HERPETOFAUNAL DIVERSITY IN SWAMP (VAYAL) ECOSYSTEMS IN PERIYAR TIGER RESERVE, WESTERN GHATS

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requirements for the Degree of

DOCTOR OF PHILOSOPHY in ZOOLOGY

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CERTIFICATE

This is to certify that the thesis entitled **Herpetofaunal Diversity in Swamp (Vayal) Ecosystems in Periyar Tiger Reserve, Western Ghats** is an authentic record of research work carried out by **Mr. K. P. Rajkumar** under my supervision and guidance in KSCSTE- Kerala Forest Research Institute in partial-fulfilment of the requirements for the degree of Doctor of Philosophy of the University of Calicut. The work has not been previously submitted for the award of any degree, diploma, associateship or other similar titles to any candidate of any university.

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DECLARATION

I, Rajkumar K.P. do hereby declare that the thesis entitled **Herpetofaunal Diversity in Swamp (Vayal) Ecosystems in Periyar Tiger Reserve, Western Ghats** is an authentic record of the research work carried out by me in KSCSTE - Kerala Forest Research Institute under the guidance of **Dr. P.S. Easa**. I further declare that no part of this thesis has been submitted previously for any other degree or diploma of this or any other university.

Rajkumar K.P.

Thrissur
February 22, 2022

Dedicated to my father and uncle

Table of Contents

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Abstract

Amphibians and reptiles are considered to be an integral part of an ecosystem and are reported to play a key role in the maintaining the ecosystem balance providing considerably to the ecosystem services. These groups of animals, together knows as herpetofauna, face severe threats in the wake of habitat loss, land use change and global climate change. The problem is exacerbated mostly because of their morphological and physiological features and confinement to very specialized habitats. Though a number of studies have contributed to the understanding of the species, most of them were species descriptions and a few on the ecological aspects. The Western Ghats, a biodiversity hotspot, has witnessed several new species descriptions recently using a combination of traditional and molecular taxonomy methods. However, detailed investigations on the distribution and ecological requirements have not been addressed.

Periyar Tiger Reserve, the largest Protected Area in Kerala provide varied variety of habitats supporting diverse animals and plants. The area with different types of vegetation types are interspersed with very unique ecosystem called *vayals* (swamps). A number of explorations in the Reserve have documented floristic and faunistic diversity in the Tiger Reserve. As a part of these investigations, the herpetofauna has also been listed. However, there had not been any habitat specific or species specific studies. The present study attempts to fill this lacuna with focus on the species richness and abundance in the *vayal* ecosystem surrounded by different vegetation types, plant composition, extent and elevation. The study also investigated the distribution of habitat restricted amphibian *Raorchestes travancoricus* along with the mechanism of niche separation of the species with sympatrics.

Reconnaissance surveys were conducted documenting the *vayals* along with their location, surrounding vegetation, plant composition, extent and elevation. The *vayals* were grouped into different categories mainly depending on the surrounding vegetation types. Forty seven *vayals* were selected as sampling units for intensive studies from 2015 to 2018 covering different seasons. These sampling units were surveyed using quadrat survey, line transect survey and visual encounter survey. Amphibian and reptile species richness was more close to the calculated mean species richness from time constrained visual encounter survey compared to the results obtained from other methods. Hence, data from visual encounter surveys were used for further analysis. Diversity indices were estimated for the herpetofauna in the *vayals* and surrounding vegetation for understanding the difference in the diversity between *vayals* and the surrounding vegetation. Diversity t - test was conducted for testing the significance of the diversity richness between *vayals* and surrounding vegetation. The result thus obtained was subjected to perMANOVA test for confirming the results of the t-test.

The *vayals* were ranked based on plant composition. These vayals were classified into different groups based on the extent, surrounding vegetation, elevation and plant composition. The diversity within *vayals* was tested for identifying the influence of surrounding vegetation, plant composition and elevation of the sampled *vayals* through cluster analysis. Rank abundance curves were generated for understanding the dominance of different herpetofauna in *vayals*. This information was used to identify generalist and habitat specific species. Non-metric multidimensional scaling (NMDS) ordination biplots were generated for further understanding the factors influencing diversity in *vayals*.

Raorchestes travancoricus was rediscovered recently and considered to be range restricted only known from three localities. Later, eight more distribution locations were identified from Periyar Tiger Reserve during the study. Based on features of these eleven locations, species distribution modelling was done using MaxEnt. Based on the model, further ground trothing surveys were conducted. Spatial and temporal niche partitioning was studied through visual encounter survey and audio-strip transects. Different parameters of vocalization was also studied.

Amphibian diversity in the vayals and its immediate surrounding vegetation were seen similar. But the reptile diversity varied considerably. The species richness of amphibians and reptiles were higher in the surrounding vegetation. This is attributed to fewer micro-habitats and low structural complexity of *vayals.* Further, lack of connectivity between *vayals* also contributed to this situation. There was no *vayal* specific herpetofauna identified during the study indication avoidance of extinction possibility because of lack of connectivity with the nearby *vayals*.

Some of the widely distributed amphibians and reptiles were recorded from *vayals* in all the five different vegetation types. Statistical analyses show that the amphibian diversity in the *vayals* were significantly associated with surrounding vegetation, altitude and plant composition of *vayals* and not with the extent. On the other hand, reptiles were significantly associated with the altitude and surrounding vegetation of *vayals* and not with the plant composition and extent. SDM-based distribution survey yielded 12 new locations of the rare *R. travancoricus* within Periyar thereby increasing the number of locations to twenty three. The grass species, *Chrysopogon hackelii* was found to be the preferred niche for *R. travancoricus* in grasslands. *R. travancoricus* and its three sympatric bush frogs spatially partition niches and also temporally partition acoustic activity. This helps Anurans to avoid competition and improve their breeding success. The call repertoire and morphometric studies yielded additional quantitative information on advertisement call parameters and morphometrics of the rare and endangered *R travancoricus.*

List of Figures

List of Tables

Chapter 1

Introduction

Chapter 1. Introduction

The biosphere we live in is immensely rich in biodiversity. Unfortunately, these are under serious threats from human interventions. We count all terrestrial and aquatic organisms including plants, animals, and microbes as our biodiversity with different scales like genetic, species and ecosystem diversity. The current knowledge is limited to the ecosystem diversity. Based on the recent calculations there are about 1.74 million known species on earth (Chapman, 2009; May, 2010; Costello, 2013). There is still an uncertainty regarding the total number of species in the world and more species are considered yet to be described. Mora *et al.* (2011) estimated the number as 8.7 million species. According to May (2010), it is between 3 to 100 million. At the current rate of extinction and the rate of describing new species, it is feared that majority of the species would go extinct before we describe them. For describing the remaining species in our planet, It may take 1200 years, 303000 taxonomists and 364 Billion US dollars for describing the remaining undiscovered species (Mora *et. al* 2011).

According to some authors, the global biodiversity is currently facing the sixth mass extinction (Wake and Vrendenburg, 2008; Cafaro, 2015; Ceballos *et al*., 2015; Ceballos, 2017). Though extinctions are part of the history of the planet, the current extinction rate is believed to be 1000 times higher than the last five mass extinction (Pimm, 1995; Ceballos *et al*., 2015). Asteroids, volcanic eruptions and natural climate change caused the last five mass extinctions. However, the current mass extinction is human-induced (Pimm, 1995; Wake and Vredenburg, 2008; Cafaro, 2015; Ceballos *et al*., 2015). Habitat modifications and degradation severely affect global biodiversity and contribute to climate change, which in turn contribute more to the loss of species. Major victims of the current extinction are the species that are rare, elusive, range-restricted and endemic (Pimm, 1995). Tropical moist forests with complex habitats and high biodiversity hold two-thirds of all species on earth with a high rate of endemism (Pimm, 1995; Myers *et al*., 2000; Bohm *et al*., 2013). The tropical region, with all these characteristic features, is expected to witness the highest loss of species (Ricketts *et al*., 2005) because of the human induced factors (Ceballos *et al*., 2015). .

Amphibians are the major victims of this global crisis with the highest species loss. More than 200 species of amphibians have gone extinct and close to 40% of them are reported to be at the brink of extinction (Wake and Vredenburg, 2008; Alroy, 2015). According to Ricketts *et al*. (2005), about 423 species of amphibians and 15 species of reptiles may soon go extinct (. Restricted distribution of species with the destruction of their current habitat, fragmentation, disease, and climate change are the major triggering factors for extinction (Wake and Vredenburg, 2008). The tropical regions have very high amphibians and reptile species richness and also the highest number of threatened and data deficient species (Bohm *et al*., 2013). Many recently described amphibians and reptiles have very restricted distribution, especially the ones in the tropics. This diversity loss will hamper the equilibrium of the ecosystem and ecosystem services. Site-specific actions are required to protect them.. However, our knowledge on the species requirements are scarce and hence detailed studies on community ecology are essential. The importance of studies on diversity, distribution and status for priority actions and utilization of our limited resources efficiently have been stressed by a number of authors (Salafsky *et al*., 2008; Balaji *et al*., 2014). Several studies addressed this aspect and suggested priority areas for birds (Brooks *et al*., 2004; Orme *et al*., 2005; Lamoreux *et al*., 2006), mammals (Brooks *et al*., 2004; Ceballos and Ehrlich, 2006; Lamoreux *et al*., 2006), amphibians (Brooks *et al*., 2004; Lamoreux *et al*., 2006) and reptiles (Lamoreux *et al*., 2006).

The term herpetology refers to the study of both amphibians and reptiles because of several physiological, generalized morphological, behavioural, and ecological similarities which help biologists to study them together (Vitt and Caldwell, 2014). Though many groups of ancestors went extinct, several other groups survived the mass extinctions (Wake and Vrendenburg, 2008; Vitt and Caldwell, 2014). Amphibians evolved in the late Devonian and survived the second mass extinction event that took place in the late Devonian period. They survived not only the second mass extinction but also the third (Permian–Triassic extinction), fourth (End Triassic extinction), and the fifth (Cretaceous-Tertiary extinction) mass extinction (Wake and Vrendenburg, 2008). Amphibians were the first land vertebrates but they were always associated with water and moisture whereas reptiles were the first land vertebrates that radiated to almost all the microhabitats, from wet to dry and fossorial to arboreal. All these acquired majorly two adaptations 1) ability to reproduce on land in the absence of water and 2) absence of wet skin.

Mostly in amphibian and reptile males and females are an integral part of reproduction. But there are several exceptions in amphibians and reptiles (Asher and Nace, 1971; Maslin, 1971; Bi *et al*., 2007; Kearney *et al*., 2009; Abdala *et al*., 2016). Directly or indirectly, the environmental cues such as photoperiod, precipitation and temperature are triggering reproduction. But more control over the timing of reproduction is possessed by hormones (Vitt and Caldwell, 2014). Amphibians show both external (anamniotic egg) and internal fertilization while reptiles show internal fertilization (amniotic egg). When we look at the males' and females' contribution in reproduction, relatively females spend more energy for producing eggs than the males that produced millions of sperms (Wells, 2007; Vitt and Caldwell, 2014). In amphibians and reptiles, the breeding behavior varies considerably. They use tactile, visual, chemical, and acoustic cues during courtship. This not only helps individuals to come together for breeding but also serves as a sexual selection criterion (Wells, 2007; Vitt and Caldwell, 2014). The reproductive ecology of amphibians varies considerably. Many amphibians lay eggs in water and have an indirect development, many others on land and several other species have arboreal oviposition sites. Detailed studies on the breeding ecology of anurans alone identified 39 breeding modes (Crump, 2015). Most reptiles lay eggs in constructed nests (oviparous) and the viviparous reptiles give birth to young ones (Vitt and Caldwell, 2014). Among the oviparous reptiles, a number species of crocodiles, lizards and turtles show temperature-mediated sex determination. Several species of amphibians and reptiles breed seasonally but many others breed whenever they find favorable conditions. A high level of seasonality in breeding is reported especially among those in temperate zone (Vitt and Caldwell, 2014).

Movement and utilization of home range in amphibians and reptiles vary considerably. Physical characteristics of their habitat and their requirement play a crucial role in their distribution (Wells, 2007; Vitt and Caldwell, 2014). Amphibians and reptiles are mostly philopatric (Gibbons, 2000). Studies have reported that many species use the same home range for years (Marvin, 2001; Rebelo and Leclair, 2003; Wells, 2007). The size of the home range varies according to age, size, sex, and availability of resources (Wells, 2007; Vitt and Caldwell, 2014). A part of the home range with defendable resources will be maintained and defended by the animal and in some cases, the entire home range is defended (Vitt and Caldwell, 2014). Amphibians and reptiles use different communication methods like chemical (caecilians, salamanders, turtles, lizards, snakes), tactile (salamanders, anurans, turtles), visual (salamanders, anurans, crocodiles, lizards, snakes) and acoustic (anurans, lizards, crocodiles). The chemical communication method is highly developed and the chemicals produced for communication are detected by only conspecifics. In visual communication, they use different methods like particular body or body part movements like movement of hind limb or forelimb in a particular pattern, head bobs, or showing particular body part with distinct colour and shape like dewlap, head, etc. (Vitt and Caldwell, 2014). All these communication methods help them in breeding success. Apart from this, sexual dimorphism in amphibians and reptiles also plays a crucial role in sexual selection and breeding success.

Even though a wide variety of food items are available for amphibians and reptiles, they show preference in selecting the food and not feeding everything (Wells, 2007; Vitt and Caldwell, 2014). The diet of herpetofauna comprises a variety of food from plants to invertebrates and vertebrates. Anurans, salamanders, and lizards mostly feed on insects or invertebrates; caecilians mainly feed on earthworms and other invertebrates; turtles feed on plants, invertebrates, and vertebrates; snakes prefer invertebrates and vertebrate prey and a few of the lizards are herbivores (Wells, 2007; Dodd, 2009; Vitt and Caldwell, 2014; Dodd, 2016). Food preference and capturing methods have evolutionary significance; related species mostly prefer same food and follow similar methods to acquire an injection of food (Vitt and Caldwell, 2014). There are mainly two types of foraging modes; active foraging and sit-and-wait foraging. Active foragers spend more energy in searching for prey and less during capture and handling. The sit-and-wait predators spend not much energy for finding the prey but spend more energy during capture and handling (Vitt and Caldwell, 2014). Sit and wait predators find suitable locations with high prey abundance and stay stationary until they find prey close to their range for capture. They rely on a wide variety of cues like visual, tactile, chemical, auditory, and thermal cues for detecting prey. These cues are well developed and help them in locating the prey, identifying the prey, speed of prey movement, distance to the prey, etc. After capturing the prey, amphibians and reptiles swallow their prey. The process involves a variety of methods like biting and grasping, constricting, injecting venom, projectile tongue, and inertial suction feeding (Smith, 1935; Vitt and Caldwell, 2014) based on the food preference. Like the cues used for finding prey and conspecifics, amphibians and reptiles use these cues for avoiding predators with a combination of adaptation like cryptic coloration, disruptive colouration, mimicry, aposematic colouration, warning postures and displays, adapting acoustic signals, autotomy, acting dead and producing chemicals to deter a predator.

The diversity and distribution among amphibians and reptiles is always a fascinating world for ecologists. Not all the species are found in all the available habitats and not all prefer all the food items available. They partition their resources with others to survive in a community. Their interactions with conspecifics and other species lead ecologists to consider them as model organisms to study the evolution of behavioural ecology

(Cannatella *et al*., 1993; Shaffer, 1993; Qualls and Shine, 1995; Blackburn, 2006; Wells, 2007; Vitt and Caldwell, 2014). Currently, the living amphibians are represented by three orders *viz*. Caudata (Newts and Salamanders), Anura (Frogs and Toads) and Apoda (Caecilians) and reptiles by four orders *viz*. Testudines (Turtles), Rhynchocephalia (tuatara), Squamata (snakes and lizards) and Crocodilia (Crocodiles). In India, we have representatives of all the three orders of amphibians. In reptiles, we have representatives of three orders *viz*. Testudines, Squamata and Crocodilia. The order Rhynchocephalia is endemic to New Zealand. A total of 8,428 species of amphibians (till 15th February 2022) and a total of 11,690 species of reptiles (till November 2021) were recorded globally (Amphibia Web, 2022; Uetz *et al*., 2021). More than 150 species of amphibians and reptiles are described every year. At the same time, these species are facing a severe threat of extinction (Ricketts *et al*., 2005; Wake and Vredenburg, 2008; Maxell, 2009; Alroy, 2015). Habitat destruction, climate change, and diseases are the prime factors that destroy this rich herpetofaunal diversity (Pimm, 1995; Gibbons *et al*., 2000; Ricketts *et al*., 2005; Araujo *et al*., 2006; Wake and Vredenburg, 2008; Garmyn *et al*., 2012; Bohm *et al*., 2013; Alroy, 2015).

Most of the amphibians (90%) and reptiles (59%) present in Kerala are endemic to the Western Ghats hill ranges (Nameer *et al*. 2015). In the current face of 6th mass extinction, these endemic and range-restricted species are going to be the prime victims. Understanding their ecological information like habitat, community ecology, status, and behavioral ecology are essential to formulate conservation strategies. It is a crucial time to study the amphibians and reptiles and generate data locally that will contribute to the herpetofaunal and biodiversity conservation.

The studies particular to Periyar started around seven decades back. A number of scientific papers have been published based on the studies in the area. The fauna of the area was described by several authors (Chacko, 1948; Jackson, 1971; Horwich, 1972; Vijayan, 1980; Mathavan and Miller, 1988; Srivastava *et al.*, 1993; Palot *et al.,* 1997; Zacharias, 1997; Joseph *et al.,* 1998; Ramakrishnan *et al.,*1998; Radhakrishnan, 1999; Easa, 2001; Easa and Jahas, 2002; Andrews *et al.,*2005a and 2005b; Sivadasan *et al.,* 2013; Sathiandran *et al.,* 2015; Nameer *et al.,* 2015; Rajkumar *et al.,* 2018; David *et al.,* 2019). The floristic studies include Srivastava *et al.* (1994), Rajesh *et al*. (1997), Sasidharan *et al.* (1997), Sasidharan*et et al.* (1998), Augustine *et al.* (1999), Sasidharan *et al.* (2000) and Sundarapandian and Karoor (2013).

A number of studies on ecological aspects of the Protected Area were also reported (Nair *et al.,* 1985; Srivastava *et al.,* 1995; Srivastava *et al.,* 1996 a, b, c; Harikumar *et al.,* 2001; Arun *et al.*, 2001; Sajan and Veeramani, 2002; Nair, 2002). Ramachandran *et al.* (1987) reviewed the management practices in Periyar. Results of short and long term studies on various socio-economic aspects, tourism, pilgrimage and eco-development programmes were also published (Sankar *et al.,* 2000; Gurukkal, 2003; Kutty and Nair, 2005; Thampi, 2005; Gubbi, 2006; Pillai and Suchintha, 2006; Gubbi and McMillan, 2008; Gubbi *et al.,* 2008; Damayanti and Masuda, 2008; Chundamannil and Krishnankutty, 2009; Krishnankutty and Chundamannil, 2009; Libinson and Muraleedharan, 2011; Daniel and Baby, 2012; Gubbi and Linkie, 2012; Mathew *et al.,* 2012; Augustine *et al.,* 2010; Parr, 2015; Jose, 2015; Ajin *et al.,* 2016).

Amphibians and reptiles were comparatively least studied and were confined to inventories. In addition, the species richness of this group is documented based on short-term studies (Ravichandran *et al*., 1990; Zacharias and Bharadwaj, 1996; Zacharias, 1997; Das *et al*., 2015; Rajkumar *et al*., 2018). Being the largest Protected Area in Kerala, Periyar Tiger Reserve offers high diversity of habitats with very good opportunity to document the amphibians and reptiles. The swamp habitats in Periyar Tiger Reserve is a unique wetland habitat that plays an important role in maintaining forest biodiversity and water regime (Sreejith *et al.,* 2014). Wetlands act as inevitable habitat for many amphibians and reptiles (Scott, 1982; Icochea *et al*., 2002; Bolen, 2003; Menegon, 2005; Araujo *et al*., 2006; Behangana *et al*., 2009; Maxell, 2009; Jestrzemski *et al*., 2013; Balaji *et al*., 2014; Roth-Monzón *et al*., 2018). On comparing with vernal pools seen in the Mediterranean climate, vayals share several similar characteristics. Vernal and similar man-made pools support herpetofaunal assemblage and for the conservation of amphibians (Calhoun *et al*., 2003; McGreavy *et al*., 2012; Franzem *et al*., 2017; Snyder, 2020). The vayals in Periyar are also unique in that they vary a lot due to the difference in the locations. They are seen in all types of larger habitats and thus are surrounded by varying vegetation types. Therefore, a long-term study on the herpetofaunal assemblage in these vayal habitats will generate information useful for planning strategies for the conservation of these unique wetlands and its unique, highly endemic herpetofaunal assemblage.

The predictions of impact due to climate change indicate drastic effect on the wetlands and the related species. This impact would be greater on habitat specialists and species with restricted distribution. Considering the importance of vayal ecosystem in providing the unique habitat for maintaining a good population of herpetofauna, the present investigation focused on generating information to understand the herpetofaunal assemblage in the vayal ecosystem and its association with the vayal habitat. The major thrust of the present study were;

1. Documentation of diversity and distribution of reptiles and amphibians in the swamps ecosystem and the immediate surrounding vegetation.
2. Assessment of herpetofaunal diversity in relation to the size and composition of swamps and surrounding vegetation.
3. Detailed study on the status, distribution, and behaviour of *Raorchestes travancoricus* in Periyar Tiger Reserve.

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Chapter 2

Literature Review

Chapter 2. Literature Review

2.1 Introduction

Biologists have grouped amphibians and reptiles under the term herpetofauna and the study of herpetofauna is called herpetology. Amphibians and reptiles are considered to share several physiological, generalized morphological, behavioural and ecological characters (O'Rourke, 2007; Wells, 2007; Vitt and Caldwell, 2014). The term herpetology was first used in 1824 (Merriam-Webster.com) and referred to study amphibians and reptiles. There are books on amphibians and reptiles that were published in 1858 (Girard, 1858) and this could be one of the first books on these two taxa together. Currently, we have a total of 8,428 species of amphibians (till 15th February 2022) and 11,690 species of reptiles (till November 2021) globally (Amphibia Web, 2022; Uetz *et al*., 2021), and every year more than 150 new amphibians and reptiles are being added to the list.

