiles into five guilds based on the microhabitat preferences The major guild are Surface rock-dwelling, boulder-dwelling, ground-dwelling, semi-arboreal and arboreal. The ground-dwelling guild formed the largest guild with all forest floor species. The classification of reptile communities into broad microhabitat guilds can help in long-term conservation planning of reptile communities and their natural habitats in the study area. The habitat association analysis revealed that reptile assemblages were more influenced by the structure of the habitat compared to tree species composition in Agasthyamalai Hills. However, lizards showed comparatively higher association with tree species composition than the structural complexity of habitat.

6.3 Ecological Niche Modeling

Being a modern tool for predicting the geographical distribution and planning conservation actions of a species, Ecological Niche Modeling (ENM) technique was applied for two selected endemic reptiles. Prediction maps with the help of Maximum Entropy (Maxent) modeling were developed for the Indian Kangaroo Lizard (*Otocryptis* *beddomii*) and Captain's Wood Snake (*Xylophis captaini)* to understand their probable distribution ranges in the Western Ghats. These two reptiles are little known and distributed only in southern India. Both of these species showed narrow distribution ranges within the Western Ghats, largely south of Palghat Gap. The potential distribution range of *Otocryptis beddomii* and *Xylophis captaini* are 934 km^2 and 3584 km^2 respectively. Precipitation seasonality (37.4%) and mean diurnal range (36.9%) were the major factors contributed to the model prediction for *Otocryptis beddomii*. For *Xylophis captaini*, the major factors contributed were mean diurnal range (27.8%), precipitation of the driest quarter (26.1%) and tree cover (23.3%). The results of the ENM can help in locating new populations of these little known endemics and to help in conservation planning in the Western Ghats.

In conclusion, the present study systematically documented the elevational patterns in species richness and explained some of the possible underlying mechanisms responsible for these patterns. The study provided valuable information on the community ecology of reptiles by analyzing the ecological niche, macro, and microhabitat relationships. The prediction maps developed using Ecological Niche Models (ENM) can be effectively used for conservation planning of these two little known reptiles, *Otocryptis beddomii* and *Xylophis captaini*. It will also help to explore unknown populations within their range. Moreover, this ENM approach opens new avenues for spatial modeling tools in conservation that can be used for many cryptic and endemic reptiles in the Western Ghats.

6.4 Future directions

Long term research projects covering other mountain ranges in the Western Ghats can provide a better understanding of elevational diversity patterns of reptiles. Such studies would be important in studying the impact of global climate change on species ranges in future. Moreover, the elevational patterns can be effectively used in prioritization of elevational gradients for conservation planning. Detailed data on microhabitat preferences and habitat associations can be used in habitat conservation of herpetofauna in the fast changing landscapes like the Western Ghats. The study highlighted the scope of Ecological Niche Modeling (ENM) techniques in predicting reptile distributions. Having many data deficient and endemic reptiles in the Western Ghats, our conservation approaches can be much more effective with the help of such modern tools.

References

Abrams, P. (1980) Some comments on measuring niche overlap. *Ecology*, **61**, 44–49.

Acharya, B.K., Chettri, B. & Vijayan, L. (2011a) Distribution pattern of trees along an elevation gradient of Eastern Himalaya, India. *Acta Oecologica*, **37**, 329–336.

Acharya, B.K., Sanders, N.J., Vijayan, L. & Chettri, B. (2011b) Elevational gradients in bird diversity in the Eastern Himalaya: an evaluation of distribution patterns and their underlying mechanisms. *PLoS One*, **6**, e29097.

Agarwal, I., Mirza, Z.A., Pal, S., Maddock, S.T., Mishra, A. & Bauer, A.M. (2016) A new species of the Cyrtodactylus (Geckoella) collegalensis (Beddome, 1870) complex (Squamata: Gekkonidae) from Western India. *Zootaxa*, **4170**, 339–354.

Aguilar, M. & Lado, C. (2012) Ecological niche models reveal the importance of climate variability for the biogeography of protosteloid amoebae. *The ISME journal*, **6**, 1506–1514.

Anderson, R.P., Peterson, A.T. & Gómez-Laverde, M. (2002) Using niche-based GIS modeling to test geographic predictions of competitive exclusion and competitive release in South American pocket mice. *Oikos*, **98**, 3–16.

Belll, S., McCoy, E.D. & Mushinsky, H.R. (2012) *Habitat structure: the physical arrangement of objects in space*, Springer Science & Business Media. 438p

Bhupathy, S. & Kannan, P. (1997) Status of agamid lizards in the Western Ghats of Tamil Nadu, India. *Salim Ali Centre for Ornithology and Natural History Technical Report*, **5**, 1–28.

Bhupathy, S. & Nixon, A.M.A. (2011) Status of reptiles in upper Nilgiris, Nilgiri Biosphere Reserve, Western Ghats, India. *Journal of the Bombay Natural History Society*, **108**, 103.

Bhupathy, S., Jins.V.J., Babu, S. & Jose, J. (2016) Distribution and conservation status of the caenophidian snake, Xylophis captaini Gower & Winkler, 2007 in the Western Ghats, India. *Current Science*, **110**, 908-912

Bickford, D., Howard, S.D., Ng, D.J. & Sheridan, J.A. (2010) Impacts of climate change on the amphibians and reptiles of Southeast Asia. *Biodiversity and conservation*, **19**, 1043–1062.

Biju, S.D. & Bossuyt, F. (2009) Systematics and phylogeny of Philautus Gistel, 1848 (Anura, Rhacophoridae) in the Western Ghats of India, with descriptions of 12 new species. *Zoological Journal of the Linnean Society*, **155**, 374–444.

Bishop, J.A. & Myers, W.L. (2005) Associations between avian functional guild response and regional landscape properties for conservation planning. *Ecological Indicators*, **5**, 33–48.

Blaum, N., Mosner, E., Schwager, M. & Jeltsch, F. (2011) How functional is functional? Ecological groupings in terrestrial animal ecology: towards an animal functional type approach. *Biodiversity and Conservation*, **20**, 2333–2345.

Bonsall, M.B., Jansen, V.A. & Hassell, M.P. (2004) Life history trade-offs assemble ecological guilds. *Science*, **306**, 111–114.

Bossuyt, F., Meegaskumbura, M., Beenaerts, N., Gower, D.J., Pethiyagoda, R., Roelants, K., Mannaert, A., Wilkinson, M., Bahir, M.M., Manamendra-Arachchi, K. & others (2004) Local endemism within the Western Ghats-Sri Lanka biodiversity hotspot. *Science*, **306**, 479–481.

Bourg, N.A., McShea, W.J. & Gill, D.E. (2005) Putting a CART before the search: successful habitat prediction for a rare forest herb. *Ecology*, **86**, 2793–2804.

Brown, J.H. (1995) *Macroecology*, University of Chicago Press.

Brown, J.H. (2001) Mammals on mountainsides: elevational patterns of diversity. *Global Ecology and Biogeography*, **10**, 101–109.