Historical herpetofaunal studies are mainly based on the collections done during the expeditions done by Western people around the globe (Girard, 1858; Deraniyagala, 1974; Bauer and Adler, 2001). These studies mainly focused on describing new species and cataloging amphibians and reptiles in different Natural History Museums. Studies on biology and natural history date back to the 18th century (O'Rourke, 2007). According to McCallum and McCallum (2006), natural history studies on herpetofauna are declining though this is considered to be an inevitable part of conservation (McCallum and McCallum, 2006).

The field of herpetology deals with different aspects like physiology (Brattstrom, 1979; Blackbum, 1999; Shine and Kearney, 2001; Seebacher and Shine, 2004; Blackburn, 2006; Burggren and Warburton 2007; Veeranagoudar *et al*., 2010), anatomy (Irwin and Ferguson, 1986; Doving and Trotier, 1998; Rehorek *et al*., 2000; Nishikawa and Schwenk, 2002; deRicqles *et al*., 2004; Elias-Costa *et al*., 2017; Strong *et al*., 2021), behaviour (Marcellini, 1974; Lopez *et al*., 1988; Ryan, 1988; Peterson and Stone, 2000; Rebelo and Leclair, 2003; Cooper, 2006; Radder *et al*., 2006; Crump, 2015), ecology (Heying, 2001; Luiselli and Akani, 2002; Giaretta and Kokubum, 2004; Baker and Richardson, 2006; Biju, 2009; Akani and Luiselli, 2010; Meng *et al*., 2016; Mikula *et al*., 2018), evolution (Johnson, 1956; Kochva, 1987; Altig and McDiarmid, 2007; Carroll, 2009; Brinkman *et al*., 2013; Dutta *et al*., 2004; Schoch, 2014; Fry, 2015; Meegaskumbura *et al*., 2015; Antunes, 2020; Sues, 2019), taxonomy (Beddome, 1878; Boulenger, 1891; Pillai and Pattabiraman, 1981; Das, 1991; Hoogmoed and Prudente, 2003; Das *et al*., 2008; Passos and Fernandes, 2008; Biju and Bossuyt, 2009; Vassilieva *et al*., 2014; Rojas *et al*., 2015; Vijayakumar *et al*., 2014; Chaitanya *et al*., 2019) and biogeography (Martin, 1958; Lanza, 1990; Datta-Roy and Karanth, 2009; Datta-Roy *et al*., 2012; Sillero *et al*., 2014).

2.2 Herpetofauna - World

Amphibians and reptiles are philopatric (except sea turtles and some lizards) and this makes them the most vulnerable group of vertebrates to habitat modifications (Gibbons, 2000). This is far more detrimental than the global temperature rise (Araujo *et al*., 2006). The exponential growth of the human population leads to the expansion of agriculture and farmlands resulting in clearing of more natural habitats like the forest, grassland, aquatic ecosystems, etc. (Vitt and Caldwell, 2014). This leads to a reduction in the herpetofaunal abundance in the edges of modified areas. Conversion of natural habitats reduces the humidity and increases light intensity (Vitt and Caldwell, 2014) and this is not desirable for amphibians. The rise in global temperature rise melting of polar ice will exacerbate the life of species in the coastal areas and plains (Vitt and Caldwell, 2014).

Moist forests in the tropical region are complex and hold two-thirds of all species on earth (Pimm, 1995; Myers *et al*., 2000; Bohm *et al*., 2013). The highest amphibians and reptile species richness was also reported from tropical forests with a high rate of threatened and data deficient species (Bohm *et al*., 2013).

2.3 Herpetofauna – India and the Western Ghats

First records of Indian amphibians and reptiles were reported in the piece of literature in the Western world. Earlier reports were based on the collections of amphibians and reptiles from India, Portuguese, German, Dutch, and French writers had mentioned in their literature in the 16th century about Indian herpetofauna (Deraniyagala, 1974). Studies on amphibians and reptiles started around 200 years ago (Palot, 2015). Some of the pioneering works are done by Jerdon (1853); Theobald (1868; 1876); Anderson (1871); Beddome (1878; 1886) and Boulenger (1882; 1890). Jerdon (1853) published the reptiles from peninsular India. The book by Gunther (1864) had reported 52 species of amphibians and 371 reptiles from India. Theobald (1876) published a descriptive book on the 463 reptiles and and the work by Anderson (1871) had a detailed description of 24 species of amphibians and 90 species of reptiles. Beddome (1878) described six new fossorial snakes from southern India. There were a few remarkable books like the one by Ewart (1878) on venomous snakes. There were several detailed descriptions of known and new amphibians and reptiles were published (Boulenger, 1882; Beddome, 1886; Boulenger, 1891; Sclater, 1891; Ferguson, 1895; Wall, 1912). The book titled 'Fauna of British India including Ceylon and Burma' by Boulenger (1890) was an important one. It has a detailed description of 130 species of amphibians and 538 species of reptiles. The work by Annandale and Rao (1916 and 1917) and Annandale (1918) on tadpoles of several Indian amphibians was a remarkable work. One of the major contributions to Indian herpetology was from Smith. The three volumes of 'Fauna of British India' (1931, 1935 and 1943) are considered to be the bible of Indian herpetology. Most of the studies prior to 1940s focused on species descriptions. From the 1940s till the 1980s, not many publications on the group was seen.

Diversity studies picked up momentum after the 1980s and herpetofaunal surveys mostly focused on documenting the diversity. In-between, a few amphibians and reptiles were described (Pillai and Pattabiraman, 1981; Dubois, 1984; Inger *et al*., 1984; Chanda, 1986; Pillai, 1986; Chanda, 1990a, 1990b; Pillai and Pattabiraman, 1990; Ray, 1992a, 1992b; Dutta, 1997; Das and Chanda, 1997; Ravichandran, 1997; Das and Chanda, 1998; Das and Bauer, 2000; Das and Sengupta, 2000; Vasudevan and Dutta, 2000; Bauer, 2002; Bossuyt, 2002; Biju and Bossuyt, 2003; Giri *et al*., 2003; Bhatta and Srinivasa, 2004; Giri *et al*., 2004).

Some of the diversity documentation studies on herpetofauna of the Western Ghats regions were published by various authors. Murthy (1981, 1986) reported the findings of the survey on reptile diversity of Silent Valley and New Amarabalam. Shieldtail snakes of the Western Ghats described with taxonomy, ecology, biology and distribution by Rajendran (1985). Amphibians and reptiles by Inger *et al*. (1984), Uropeltid snakes by Murthy (1992), reptiles of Silent Valley by Thomas and Easa (1997), Wayanad by Thomas *et al*. (1997), amphibians of India by Dutta (1997) and Das and Dutta (1998), amphibians and reptiles of Nilgiri Biosphere Reserve by Easa (1998), reptiles of Chinnar by Abraham *et al*. (1999) and two rare snakes by Ajit (2000) and amphibians and reptiles of Kalakkad by Cherian *et al*. (2000) were a few of the noted publications. Vasudevan *et al*. (2001) published a detailed report on the amphibian communities in Kalakkad-Mundanthurai Tiger Reserve with descriptions of their structure and composition. Palot and Radhakrishnan (2002) reported the amphibian and reptile diversity from Madayipara, one of the isolated hillock in Kannur district. .

In 2003, Biju studied and described breeding modes in the shrub frog *Philautus glandulosus*. Amphibians and reptiles of Nallamala Hills were reported by Srinivasulu and Das (2008). Dinesh *et al*. (2009) compiled a checklist of amphibians in India. Amphibian and reptile diversity in Cardamom Hill Reserve and Ponmudi hills were studied by Chandramouli and Ganesh (2010). A checklist of reptiles in Kerala was prepared by Palot and Radhakrishnan (2011) and the list for India was updated by Aengals *et al*. (2011). Srinivas and Bhupathy (2013) surveyed the Meghamalai area over three years and reported 35 species of amphibians. Bhupathy and Sathishkumar (2013) surveyed the same areas for over two years and updated the checklist of reptiles with a total of 90 reptiles belonging to 14 families. Ganesh *et al*. (2014) studied the snake diversity of the High Wavy Mountains Chaitanya *et al*. (2018) studied the amphibian and reptile diversity in the Meghamalai Wildlife sanctuary and added five amphibians and nine reptiles to the existing checklist.

There were a few behavioural and ecological studies conducted during this period. These include Radder *et al*. (2006a and 2006b) on the behavioral aspects of *Psammophilus dorsalis* and the influence of elevation on amphibian richness by Naniwadekar and Vasudevan (2007). The study of *Pseudophilautus kani* and *Raorchestes graminirupes* by Bee *et al*. (2013a, 2013b) was probably the first study on vocal repertoire. Flight initiation study on *Psammophilus dorsalis* by Sreekar and Quader (2013), visual signals and behavior during breeding in fan throated lizards by Patankar *et al*. (2013), the novel reproductive mode described in the genus *Raorchestes* by Seshadri *et al*. (2014) were a few other studies on behavior.

There was a major shift in amphibian and reptile research in India starting from 2005/2010. Biologists initiated amphibian surveys in unexplored or underexplored areas describing new species and the same trend is visible in reptiles after 2010. The studies were based on the combination of molecular and classical taxonomic tools. In amphibians' descriptions, their acoustic characters also played an important role. Vasudevan and Dutta (2000) described a new species of flying frog and Bossuyt (2002) described new bush frog. Das and Sengupta (2000), Das and Bauer (2000) and Bauer (2002) described new species of lizards from the genus *Cnemmaspis*. Biju and Bossuyt (2003) described *Nasikabatrachus sahyadrensis*, which is considered to be a living fossil. New species of shrub frogs by Biju and Bossuyt (2005a and 2005b), new *Cnemaspis* by Mukherjee *et al*. (2005) and a night frog (*Nyctibatrachus*) by Das and Kunte (2005) were other notable ones. The description of new species continued as a result of surveys in different areas. These include shrub frogs by Biju and Bossuyt

(2006), night frog (*Nyctibatrachus*) by Biju *et al*. (2007), four new Ranid species by Kuramoto *et al*. (2007), new species of gecko (*Hemidactylus*) by Giri (2007), 12 new bush frogs by Biju and Bossuyt (2009), day gecko (*Cnemaspis*) by Giri *et al*. (2009), new *Hemidactylus* sp. by Mahony (2009), one new bush frog by Biju *et al*. (2010), 12 new night frogs by Biju *et al*. (2011), tree snake by Vogel and Rooijen (2011) and nine new species of bush frogs by Zachariah *et al*. (2011). In 2013, Abraham *et al*. described a new species of tree frog belonging to a monotypic genus and a new species of fossorial snake was reported by Aengals and Ganesh (2013). A new species of ground-dwelling day gecko from Kottiyoor was reported by Cyriac and Umesh (2014).

Systematic revision of the genus *Hylarana* had description of seven new species (Biju *et al*., 2014) and reported nine new species of bush frogs Vijayakumar *et al*. (2014). New day geckos belonging to the genus *Cnemaspis* was described by Srinivasulu *et al*. (2015) from Karnataka, from Amboli by Sayyed *et al*. (2016), from the southern Western Ghats by Cyriac *et al*. (2018), from the northern Western Ghats by Sayyed *et al*. (2018), from Tamil Nadu by Khandekar *et al*. (2019). A new species of *Fejervarya* was reported by Dinesh *et al*. (2015), four species belonging to Ranixalidae by Dahanukar *et al*. (2016), two bush frogs by Zachariah *et al*. (2016), and two *Indirana* by Garg and Biju (2016). A new species of frog *Nasikabatrachus bhupathi* was reported from the eastern slopes of Western Ghats by Janani *et al*. (2017). Garg and Biju (2017) described four new species of burrowing frogs, Giri *et al*. (2017) a snake and Murthy *et al*. (2015) a gecko. New species of snake by Jins *et al*. (2018), Narrow-mouthed Frog by Vineeth *et al*. (2018), *Fejervarya* frogs by Raj *et al*. (2018), a snake by Deepak *et al*.

(2019), *Cnemaspis* geckos by Khandekar *et al*. (2019), six geckos by Chaitanya *et al*. (2019), a narrow-mouthed frog by Garg *et al*. (2019) and another one by Das *et al*. (2019) and one more by Biju *et al*. (2019) were yet another land mark studies. Cyriac *et al*. (2020) described a fossorial snake (shield tail), Deepak *et al*. (2020) described a new species of fossorial (*Xylophis*), Mallik *et al*. (2020) described five new species of Vine Snake (*Ahaetulla*) and Mallik *et al*. (2021) four new species of Pit Viper and Garg *et al*. (2021) described five new species of bush frogs.

2.4 Species Distribution Model Studies

Studying rare and cryptic species is always difficult. Using limited resources in a limited time to generate more quantitative data on such species is always challenging. Species Distribution modelling is a tool that helps to focus survey efforts and avoid spending resources in the least possible locations like the studies by Siqueira *et al*. (2009), Schingen *et al*. (2014), Singh *et al*. (2015), McCune (2016) and Helmstetter *et al*. (2021). Pearson *et al*. (2007) suggested the MaxEnt model for predicting the distribution of rare species with sample size as low as 5. Species distribution model studies got more attention after 2005 (Pearson *et al*., 2007; Siqueira *et al*., 2009; Singh *et al*., 2015).

2.5 Vocal Repertoire Studies

Some of the earlier studies on acoustic behavior and different parameters in vocalizations are by Ryan (1983), Rand (1985), Lopez *et al*. (1988), Ryan and Wilcynski (1991) and Gerhardt (1991). They investigated adaptations in vocalization and how it communicates with conspecifics and other animals. In the last ten years, acoustic studies got more importance and became an important parameter for describing and identifying species (Bee *et al*., 2013a and 2013b; Gingras *et al*., 2013; Sabino-Pinto *et al*., 2014; Thomas *et al*., 2014; Vijayakumar *et al*., 2014; Padhye *et al*., 2015; Rajkumar *et al*., 2016; Zachariah *et al*., 2016; Garg *et al*., 2017; Garg and Biju, 2017; Garg *et al*., 2021).

2.6 Herpetofauna – Periyar

Herpetofaunal studies from Periyar include the study by Zacharias (1997) on reptiles from 1992 to 1994 recording 45 species of reptiles. A study on amphibian by Zacharias and Bhardwaj (1996) reported a total of 16 species. Radhakrishnan (1999) reported the lizard and snake diversity from Periyar with 16 species. Andrews *et al*. (2005) compared the amphibian assemblage in Protected Areas including Periyar and reported 12 species. Das *et al*. (2015) conducted an amphibian survey in Periyar and recorded a total of 49 species. Rajkumar *et al*. (2018) conducted a detailed survey of amphibians and reptiles in 21 locations in Periyar and reported a total of 64 species of amphibians and 68 species of reptiles.

Some of the new species of amphibians had a collection from Periyar Tiger Reserve. Zachariah *et al*. (2011) described *Raorchestes uthamani*, a small-sized bush frog that was collected from the reed patches in Gavi. Vijayakumar *et al*. (2014) collected *Raorchestes flaviocularis* from Upper Manalar, Garg *et al*. (2017) collected *Nyctibatrachus manalari* and *N. sabarimalai* from Upper Manalar and

Sabarimalai respectively. Pal *et al*. (2018) described *Monilesaurus acanthocephalans* from the Upper Manalar landscape. Chaitanya *et al*. (2019) described a *Dravidogecko* that was collected from Meghamalai Wildlife Sanctuary, which is contiguous with Periyar Tiger Reserve. Garg *et al*. (2021) described *Raorchestes keirasabinae*, from a few specimens collected from Periyar Tiger Reserve.

2.7 Vayal Ecosystem

Wetlands are unavoidable habitat for many amphibians and reptiles (Scott, 1982; Icochea *et al*., 2002; Bolen, 2003; Menegon and Salvidio, 2005; Araujo *et al*., 2006; Behangana *et al*., 2009; Maxell, 2009; Jestrzemski *et al*., 2013; Balaji *et al*., 2014; Roth-Monzon *et al*., 2018). The only available first-ever study specifically on vayals is by Pushpakaran and Gopalan (2013), who studied and mapped vayals in Mudumalai Tiger Reserve. Later, Sreejith *et al*. (2014) studied and documented 23 vayals from the Pamba forest range in Periyar. Sreejith *et al*. (2014) reported the presence of exotic plants and invasion by tree seedlings in vayals. Pushpakaran and Gopalan (2013) and Sreejith *et al*. (2014) reported the shrinkage of vayal areas. The above review, especially pertained to Periyar Tiger Reserve and the vayal ecosystem indicate absence of habitat/species specific studies in the region. This has prompted to select the present topic on reptiles and amphibians focusing on the unique vayal ecosystem with all its characteristic features and also on *Raorchestes travancoricus* with limited/restricted geographical distribution.

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Chapter 3
Study Area

Chapter 3. Study Area

3.1. History

Periyar is the first and the largest protected area in Kerala. After the construction of Mullaperiyar Dam in 1895, the forest around the catchment area was declared as Periyar Lake Reserve and protected for ensuring the water supply to parts of Tamil Nadu. But when we look at the history, this landscape was owned by the Pandya Kings of Madurai. King Sundara Pandian owned the Periyar region and later purchased the whole high ranges starting from Athirappilly (northern limit) to Manimala (southern limit). Later in the 1840s, all these areas were surrendered to the Kings of Travancore. This area was inhabited by the tribes like Uralis, Paliyars, Mala Arayans, Mannans and Malampandarams and they were engaged in cultivating paddy and ragi, and collecting honey, fishes and tubers. They also practiced shifting cultivation and moved their settlements almost every year. Mostly they had temporary houses but they usually stored grains in granaries (Bourdillon, 1893). During this period, game hunting was popular among the kings.

Later on, restrictions were imposed on game hunting activities in this area and elevated as Nellikkampatty Game Reserve in 1934. The surrounding forests were added to Nellikkampatty Game Reserve and about 777 km^2 area of forest was declared as Periyar Wildlife Sanctuary in 1950. When tourism developed, the area became one of the best tourism destinations in Kerala and in 1978, it was added to the Project Tiger programme and elevated as Periyar Tiger Reserve. This was the tenth Tiger reserve in the country. In 2007 an area of 148 km^2 was added to Periyar. The Periyar Tiger Reserve covers around 10% (925 km^2) of the total forest area in Kerala and it is the largest protected area and the first Tiger Reserve in Kerala. This area lies between the latitudes 9^o 17' 56.04” and 9^o 37' 10.2” N and longitudes 76^o 56' 12.12” and 77^o 25' 5.52” E (Fig. 3.1).

The altitude of this Protected Area varies between 100 msl at Pambavalley to 2016 msl at Kottamala and most of the areas lie between 700-1200 msl (Fig. 3.2). Periyar is contiguous with the forest areas of Theni Forest Division, Megamalai Wildlife Sanctuary, Srivilliputhur Grizzled Squirrel Sanctuary and Tirunelveli Forest Division in Tamil Nadu and Kottayam, Ranni, Konni, Achenkovil, Punalur and Thenmala Forest Divisions in Kerala. The contiguous connectivity with forests of Kerala and Tamil Nadu and very less conflict with human demands on forest resources makes Periyar one of the best Protected Areas in Kerala (Thomas *et al.,* 2012).

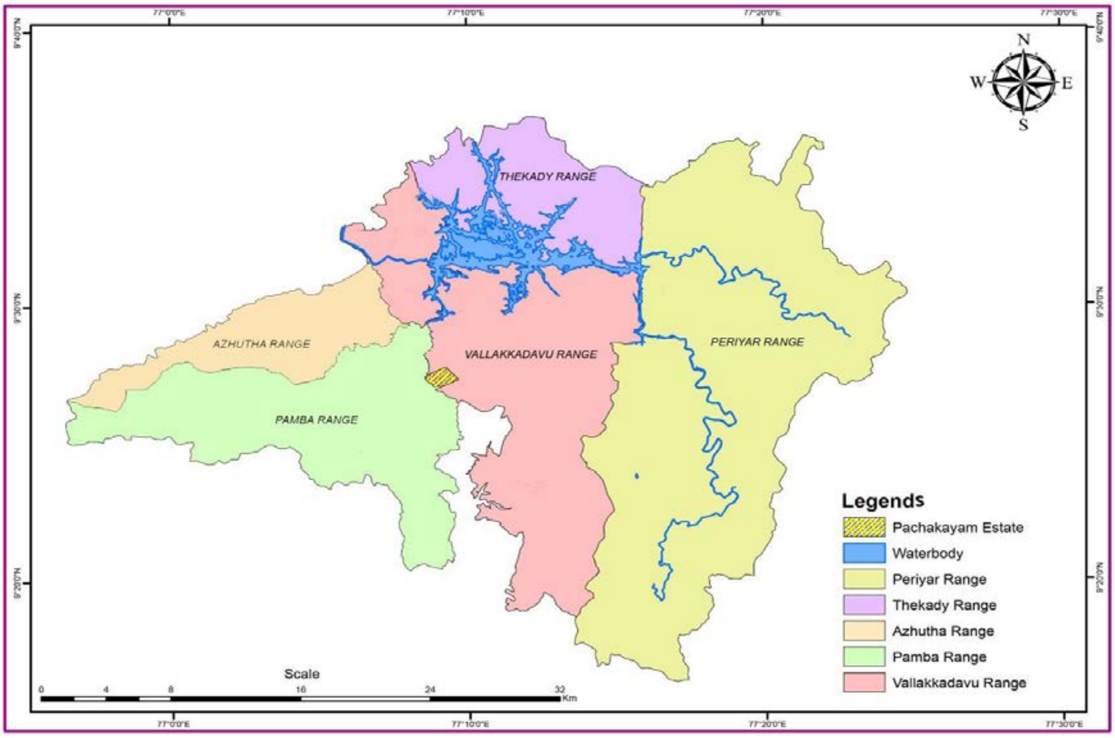

Fig. 3. 1 Map of Periyar Tiger Reserve

3.2. Location and Topography

Periyar Tiger Reserve is located in the Cardamom Hills and Pandalam Hills of the Southern Western Ghats (Nair, 1988; Nair and Jayal, 1991). It is part of a larger landscape unit covering around 4077 km^2 spread across Kerala and Tamil Nadu and its northern limit starts from the Cardamom Hill Reserve and the southern limit is till the northern fringe of Shenkotta Gap. Major part of this landscape unit (around 2724 km^2 area) is in Kerala, which is part of 16 Forest Ranges coming under eight Forest Divisions *viz*., Kottayam, Ranni, Konni, Achenkovil, Thenmala, Punalur, Periyar west and Periyar East Divisions. Forest Ranges under Ranni Forest Divisions are Ranni, Vadasserikkara and Goodrical. Naduvathumoozhy and Mannarappara Forest Ranges come under Konni Forest Division. Three Forest Ranges *viz*., Kallar, Kanayar and Achenkovil are under the Achencovil Forest Division. Erumely, Arienkavu and Pathanapuram Forest Ranges are part of Kottayam, Thenmala and Punalur Forest Divisions respectively. Periyar, Thekkady and Vallakadavu Ranges fall in Periyar East Forest Division and Pamba and Azhutha Forest Ranges under Periyar West Forest Division. Forests of Megamalai sanctuary, Srivilliputhur sanctuary, Theni and Tirunelveli Forest Divisions form the contiguous areas in Tamil Nadu (Fig. 3.3).

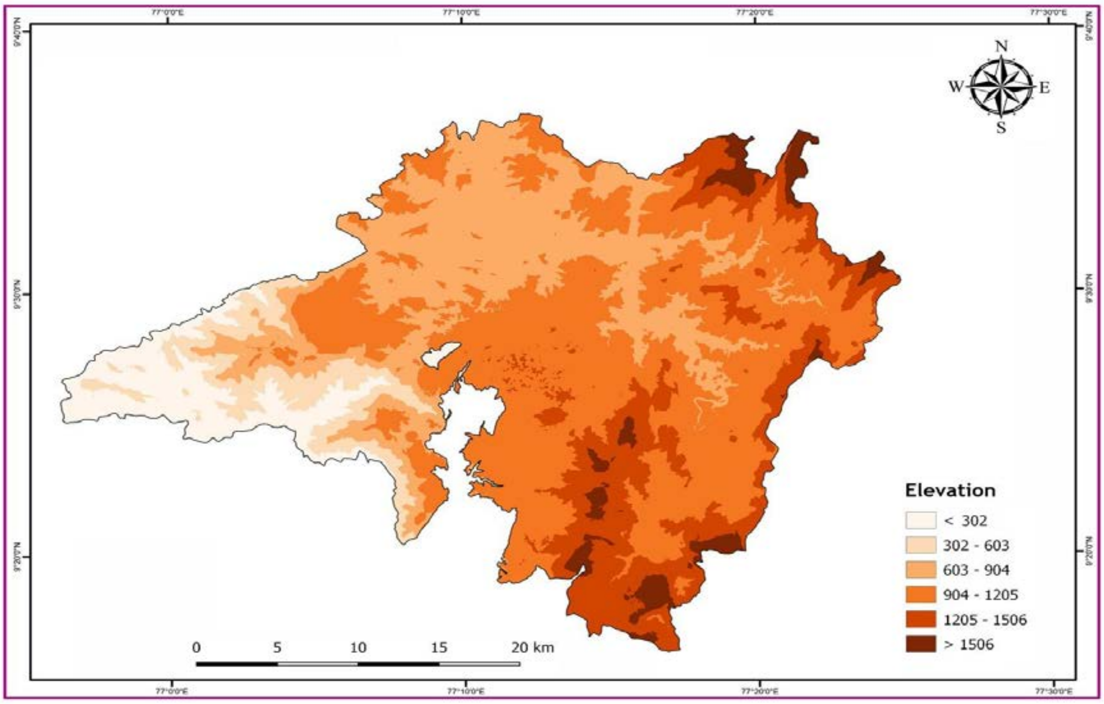

Fig. 3. 2 Map showing the elevation range of Periyar Tiger Reserve

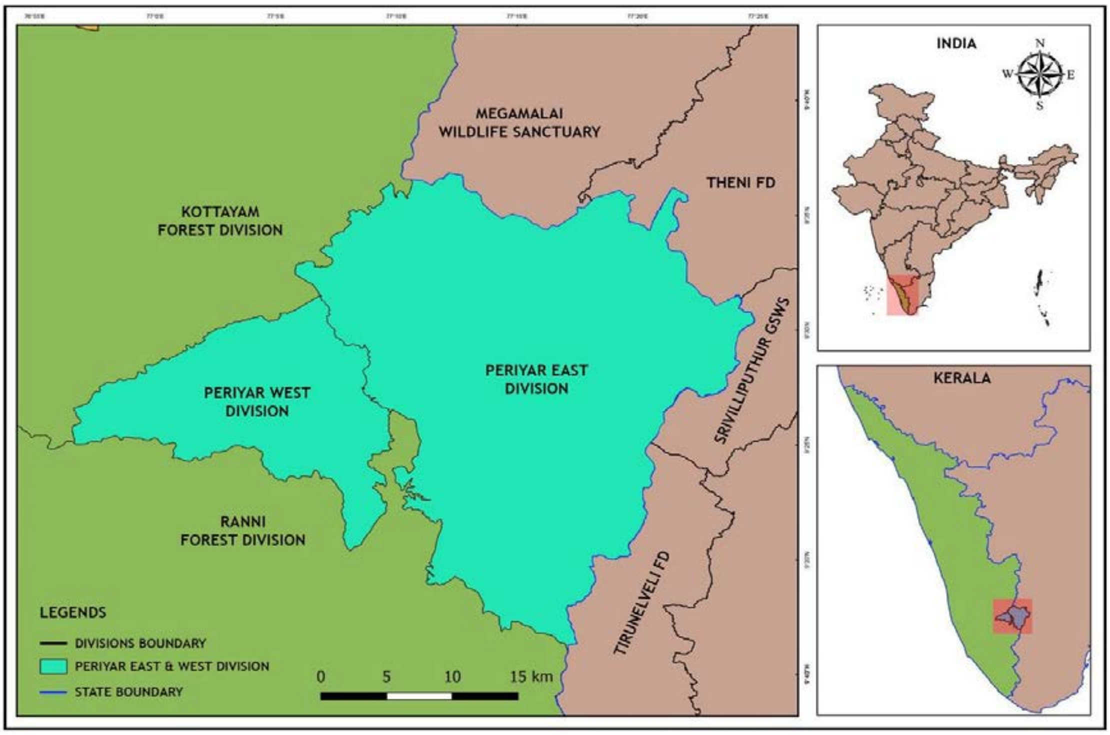

Fig. 3. 3 Location map of Periyar Tiger Reserve

3.3. Climate

Generally the temperature varies between 12^0 and 32^0C. The mean annual temperature is 22.9^0C. December to February are cooler months and the temperature in high elevated areas goes below 9^0 C. March to May are hotter and the temperature rises up to 37^0C. The mean temperature change in Periyar is given in Fig. 3.4.

Periyar is benefited from both south-west and north-east monsoons. In some years, the annual rainfall reaches up to 3100 mm. The months from June to November experience around more than 2400 mm rainfall, which is about 82% of annual rainfall and the months from December to April contribute 18%. The mean annual rainfall reaches up to 2076 mm. July is the wettest month with an average rainfall of 556 mm, which is about 26.78 % of mean annual rainfall and the driest month is January with an average rainfall of 26 mm which is about 1.25 % of the mean annual rainfall (Fig. 3.5).

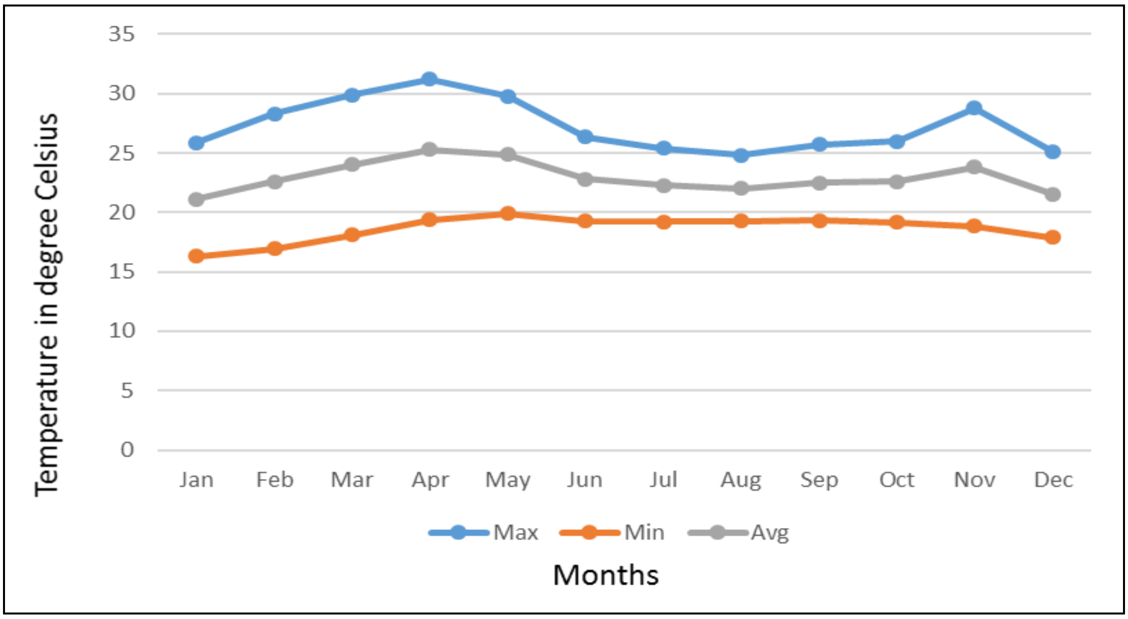

Fig. 3. 4 Monthly maximum, minimum and average temperature changes in Periyar Tiger Reserve in Celsius. (Max-Maximum, Min-Minimum, Avg-Average)

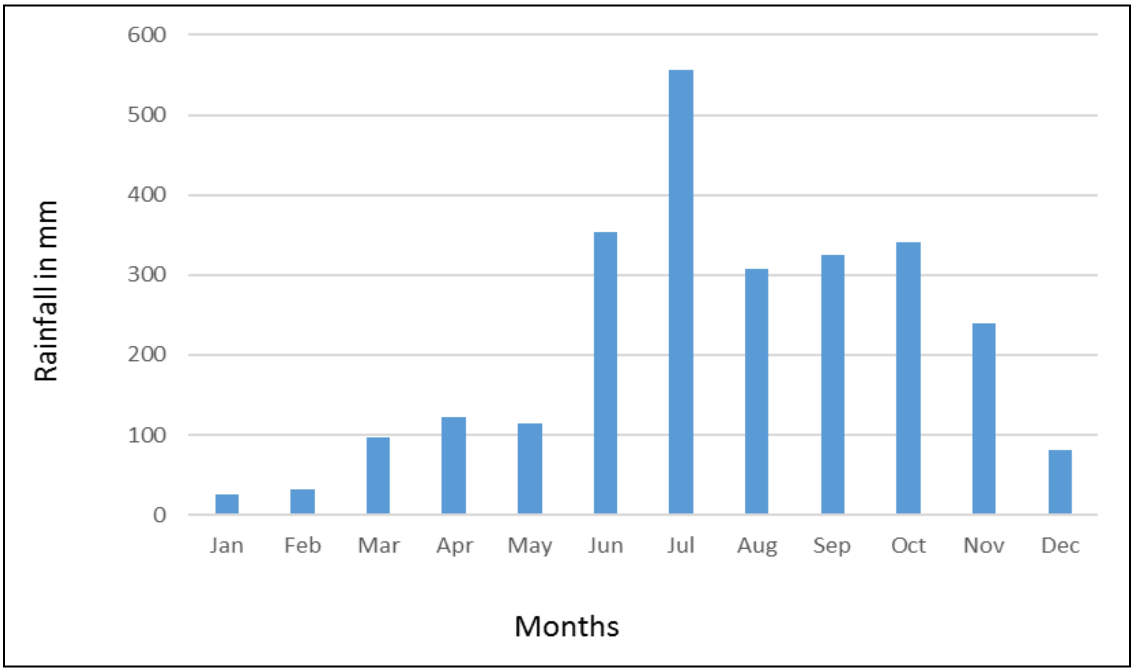

Fig. 3. 5 Monthly precipitation in Periyar Tiger Reserve

The humidity in Periyar touches 100% in many areas. The annual mean humidity is 84%. From May to January, the mean monthly humidity goes beyond 80%. April is comparatively less humid than other months with around 78% humidity (Fig. 3.6).

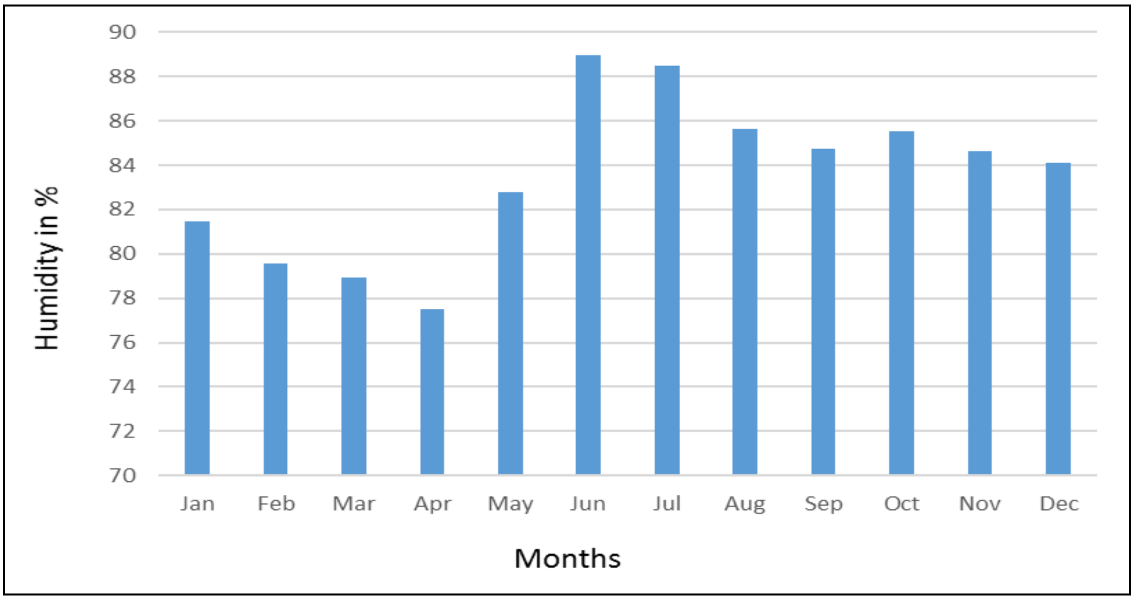

Fig. 3. 6 Monthly humidity changes in Periyar Tiger Reserve in percentage

3.4. Geology and Soil

The rocks in Periyar Tiger Reserve are from the Precambrian age and are complex of Charnockite-Khondalite-Migmatite. The major soil form seen in Periyar Tiger Reserve is forest loam and the grasslands and other lower areas are characterised with laterite soil.

3.5. Vegetation

Periyar Tiger Reserve provides a wide range of habitat that lies between 100 to 2020 msl. The undulated terrain offers a wide range of microclimatic variations that support rich and diverse flora (Sasidharan, 1998), out of which many are rare and endemic to Periyar. Apart from the natural vegetation, there are eucalyptus plantations (Fig. 3.7) established in the 1960s as a part of the grassland afforestation programme. According to Chandrasekharan (1962) and Champion and Seth (1968), the forests in Periyar is classified to following seven types.

1. **West coast tropical wet evergreen forests**
2. **West coast semi-evergreen forests**
3. **Southern moist mixed deciduous forests**
4. **Southern hill-top tropical evergreen forests**
5. **Southern montane wet temperate forests**
6. **South Indian sub-tropical hill savannahs**
7. **Southern wet montane grasslands**

3.5.1. West Coast Tropical Evergreen Forests (Evergreen)

This forest type is found between 100-1300 m and comprise tall trees with multi-layered dense vegetation. About 36.38% (336.6 km^2) of the total area of Periyar is covered with West Coast Tropical Evergreen Forests, especially in the Sabarimala, Sundaramala, Moolavaiga, Koruthodu areas. The top canopy are *Dipterocarpus indicus, D. bourdillonii, Hopea parviflora, Vateria indica, Calophyllum polyanthum, Polyalthia coffeoides, Palaquium ellipticum, Pterygota alata, Holigarna grahamii,Artocarpus hirsute,* etc. The middle canopy trees are *Drypetes malabarica, D. elata, Diospyros bourdillonii, D. paniculata, Garcinia spicata, Semecarpus travancorica, Baccaurea courtallensis, Hydnocarpus pentandra,* etc. and the lower story composed of *Orophea erythrocarpa, O. uniflora, Goniothalamus rhynchantherus, Glycosmis macrocarpa, Strobilanthes warreensis, S. heyneanus,*etc (Fig. 3.8).

3.5.2. West Coast Semi-evergreen Forests (Semi-evergreen)

About 24.12% (223.2 km^2) of the total area of Periyar is covered with semi-evergreen vegetation. This type of forests is found in the Ummikkuppan, Poovarashu and Thekkady areas. The top canopy consists of *Terminalia bellirica, Ficus virens, F. drupacea, Bischofia javanica, Syzygium hemisphericum, Mangifera indica, Tetrameles nudiflora, Myristica dactyloides, Litsea oleoides,* etc. and the middle canopy is composed of *Dimocarpus longan, Litsea deccanensis, L. floribunda, Syzygium cumini, Diospyros ovalifolia, Otonephelium stipulaceum, Harpullia arborea, Trewia nudiflora, Phoebe lanceolata, Pterospermum reticulatum,* etc. The lower story of this forest type is mainly composed of *Ixora brachiata, Syzygium mundagam, Archidendronmon adelphum, Clausena indica, Croton laccifer, Memecylon talbotianum, Aidia gardneri,*etc (Fig. 3.9).

3.5.3. Southern Moist Mixed Deciduous Forests (Moist Deciduous)

This forest type is mainly found in the Mavady, Mullakkudy and Thanikkudy areas. About 10.81% (100 km^2) of the total area of Periyar is covered with moist deciduous forest. In this forest type the upper canopy was composed of *Tectona grandis, Dalbergia sissoides, D. lanceolaria, Pterocarpus marsupium, Terminalia crenulata, T. paniculata, Bombax ceiba, Grewia tiliifolia, Xylia xylocarpa, Lagerstroemia microcarpa, Phyllanthus emblica,* etc. and the middle canopy comprise *Glochidion tomentosum, G. ellipticum, Careya arborea, Olea dioica, Litsea coriacea,* etc. and the lower story comprise *Helicteres isora, Clausen adentata, Wrightia tinctoria, Catunaregam spinosa,* etc (Fig. 10).

Fig. 3. 7 View of Eucalyptus Plantation

Fig. 3. 8 View of West Coast Tropical Evergreen Forests

Fig. 3. 9 View of West Coast Semi-evergreen Forests

Fig. 3. 10 View of Southern Moist Mixed Deciduous Forests

3.5.4. Southern Hill-top Tropical Evergreen Forests (Hill-top Evergreen)

This vegetation type is found between 1300 and 1700 meters from sea level and mainly seen in the eastern side of Ummikuppan and southern side of Periyar River. The trees like *Cullenia exarillata, Acrocarpus fraxinifolius, Syzygium gardneri, S. hemisphericum, S. zeylanicum,Palaquium ellipticum, Dysoxylum binectariferum, Cassine paniculata,* etc. forms the upper storey and the trees like *Diospyros neilgherrense, D. ovalifolia, Casearia rubescens, Lepisanthes tetraphylla, Bhesa indica, Hydnocarpus alpinia, Chionanthus ramiflorus, Drypetes wightii, Agrostistachys borneensis,Coffea crassifolia, Dysoxylum beddomei*,etc. forms the middle canopy. The lower storey are of *Erythroxylum monogynum, Litsea ligustrina, Aglaias implicifolia, Meliosmas implicifolia, Aporusa ficiforme,Goniothalamus wightii, Microtropis stocksii, Acronychia pedunculata,Meiogyne pannosa*, etc (Fig. 3.11).

3.5.5. Southern Montane Wet Temperate Forests (Shola)

Different layers of canopy structure is not evident in this vegetation type. This forest is seen in the Poosinikkakuchi, Manikamala, Chembakavally, Uppermanalar areas. The trees are short with stout branches and small leaves and are easily distinguishable from other forest types. The trees like *Rhododendron arboreum, Actinodaphne campanulata, Eugenia discifera, Cryptocarya stocksii, Ternstroemia japonica, Syzygium rubicundum, Cinnamomum wightii, Garcinia cowa, Alseodaphne semecarpifolia, Bhesa indica*, etc. are seen in the shola forests (Fig. 3.12).

3.5.6. South Indian Sub-tropical Hill Savannahs (Savannah)

This vegetation type is mainly found near Thannikkudy, above Mullayar, above Manakkavala areas. The grass species found in this vegetation are *Chrysopogon hackelii*, *Ischaemum timorense*, *Themeda cymbaria*, *Eulalia trispicata*, *Cymbopogon flexuosus*, *Apluda mutica,* etc. *Careya arborea, Dillenia pentagyna, Terminali achebula, T. paniculata, Anogeissus latifolia, Pterocarpus marsupium, Dalbergia sissoides, Buchanania lanzan,* etc. are the major tree species found in this type of vegetation (Fig. 3.13).

3.5.7. Southern Wet Montane Grasslands (Grassland)

This vegetation type is mainly dominated with grass species with shrubs and bamboo thickets. The major grass species found here are *Themeda cymbaria, Chrysopogon zeylanicum, Eulalia trispicata, Tripogon bromoides, Arundinella ciliata, A. purpurea, Dimeria thwaitesii, Apocopis mangalorensis,* etc. Some of the shrub species seen in these grasslands are *Hypericum mysorense, Thalictrum japonicum, Phoenix humilis, Indigo ferapulchella, Lilium wightianum,* etc. These rolling grasslands are seen in Uppupara, Kumarikulam, Sathram, Undenmedu, Navikkayam areas. Some of these grassland habitats were converted into eucalyptus plantation in the 1960s (Fig. 3.14).