Brown, J.H. (1971) Mammals on mountaintops: nonequilibrium insular biogeography. *The American Naturalist*, **105**, 467–478.

Buckley, L.B. & Jetz, W. (2008) Linking global turnover of species and environments. *Proceedings of the National Academy of Sciences*, **105**, 17836–17841.

Busby, J.R. (1991) *BIOCLIM–A bioclimatic analysis and prediction system. In "Nature Conservation: Cost Effective Biological Surveys and Data Analysis".(Eds CR Margules and MP Austin.) pp. 64–68*, CSIRO: Melbourne.

Cadle, J.E. & Patton, J.L. (1988) *Distribution patterns of some amphibians, reptiles, and mammals of the eastern Andean slope of southern Peru*. *Proceedings of a workshop on Neotropical distribution patterns*, Academia Brasileira de Ciencias Río de Janeiro. pp. 225–244.

Campbell, H.W. & Christman, S.P. (1982) Field techniques for herpetofaunal community analysis. *Herpetological communities*, 193–200. USDI Fish and Wildlife Service. *Wildlife research report, 13*.

Cardelús, C.L., Colwell, R.K. & Watkins, J.E. (2006) Vascular epiphyte distribution patterns: Explaining the mid-elevation richness peak. *Journal of Ecology*, **94**, 144–156.

Cardelus, C.L., Colwell, R.K. & Watkins, J.E. (2006) Vascular epiphyte distribution patterns: explaining the mid-elevation richness peak. *Journal of Ecology*, **94**, 144–156.

Carpenter, G., Gillison, A.N. & Winter, J. (1993) DOMAIN: a flexible modelling procedure for mapping potential distributions of plants and animals. *Biodiversity and conservation*, **2**, 667–680.

Champion, H.G. & Seth, S.K. (1968) A revised classification of the Forest Types in India. *Manager Publication, Government of India, Delhi*.

Chandramouli, S.R. (2009) Status and microhabitat preference of Otocryptis beddomii Boulenger, 1885 (Reptilia: Agamidae) in Ponmudi Hills, Western Ghats, Kerala, India. *Taprobanica*, **1**, 107–110.

Chandramouli, S.R. & Ganesh, S.R. (2010) Herpetofauna of southern Western Ghats, India–reinvestigated after decades. *Taprobanica: The Journal of Asian Biodiversity*, **2**, 72-85.

Chettri, B. (2007) Distribution and resource use patterns of reptiles along the Teesta valley, Eastern Himalayas, Sikkim, India. *Ph.D. Dissertation*, Bharathiar University, Coimbatore.

Chettri, B., Bhupathy, S. & Acharya, B.K. (2010) Distribution pattern of reptiles along an eastern Himalayan elevation gradient, India. *Acta Oecologica*, **36**, 16–22.

Colles, A., Liow, L.H. & Prinzing, A. (2009) Are specialists at risk under environmental change? Neoecological, paleoecological and phylogenetic approaches. *Ecology Letters*, **12**, 849–863.

Colwell, R.K., Brehm, G., Cardelús, C.L., Gilman, A.C. & Longino, J.T. (2008) Global warming, elevational range shifts, and lowland biotic attrition in the wet tropics. *science*, **322**, 258–261.

Colwell, R.K. & Hurtt, G.C. (1994) Nonbiological gradients in species richness and a spurious Rapoport effect. *The American Naturalist*, **144**, 570–595.

Colwell, R.K. & Lees, D.C. (2000) The mid-domain effect: geometric constraints on the geography of species richness. *Trends in ecology & evolution*, **15**, 70–76.

Colwell, R.K., Rahbek, C. & Gotelli, N.J. (2004) The mid-domain effect and species richness patterns: what have we learned so far? *The American Naturalist*, **163**, E1–E23.

Colwell, R.K., Rahbek, C. & Gotelli, N.J. (2005) The mid-domain effect: there'sa baby in the bathwater. *The American Naturalist*, **166**, E149–E154.

Crump, M.L., & Scott, N.J. (1994) Visual encounter survey. In: *Measuring and monitoring biological diversity: standard methods for amphibians* (W.R. Heyer, M.A. Donnelly, R.W. Mcdiarmid, L.C. Hayek and M.S. Foster eds.), Smithsonian Institution Press. pp. 84-96.

Currie, D.J. & Kerr, J.T. (2008) Tests of the mid-domain hypothesis: a review of the evidence. *Ecological Monographs*, **78**, 3–18.

Daniels, R.J.R. (1991) *Ecology and status of a little known lizard Otocryptis beddomii (Boulenger). Cobra*, pp. 3–4.

Darwin, C. (1859) On the origin of species by means of natural selection, or the Preservation of Favoured Races in the Struggle for Life. *London, Murray.*

Dean, R.L. & Connell, J.H. (1987) Marine invertebrates in an algal succession. III. Mechanisms linking habitat complexity with diversity. *Journal of Experimental Marine Biology and Ecology*, **109**, 249–273.

Deepak, V., Giri, V.B., Asif, M., Dutta, S.K., Vyas, R., Zambre, A.M., Bhosale, H. & Karanth, K.P. (2016) Systematics and phylogeny of Sitana (Reptilia: Agamidae) of Peninsular India, with the description of one new genus and five new species. *Contributions to Zoology*, **85**, 67–111.

Deepak, V. & Vasudevan, K. (2008) Density and microhabitat association of Salea anamallayana in Eravikulam National Park, Western Ghats, India. *The Herpetological Journal*, **18**, 165–170.

Ding, T.-S., Yuan, H.-W., Geng, S., Lin, Y.-S. & Lee, P.-F. (2005) Energy flux, body size and density in relation to bird species richness along an elevational gradient in Taiwan. *Global Ecology and Biogeography*, **14**, 299–306.

Dunn, R.R., McCain, C.M. & Sanders, N.J. (2007) When does diversity fit null model predictions? Scale and range size mediate the mid-domain effect. *Global Ecology and Biogeography*, **16**, 305–312.

Elith, J., Graham, C. H., Anderson, R. P., Dudı´k, M., Ferrier, S., Guisan, A., Hijmans, R. J., Huettmann, F., Leathwick, J. R., Lehmann, A., Li, J., Lohmann, L. G., Loiselle, B. A., Manion, G., Moritz, C., Nakamura, M., Nakazawa, Y., Overton, J. McC., Peterson, A. T., Phillips, S. J., Richardson, K. S., Scachetti-Pereira, R., Schapire, R. E., Sobero´n, J., Williams, S., Wisz, M. S. & Zimmermann, N. E. 2006. Novel methods improve prediction of species' distributions from occurrence data. *Ecography* **29**: 129-151.

Fauth, J.E., Crother, B.I. & Slowinski, J.B. (1989) Elevational patterns of species richness, evenness, and abundance of the Costa Rican leaf-litter herpetofauna. *Biotropica*, **21**, 178–185.

Ferguson, H.S. (1895) List of snakes taken in Travancore from 1888 to 1895. *Journal of Bombay Natural History Society*, **10**, 68–77.