Fig. 3. 11 View of Southern Hill-top Tropical Evergreen Forests

Fig. 3. 12 View of Southern Montane Wet Temperate Forests

Fig. 3. 13 View of South Indian Sub-tropical Hill Savannahs

Fig. 3. 14 View of Southern Wet Montane Grasslands

3.6. The Swamp Ecosystem (Vayal)

The word "Vayal" is colloquially used to address the seasonally waterlogged and grass dominated areas. These swamps/marshy grasslands are better fit in the "wetlands" category under the Article 1.1 of the Ramsar convention (Ramsar Convention Secretariat, 2013). The Ramsar Bureau grouped wide variety of landscape units into a single definition called wetlands. But these ecosystems are strongly influenced by water (Vandewalle *et al.,* 2008). Ramsar Convention Manual defines swamp ecosystems as "areas of marsh, fen, peat land or water, whether natural or artificial, permanent or temporary with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters". Pushpakaran and Gopalan (2013) suggest that these ecosystems fall under the category "Ts" of

Ramsar Convention i.e. seasonal or intermittent freshwater marshes or pools on inorganic soils. According to Dugan and Dugan (1990), these broad ecosystem units fall under seven landscape units like estuaries, open coasts, floodplains, freshwater marshes, lakes and ponds, bogs and peat lands and swamp forests. In this classification, the vayals fit better into the freshwater marshes landscape unit. According to Weller (1994), freshwater marshes or swamps are „any areas that will hold water over soil, even temporarily, forming a suitable basin for the invasion of water-tolerant, rooted, soft-stemmed plants such as grasses, sedges, cattail and bulrush and which forms a diverse habitat for many types of animals‟.

According to Kotagama and Bambaradeniya (2006), wetlands are one of the very important and highly vulnerable ecosystems, which support both flora and fauna including human communities. The fauna includes invertebrates, fishes, amphibians, reptiles, birds and mammals. The availability of fresh grasses, sedges and water makes these habitats ideal for herbivores. In Western Ghats, these unique ecosystems have not been explored so far for its distribution, services, and ecological significance (Sreejith *et al.,* 2014). Considering all the above definitions„vayals‟ are ecosystem units that may be water logged for some time or not necessarily filled with water or standing water, but the soil would hold sufficient amount of water/moisture that supports the growth of hydrophytes and other grasses and sedges that prefer high soil moisture (Fig. 3.15).

The structure and species composition of vayal ecosystem are unique and are different from the adjacent areas. Even though vayals are smaller ecosystem units compared to the adjoining forests, it supports a wide variety of fauna. The plant communities determine the physical structure of the habitat (Tews *et al.,* 2004) and the physical

Fig. 3. 15 View of a typical vayal ecosystem

structure of a plant community is more important than the plant composition in supporting the animal community (MacArthur and MacArthur, 1961). In vayals, the physical structure is different and unique from the surrounding vegetation. The uniqueness of this habitat is fading as it is infested by the invasion of non-vayal plant species. In Kerala, apart from Periyar Tiger Reserve, vayals were recorded from Wayanad Wildlife Sanctuary, Silent Valley National Park and Parambikulam Tiger Reserve. Vayals are also seen in the Reserve Forests outside Protected Areas. Pushpakaran and Gopalan (2013) conducted a study on vayal ecosystem of Mudumalai Tiger Reserve in Tamil Nadu to map and analyse the structure and composition. They classified the vayals in Mudumalai into natural and converted cultivated vayals. The converted cultivated vayals were converted for cultivation of paddy. Pushpakaran and Gopalan (2013) also found that the invasion and colonization of invasive plants suppresses the growth of indigenous flora. The major exotic/invasive species they recorded are *Lantana camara*, *Chromolaena odorata, Mimosa pudica* and *Ageratum conizoides.* The tree invasion happens around the edges of vayals mostly by *Anogeisus latifolia, Bischofia javanica, Butea monosperma*, *Salix tetrasperma*, *Syzygium cuminii*, *Glochidion zeylanicum, Phyllanthus emblic, Persea macrantha* and *Randia tamilnadensis*.

Based on the food and feeding habit studies done in Periyar, tiger prefers sambar, gaur and wild boar. These animals mainly feed on grasses and sedges which are abundant in vayals, thereby ensuring food for the prey species of tiger. Periyar Tiger Reserve is managing 60 vayals. As per the Tiger Conservation Plan, eradication of invasive plants, weeds, woody plants have been done every year in selected vayals. Besides being good feeding ground for herbivores, these vayals act as breeding ground for many arthropods, amphibians, reptiles and birds. Vayals are major water storing areas and most of them drain throughout the year. But for some opportunistic observations during other surveys conducted on mammals, birds and butterflies, the faunal diversity in vayals are not well documented. In spite of providing important ecological services and covering all the strata of a food web, these ecosystems have not received the attention that they truly deserve.

3.7. Flora and Fauna

The flora and fauna of Periyar Tiger Reserve is comparatively well documented. Periyar is a treasure house of plants and animals and it is evident from the new descriptions, rediscoveries and presence of many threatened species (Menon and Remadevi, 1995; Rajesh *et al*., 1996; Daltry and Martin, 1997; Sajeev *et al.,* 1998; Augustine and Sasidharan, 1999; Gopi, 2000; Kurup and Radhakrishnan, 2005; Biju and Bossuyt, 2009; Radhakrishnan and Kurup, 2010; Biju *et al.,* 2011; Rajkumar *et al.,* 2016; Garg*et al.,* 2017). Periyar holds the highest number of plants compared to any other Protected

Areas in Kerala, which is around 41% (1,985) of total plants recorded from Kerala. This 1,985 plants belong to 823 genera and 159 family and around 26%of the plant species are endemic to Western Ghats (Sasidharan, 1998; Sasidharan and Augustine, 1999; Augustine and Sasidharan, 1999; Sasidharan *et al.,* 2000; Sasidharan *et al.,* 2002; Augustine, 2002).

The faunal wealth of Periyar Tiger Reserve is also higher than any other Protected Area in Kerala. Periyar harbours around 68% (66) of the total non-marine mammals reported from Kerala. This 66 species of mammals belong to 25 families under 11 orders. The family Muridae (13) represents highest number of species followed by Sciuridae and Felidae with six species each. Periyar holds around 65% (323) of the total avian diversity of Kerala. Out of the 323 species, majority are from the family Muscicapidae (52) followed by Accipitridae (33) and Ardidae (14). Periyar is a paradise for herpetofauna. A total of 68 species of reptiles belonging to 15 families under 43 genera were recorded. The family Colubridae (14) represents the highest number followed by Geckonidae, Scincidae and Agamidae with 10, eight and seven species respectively. Out of the 68 species recorded, 27 (39%) are endemic to Western Ghats. Eleven species of reptiles fall under different IUCN threatened categories and 40 species are protected under Wildlife (Protection) Act, 1972. A total of 64 amphibians belonging to 10 families under 23 genera are recorded from Periyar. The family Rhacophoridae (27) represents most number of species followed by Microhylidae and Nyctibatrachidae with 7 and 6 species respectively. Fifty six (87%) of the total 64 species reported are endemic to Western Ghats. Seventeen species come under various IUCN threatened categories and seven species are protected under the Wildlife (Protection) Act, 1972. The aquatic ecosystems in Periyar is very important in terms of fish diversity. A total of 54 species of fishes belonging to 19 families from six orders were recorded from Periyar and out of which six species are endemic to Periyar Tiger Reserve. Apart from the vertebrate diversity, the invertebrate diversity is also very high. A total of 247 species of butterflies, 37 species of moths, 35 species of dragonflies, 31species of wasps, bees and ants, 47 species of bugs and cicadas and 27 species of beetles (Radhakrishnan and Kurup, 2010;) were also recorded from Periyar.

3.8. Indigenous Communities

The buffer zone of Periyar Tiger Reserve has five settlements. Uralis, Paliyars, Mala Arayans, Mannans and Malampandarams are the indigenous tribes in the area. Mannan and Paliyar tribes are at Labbakandam, Uralis in Vanchivayal and Malampandaram and Mala Arayans at Moozhikkal. Pamba valley settlement has both Mala Arayans and non-tribal communities. These settlements occupy an area of 728.64 Ha.

3.9. Tourism and Pilgrimage

Apart from the ecological importance, Periyar is one of the well-known tourism destinations of India. Kumily is the centre point of tourism activities in Periyar. There are several different types of tourism activities like trekking, tenting, nature walks, boating, bird-watching, night walks, safari, bamboo rafting and cultural programmes by indigenous community members. Every year more than six lakh tourists are seen visiting Periyar.

There are two ancient pilgrim centres inside the Periyar Tiger Reserve,Sabarimala Temple and Mangaladevi Temple. Every year more than 30 million pilgrims are visiting Sabarimala (Joseph *et al.,* 2016).

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Chapter 4
General Methods

Chapter 4. General Methods

4.1 Introduction

Amphibians and reptiles are highly diversified groups of animals that are known to use almost all types of microhabitats. Most of them are arboreal, terrestrial while a few are mainly fossorial and the others are aquatic. Some of the amphibians and reptiles are very specific to their microhabitats. But many of them show preference to two or more microhabitats like semi-arboreal (arboreal + terrestrial), semi-terrestrial (terrestrial + fossorial); semi-fossorial (fossorial + aquatic); and semi-aquatic (aquatic + terrestrial) and there are other combinations too (Campbell and Christman, 1982; Heyer *et al.*, 1994; Dodd, 2009; Dodd, 2016). This nature of amphibians and reptiles makes it difficult to study them.

The studies on amphibians and reptiles range from species specific to community ecology studies. It could be an inventory study, or studies related to species diversity, species distribution, species abundance, population, acoustics, acoustic activity pattern, niche partitioning, temporal activity, thermoregulation, food and feeding habits, breeding behaviour and monitoring breeding population of a species or all the species in an area (Heyer *et al.*, 1994; Dodd, 2009; Dodd, 2016). The effort and expertise required to study each aspect is different and it is not possible to study all the above mentioned aspects using a single method. There are several standardised methods to study the above mentioned aspects like the systematic sampling survey, visual encounter survey, quadrat survey, line transect survey, removal survey, capture mark recapture survey, drift fencing, pitfall traps, glue traps, acoustic monitoring, tracking marked animals, digital identification techniques, focal animal observations, stomach flushing, dissection, fumigation method and so on (Heyer and Berven, 1973; Heyer *et al.,* 1994; Sutherland, 2006; Leache *et al*., 2006; Dodd, 2009; Dodd, 2016; Leyte-Manrique *et al*., 2019). The microhabitat preference and related aspects we selected for study are the two key factors to select the appropriate method or methods for conducting the study.

On considering the inventory and monitoring studies, there are at least ten different methods which are standardised and widely used (Heyer *et al*., 1994; Sutherland, 2006; Dodd, 2009; Dodd, 2016) and there is no single standard method which can represent all the microhabitats or all the species in a community (Heyer *et al*., 1994; Doan, 2003). These methods have several benefits and limitations. Therefore, most of the time two or more methods are combined together for obtaining better results (Andreone *et al*., 2001; Ibrahim, 2001; Doan, 2003; Rodel and Ernst, 2004; Menegon and Salvidio, 2005; Leache *et al*., 2006; Behangana *et al*., 2009; Akani and Luiselli, 2009; Pal *et al*., 2012; Hua *et al*., 2013; Balaji *et al*., 2014; Akani *et al*., 2014a; Akani *et al*., 2014b; Das *et al*., 2020).

One hundred and forty one vayals have been identified in Periyar Tiger Reserve. However, only 83 were documented at the time of initiation of this study. As mentioned earlier, the vayals are distributed in different vegetation types. Thus the vayals are surrounded by different vegetation types. To study the influence of the surrounding vegetation and considering the extent, only 47 vayals were selected as sampling units in the study. The details are given in the respective chapters.

In the present study, a combination of methods were used to meet the objectives; a) to document the diversity and distribution of reptiles and amphibians in the vayal ecosystem and the immediate surrounding vegetations, b) assessing the herpetofaunal diversity in relation to the size and composition of vayals and its surrounding vegetation and c) to study the status, distribution and behaviour of *Raorchestes travancoricus* in Periyar Tiger Reserve. Vayals are highly dynamic ecosystems. Some of the vayals are water logged for around six months in a year and some are without any standing water and the plant composition of these vayals varies from small grass to trees with several meters of height. So it is necessary to cover fossorial, terrestrial, arboreal and semi-aquatic amphibians and reptiles. Therefore quadrat survey, visual encounter surveys and transect methods were chosen for meeting objectives one and two. Visual encounter survey and audio strip transect survey were chosen for the objective three. There are several limitations in conducting drift fences and pitfall traps, like demand for more man power for execution, difficulty in fixing the drifts and pitfall traps in forests because of roots, rocky area, laterites etc. Moreover, it is more time consuming. In the long run, the area covered will be really small compared to other methods. Moreover, it is hard to get permission to fix the drift fences and pitfall traps in Protected Areas since it is a passive method which creates disturbance to the habitat and there is a high chance of predation or mortalities in the pitfall.

More surveys were conducted to document the fossorial amphibians and reptiles in the monsoon season when these animals are mostly encountered outside the soil and this method is considered successful next to trapping to document fossorial animals (Rodel and Ernst, 2004).

A detailed description of the methods normally followed for herpetology study is given below. The methods followed for achieving the objectives of the study are highlighted here and also later in the respective chapters.

4.2. Quadrat sampling

Quadrats are square plots that are laid in each sampling unit and the area inside the square plots are thoroughly searched for amphibians and reptiles (Heyer *et al*., 1994). This method is used to study the species assemblage in an area or in inventory studies and also for studying the changes in species composition in an area over time (Heyer *et al*., 1994; Sutherland, 2006; Dodd, 2009). When there are sufficient numbers of randomly laid quadrats, the data from each quadrat will be considered as independent samples from which species density, diversity and relative abundance can be derived (Heyer and Berven, 1973; Heyer *et al*., 1994; Sutherland, 2006; Dodd, 2009). The size of quadrats varies from 0.5 m^2 to couple of hectares based on the target species or group of species and considering the area of interest (Campbell and Christman, 1982; Dodd, 2009; Akani *et al.,* 2014b). The number of observers are also fixed based on the above mentioned factors.

In the present study, quadrat sampling was used for documenting the diversity of amphibians and reptiles. The details are given in the chapter 5 on diversity of the herpetofauna.

4.3. Line transect survey

Line transects are straight lines that are marked with a uniform distance and sampled for amphibians and reptiles. This method is widely used for studying birds and mammals (Heyer *et al*., 1994; Sutherland, 2006). The transects are marked prior to the survey, sometimes several days before sampling to minimize the effect of disturbance made during marking of transects. In more open habitats, both the start and end points are marked while in dense forest areas, the entire transects will be marked to ensure the surveyor can follow the transect in a straight line and collect data (Dodd, 2016). During sampling, the lines are walked and all the animals found on the line and on either side of the line counted. The probability of detecting animals will reduce as the distance from the line increases especially for lesser fauna like amphibians and reptiles.

Transects with fixed width (strip transects) are widely used for herpetological studies and this will minimise the detection probability issues (Heyer *et al*., 1994; Balaji *et al*., 2014). The area inside the strip transects are thoroughly searched for amphibians and reptiles and all possible microhabitats like leaf litter, fallen logs, rock crevices etc. are covered (Balaji *et al*., 2014). The assumption made during the survey is that all the individuals inside the strip is counted and often this method is considered as rectangular quadrats (Seber, 1982).

This method was also used in the present study for documentation of herpetofauna (Chapter 5).

4.4. Visual Encounter Survey

Visual Encounter Surveys (VES) are systematic search for amphibians and reptiles in the target habitat in all possible microhabitats like under rock, under logs, leaf litter, rock crevices etc. This method is well suited for inventory studies. This method is widely used for species richness, diversity and relative abundance studies and not recommended for studying density (Heyer *et al*., 1994). The method is less expensive and requires less manpower and minimal equipment like torch lights and field notes. It can be done in almost all the habitats, more area can be covered and thus widely used in short and long term herpetological studies (Menegon and Salvidio, 2005; Leache *et al*., 2006; Minh, 2007; Behangana *et al*., 2009; Dodd, 2009; Balaji *et al*., 2014; Akani *et al*., 2014a; Akani *et al.*, 2014b; Dodd, 2016; Roth-Monzon, *et al.*, 2018; Das *et al.,* 2020). VES method is well conducted within a specified area, fixed effort or time and this helps standardise the protocol to increase the chance for repeatability and to compare the results of other works (Heyer *et al*., 1994; Doan, 2003; Dodd, 2009; Dodd, 2016). It is also easy to repeat after some period of time to monitor the trend. The area can be a large plot with several transects of equal length laid and placed keeping enough distance to avoid animal movement and recounting. The transects are walked in a constant pace while collecting data (Doan, 2003; Rodel and Ernst, 2004). The existing trek paths in the study area also can be used as transects with a fixed width of 1m on both side from the middle of the trek path for VES studies. To avoid recounting, the next transect should be laid away from the recently sampled area (Dodd, 2016). The data from each VES effort will be considered as independent (Doan, 2003; Rodel and Ernst, 2004; Dodd, 2016). More number of species and individuals are obtained through VES and it is one of the best methods for surveying fast moving, secretive and arboreal amphibians and reptiles (Campbell and Christman, 1982; Doan, 2003; Dodd, 2009; Dodd, 2016; Das *et al*., 2020) and also for studying the population structure, demography, habitat preference and activity pattern of animals (Dodd, 2016).

Visual Encounter Survey was carried out for collecting information on diversity and relative abundance (Chapters 5 – 7).

4.5. Audio strip transects

Audio strip transects are line transects with fixed width. During the sampling in this method, the observer walks along the transect and counts all the vocalising amphibians inside the strip and the transects are surveyed repeatedly (Heyer *et al*., 1994; Leyte-

Manrique *et al*., 2019). These transects are placed apart to avoid recounting of animals and to get independent data (Heyer *et al*., 1994; Ficetola *et al*., 2008). This method is widely used for studying birds and amphibians (Heyer *et al*., 1994). In amphibians, only the frogs and toads have the ability to vocalize while the caecilians and salamanders do not. In frogs and toads, mostly the males vocalize and females do not possess a vocal sac. The males produce sound to advertise and defend their territory and also for getting mates (Ryan, 1988). In this method, the advantage of this behaviour is used for monitoring amphibians. During this survey, only the calling males are represented and the females, non-vocalising males and juveniles are not represented. Acoustic monitoring method is used for studying population, relative abundance of vocalising males, breeding activity pattern, vocalisation behaviour of amphibians, temporal niche partitioning and phylogenetic similarity (Lopez *et al*., 1988; Kanamadi *et al*., 1993; Roy and Elepfandt, 1993; Luddecke *et al*., 2000; Bastos and Haddad, 2002; Rodel and Ernst, 2004; Sinsch *et al*., 2012; Gingras *et al*., 2013; Bee *et al*., 2013a; 2013b; Das *et al*., 2020). The length and width of transects were fixed based on the target species or group of species and on the habitat (Heyer *et al*., 1994). The width of the transect can be as much as double the distance of the maximum distance of a frog call that can be heard in the field (Emlen, 1984). All the species or the target species that vocalised during the sampling are counted. Each vocalising animal is counted once in a sampling. The distance of the vocalising animal should remain the same during sampling. Survey is conducted during the peak activity period of target species or group of species and the observer should be the same throughout the survey to minimise the bias in detection capacity of observer. These are of the assumptions while conducting audio strip transects (Heyer *et al*., 1994).

The method was followed for acoustic activity pattern and the details are in Chapter 7.

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Chapter 5

Diversity and Distribution of Amphibians and Reptiles in vayals in relation to Immediate Surrounding Vegetation

Chapter 5. Diversity and Distribution of Amphibians and Reptiles in vayals in relation to Immediate Surrounding Vegetation

5.1 Introduction

Species diversity supports the ecosystem functioning through which the ecosystem services are maintained (Loreau *et al*., 2001; Diaz *et al*., 2006; Worm *et al*., 2006; Cardinale *et al*., 2012; Roth-Monzón *et al*., 2018). Therefore it is important to understand the species diversity of an area for better conservation and formulation of management strategies of an ecosystem (Diaz *et al*., 2006; Worm *et al*., 2006; Chakraborty *et al*, 2015). The last couple of decades have witnessed discussions on the serious issue of global warming and connected biodiversity loss. The present decade has already started witnessing an alarming rate of biodiversity loss. Human interventions are the root cause of this unabated biodiversity loss (Loreau *et al*., 2001; Diaz *et al*., 2006; Roth-Monzón *et al*., 2018). Human population explosion and related conversion of natural habitats for living space and farming lead to habitat destruction and fragmentation and over- exploitation of natural resources, pollution, contribution to greenhouse gases, global temperature rise, spread of invasives and pathogens all of which burgeons the threats to herpetofauna.

Amphibians are the major victims of this global crisis with more than 200 species gone extinct and close to 40% of the amphibians on the brink of extinction (Wake and Vredenburg, 2008; Alroy, 2015). Many recently described species are showing very restricted distribution and are highly threatened. The ones in the tropics are especially highly vulnerable due to the narrow geographical range (Wake and Vredenburg, 2008).

Diversity loss will hamper the equilibrium of the ecosystem and ecosystem services. Therefore it is essential to study and understand the diversity and conserve it before it is lost (Cardinale *et al*., 2012) to save our planet. Revival of biodiversity and ecosystem services are possible through immense conservation efforts. But scientists are worried as the time for such revival or restoration of biodiversity is inadequate (Wake and Vredenburg, 2008: Ceballos *et al*., 2015). Therefore it is important to understand the current biodiversity for better management and wellbeing. Studying the species diversity, relative abundance, population status and functional organizations are vital for the conservation and management of an ecosystem (Diaz *et al*., 2006). We cannot protect or conserve every species on earth due to limitations in time and resources. Understanding the diversity, distribution and status will help prioritize our limited resources efficiently (Salafsky *et al*., 2008; Balaji *et al*., 2014), because many species that are considered to be endangered or gone extinct are in reality having a better population in several fragments (Pal *et al*., 2010). Therefore biodiversity surveys play a crucial role in conservation and management.

Though amphibians and reptiles are very sensitive to habitat modifications, global warming, pollution and diseases, these are one of the least studied groups of vertebrates compared to mammals and birds. (Gibbons *et al*., 2000; Araújo *et al*., 2006; Bohm *et al*., 2013; Leyte-Manrique *et al*., 2019). These two vertebrate groups face similar kinds of threats and connected decline (Bohm *et al*., 2013). Amphibians and reptiles are philopatric (except sea turtles and some lizards) making them the most vulnerable group of vertebrates to habitat modifications (Gibbons, 2000). According to Araújo *et al*. (2006), this is far detrimental than the global temperature rise The exponential growth of human population leads to the expansion of agriculture and farmlands resulting in clearing of natural habitats like the forest, grassland and, aquatic ecosystems. (Vitt and Caldwell, 2014). This leads to a reduction in the herpetofaunal abundance in the edges of modified areas. Conversion of natural habitats reduces the humidity and increases light intensity (Vitt and Caldwell, 2014), which adversely affects especially the amphibians. The global temperature rise and melting of polar ice will exacerbate the life of species in the coastal areas and plains (Vitt and Caldwell, 2014).

The tropical regions are rich in amphibian and reptile species and also with highest number of threatened and data deficient species (Bohm *et al*., 2013). Data deficiency is also a limiting factor for planning strategies for management and conservation of species and their habitats (Bohm *et al*., 2013). Nineteen percent of the world's reptiles are threatened and another 7% are Near Threatened and highly vulnerable to threats (Bohm *et al*., 2013). About 80% of the world's threatened reptiles are affected by more than one man-made threat (Bohm *et al*., 2013). Therefore it is important to have information on the diversity, distribution, population and status of the amphibians and reptiles for tropical region.

The collection and documentation of Indian herpetofauna started long back in the 1700s. The Portuguese, German, Dutch and French writers had written about the herpetofaunal wealth in their literature (Deraniyagala, 1974). These collections were for their respective country's Natural History Museums. The research on the group was started around 200 years ago (Palot, 2015). Jerdon (1853) catalogued the reptiles inhabiting peninsular India. Gunther published a book of reptiles of British India in 1864, which includes 52 species of amphibians and 479 species of reptiles, out of which 108 species were non-Indian (Theobald, 1876). Theobald (1876) published an updated book, 'Descriptive catalogue of the Reptiles of British India' with 463 reptiles. Before this, Theobald (1868) published the catalogue of reptiles and amphibians in the museum of the Asiatic Society of Bengal. The species were mainly from India and Sri Lanka and also from England, France and Europe. Anderson (1871) published a detailed description of 24 species of amphibians and 90 species of reptiles. Six species of snakes belonging to the family Uropeltidae were described from Sirumallay Hills (1), Pulney (Palani) Hills (1), Nelliampathy Hills (2) and High Wavy Hills (2) by Beddome (1878). Joseph Ewart (1878) published a detailed book on the venomous snakes of India, which includes land and sea turtles. Beddome (1886) published a detailed note on fossorial snakes belonging to the family Uropeltidae from India and Sri Lanka. A total of 37 species in seven genera were included. One new genus and two new species were also included. A detailed description of amphibians with sketches was published by Boulenger (1882), which includes a description of 118 species with 30 plates. Boulenger (1890) published a book on reptiles and amphibians of India including Sri Lanka and Myanmar as 'Fauna of British India including Ceylon and Burma'. This had 130 species of amphibians and 538 species of reptiles.

The Deputy Superintendent of the Indian Museum, Sclater published a list of snakes in the Indian Museum in 1891. There were around 350 species of snakes from India (210) and abroad (110) with a total of 3001 specimens (2615 and 286 specimens respectively). Boulenger (1891) described the Travancore Bush Frog in based on the specimen collected by H.S. Ferguson. Ferguson (1895) added the snakes that were collected from Travancore and Wall (1905, 1918) added the collection of snakes from Cannanore and Nilgiris. He has also published a book on snakes of India with detailed descriptions with colour plates in 1912. Annandale and Rao (1916, 1917) described the tadpoles of many Indian amphibians. Later, Annandale (1918) described six species of tadpoles from southern India and Rao (1918) described 11 species of tadpoles. One of the major works was done by Smith, who published three volumes of The Fauna of British India (1931, 1935 and 1943), which is considered to be the pioneering work on Indian herpetology. Later there were only very few works till the 1980s.

After the 1980s, the studies mostly focused on diversity though there were some species descriptions. Murthy (1981, 1986) reported reptile diversity in Silent Valley National Park and the adjoining New Amarambalam area and listed 24 species of reptiles including 12 species of lizards {(Agamidae (5), Gekkonidae (3), Scincidae (4)} and 12 species of snakes {(Uropeltidae (1), Colubridae (8), Elapidae (1) and Viperidae (2)}. Rajendran (1985) published a book on the shieldtail snakes in the Western Ghats (Kerala and Tamil Nadu part). He had surveyed more than 100 locations starting from Nagarcoil in the south to Moyar in the north and gave a detailed description of 20 uropeltid snakes with taxonomy, ecology, biology and distribution. Inger *et al*. (1984) published the results of a six-week expedition in Ponmudi, Kerala and listed 19 species of amphibians and 33 species of reptiles with photographs. Later, Inger *et al*. (1987) published the elevational distribution, habitat preference, niche partitioning and niche overlap of the amphibians and reptiles collected from Ponmudi in the 1984 expedition. A detailed distributional record of shieldtail (Uropeltid) snakes found in India and Sri Lanka was published by Murthy (1992). Distributional details of 44 species of snakes were discussed in the paper out of which 11 were from Sri Lanka.

Thomas and Easa (1997) reported the reptile fauna of Silent Valley and updated the checklist with a total of 35 specie. Of these, 11 species were additions to the park. Thomas *et al*. (1997) reported 44 species of reptiles from forest areas in Wayanad. Dutta

(1997) published a detailed list of amphibians found in India and Sri Lanka and Das and Dutta (1998) compiled the checklist of amphibians found only in India. Easa (1998) reported 33 species of amphibians (Anura: 29, Gymnophiona: 4) and 62 species of reptiles (Crocodylia: 1, Testudines: 4, Squamata: 57) from the Nilgiri Biosphere Reserve areas in Kerala. Abraham *et al*. (1999) reported 51 species of reptiles (Testudines: 2, Squamata: 49) from Chinnar Wildlife Sanctuary. Two rare species of worm snakes were rediscovered from the north of the Palghat Gap by Ajit (2000). Cherian *et al*. (2000) reported 35 species of amphibians and 30 species of reptiles from Kalakkad, Tamil Nadu. Vasudevan *et al*. (2001) reported 35 species along with details on their structure and composition in the forest floor in Kalakkad – Mundanthurai Tiger Reserve. . The amphibian and reptile diversity in the Madayipara laterite hills was studied by Palot and Radhakrishnan (2002). Srinivasulu and Das (2008) reported 20 species of amphibians and 64 species of reptiles si from Nallamala Hills in the Eastern Ghats. Dinesh *et al*. (2009) published an annotated checklist of amphibians of India with a description of 284 species of amphibians belonging to 50 genera and 14 families. Chandramouli and Ganesh (2010) studied the amphibian and reptile diversity in the Cardamom Hills and Ponmudi for four months and reported 28 species of amphibians. Palot and Radhakrishnan (2011) published the checklist of reptiles in Kerala. In 2013, Dinesh *et al*. (2013) published an online version of an updated checklist of amphibians in India with 342 species. Aengals *et al*. (2011) published an updated checklist of reptiles in India, which included 518 species of reptiles from three orders. Srinivas and Bhupathy (2013) surveyed the Meghamalai area and reported 35 species of frogs and toads (Anurans) and Bhupathy and Sathishkumar (2013) surveyed the same areas and updated the checklist of reptiles of Meghamalai with 90 reptiles. Ganesh *et al*. (2014)

studied the snake diversity of the High Wavy Mountains and updated the list with 62 species. Chaitanya *et al*. (2018) studied the amphibian and reptile diversity in the Meghamalai Wildlife sanctuary area and added five amphibians and nine reptiles.

After 2005, majority of the amphibian studies focused on taxonomy and new descriptions and in reptiles, this shift in studies happened after 2010. The studies used an integrated method of combining molecular taxonomic tools with classical taxonomy for both amphibians and reptiles and the acoustic parameters were also incorporated for describing new amphibians. Vasudevan and Dutta (2000) described a new species of flying frog (*Rhacophorus pseudomalabaricus*) from the southern Western Ghats. A new species of Day Gecko (*Cnemmaspis assamensis*) was described by Das and Sengupta (2000) from the evergreen forests of Assam. Das and Bauer (2000) described two more new species, *Cnemaspis otai* and *Cnemaspis yercaudensis* from Vellore and Sheveroy Hills (Tamil Nadu) respectively. Bossuyt (2002) described a new species of bush frog (*Raorchestes*) from Munnar. Bauer (2002) described two new species of Day Geckos (*Cnemaspis*). Biju and Bossuyt (2003) described a new genus and a new species of frog (*Nasikabatrachus sahyadrensis*) from the Western Ghats. Biju and Bossuyt 2005a and b) described three new species of shrub frogs belonging to the family Rhacophoridae from Kerala. Mukherjee *et al*. (2005) described a Day Gecko *Cnemaspis* from Anakatti Hills, Southern Western Ghats. A new species of Night Frog *Nyctibatrachus petraeus* was described from the Karwar district of Karnataka by Das and Kunte (2005).

Two new species of shrub frogs, *Racorchestes anili* and *R. dubois* belonging to the family Rhacophoridae were described by Biju and Bossuyt (2006). The specimens were collected from Wayanad and Kodaikanal respectively. Biju *et al*. (2007) described one of the smallest frogs in India, the *Nyctibatrachus minimus* from Kurichiyarmala, Wayanad. Kuramoto *et al*. (2007) compared the species in the genus *Fejervarya* (Ranidae) in the central Western Ghats and described four new species. Giri (2007) described a new species of gecko *Hemidactylus aaronbaueri* from the Northern Maharashtra. Biju and Bossuyt (2009) studied the phylogeny of the genus *Philautus* (revised as Raorchestes) in the Western Ghats and reported 12 new species. Giri *et al*. (2009) described a new species of Day Gecko *Cnemaspis kolhapurensis* from Northern Western Ghats, Maharashtra. Mahony (2009) described a new species of gecko *Hemidactylus treutleri* that inhabit the rocky areas near Golconda fort, Hyderabad. Biju *et al*. (2010) described a new species of ground-dwelling bush frog *Raorchestes resplendens* from the highest peak of Western Ghats, the Anamudi. Biju *et al*. (2011) conducted a systematic revision of the Night Frogs ofthe Western Ghats endemic family Nyctibatrachidae and described twelve new species. Vogel and Rooijen (2011) described a Bronze-back Tree Snake (*Dendrelaphis girii*) from the southern Western Ghats. Zachariah *et al*. (2011) described nine new species of bush frogs of the genus *Raorchestes* from Kerala (7) and Tamil Nadu (2). One new species of tree frog and two new monotypic genera belonging to the family Rhacophoridae were described from the southern Western Ghats by Abraham *et al*. (2013). A new species of fossorial snake belonging to the family Uropeltidae and the genus *Rhinophis* was described from the southern parts of Eastern Ghats by Aengals and Ganesh (2013). A new species of ground-dwelling gecko belonging to the genus *Cnemaspis* was described from the evergreen forests in Kottiyoor reserve forests and adjoining areas by Cyriac and Umesh (2014) and the species was named after its type locality Kottiyoor as *Cnemaspis kottiyoorensis*. Biju *et al*. (2014) conducted a systematic revision of the genus *Hylarana* from the family Ranidae and described seven new species from the

Western Ghats. Vijayakumar *et al*. (2014) described nine new species of bush frogs of the genus *Raorchestes* from the Western Ghats.

Srinivasulu *et al*. (2015) described a Day Gecko *Cnemaspis adii* from Hampi in Karnataka. Dinesh *et al*. (2015) did a systematic revision of genus *Fejervarya* belonging to the family Dicroglossidae and described a new species *Fejervarya gomantaki* from Goa. Murthy *et al*. (2015) described a new species of gecko *Hemidactylus yajurvedi* from the Kanker district of Chhattisgarh, India. Sayyed *et al*. (2016) described a new species of Day Gecko *Cnemaspis flaviventralis* from Amboli, Northern Western Ghats. Dahanukar *et al*. (2016a) conducted a systematic revision of the frogs under the family Ranixalidae from the Western Ghats and described a new genus *Sallywalkerana* (2016b) and four new species. Zachariah *et al*. (2016) described two new species of bush frogs *Raorchestes silentvalley* and *R. lechiya* from Silent Valley National Park, Kerala. Garg and Biju (2016) described two new species of frogs, the *Indirana bhadrai* and *I. paramakri* from Bhadra Wildlife Sanctuary, Karnataka and Wayanad, Kerala respectively. Janani *et al*. (2017) described a new species of frog *Nasikabatrachus bhupathi* from the ancient lineage family Nasikabatrachidae from the eastern slopes of Western Ghats. Garg *et al*. (2017) described seven new Night Frogs from the southern Western Ghats. Garg and Biju (2017) described four new species of burrowing frogs in the family Dicroglossidae from the Western Ghats. Giri *et al*. (2017) described a new species of snake, *Rhabdops aquaticus* which inhabit waterlogged areas in the southern parts of Maharashtra and northern parts of Karnataka. Cyriac *et al*. (2018) described two new species of Day Geckos *Cnemaspis maculicollis* and *Cnemaspis anamudiensis* from Agsthyamalai and Anamalai hills respectively.

Sayyed *et al*. (2018) described four new species of Day Geckos *Cnemaspis limayei*, *C. ajijae*, *C. amboliensis* and *C. mahabali* from northern Western Ghats, Maharashtra.

Jins *et al*. (2018) described a new species of fossorial snake, *Uropeltis bhupathyi* from the Anaikatty Hills, Southern Western Ghats. Vineeth *et al*. (2018) described a new species of Narrow-mouthed Frog *Microhyla kodiyal* from Mangaluru, Karnataka. Raj *et al*. (2018) described two new species of frogs from the family Dicroglossidae; the *Fejervarya kalinga* and *F. krishnan* from Odisha and Karnataka states respectively. Deepak *et al*. (2019) described a new widespread yet rare species of Ahaetulla (Colubridae) from Odisha and Rajasthan. Khandekar *et al*. (2019) described two new Day Geckos, *Cnemaspis shevaroyensis* and *C. thackerayi* from Shevaroy Hills, Tamil Nadu. Chaitanya *et al*. (2019) revised the genus *Dravidogecko* and described six new species from the southern Western Ghats. Khandekar (2019) described a new species of Dwarf Gecko (*Cnemaspis agarwali*) from the Shevaroy hills near Salem, Tamil Nadu. Garg *et al*. (2019) conducted a systematic revision of narrow-mouthed frog belonging to the genus *Microhyla* and described a new species from Southern Western Ghats, Kerala and Das *et al*. (2019) described a new species of Microhylid frog *Micryletta aishani* with distribution in Assam, Tripura, and Manipur states. Biju *et al*. (2019) described another new species of Narrow-mouthed Frog, *Microhyla eos* from Arunachal Pradesh. Cyriac *et al*. (2020) described a new species of fossorial snake, *Rhinophis melanoleucus* from Lakkidi in Wayanad and Southern Western Ghats. Deepak *et al*. (2020) described a new species of fossorial snake, *Xylophis mosaicus* and the species was known from three locations; Kodaikanal, Eravikulam National Park, and Meeshapulimala. Mallik *et al*. (2020) described five new species of Vine Snake (*Ahaetulla*) from peninsular India. Garg *et al*. (2021) described five new species of shrub frogs from the family Rhacophoridae *viz. Raorchestes drutaahu, R.*

kakkayamensis, R. keirasabinae, R. sanjappai and *R. vellikkannan*, all of which were collected from Kerala part of Southern Western Ghats.

The herpetofaunal studies in Periyar Tiger Reserve were by Zacharias (1997), who recorded 45 species of reptiles from two orders belonging to 12 families. Family Colubridae (15 species) had more species representation followed by Viperidae and Agamidae with five species each. The study reported four species of lizards and 13 species of snakes endemic to the Western Ghats. Ravichandran and Pillai (1990) reported 14 species of frogs and toads. The amphibian fauna of Periyar Tiger Reserve was reported by Zacharias and Bhardwaj (1996). They reported 16 species of amphibians. Radhakrishnan (1999) studied the lizard and snake diversity in four Protected Areas in Idukki Districts including Periyar Tiger Reserve and recorded 32 species of reptiles, with highest number of species (16) in Periyar. Andrews *et al.* (2005) compared the amphibian assemblage and community structure in three different Protected Areas in Kerala. The study reported more amphibians from Periyar Tiger Reserve and Peppara Wildlife Sanctuary with 12 species each. In Periyar Tiger Reserve, *Rana temporalis* (revised as *Indosylvirana temporalis*) was the dominant species that contributed more than 40% of the amphibian diversity. They reported that amphibian diversity was high in Periyar (H'-2.830) followed by Peppara (H'-2.665) and Agasthyamalai (H'-2.064). In 2014, Das *et al.* conducted an amphibian survey in 13 locations in Periyar Tiger Reserve and recorded 49 species belonging to 10 families under 20 different genera. According to the study, about 40% of the amphibians in Periyar Tiger Reserve belong to the family Rhacophoridae followed by Bufonidae and Microhylidae (each family contributes 11%). Vallakadavu was the amphibian richest location with 30 species followed by Gavi (28) and Upper Manalar (23). In 2017, Rajkumar *et al*., (2018) conducted a detailed survey of amphibians and reptiles in 21 locations in Periyar for three days and updated the checklist. Sixty four species of amphibians belonging to 10 families under 23 genera were recorded. About 87% (56 species) of the amphibians recorded are endemic to the Western Ghats and 17 species come under various IUCN threatened categories. The *Raorchestes munnarensis*, *R. ponmudi*, *R. griet*, *R. chlorosomma* and *Rhacophorus pseudomalabaricus* are Critically Endangered (CR). The family Rhacophoridae (27) represents the highest number of species followed by Microhylidae and Nyctibatrachidae with 7 and 6 species respectively. This study also highlighted Vallakadavu as the amphibian richest location in Periyar with a total of 36 species followed by Anathodu, Gavi and Upper Manalar with 32, 31 and 27 species respectively. A total of 68 species of reptiles belonging to 15 families under 43 genera were recorded. The family Colubridae (14) represented the highest number of species followed by Geckonidae, Scincidae and Agamidae with ten, eight and seven species respectively. Out of the 68 species recorded, 27 (39%) are endemic to the Western Ghats and the *Cnemaspis wynadensis* and *Boiga dightoni* are endemic to Kerala. Eleven species fall under different IUCN threatened categories; the *Vijayachelys silvatica*, *Dasia subcaeruleum*, and *Cnemaspis wynadensis* are under the Endangered category of the IUCN red list. In the case of amphibians, Vallakadavu and Anathodu were species-rich areas with 30 and 29 species of reptiles respectively followed by Mavady and Sabarimala with 25 and 20 species.

Some of the new species of amphibians and reptiles described in the last 10 to 15 years were collected from Periyar Tiger Reserve. Zachariah *et al*. (2011) described *Raorchestes uthamani* a, small-sized bush frog collected from the reed patches in Gavi and which shows point endemism, only found inside Periyar Tiger

Reserve. Vijayakumar *et al*. (2014) described nine new species of bush frogs from the Western Ghats of which *Raorchestes flavioculari*s was collected from Upper Manalar, Periyar Tiger Reserve. Garg *et al*. (2010) described seven new species of Night Frogs from the genus *Nyctibatrachus* from the southern Western Ghats and the type locality of two of the species are inside Periyar Tiger Reserve. The two species are *Nyctibatrachus manalari* and *Nyctibatrachus sabarimalai* and the type localities of these species are Upper Manalar and Sabarimalai as the name suggests. Pal *et al*. (2018) described two new species of lizards from the Western Ghats. Oneof these, *Monilesaurus acanthocephalans* was collected from the Upper Manalar landscape. Chaitanya *et al*. (2019) described six new species of Geckos from the genus *Dravidogecko* and one of these was from Meghamalai Wildlife Sanctuary in Tamil Nadu, contiguous with Periyar Tiger Reserve. Garg *et al*. (2021) described five new species of bush frogs from the Western Ghats and one species *Raorchestes keirasabinae* was described based on the specimens from Thiruvananthapuram and Vallakadavu, Periyar Tiger Reserve.

The grasslands in Periyar Tiger Reserve were divided into Tropical Montane Grasslands and South Indian Sub-tropical Hill Savannahs. Based on the distribution, these grasslands were further divided into three, (1) grasslands in the hilltops, along the hill slopes, and (2) savannahs and in the (3) lakeshores and marshes (Srivastava *et al*., 1994). The grasslands in the marshes are the vayals and some of the grasslands in the lake shores are man-made vayals (Sreejith *et al*., 2014). These vayals were not studied in detail to understand the goods and services provided by the habitat (Sreejith *et al*., 2014). Pushpakaran and Gopalan (2013) conducted a study on vayals in Mudumalai Tiger Reserve, and mapped and calculated extent of vayals. They have also studied the threats and discussed the presence of exotic plants and invasion by tree seedlings to vayals. According to their study, these vayals are categorized as marshy wetlands under article 1.1 of the Ramsar convention. In Periyar, an inventory of vayal ecosystem in Pamba Forest Range was done by Sreejith *et al*., and a preliminary report was submitted in 2014. Twenty-three vayals were surveyed and mapped. The total extent of vayal ecosystems in Pamba was 22.36 ha, the floral composition was also documented with a total of 118 angiosperms. The extent of vayals varies considerably, ranging from 0.02 ha to 4.73 ha. Vayals play an important role in maintaining forest biodiversity and water regime (Sreejith *et al*., 2014) and are ideal habitats for amphibians and reptiles.