Fu, C., Hua, X., Li, J., Chang, Z., Pu, Z. & Chen, J. (2006) Elevational patterns of frog species richness and endemic richness in the Hengduan Mountains, China: geometric constraints, area and climate effects. *Ecography*, **29**, 919–927.

Fu, C., Wang, J., Pu, Z., Zhang, S., Chen, H., Zhao, B., Chen, J. & Wu, J. (2007) Elevational gradients of diversity for lizards and snakes in the Hengduan Mountains, China. *Biodiversity and Conservation*, **16**, 707–726.

Garden, J.G., McAlpine, C.A., Possingham, H.P. & Jones, D.N. (2007) Habitat structure is more important than vegetation composition for local-level management of native terrestrial reptile and small mammal species living in urban remnants: A case study from Brisbane, Australia. *Austral Ecology*, **32**, 669–685.

Gaston, K.J. (2000) Global patterns in biodiversity. *Nature*, **405**, 220–227.

Gibbon, J.W., Scott, D.E., Ryan, T.J., Buhlmann, K.A., Tuberville, T.D., Metts, B.S., Greene, J.L., Mills, T., Leiden, Y., Poppy, S. & others (2000) The Global Decline of Reptiles, Déjà Vu Amphibians: Reptile species are declining on a global scale. Six significant threats to reptile populations are habitat loss and degradation, introduced invasive species, environmental pollution, disease, unsustainable use, and global climate change. *BioScience*, **50**, 653–666.

Gotelli, N.J. & Entsminger, G.L. (2001) *EcoSim: Null models software for ecology*, version.

Gower, D.J., Giri, V., Captain, A. & Wilkinson, M. (2016) A reassessment of Melanophidium Günther, 1864 (Squamata: Serpentes: Uropeltidae) from the Western Ghats of peninsular India, with the description of a new species. *Zootaxa*, **4085**, 481-503.

Gower, D.J. & Winkler, J.D. (2007) Taxonomy of the Indian snake Xylophis Beddome (Serpentes: Caenophidia), with description of a new species. *Hamadryad*-**31**, 315.

Gotelli, N.J & G.L, Entsminger (2000). EcoSim: Null Model Software for Ecology. Acquired Intelligence Inc, New York.

Graham, C.H., Ron, S.R., Santos, J.C., Schneider, C.J., Moritz, C. & Cunningham, C. (2004) Integrating phylogenetics and environmental niche models to explore speciation mechanisms in dendrobatid frogs. *Evolution*, **58**, 1781–1793.

Griffiths, R.A. (1987) Microhabitat and seasonal niche dynamics of smooth and palmate newts, Triturus vulgaris and T. helveticus, at a pond in mid-Wales. *The Journal of Animal Ecology*, **56**, 441–451.

Grinnell, J. (1917) Field tests of theories concerning distributional control. *The American Naturalist*, **51**, 115–128.

Groff, L.A., Marks, S.B. & Hayes, M.P. (2014) Using ecological niche models to direct rare amphibian surveys: A case study using the Oregon Spotted Frog (Rana pretiosa). *Herpetological Conservation and Biology*, **9**, 354–368.

Guisan, A., Lehmann, A., Ferrier, S., Austin, M., Overton, J., Aspinall, R., Hastie, T. & others (2006) Making better biogeographical predictions of species' distributions. *Journal of Applied Ecology*, **43**, 386–392.

Guisan, A., Tingley, R., Baumgartner, J.B., Naujokaitis-Lewis, I., Sutcliffe, P.R., Tulloch, A.I., Regan, T.J., Brotons, L., McDonald-Madden, E., Mantyka-Pringle, C. & others (2013) Predicting species distributions for conservation decisions. *Ecology letters*, **16**, 1424–1435.

Guo, Q., Kelt, D.A., Sun, Z., Liu, H., Hu, L., Ren, H. & Wen, J. (2013) Global variation in elevational diversity patterns. *Scientific reports*, **3**, 3007p.

Hansen, M.C., DeFries, R.S., Townshend, J.R.G., Carroll, M., Dimiceli, C. & Sohlberg, R.A. (2003) Global percent tree cover at a spatial resolution of 500 meters: First results of the MODIS vegetation continuous fields algorithm. *Earth Interactions*, **7**, 1–15.

Hawkins, B. a. & Diniz-Filho, J. a F. (2002a) The mid-domain effect cannot explain the diversity gradient of Nearctic birds. *Global Ecology and Biogeography*, **11**, 419–426.

Hawkins, B.A. & Diniz-Filho, J.A.F. (2002b) The mid-domain effect cannot explain the diversity gradient of Nearctic birds. *Global Ecology and Biogeography*, **11**, 419–426.

Hawkins, B.A., Field, R., Cornell, H.V., Currie, D.J., Guégan, J.-F., Kaufman, D.M., Kerr, J.T., Mittelbach, G.G., Oberdorff, T., O'Brien, E.M. & others (2003) Energy, water, and broad-scale geographic patterns of species richness. *Ecology*, **84**, 3105–3117.

Heaney, L.R. (2001) Small mammal diversity along elevational gradients in the Philippines: an assessment of patterns and hypotheses. *Global Ecology and Biogeography*, **10**, 15–39.

Heatwole, H. (1982) A review of structuring in herpetofaunal assemblages. *US Fish and Wildlife Service Wildlife Research Report*, **13**, 1–19.

Heinen, J.T. (1992) Comparisons of the leaf litter herpetofauna in abandoned cacao plantations and primary rain forest in Costa Rica: some implications for faunal restoration. *Biotropica*, **24**, 431–439.

Heyer, R., Donnelly, M.A., Foster, M. & Mcdiarmid, R. (2014) *Measuring and monitoring biological diversity: standard methods for amphibians*, Smithsonian Institution.

Heyer, W.R. (1967) A herpetofaunal study of an ecological transect through the Cordillera de Tilarán, Costa Rica. *Copeia*, **2**, 259–271.

Heyer, W.R. & Berven, K.A. (1973) Species diversities of herpetofaunal samples from similar microhabitats at two tropical sites. *Ecology*, **54**, 642–645.

Heyer, W.R., Donnelly, M.A. & MacDiarmid, R.W. (1994) Measuring and monitoring biological diversity: standard methods for amphibians. *Biological diversity handbook series*. Smithsonian Institution Press. Washington.

Hijmans, R.J., Cameron, S.E., Parra, J.L., Jones, P.G. & Jarvis, A. (2005) Very high resolution interpolated climate surfaces for global land areas. *International journal of climatology*, **25**, 1965–1978.

Hijmans, R.J. & Graham, C.H. (2006) The ability of climate envelope models to predict the effect of climate change on species distributions. *Global change biology*, **12**, 2272–2281.

Hirzel, A.H., Hausser, J., Chessel, D. & Perrin, N. (2002) Ecological-niche factor analysis: how to compute habitat-suitability maps without absence data? *Ecology*, **83**, 2027–2036.

Hofer, U., Bersier, L.-F. & Borcard, D. (2000) Ecotones and gradient as determinants of herpetofaunal community structure in the primary forest of Mount Kupe, Cameroon. *Journal of tropical ecology*, **16**, 517–533.

Hofer, U., Bersier, L.-F. & Borcard, D. (1999) Spatial organization of a herpetofauna on an elevational gradient revealed by null model tests. *Ecology*, **80**, 976–988.

Holt, R.D. (2009) Bringing the Hutchinsonian niche into the 21st century: ecological and evolutionary perspectives. *Proceedings of the National Academy of Sciences*, **106**, 19659–19665.

Hutchinson, G.E. (1957) Cold spring harbor symposium on quantitative biology. *Concluding remarks*, **22**, 415–427.

Inger, R.F., Shaffer, H.B., Koshy, M. & Bakde, R. (1984) A report on a collection of amphibians and reptiles from the Ponmudi, Kerala, South India. *Journal of the Bombay Natural History Society*, **81**, 406–427.

Inger, R.F., Shaffer, H.B., Koshy, M. & Bakde, R. (1987) Ecological structure of a herpetological assemblage in South India. *Amphibia-Reptilia*, **8**, 189–202.

Irfan-Ullah, M., Amarnath, G., Murthy, M.S.R. & Peterson, A.T. (2007) Mapping the geographic distribution of Aglaia bourdillonii Gamble (Meliaceae), an endemic and threatened plant, using ecological niche modeling. *Biodiversity and Conservation*, **16**, 1917–1925.

Ishwar, N.M., Chellam, R. & Kumar, A. (2001) Distribution of forest floor reptiles in the rainforest of Kalakad-Mundanthurai Tiger Reserve, South India. *Current Science*, **80**, 413–418.

Işik, K. (2011) Rare and endemic species: why are they prone to extinction? *Turkish Journal of Botany*, **35**, 411–417.

Jankowski, J.E., Robinson, S.K. & Levey, D.J. (2010) Squeezed at the top: interspecific aggression may constrain elevational ranges in tropical birds. *Ecology*, **91**, 1877–1884.

Jayapal, R., Qureshi, Q. & Chellam, R. (2009) Importance of forest structure versus floristics to composition of avian assemblages in tropical deciduous forests of Central Highlands, India. *Forest ecology and management*, **257**, 2287–2295.

Jayson, E.A. & Christopher, G. (2008) Human-elephant conflict in the southern Western Ghats: a case study from the Peppara Wild Life Sanctuary, Kerala, India. *Indian Forester*, **134**, 1309–1325.

Jetz, W. & Rahbek, C. (2001) Geometric constraints explain much of the species richness pattern in African birds. *Proceedings of the National Academy of Sciences*, **98**, 5661–5666.

Jins, V.J., Bhupathy, S. & Panigrahi, M. (2014) New record of Beddome's coral snake Calliophis beddomei Smith, 1943 from the southern Western Ghats, India. *Herpetology Notes*, **7**, 555–557.

Jose, J., Ramachandran, K.K. & Nair, P.V. (2007) A rare and little known lizard, Otocryptis beddomi, from the Myristica swamps of southern Kerala, India. *Herpetological bulletin*, **101**, 27–31.

Kanagavel, A. & Raghavan, R. (2012) Local ecological knowledge of the threatened Cochin forest cane turtle Vijayachelys silvatica and Travancore Tortoise Indotestudo travancorica from the Anamalai Hills of the Western Ghats, India. *Journal of Threatened Taxa*, **4**, 3173–3182.

Karr, J.R. & Roth, R.R. (1971) Vegetation structure and avian diversity in several New World areas. *The American Naturalist*, **105**, 423–435.

Kattan, G.H. & Franco, P. (2004) Bird diversity along elevational gradients in the Andes of Colombia: area and mass effects. *Global Ecology and Biogeography*, **13**, 451–458.

Kearney, M. (2006) Habitat, environment and niche: what are we modelling? *Oikos*, **115**, 186–191.

Kendall, V.J. & Haedrich, R.L. (2006) Species richness in Atlantic deep-sea fishes assessed in terms of the mid-domain effect and Rapoport's rule. *Deep Sea Research Part I: Oceanographic Research Papers*, **53**, 506–515.

Kessler, M., Herzog, S.K., Fjelds\a a, J. & Bach, K. (2001) Species richness and endemism of plant and bird communities along two gradients of elevation, humidity and land use in the Bolivian Andes. *Diversity and distributions*, **7**, 61–77.

Kluge, J., Kessler, M. & Dunn, R.R. (2006) What drives elevational patterns of diversity? A test of geometric constraints, climate and species pool effects for pteridophytes on an elevational gradient in Costa Rica. *Global Ecology and Biogeography*, **15**, 358–371.

Kryštufek, B., Janžekovič, F. & Donev, N.R. (2008) Elevational diversity of reptiles on two Dinaric mountains. *Journal of natural history*, **42**, 399–408.

Kumar, A., Chellam, R., Choudhury, B.C., Mudappa, D., Vasudevan, K., Ishwar, N.M. & Noon, B.R. (2002) Impact of rainforest fragmentation on small mammals and herpetofauna in the Western Ghats, south India. *WII-USFWS Collaborative Project Final Report, Wildlife Institute of India, Dehradun, vii+ 146pp*.

Kunhi & Shankar (2002. Environmental impact assessment of Pilgrimage in Agasthyamalai region. *Kerala Forest Research Institute (KFRI), Research report* 238.

Kwon, T.-S., Kim, S.-S. & Chun, J.H. (2014) Pattern of ant diversity in Korea: An empirical test of Rapoport's altitudinal rule. *Journal of Asia-Pacific Entomology*, **17**, 161–167.

Laurance, W.F. (1990) Comparative responses of five arboreal marsupials to tropical forest fragmentation. *Journal of Mammalogy*, **71**, 641–653.

Laurance, W.F., Delamônica, P., Laurance, S.G., Vasconcelos, H.L. & Lovejoy, T.E. (2000) Conservation: rainforest fragmentation kills big trees. *Nature*, **404**, 836–836.

Levins, R. (1968) *Evolution in changing environments: some theoretical explorations*, Princeton University Press.

Li, J.S., Song, Y.L. & Zeng, Z.G. (2003) Elevational gradients of small mammal diversity on the northern slopes of Mt. Qilian, China. *Global Ecology and Biogeography*, **12**, 449–460.

Lomolino, M. (2001) Elevation gradients of species-density: historical and prospective views. *Global Ecology and biogeography*, **10**, 3–13.

Lomolino, M.V. & Brown, J.H. (2004) *Foundations of biogeography: classic papers with commentaries*, University of Chicago Press.

Losos, J.B., Warheit, K.I. & Schoener, T.W. (1997) Adaptive differentiation following experimental island colonization in Anolis lizards. *Nature*, **387**, 70.

MacArthur, R.H. (1972) *Geographical ecology: patterns in the distribution of species*, Princeton University Press.