Pushpakaran and Gopalan (2013; Sreejith *et al*., 2014) observed shrinkage of the extent of vayal habitat and were highly threatened from the invasion of both native and exotic plants. There was no study to documents vayal- specific amphibian or reptile with habitat preference. Lack of such information combined with the threat to the habitat could be detrimental to such habitat specific reptiles and amphibians. Pal *et al*. (2010) have reported abundance of several cryptic and elusive species in several fragments of its distribution. This also indicates that such habitat specific studies would bring out information also on the stataus of threatened species in the area. Hence, it was considered important to understand the herpetofaunal diversity in the vayals and also identify vayal-specific species.

5.2. Methods

Prior to the beginning of this study, several reconnaissance surveys were carried out from July to December 2014. Several degraded and non-degraded vayals at different elevations in Periyar and with varying vegetation in the surroundings were visited. Most of the fast moving species in leaf litter were captured and identified during this period.

The full-fledged data collection for this study was started in January 2015 and surveys were carried out till November 2017. Surveys were done every month to cover the species that are active during pre-monsoon, monsoon and post-monsoon period. The aim of this study was to check the presence of reptiles or amphibians that are very specific to this vayal habitat. To confirm this, the amphibian and reptile assemblage inside the vayals and in the immediate surrounding vegetation of vayals is needed. The survey methods were chosen based on chapter 4 (General Methods). Since amphibians and reptiles are known to prefer a variety of microhabitats (Campbell and Christman, 1982; Heyer *et al*., 1994; Dodd, 2009; Dodd, 2016) and the vayals and its immediate surrounding vegetation offer many of these microhabitats, a combination of methods were used to study the amphibian and reptile assemblage inside vayals and in the surrounding vegetation. The methods used were quadrat survey, visual encounter survey and line transect survey. Survey was conducted both during day time and night time to record the diurnal and nocturnal amphibians and reptiles. Sampling effort was kept equal in the vayals and surrounding vegetation.

5.2.1. Quadrat survey

Quadrats of 5m × 5m were marked at least one day prior to the actual survey. Since the size of vayals varied considerably, laying 10m × 10m or larger quadrats were not possible. On a sampling day, same number of quadrats were laid in the vayal and in the surrounding vegetation. In the vayals with smaller area, less number of quadrats were laid inside like one quadrat inside and two in the surrounding vegetation. The quadrats were placed randomly based on spatial replication method to minimize the recounting of same individual. All the microhabitats inside the quadrat were searched including under the logs, rock crevices, under stones, in leaf litter, in water and for getting arboreal species the trees and shrubs were searched up to about two meter height. The distance between two quadrats on a sampling occasion was kept to a minimum of 20m to avoid chances of recounting because of animal movement between the areas during sampling. The quadrats were sampled by two persons (myself and a field assistant or a trained department staff) starting from opposite corners of the quadrat and moving to the center of the quadrat by walking along the side length. This was to reduce the chance of animals escaping from the quadrat to outside. This also ensured a high chance for animals to move towards the center, making it possible for any of the surveyors to record such individuals. Since two people were involved, there were more chance to find all the animals inside the quadrat. All the amphibians and reptiles encountered during the survey were bagged (in polythene zip lock bags) to avoid recounting. The fast moving animals like the ground-dwelling skinks were not caught and these animals were noted during the survey. After the survey, the animals were identified and released back to the same quadrat. While sampling more than one quadrat, all the captured animals were kept till completion of sampling in all the quadrats. Each bag were marked and the animals released back to the respective quadrats. Care was taken to avoid overlapping of quadrats in two habitats, vayals and surrounding vegetation.

5.2.2. Line transect survey

Line transect surveys were done with a fixed width that was marked a day prior to the sampling. The length of the transect was limited to 20m since some of the vayals were very small in size and even the longest parts are not more than 20m. The width of the transect was fixed to one meter distance perpendicular to the line transect. Equal number of transects were done during day and night and also in vayal and in the immediate surrounding vegetation. The transect was walked in a uniform pace by two trained people, one person checking one side and the other person checking the other side to get maximum sightings. All the microhabitats (fallen logs, under stones, in leaf litter, tree bark etc.) inside the transect were thoroughly searched. The trees and shrubs up to 2 meter height were also searched for documenting arboreal and semi-arboreal species. All the amphibians and reptiles found in the transect were bagged in a polythene zip lock bag. After completion of the survey, the animals were identified and released back to the same area. While doing more transects in a location, the animals were kept till all transects were surveyed, which reduces the chance for recounting the same individuals. The distance between transects was kept at least 20 m to avoid recounting of the animals that are not captured. Since amphibians and reptiles vary in size from 2cm to couple of feet, a width of 1m meter was chosen to get maximum detection probability. The width was fixed based on the experience gained during the reconnaissance survey. The night surveys were really challenging to find animals that are present away from transect. Night surveys were done with the help of trained assistants using powerful torches

5.2.3. Visual encounter survey

Visual encounter surveys (VES) were carried out with constrained time of 15 minutes. The survey was conducted with a uniform pace and all the microhabitats in that area were searched for semi-fossorial, terrestrial, semi-arboreal and arboreal amphibian and reptile species. Trees, tree barks, shrubs, grass clumps, boulders, leaf litter, fallen logs, and under stones were searched. Surveys were conducted both during day and night hours with equal sampling effort to cover diurnal and nocturnal species. The night surveys were done with the help of trained forest trackers using good torch lights. Day time surveys were done between 08:00 and 18:00 hours and night surveys between 18:00 and 01:00 hours. While doing more than one sampling at a location, the area for the next survey was chosen away from the last one to avoid recounting of animals that moved out from the last sampled area. All the animals found during the survey were captured and put in separate polythene zip lock bags and the fast moving animals were closely observed for identification. The collected species were released at the collection location after identification soon after the completion of the survey in that unit.

5.2.4. Data analysis

Species accumulation curve was plotted from the data collected from quadrat, VES and line transect methods. The mean species richness and estimated species richness for all the three methods were also estimated. Based on these two analyses, the data set for further analysis was selected. The software Estimate S 9.1.0 was used to find out the species accumulation curve and estimated species richness. Monthly species richness, abundance and diversity (H') were estimated and plotted against monthly mean temperature, mean humidity and precipitation. For checking the similarity between the vayals and its surrounding vegetation, diversity t-test was done for all the 47 vayals and its surrounding vegetation. perMANOVA using the PAST 4.03 was used for confirming the results of t-test.

The estimated species richness was estimated using the formula:

$$\hat{S}_{Chao2} = S_{obs} + \left(\frac{m-1}{m}\right)\frac{Q_1^2}{2Q_2}$$

Shannon diversity indices (H') –

$$H = -\sum_{i} \frac{n_i}{N} \ln \frac{n_i}{N}$$

perMANOVA 1 –

$$\mathrm{SS_T} = \frac{1}{N}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N} d_{ij}^2$$

5.2.5. Distribution of amphibians and reptiles

GPS points for each sampling vayal was collected with Garmin 30 GPS device during the survey and the information was used to prepare the distribution map for each amphibian and reptile species and the map was created with the help of QGIS Desktop 3.14.0.

5.3. Results

A total of 482 quadrat surveys, 130 line transect and 775 time constrained VES were done. VES yielded more number of species than quadrat surveys and line transect surveys.

5.3.1. Diversity from Quadrat survey

A total of 482 quadrat surveys were done inside the vayals (237) and in the immediate surrounding vegetation (245). Fourteen species of amphibians and 15 of reptiles were recorded from vayals and 16 species of amphibians and 18 species of reptiles from the surrounding vegetation. The species accumulation curve of amphibians nearly reached a stable point after 390 surveys and it more or less attained a stable point after 460 survey efforts in reptiles. The mean species richness of amphibians is 23.18 and the estimated species richness is 24.19. It is 17.35 and 23.46 respectively for reptiles. The results show a good sampling effort and indicate that the data can be used for further studies (Figs. 5.1 and 5.2)

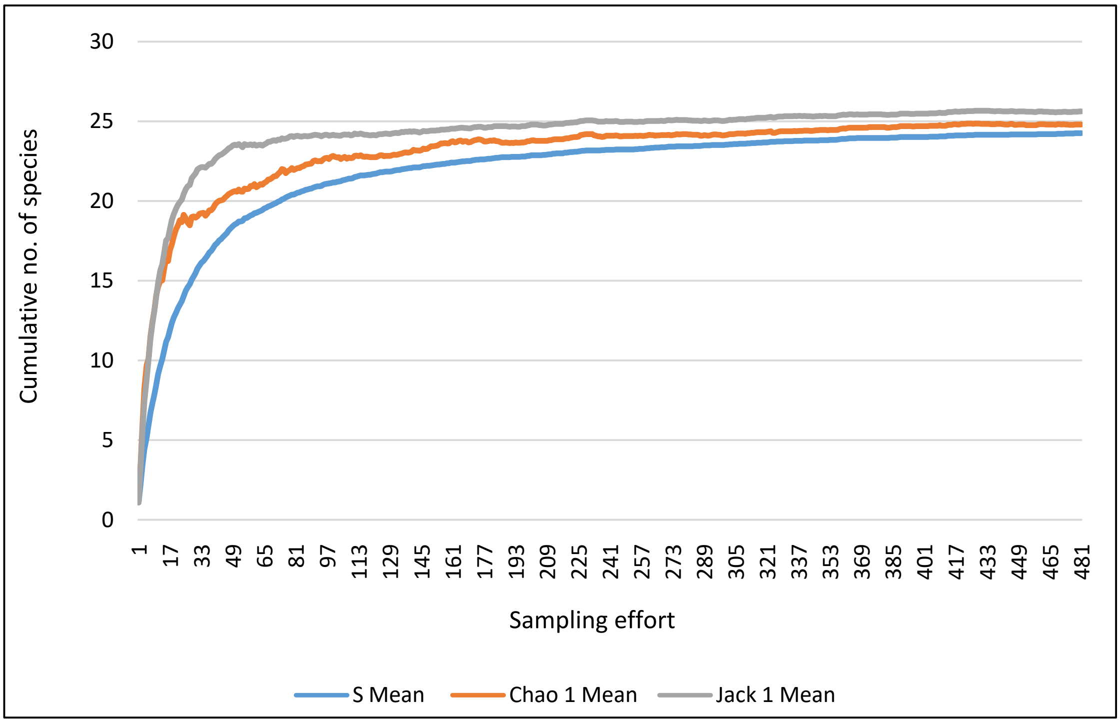

Fig. 5. 1 Amphibian species accumulation curve with estimated Chao and Jackknife accumulation curves based on quadrat surveys

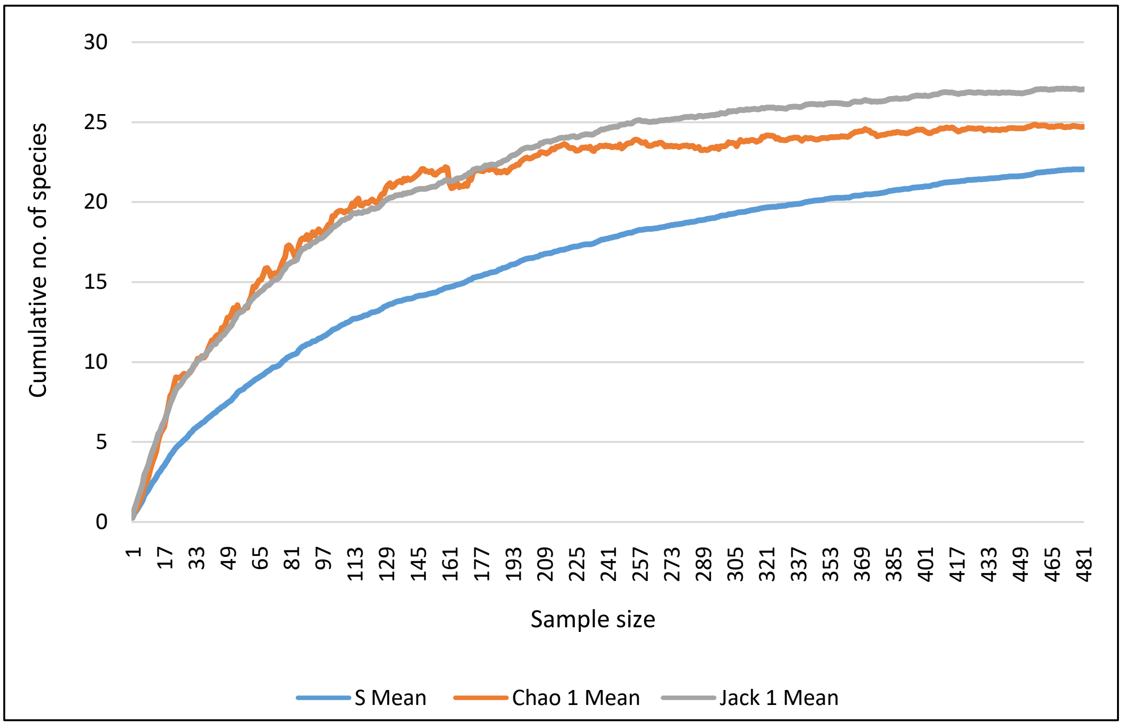

Fig. 5. 2 Reptile species accumulation curve with estimated Chao and Jackknife accumulation curves based on quadrat surveys

5.3.2. Diversity from Line transect survey

From 67 line transect surveys inside the vayals and 63 surveys in the surrounding vegetation, 18 species of amphibians and 9 species of reptiles were recorded from vayals whereas 15 species of amphibians and 9 species of reptiles were recorded from the surrounding vegetation. The amphibian species accumulation curve nearly reached a straight line after 120 surveys and if there were more sampling efforts then there could be a possibility to record more reptiles. The mean species richness of amphibians is 12.29 and the estimated species richness is 17.52 and for reptile it is 5.64 and 7.4 respectively (Figs. 5.3 and 5.4). The results indicate that the sampling effort is good enough.

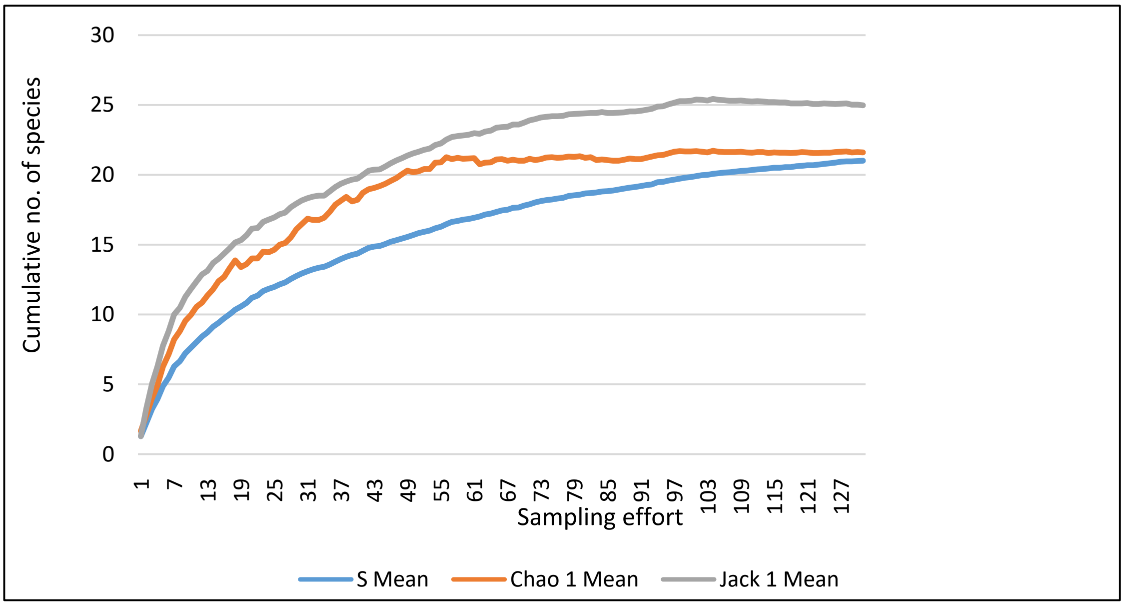

Fig. 5. 3 Amphibian species accumulati[on curve with estimated Chao and Jackknife accumulation curves based on line transect surveys

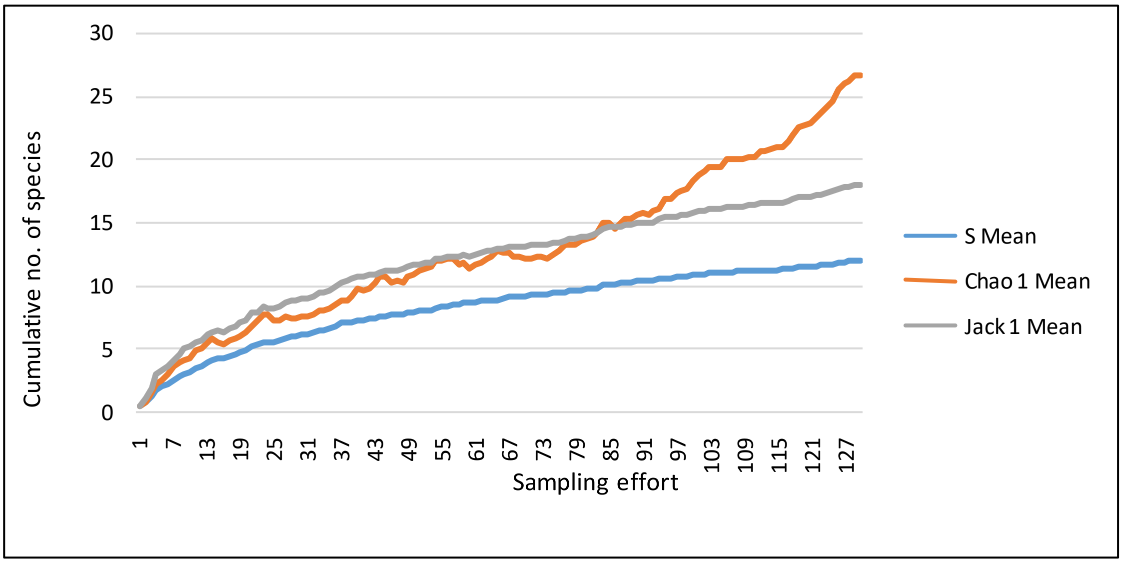

Fig. 5. 4 Reptile species accumulation curve with estimated Chao and Jackknife accumulation curves based on line transect surveys

5.3.3. Visual Encounter Surveys

Three hundred and eighty six VES surveys were carried out inside the vayals and 389 surveys in the immediate surrounding vegetation. Twenty eight species of amphibians and 24 species of reptiles were recorded from the vayals and 32 species of amphibians and 34 species of reptiles were from the surrounding vegetation. The amphibian species accumulation curve reached a straight line after 440 surveys and the reptiles after 620 surveys. The mean species richness of amphibians is 30.4 and the estimated species richness is 31.47 and for reptile it is 27.88 and 33.04 respectively (Figs. 5.5 and 5.6). It clearly says that the sampling effort is good enough.

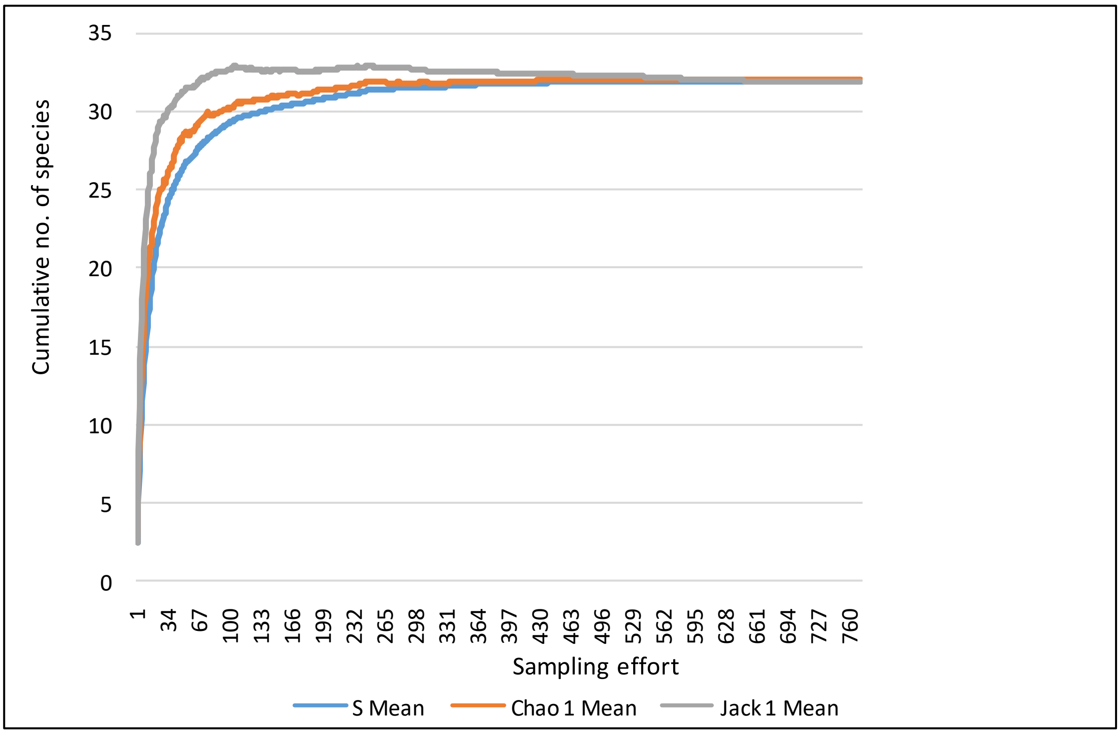

Fig. 5. 5 Amphibian species accumulation curve with estimated Chao and Jackknife accumulation curves based on time constrained VES

The estimated species richness of amphibians and reptiles was more close to the calculated mean species richness obtained from time constrained VES methods compared to that obtained from the quadrat and line transect methods. Therefore, the data collected from time constrained VES method was used for further analysis.