MacArthur, R.H. (1958) Population ecology of some warblers of northeastern coniferous forests. *Ecology*, **39**, 599–619.

MacArthur, R.H. & MacArthur, J.W. (1961) On bird species diversity. *Ecology*, **42**, 594–598.

Management Plan Neyyar Wildlife Sanctaury 2012-2013 to 2021 to 2022 (2011).

Management Plan Peppara Wildlife Sanctaury 2012-2013 to 2021 to 2022 (2011).

McCain, C.M. (2007a) Area and mammalian elevational diversity. *Ecology*, **88**, 76–86.

McCain, C.M. (2007b) Could temperature and water availability drive elevational species richness patterns? A global case study for bats. *Global Ecology and biogeography*, **16**, 1–13.

McCain, C.M. (2010) Global analysis of reptile elevational diversity. *Global Ecology and Biogeography*, **19**, 541–553.

McCain, C.M. (2003) North American desert rodents: a test of the mid-domain effect in species richness. *Journal of Mammalogy*, **84**, 967–980.

McCain, C.M. (2004) The mid-domain effect applied to elevational gradients: species richness of small mammals in Costa Rica. *Journal of Biogeography*, **31**, 19–31.

McInerny, G.J. & Etienne, R.S. (2012) Ditch the niche–is the niche a useful concept in ecology or species distribution modelling? *Journal of Biogeography*, **39**, 2096–2102.

Menon, S., Choudhury, B.I., Khan, M.L. & Peterson, A.T. (2010) Ecological niche modeling and local knowledge predict new populations of Gymnocladus assamicus a critically endangered tree species. *Endangered Species Research*, **11**, 175–181.

Michael, D.R., Cunningham, R.B. & Lindenmayer, D.B. (2008) A forgotten habitat? Granite inselbergs conserve reptile diversity in fragmented agricultural landscapes. *Journal of Applied Ecology*, **45**, 1742–1752.

Michael, D.R., Kay, G.M., Crane, M., Florance, D., MacGregor, C., Okada, S., McBurney, L., Blair, D. & Lindenmayer, D.B. (2015) Ecological niche breadth and microhabitat guild structure in temperate Australian reptiles: Implications for natural resource management in endangered grassy woodland ecosystems. *Austral Ecology*, **40**, 651–660.

Mittelbach, G.G., Steiner, C.F., Scheiner, S.M., Gross, K.L., Reynolds, H.L., Waide, R.B., Willig, M.R., Dodson, S.I. & Gough, L. (2001) What is the observed relationship between species richness and productivity? *Ecology*, **82**, 2381–2396.

Mueller-Dombois, D. & Ellenberg, H. (1974) Aims and methods of vegetation ecology.

Mukherjee, D. (2007) Resource utilization patterns of reptiles in the tropical dry mixed deciduous forest of Anaikatty Hills, Western Ghats, India. *Ph.D. Dissertation*, Bharathiar University, Coimbatore.

Murthy, T.S.N. (1980) Recent re-discovery of the rare agamid lizard Otocryptis beddomii. *J Bomb Nat Hist Soc*, **77**, 343–344.

Myers, N., Mittermeier, R.A., Mittermeier, C.G., Da Fonseca, G.A. & Kent, J. (2000) Biodiversity hotspots for conservation priorities. *Nature*, **403**, 853–858.

Nair, S.C. (1991) *The southern Western Ghats: a biodiversity conservation plan*, Indian National Trust for Art and Cultural Heritage. 88p.

Naniwadekar, R. & Vasudevan, K. (2007) Patterns in diversity of anurans along an elevational gradient in the Western Ghats, South India. *Journal of Biogeography*, **34**, 842–853.

Nathan, R. & Werner, Y.L. (1999) Reptiles and breeding birds on Mt. Hermon: patterns of altitudinal distribution and species richness. *Israel Journal of Zoology*, **45**, 1–33.

Noon, B.R. (1981) The distribution of an avian guild along a temperate elevational gradient: the importance and expression of competition. *Ecological Monographs*, **51**, 105–124.

Oommen, M.A. & Shanker, K. (2005) Elevational species richness patterns emerge from multiple local mechanisms in Himalayan woody plants. *Ecology*, **86**, 3039–3047.

Opdam, P., Foppen, R. & Vos, C. (2001) Bridging the gap between ecology and spatial planning in landscape ecology. *Landscape ecology*, **16**, 767–779.

Palni, L.M.S., Rawal, R.S., Rai, R.K. & Reddy, S. V eds. (2012) *Compendium on Indian Biosphere Reserves. Progression during two decades of conservation,.*

Parrish, J.D. (1995) Effects of needle architecture on warbler habitat selection in a coastal spruce forest. *Ecology*, **76**, 1813–1820.

Patterson, B.D., Stotz, D.F., Solari, S., Fitzpatrick, J.W. & Pacheco, V. (1998) Contrasting patterns of elevational zonation for birds and mammals in the Andes of southeastern Peru. *Journal of Biogeography*, **25**, 593–607.

Pearson, R.G. (2007) Species' distribution modeling for conservation educators and practitioners. *Synthesis. American Museum of Natural History*, **1**, 1–50.

Pearson, R.G. & Dawson, T.P. (2003) Predicting the impacts of climate change on the distribution of species: are bioclimate envelope models useful? *Global ecology and biogeography*, **12**, 361–371.

Pearson, R.G., Raxworthy, C.J., Nakamura, M. & Townsend Peterson, A. (2007) Predicting species distributions from small numbers of occurrence records: a test case using cryptic geckos in Madagascar. *Journal of biogeography*, **34**, 102–117.

Peterson, A.T. (2001) Predicting SPECIES'Geographic Distributions Based on Ecological Niche Modeling. *The Condor*, **103**, 599–605.

Peterson, A.T. & Cohoon, K.P. (1999) Sensitivity of distributional prediction algorithms to geographic data completeness. *Ecological modelling*, **117**, 159–164.

Peterson, A.T., Ortega-Huerta, M.A., Bartley, J., Sánchez-Cordero, V., Soberón, J., Buddemeier, R.H. & Stockwell, D.R. (2002) Future projections for Mexican faunas under global climate change scenarios. *Nature*, **416**, 626–629.

Petren, K. & Case, T.J. (1998) Habitat structure determines competition intensity and invasion success in gecko lizards. *Proceedings of the National Academy of Sciences*, **95**, 11739–11744.

Phillips, S.J., Anderson, R.P. & Schapire, R.E. (2006) Maximum entropy modeling of species geographic distributions. *Ecological modelling*, **190**, 231–259.

Pianka, E.R. (1981) Competition and niche theory. *Theoretical ecology principles and applications*, 167–196.

Pianka, E.R. (1966a) Convexity, desert lizards, and spatial heterogeneity. *Ecology*, **47**, 1055–1059.

Pianka, E.R. (1980) Guild structure in desert lizards. *Oikos*, 194–201.

Pianka, E.R. (1966b) Latitudinal gradients in species diversity: a review of concepts. *The American Naturalist*, **100**, 33–46.