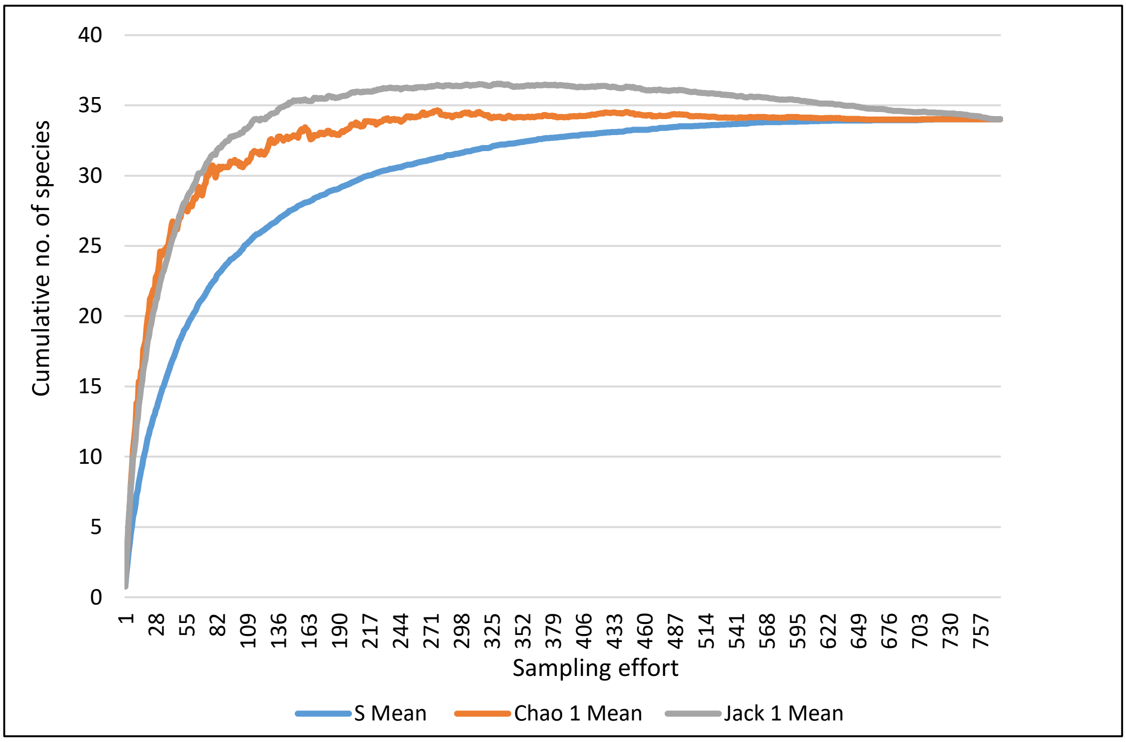

Fig. 5. 6 Reptile species accumulation curve with estimated Chao and Jackknife accumulation curves based on time constrained VES

A total of 32 species of amphibians represented by 15 genus from nine families belonging to two orders. The most common family of amphibians was Rhacophoridae with 17 species followed by Nyctibatrachidae (4), Dicroglossidae (3), Ranidae (2), Bufonidae (2), Ranixalidae (1), Microhylidae (1), Micrixalidae (1), and Icthyophidae (1) (Fig. 5.7). The order Anura of frogs and toads comprises more number of species (31) followed by order Gymnophiona (1).

Thirty four species of reptiles represented by 23 genus from 13 families belonging to two orders were recorded from the vayals and its immediate surrounding vegetation. The most common family of reptile was Colubridae (7) followed by Gekkonidae (6), Agamidae (5), Natricidae (3), Scincidae (3), Viperidae (2), Typhlopidae (2), Elapidae (1), Pythonidae (1), Uropeltidae (1), Varanidae (1), Testudinidae (1), and Geoemydidae

(1) (Fig. 5.8). The order Squamata (32) comprises more number of species followed by the order Testudines (2).

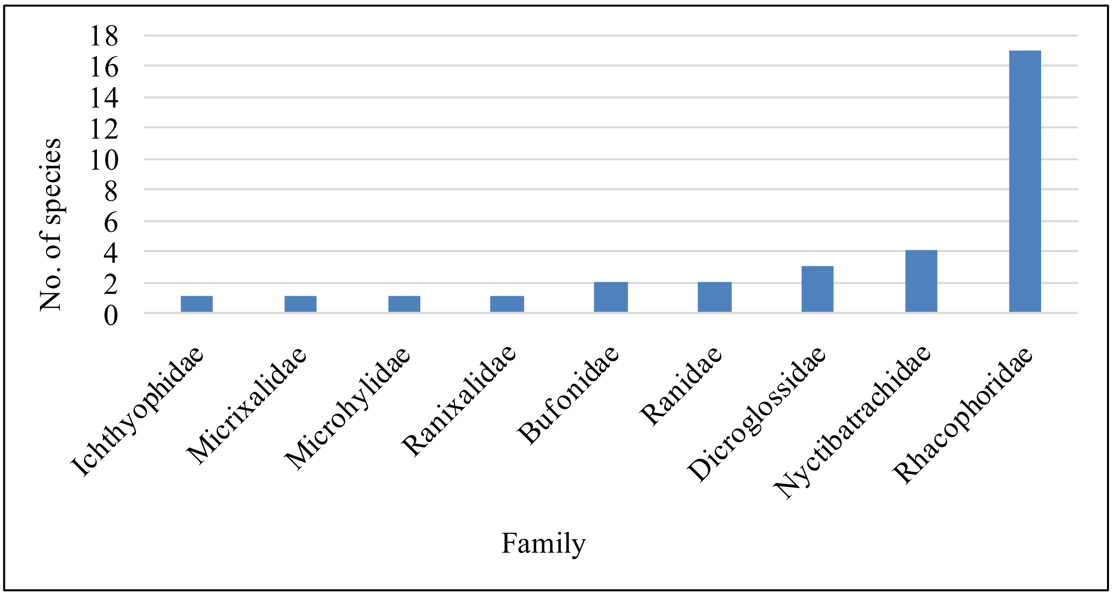

Fig. 5. 7 Family wise distribution of amphibians recorded from both vayal and its immediate surrounding vegetation

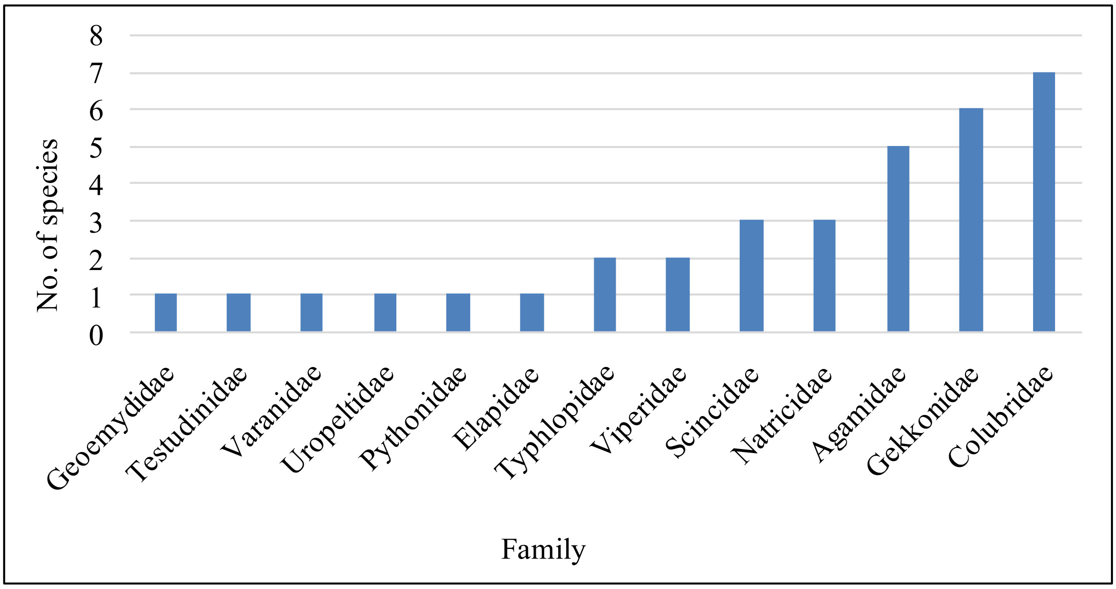

Fig. 5. 8 Family wise distribution of reptiles recorded from both vayal and its immediate surrounding vegetation

5.3.3.1 Details of Amphibians recorded from the area

Duttaphrynus melanostictus **(Schneider, 1799),** Common Indian Toad

Order: Anura

Family: Bufonidae

IUCN Category: Least Concern

Endemism: Wide spread distribution

Wildlife Protection Act, 1972: Not listed

CITES: Not listed

Distribution map is given in Fig. 5.9

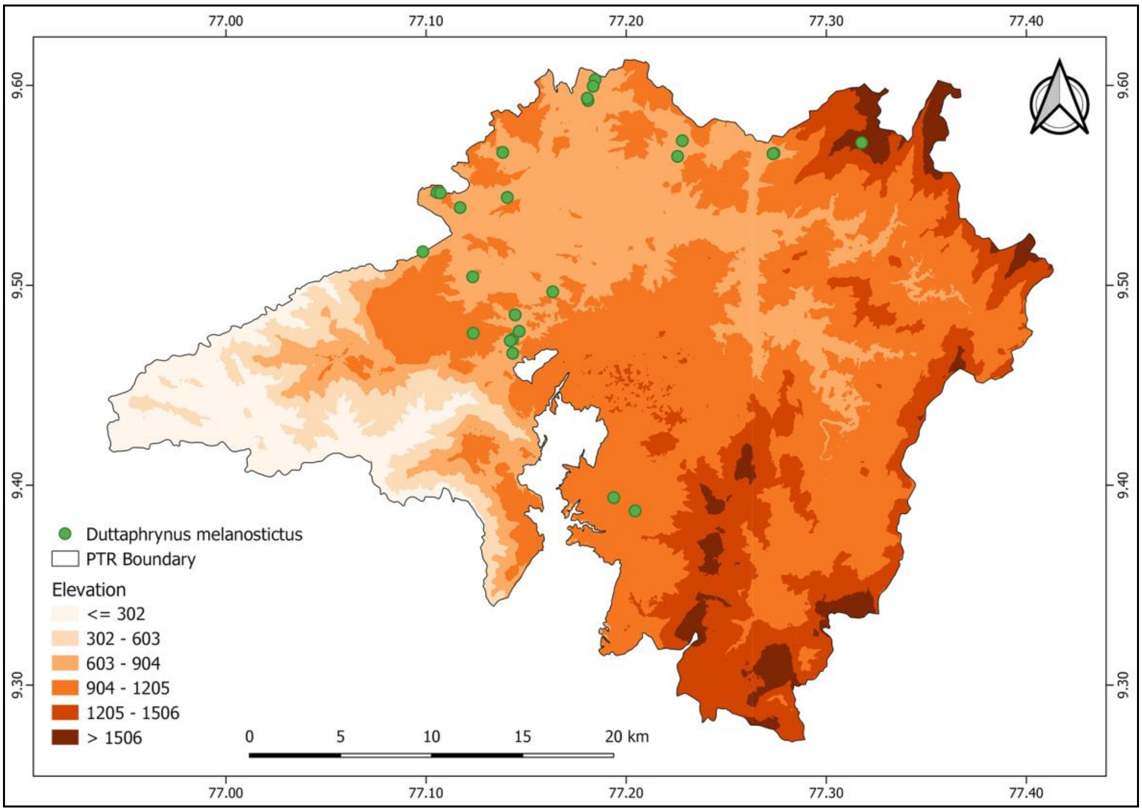

Fig. 5. 9 Distribution map of *Duttaphrynus melanostictus*

Duttaphrynus parietalis **(Boulenger, 1882),** Ridged Toad

Order: Anura

Family: Bufonidae

IUCN Category: Near Threatened

Endemism: Western Ghats

Wildlife Protection Act, 1972: Not listed

CITES: Not listed

Distribution map is given in 5.10

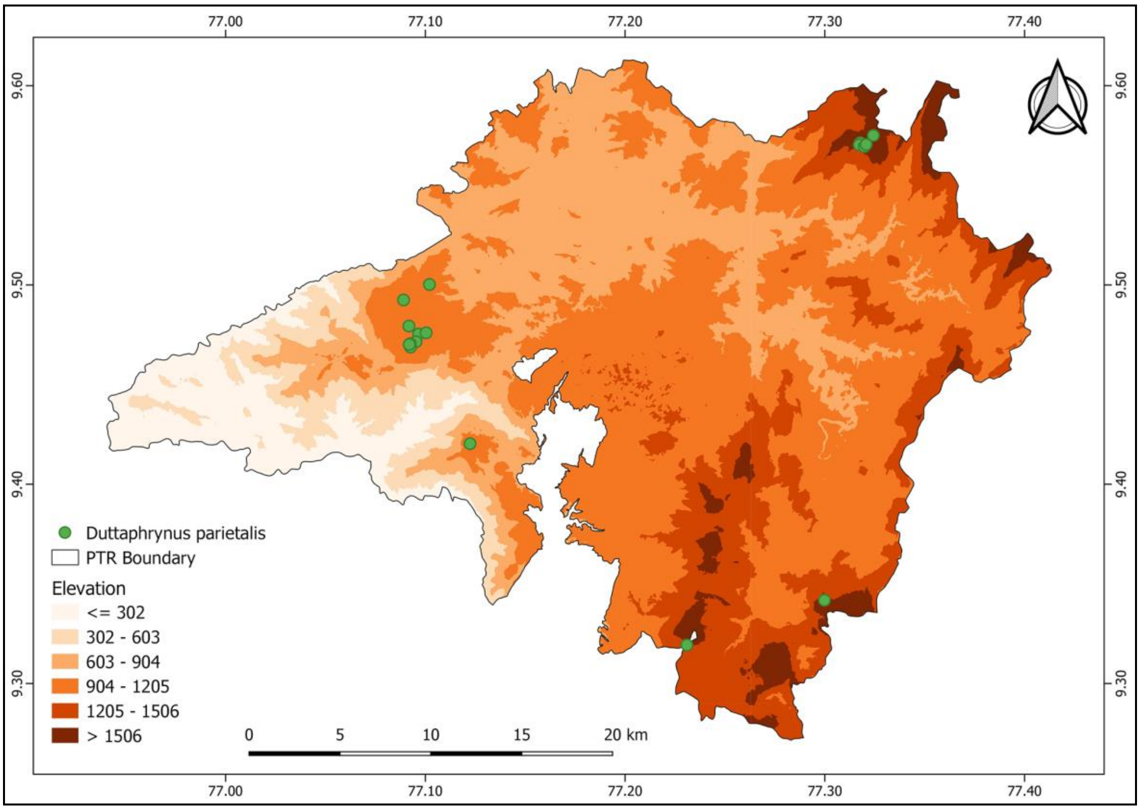

Fig. 5. 10 Distribution map of *Duttaphrynus parietalis*.

***Euphlyctis cyanophlyctis* (Schneider, 1799),** Skittering Frog

Order: Anura

Family: Dicroglossidae

IUCN Category: Least Concern

Endemism: Widely distributed

Wildlife Protection Act, 1972: Schedule IV

CITES: Not listed

Distribution map is in Fig. 5.11

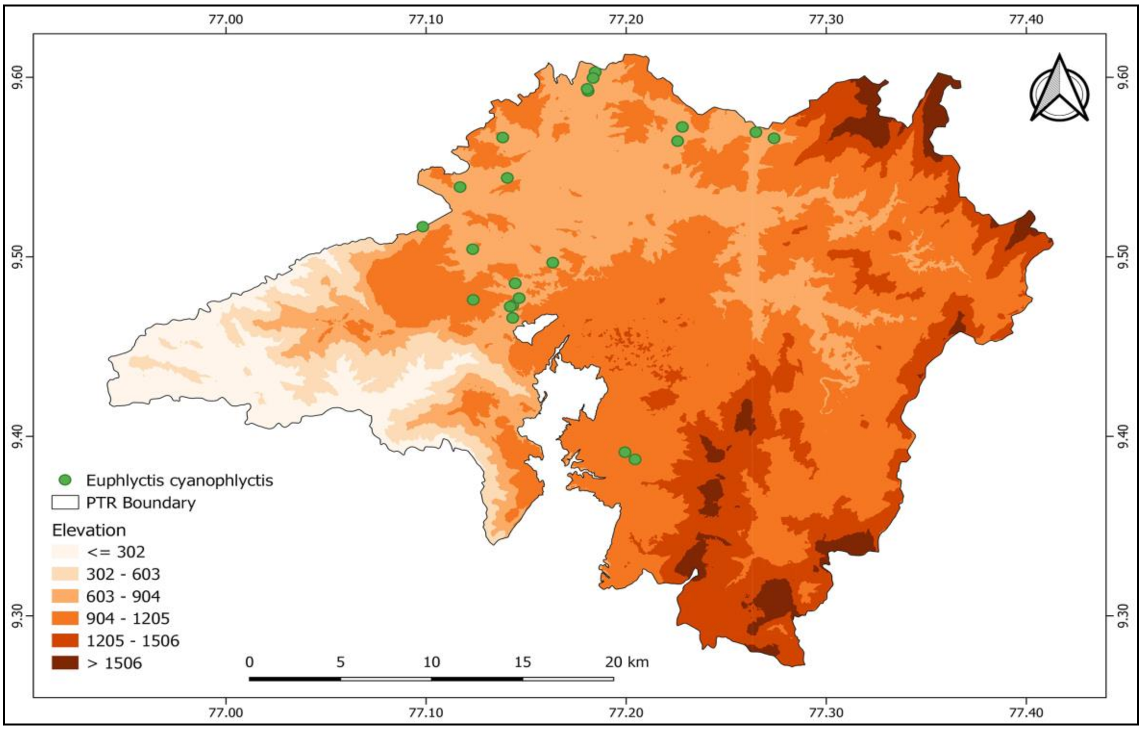

Fig. 5. 11 Distribution map of *Euphlyctis cyanophlyctis*.

***Hoplobatrachus tigerinus* (Daudin, 1803),** Indian Bullfrog

Order: Anura

Family: Dicroglossidae

IUCN Category: Least Concern

Endemism: Widely distributed

Wildlife Protection Act, 1972: Schedule IV

CITES: Schedule II

Distribution map is provided in Fig 5.12

***Minervarya keralensis* (Dubois, 1980),** Kerala Warty Frog

Order: Anura

Family: Dicroglossidae

IUCN Category: Least Concern

Endemism: Western Ghats

Wildlife Protection Act, 1972: Schedule IV

CITES: Not listed

Distribution map is given in Fig. 5.13

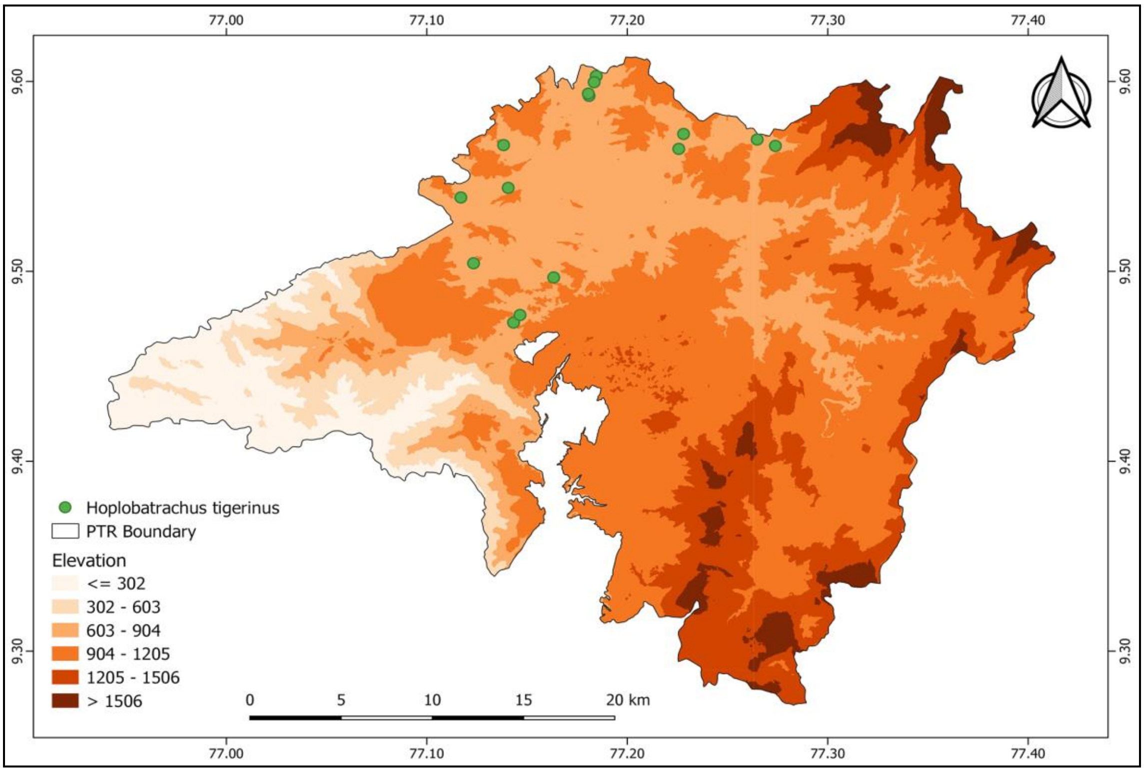

Fig. 5. 12 Distribution map of *Hoplobatrachus tigerinus*.