Pianka, E.R. (1975) Niche relations of desert lizards. *Ecology and evolution of communities*, 292–314.

Pianka, E.R. (1967) On lizard species diversity: North American flatland deserts. *Ecology*, **48**, 333–351.

Pianka, E.R. (1973) The structure of lizard communities. *Annual review of ecology and systematics*, **4**, 53–74.

Pianka, E.R. (2000) The ecological niche. *Evolutionary ecology*. Addision Wesley Educational Publishers, Inc. pp. 267-293.

Pianka, E.R. & Pianka, H.D. (1976) Comparative ecology of twelve species of nocturnal lizards (Gekkonidae) in the Western Australian desert. *Copeia*, 125–142.

Price, M.V. (1978) The role of microhabitat in structuring desert rodent communities. *Ecology*, **59**, 910–921.

Pulliam, H.R. (2000) On the relationship between niche and distribution. *Ecology letters*, **3**, 349–361.

Rahbek, C. (1995) The elevational gradient of species richness: a uniform pattern? *Ecography*, **18**, 200–205.

Rahbek, C. (1997) The relationship among area, elevation, and regional species richness in neotropical birds. *The American Naturalist*, **149**, 875–902.

Rahbek, C. (2005) The role of spatial scale and the perception of large-scale species-richness patterns. *Ecology Letters*, **8**, 224–239.

Raman, T.R., Joshi, N.V. & Sukumar, R. (2005) Tropical rainforest bird community structure in relation to altitude, tree species composition, and null models in the Western Ghats, India. *arXiv preprint q-bio/0510033*.

Ramesh, B.R., Menon, S. & Bawa, K.S. (1997) A landscape ecology approach to biodiversity conservation in the Agasthyamalai Region, Western Ghats, India. *Ambio*, **26**, 529–536.

Ramesh, M. (2008) Relative abundance and morphometrics of the Travancore tortoise, Indotestudo travancorica, in the Indira Gandhi Wildlife Sanctuary, southern Western Ghats, India. *Chelonian Conservation and Biology*, **7**, 108–113.

Raxworthy, C.J., Ingram, C.M., Rabibisoa, N. & Pearson, R.G. (2007) Applications of ecological niche modeling for species delimitation: a review and empirical evaluation using day geckos (Phelsuma) from Madagascar. *Systematic biology*, **56**, 907–923.

Raxworthy, C.J., Martinez-Meyer, E., Horning, N., Nussbaum, R.A., Schneider, G.E., Ortega-Huerta, M.A. & Peterson, A.T. (2003) Predicting distributions of known and unknown reptile species in Madagascar. *Nature*, **426**, 837–841.

Redon, M. & Luque, S. (2010) *Presence-only modelling for indicator species distribution: biodiversity monitoring in the French Alps*. *6th Spatial Analysis and Geomatics international conference (SAGEO 2010)*, p. p–42. Université de Toulouse.

Rissler, L.J. & Apodaca, J.J. (2007) Adding more ecology into species delimitation: ecological niche models and phylogeography help define cryptic species in the black salamander (Aneides flavipunctatus). *Systematic Biology*, **56**, 924–942.

Romdal, T.S. & Grytnes, J.-A. (2007) An indirect area effect on elevational species richness patterns. *Ecography*, **30**, 440–448.

Root, R.B. (1967) The niche exploitation pattern of the blue-gray gnatcatcher. *Ecological monographs*, **37**, 317–350.

Rosenzweig, M.L. (1968) Net primary productivity of terrestrial communities: prediction from climatological data. *The American Naturalist*, **102**, 67–74.

Rotenberry, J.T. (1985) The role of habitat in avian community composition: physiognomy or floristics? *Oecologia*, **67**, 213–217.

Rutishauser, M.D., Bontadina, F., Braunisch, V., Ashrafi, S. & Arlettaz, R. (2012) The challenge posed by newly discovered cryptic species: disentangling the environmental niches of long-eared bats. *Diversity and Distributions*, **18**, 1107–1119.

R Core Team (2016). R: A language and environment for statistical computing. R Foundationfor Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Sánchez-González, A. & López-Mata, L. (2005) Plant species richness and diversity along an altitudinal gradient in the Sierra Nevada, Mexico. *Diversity and Distributions*, **11**, 567–575.

Sanders, H.L. (1968) Marine benthic diversity: a comparative study. *The American Naturalist*, **102**, 243–282.

Sanders, N.J., Moss, J. & Wagner, D. (2003) Patterns of ant species richness along elevational gradients in an arid ecosystem. *Global ecology and biogeography*, **12**, 93–102.

Schoener, T.W. (1974) Resource partitioning in ecological communities. *Science*, **185**, 27–39.

Scott Jr, N.J. (1976) The abundance and diversity of the herpetofaunas of tropical forest litter. *Biotropica*, **8**, 41–58.

Segurado, P. & Araujo, M.B. (2004) An evaluation of methods for modelling species distributions. *Journal of Biogeography*, **31**, 1555–1568.

Sekercioglu, C.H., Schneider, S.H., Fay, J.P. & Loarie, S.R. (2008) Climate change, elevational range shifts, and bird extinctions. *Conservation Biology*, **22**, 140–150.

Sima Lieberman, S. (1986) Ecology of the leaf litter herpetofauna of a neotropical rain forest: La Selva, Costa Rica. *Acta Zoológica Mexicana (EUA) no. 15 p. 1-72.*

Smith, M.A. (1935) *The fauna of British India, Ceylon and Burma: Amphibia and Reptilia, Vol. II.-Sauria*, Taylor and Francis Ltd., London, xii+ 445pp.

Soberon, J. & Peterson, A.T. (2005) Interpretation of models of fundamental ecological niches and species' distributional areas. *Biodiversity Informatics*, **2,** 1-10

Srinivasulu, C., Srinivasulu, B. & Molur, S. (2014) The Status and distribution of reptiles in the Western Ghats, India. *Conservation Assessment and Management Plan (CAMP). Wildlife Information Liaison Development Society, Coimbatore, Tamil Nadu, 148pp.*

Stevens, G.C. (1992) The elevational gradient in altitudinal range: an extension of Rapoport's latitudinal rule to altitude. *The American Naturalist*, **140**, 893–911.

Stevens, G.C. (1989) The latitudinal gradient in geographical range: how so many species coexist in the tropics. *The American Naturalist*, **133**, 240–256.

Stockwell, D. (1999) The GARP modelling system: problems and solutions to automated spatial prediction. *International journal of geographical information science*, **13**, 143–158.

Surendran, H. & Vasudevan, K. (2015) The devil is in the detail: estimating species richness, density, and relative abundance of tropical island herpetofauna. *BMC ecology*, **15**, 18. *DOI: 10.1186/s12898-015-0049-5*

Sutton, W.B., Wang, Y. & Schweitzer, C.J. (2010) Habitat relationships of reptiles in pine beetle disturbed forests of Alabama, USA, with guidelines for a modified drift-fence sampling method. *Current Zoology*, 56, 411-420

Tabarelli, M., Mantovani, W. & Peres, C.A. (1999) Effects of habitat fragmentation on plant guild structure in the montane Atlantic forest of southeastern Brazil. *Biological conservation*, **91**, 119–127.

Theisinger, O. & Ratianarivo, M.C. (2015) Patterns of reptile diversity loss in response to degradation in the spiny forest of Southern Madagascar. *Herpetological Conservation & Biology*, **10**, 273–283.

Thompson, S.D. (1982) Structure and species composition of desert heteromyid rodent species assemblages: effects of a simple habitat manipulation. *Ecology*, **63**, 1313–1321.

Toft, C.A. (1985) Resource partitioning in amphibians and reptiles. *Copeia*, 1–21.

Urbina-Cardona, J.N. & Flores-Villela, O. (2010) Ecological-niche modeling and prioritization of conservation-area networks for Mexican herpetofauna. *Conservation Biology*, **24**, 1031–1041.

Varghese, A.O. & Balasubramanyan, K. (1998) Structure, composition and diversity of the tropical wet evergreen forest of the Agasthyamalai region of Kerala, Western Ghats. *Journal of South Asian Natural History*, **4**, 87–98.

Vasudevan, K., Kumar, A. & Chellam, R. (2006) Species turnover: the case of stream amphibians of rainforests in the Western Ghats, southern India. *Biodiversity & Conservation*, **15**, 3515–3525.

Vasudevan, K., Pandav, B. & Deepak, V. (2010) Ecology of two endemic turtles in the Western Ghats, *Final Technical Report, Wildlife Institute of India* 74p.

Vetaas, O.R. & Grytnes, J.-A. (2002) Distribution of vascular plant species richness and endemic richness along the Himalayan elevation gradient in Nepal. *Global Ecology and Biogeography*, **11**, 291–301.

Vitt, L.J. & Zani, P.A. (1996) Organization of a taxonomically diverse lizard assemblage in Amazonian Ecuador. *Canadian Journal of Zoology*, **74**, 1313–1335.

Vrezec, A. & Tome, D. (2004) Altitudinal segregation between Ural Owl Strix uralensis and Tawny Owl S. aluco: evidence for competitive exclusion in raptorial birds. *Bird Study*, **51**, 264–269.

Waide, R.B., Willig, M.R., Steiner, C.F., Mittelbach, G., Gough, L., Dodson, S.I., Juday, G.P. & Parmenter, R. (1999) The relationship between productivity and species richness. *Annual review of Ecology and Systematics*, **30**, 257–300.

Wallace, A.R. (1876) The Geographical Distribution of Animals: With a Study of the Relations of Living and Extinct Faunas as Elucidating the Past Changes of the Earth’s Surface: In Two Volumes.

White, R.L. & Bennett, P.M. (2015) Elevational distribution and extinction risk in birds. *PloS one*, **10**, e0121849.

Whitfield, S.M. & Pierce, M.S. (2005) Tree buttress microhabitat use by a Neotropical leaf-litter herpetofauna. *Journal of Herpetology*, **39**, 192–198.

Whittaker, R.H. (1960) Vegetation of the Siskiyou mountains, Oregon and California. *Ecological monographs*, **30**, 279–338.

Whittaker, R.H., Levin, S.A. & Root, R.B. (1973) Niche, habitat, and ecotope. *The American Naturalist*, **107**, 321–338.

Wiens, J.A. (1992) *The ecology of bird communities*, Cambridge University Press.

Wiens, J.J. & Donoghue, M.J. (2004) Historical biogeography, ecology and species richness. *Trends in ecology & evolution*, **19**, 639–644.

Wiens, J.J., Parra-Olea, G., García-París, M. & Wake, D.B. (2007) Phylogenetic history underlies elevational biodiversity patterns in tropical salamanders. *Proceedings of the Royal Society of London B: Biological Sciences*, **274**, 919–928.

Williams, S.E. & Hero, J.-M. (1998) Rainforest frogs of the Australian Wet Tropics: guild classification and the ecological similarity of declining species. *Proceedings of the Royal Society of London B: Biological Sciences*, **265**, 597–602.

Woinarski, J.C.Z. & Gambold, N. (1992) Gradient analysis of a tropical herpetofauna: distribution patterns of terrestrial reptiles and amphibians in Stage III of Kakadu National Park, Australia. *Wildlife Research*, **19**, 105–127.

Wolda, H. (1981) Similarity indices, sample size and diversity. *Oecologia*, **50**, 296–302.

Zapata, F.A., Gaston, K.J. & Chown, S.L. (2003) Mid-domain models of species richness gradients: assumptions, methods and evidence. *Journal of Animal Ecology*, **72**, 677–690.

Zapata, F.A., Gaston, K.J. & Chown, S.L. (2005) The mid-domain effect revisited. *The American Naturalist*, **166**, E144–E148.

Ziv, Y., Kotler, B.P., Abramsky, Z. & Rosenzweig, M.L. (1995) Foraging efficiencies of competing rodents: why do gerbils exhibit shared-preference habitat selection? *Oikos*, 260–268.

Appendix 1: Checklist of reptiles and their status in Agasthyamalai Hills

	Scientific name	Common Name	IUCN	#of Obs.
	ORDER: SQUAMATA			
	Family: Agamidae			
1	*Cnemaspis cf australis*	Southern Day Gecko*	DD	C
2	*Cnemaspis cf wynadensis*	Wynad Day Gecko*	EN	C
3	*Cnemaspis littoralis*	Coastal Day Gecko*	DD	C
4	*Cnemaspis nairi*	Ponmudi Day Gecko*	NT	UC
5	*Cnemaspis beddomei*	Beddome's Day Gecko*	DD	C
6	*Cnemaspis cf ornata*	Ornate Day Gecko*	NT	VR
7	*Cnemaspis spp.*	Day Gecko spp.	UI	C
8	*Hemidactylus spp.*	House Gecko spp.	UI	C
9	*Hemidactylus brooki*	Brook's House Gecko	NA	UC
10	*Gehyra mutilata*	Four-clawed Gecko	NA	VR
11	*Calotes calotes*	Green Forest Lizard	NA	UC
12	*Calotes ellioti*	Ellioti's Forest Lizard*	LC	C
13	*Calotes grandisquamis*	Large Scaled Forest Lizard*	LC	R
14	*Calotes nemericola*	Nilgiri Forest Lizard*	LC	VR
15	*Calotes versicolar*	Indian Garden Lizard	NA	C
16	*Draco dussumieri*	South Indian Flying Lizard	LC	C
17	*Otocryptis beddomii*	Indian Kangaroo Lizard*	EN	C
18	*Psammophilus dorsalis*	South Indian Rock Agama	LC	C
	Family : Scincidae			
19	*Eutropis carinata*	Common Keeled Skink	LC	C
20	*Eutropis clivicola*	Mountain Skink*	EN	R
21	*Eutropis macularia*	Bronze Grass Skink	NA	C
22	*Kaestlea travancorica*	Travancore Ground Skink*	LC	R
23	*Lygosoma punctata*	Spotted Supple Skink	NA	VR
24	*Ristella beddomei*	Beddome's Cat Skink*	NA	VR
25	*Ristella guntheri*	Gunther's Cat Skink*	DD	UC
26	*Ristella trvancorica*	Travancore Cat Skink*	DD	C
27	*Sphenomorphus dussumieri*	Dussumier's Litter Skink	LC	C
	Family : Chamaeleonidae			
28	*Chamaeleo zeylanicus*	Indian Chamaeleon	LC	VR
	Family : Varanidae			
29	*Varanus bengalensis*	Bengal Monitor	LC	R
	Family : Typhlopidae			
30	*Typhlops spp.*	Worm Snake spp.	UI	VR
	Family : Uropeltidae			
31	*Melanophidium punctatum*	Pied-belly Shieldtail*	LC	VR
32	*Teretyrus sanguineus*	Western Shieldtail*	NA	UC
33	*Uropeltis cf ceylanica*	Kerala Shieldtail	LC	VR
34	*Uropeltis cf myhendrae*	Barred Shieldtail*	DD	R
35	*Uropeltis liura*	Ashambu Shieldtail*	DD	VR
36	*Uropeltis spp*	Shieldtail spp.	UI	R
	Family : Pythonidae			
37	*Python molurus*	Indian Rock Python	NA	VR

	Family : Coulubridae			
38	*Ahaetulla nasuta*	Common Vine Snake	NA	C
39	*Ahaetulla dispar*	Gunther's Vine Snake*	NT	UC
40	*Ahaetulla pulverulenta*	Brwon Vine Snake	LC	VR
41	*Boiga beddomei*	Beddome's Cat Snake	DD	VR
42	*Boiga ceylonensis*	Ceylon Cat Snake	NA	UC
43	*Boiga nuchalis*	Collared Cat Snake*	DD	VR
44	*Boiga trigonata*	Common Cat Snake	LC	VR
45	*Chrysopelea ornata*	Ornate Flying Snake	NA	VR
46	*Coelognathus helena monticollaris*	Montane Trinket Snake	NA	VR
47	*Dendrelaphis cf ashoki*	Ashok’s Bronzeback Tree Snake*	LC	VR
48	*Dendrelaphis grandoculis*	Large Eyed Bronzeback Tree Snake*	LC	VR
49	*Dendrelaphis tristis*	Common Bronzeback Tree Snake	NA	VR
50	*Lycodon striatus*	Barred Wolf Snake	LC	VR
51	*Lycodon travancoricus*	Travancore Wolf Snake	LC	UC
52	*Oligodon travancoricus*	Travancore Kukri Snake	DD	VR
53	*Oligodon spp.*	Kukri Snake spp.	UI	VR
54	*Ptyas mucosa*	Indian Rat Snake	NA	C
55	*Sibynophis subpunctatus*	Dumeril's Black-headed Snake	NA	VR
	Family : Xenodermatidae			
56	*Xylophis captaini*	Captain's Wood Snake*	LC	UC
	Family : Natricidae			
57	*Amphiesma beddomei*	Beddome's Keelback*	LC	UC
58	*Amphiesma monticola*	Mountain Keelback*	LC	R
59	*Xenochrophis cf piscator*	Checkered Keelback	NA	R
	Family : Elaphidae			
60	*Bungarus caeruleus*	Common Indian Krait	NA	VR
61	*Calliophis beddomei*	Beddome's Coral Snake	DD	VR
62	*Calliophis nigrescens*	Stripped Coral Snake	LC	VR
63	*Naja naja*	Spectacled Cobra	NA	VR
64	*Ophiophagus hannah*	King Cobra	VU	R
	Family : Viperidae			
65	*Hypnale hypnale*	Hump-nosed Pit Viper	NA	C
66	*Trimeresurus macrolepis*	Large-scaled Pit Viper*	NT	VR
67	*Trimeresurus malabaricus*	Malabar Pit Viper*	LC	C
	ORDER: TESTUDINES			
	Family : Uropeltidae			
68	*Indotestudo travancorica*	Travancore Tortoise*	VU	R
69	*Melanochelys trijuga*	Indian Black Turtle	NT	VR
70	*Vijayachelys silvatica*	Cochin Forest Cane Turtle*	EN	VR

*****Endemic to the Western Ghats, **IUCN status**: LC-Least Concern, NT-Near Threatened, VU-Vulnerable, EN-Endangered, **#Obs =Number of Observations**: C-Common (>20), UC-Uncommon (10-20), R-Rare (5-10), VR-Very Rare (<5). ‘***cf*** ‘= to be compared.

Appendix 2: List of environmental layers considered for Maxent modeling

Sl.	Type of variable	Environmental Layers	Source
1	Bioclimatic	BIO1 = Annual Mean Temperature	WorldClim
2	Bioclimatic	BIO2 = Mean Diurnal Range (Mean of monthly (max temp - min temp))	WorldClim
3	Bioclimatic	BIO3 = Isothermality (BIO2/BIO7) (* 100)	WorldClim
4	Bioclimatic	BIO4 = Temperature Seasonality (standard deviation *100)	WorldClim
5	Bioclimatic	BIO5 = Max Temperature of Warmest Month	WorldClim
6	Bioclimatic	BIO6 = Min Temperature of Coldest Month	WorldClim
7	Bioclimatic	BIO7 = Temperature Annual Range (BIO5-BIO6)	WorldClim
8	Bioclimatic	BIO8 = Mean Temperature of Wettest Quarter	WorldClim
9	Bioclimatic	BIO9 = Mean Temperature of Driest Quarter	WorldClim
10	Bioclimatic	BIO10 = Mean Temperature of Warmest Quarter	WorldClim
11	Bioclimatic	BIO11 = Mean Temperature of Coldest Quarter	WorldClim
12	Bioclimatic	BIO12 = Annual Precipitation	WorldClim
13	Bioclimatic	BIO13 = Precipitation of Wettest Month	WorldClim
14	Bioclimatic	BIO14 = Precipitation of Driest Month	WorldClim
15	Bioclimatic	BIO15 = Precipitation Seasonality (Coefficient of Variation)	WorldClim
16	Bioclimatic	BIO16 = Precipitation of Wettest Quarter	WorldClim
17	Bioclimatic	BIO17 = Precipitation of Driest Quarter	WorldClim
18	Bioclimatic	BIO18 = Precipitation of Warmest Quarter	WorldClim
19	Bioclimatic	BIO19 = Precipitation of Coldest Quarter	WorldClim
20	Topographic	Altitude= Height above mean sea level	SRTM
21	Topographic	Slope = Degree of flow	SRTM
22	Topographic	Aspect = Direction of the slope	SRTM
23	Land Cover	Percent tree cover	MODIS
24	Land Cover	Percent non-tree vegetation= Herb cover	MODIS
25	Land Cover	Percent non-vegetated= Open area	MODIS