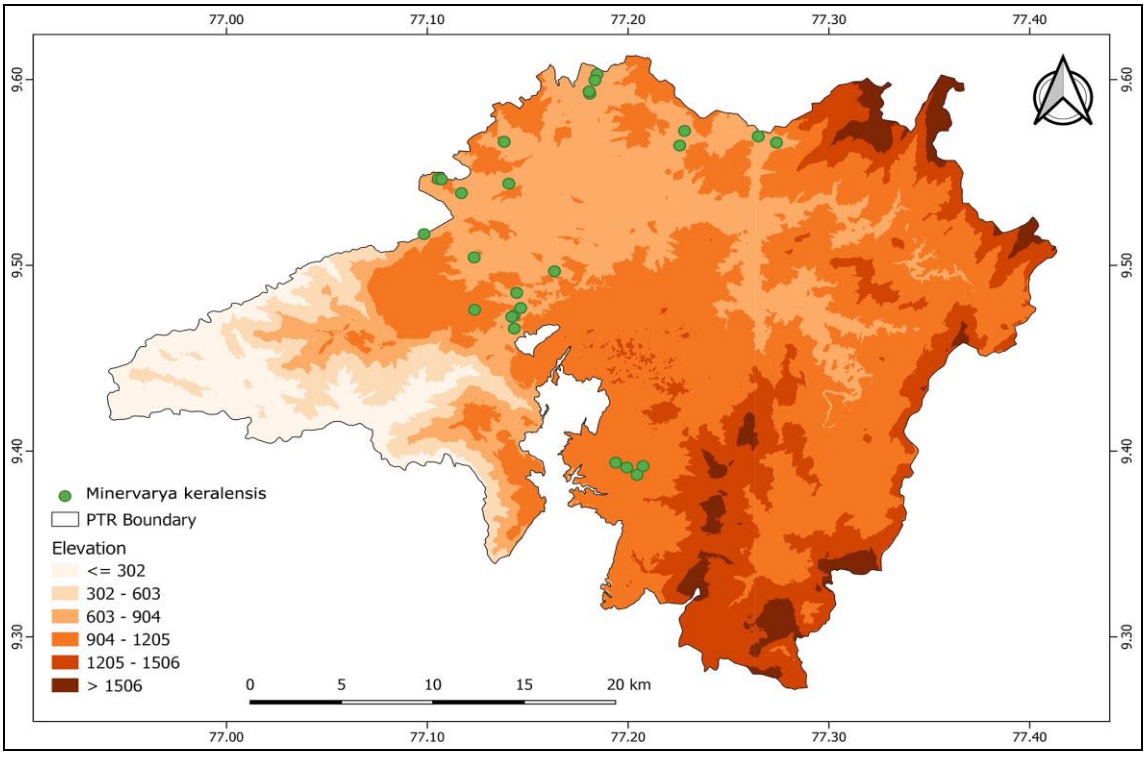

Fig. 5. 13 Distribution map of *Minervarya keralensis.*

Micrixalus adonis **(Biju, Garg, Gururaja, Shouche and Walukar, 2014),** Munnar Torrent Frog

Order: Anura

Family: Micrixalidae

IUCN Category: Not Evaluated

Endemism: Western Ghats

Wildlife Protection Act, 1972: Not listed

CITES: Not listed

Distribution map is in Fig. 5.14.

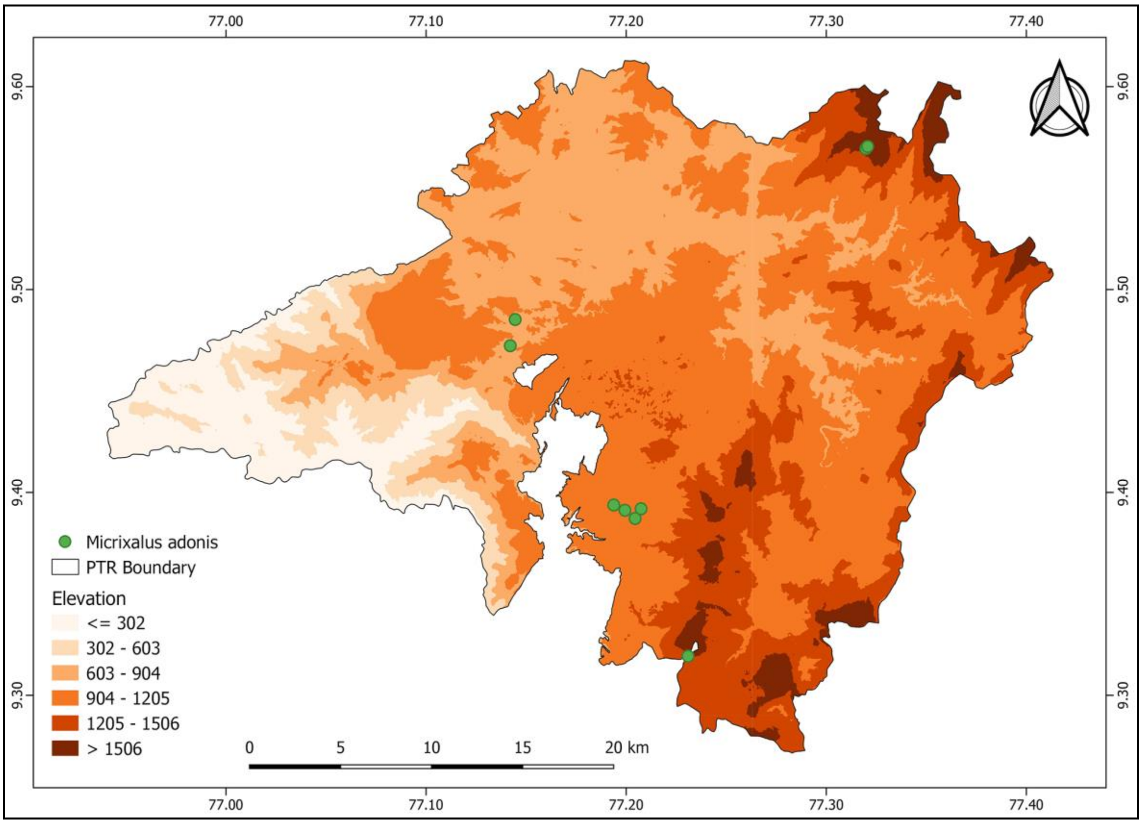

Fig. 5. 14 Distribution map of *Micrixalus adonis.*

Uperodon montanus **(Jerdon, 1854),** Jerdon's Ramanella

Order: Anura

Family: Microhylidae

IUCN Category: Near Threatened

Endemism: Western Ghats

Wildlife Protection Act, 1972: Not listed

CITES: Not listed

Distribution in Periyar Tiger Reserve is given in Fig. 5.15

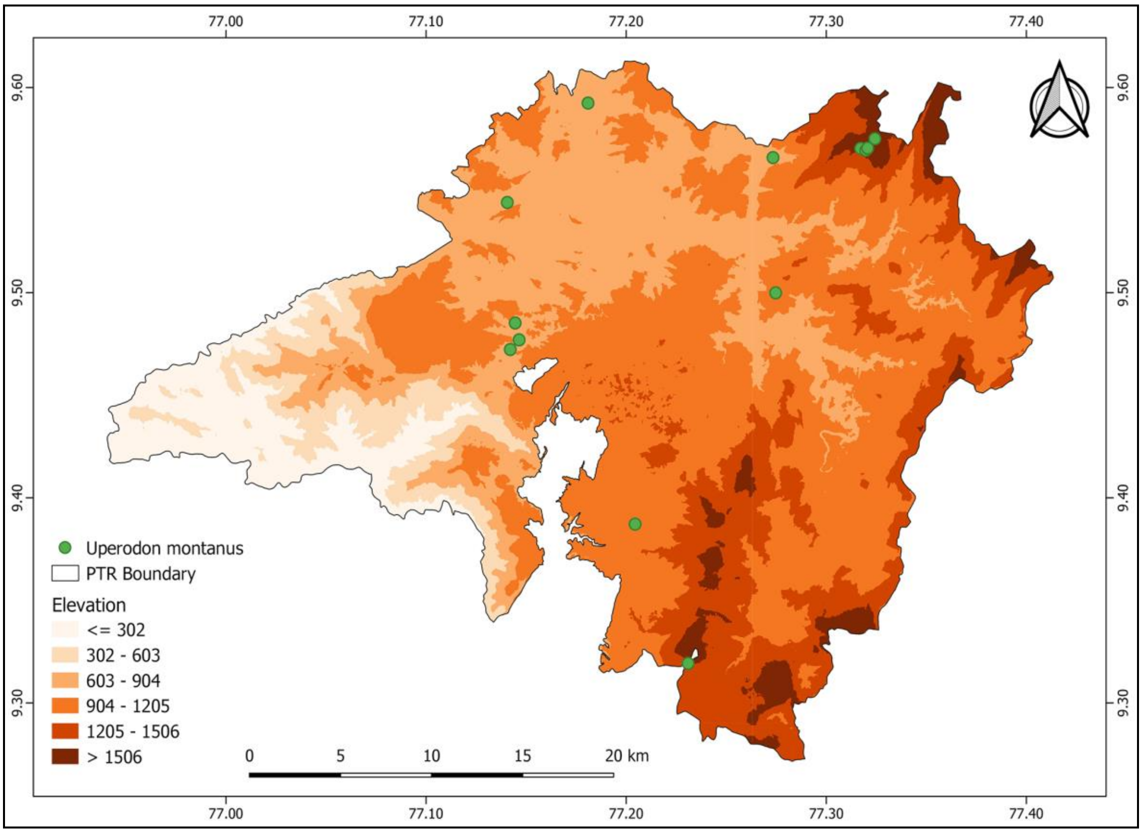

Fig. 5. 15 Distribution map of *Uperodon montanus.*

***Nyctibatrachus* sp.**, Night Frog

Order: Anura

Family: Nyctibatrachidae

IUCN Category:

Endemism:

Wildlife Protection Act, 1972:

CITES:

Distribution details from the present study are in Fig. 5.16.

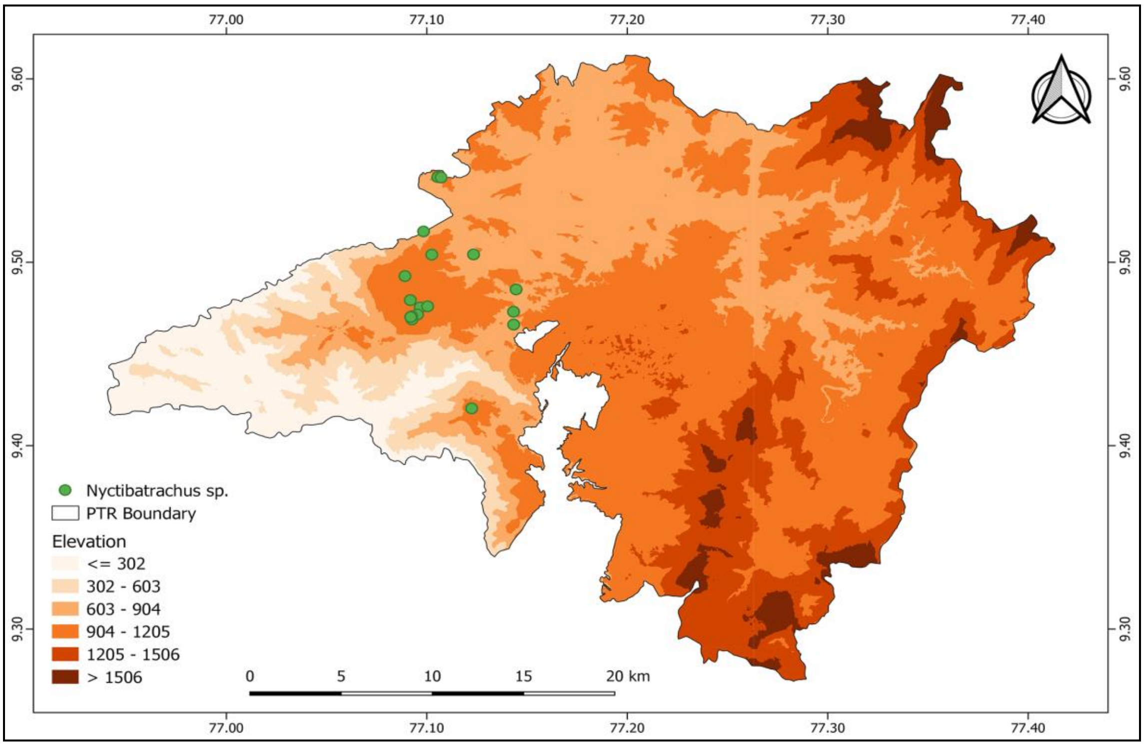

Fig. 5. 16 Distribution map of *Nyctibatrachus* sp.

***Nyctibatrachus manalari* (Garg, Suyesh, Sukeshan and Biju, 2017),** Manalar Night Frog

Order: Anura

Family: Nyctibatrachidae

IUCN Category: Not Evaluated

Endemism: Western Ghats

Wildlife Protection Act, 1972: Not listed

CITES: Not listed

Distribution details from the present study are in Fig. 5.17.

***Nyctibatrachus gavi* (Biju, Bocxlaer, Mahony, Dinesh, Radhakrishnan, Zachariah, Giri and Bossuyt, 2011),** Gavi Night Frog

Order: Anura

Family: Nyctibatrachidae

IUCN Category: Not Evaluated

Endemism: Western Ghats

Wildlife Protection Act, 1972: Not listed

CITES: Not listed

Distribution details from the present study are in Fig. 5.18.

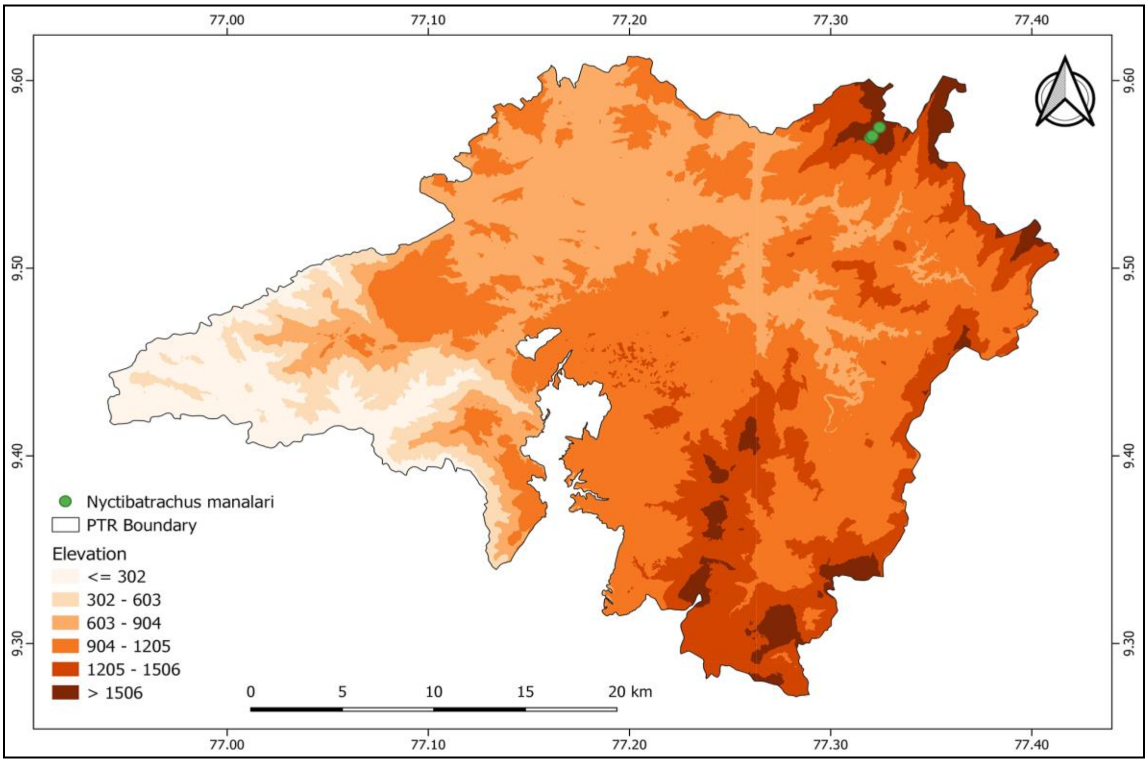

Fig. 5. 17 Distribution map of *Nyctibatrachus manalari*

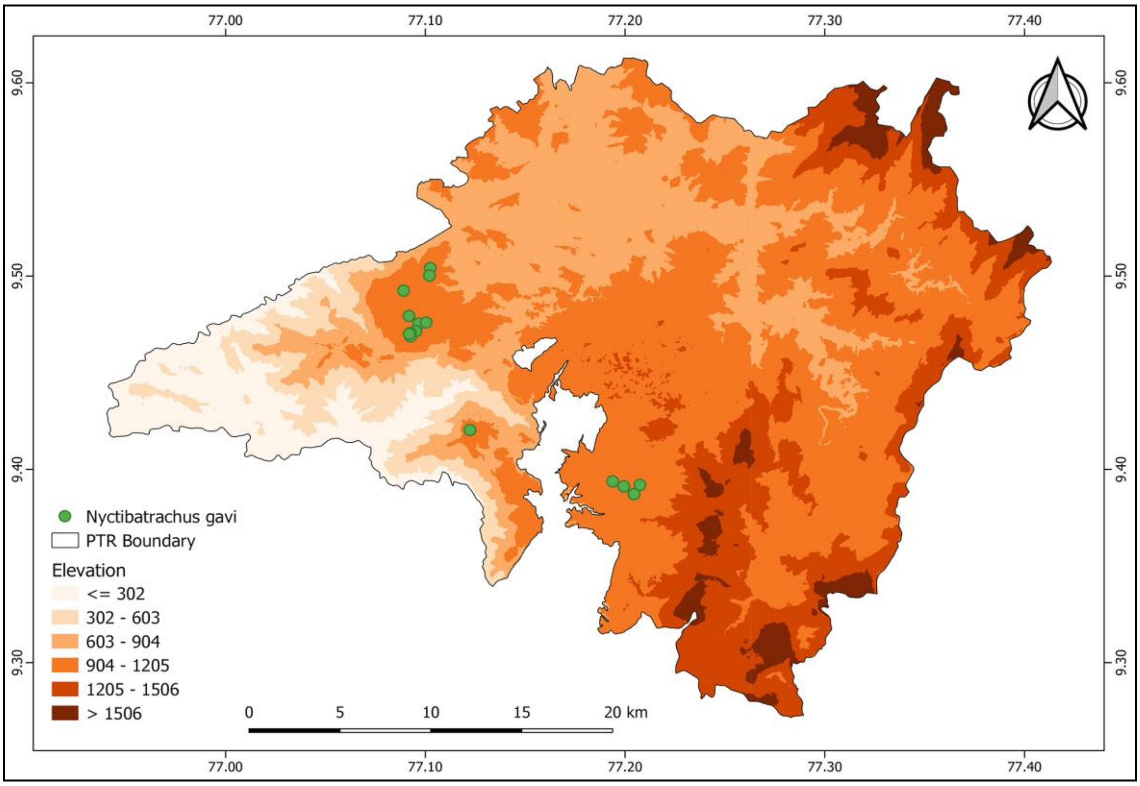

Fig. 5. 18 Distribution map of *Nyctibatrachus gavi*

***Nyctibatrachus periyar* (Biju, Bocxlaer, Mahony, Dinesh, Radhakrishnan, Zachariah, Giri and Bossuyt, 2011),** Periyar Night Frog

Order: Anura

Family: Nyctibatrachidae

IUCN Category: Not Evaluated

Endemism: Western Ghats

Wildlife Protection Act, 1972: Not listed

CITES: Not listed

Distribution of the species as observed from the present study is given in Fig. 5.19

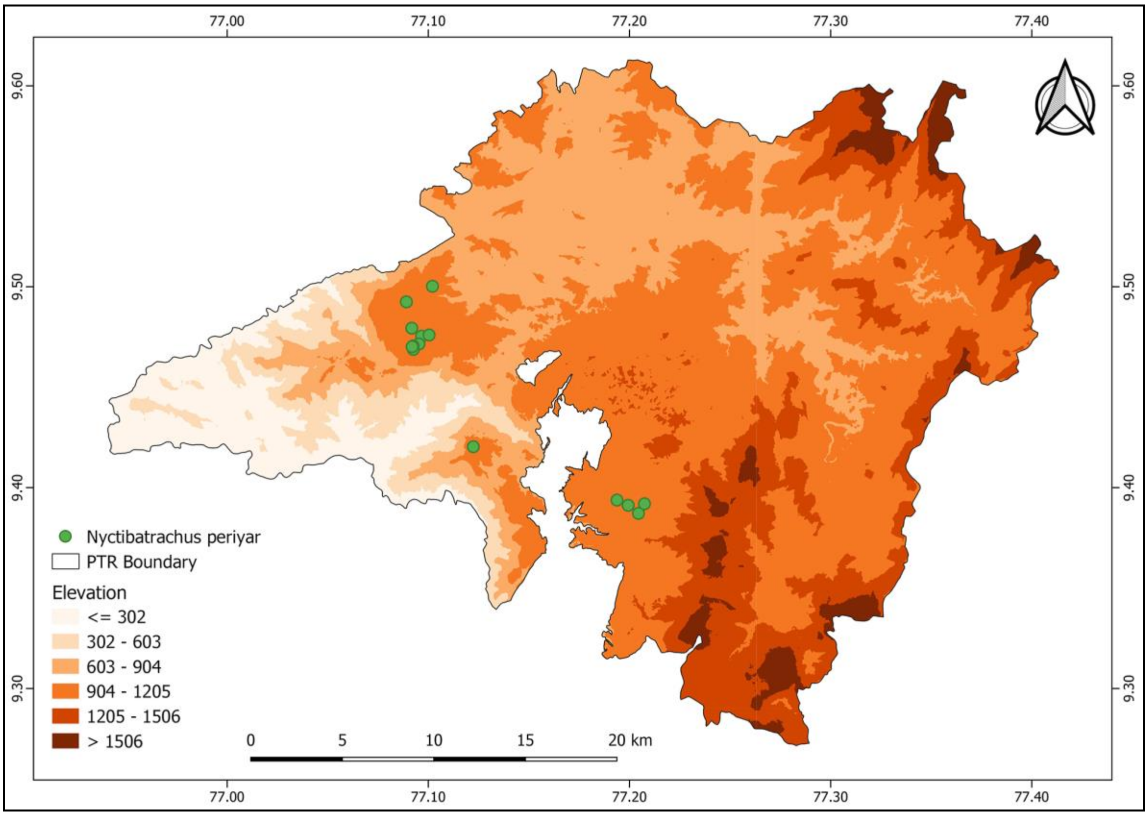

Fig. 5. 19 Distribution map of *Nyctibatrachus periyar*

***Indirana semipalmata* (Boulenger, 1882),** South Indian Frog

Order: Anura

Family: Ranixalidae

IUCN Category: Not Evaluated

Endemism: Western Ghats

Wildlife Protection Act, 1972: Schedule IV

CITES: Not listed

Distribution details from the present study are in Fig. 5.20.

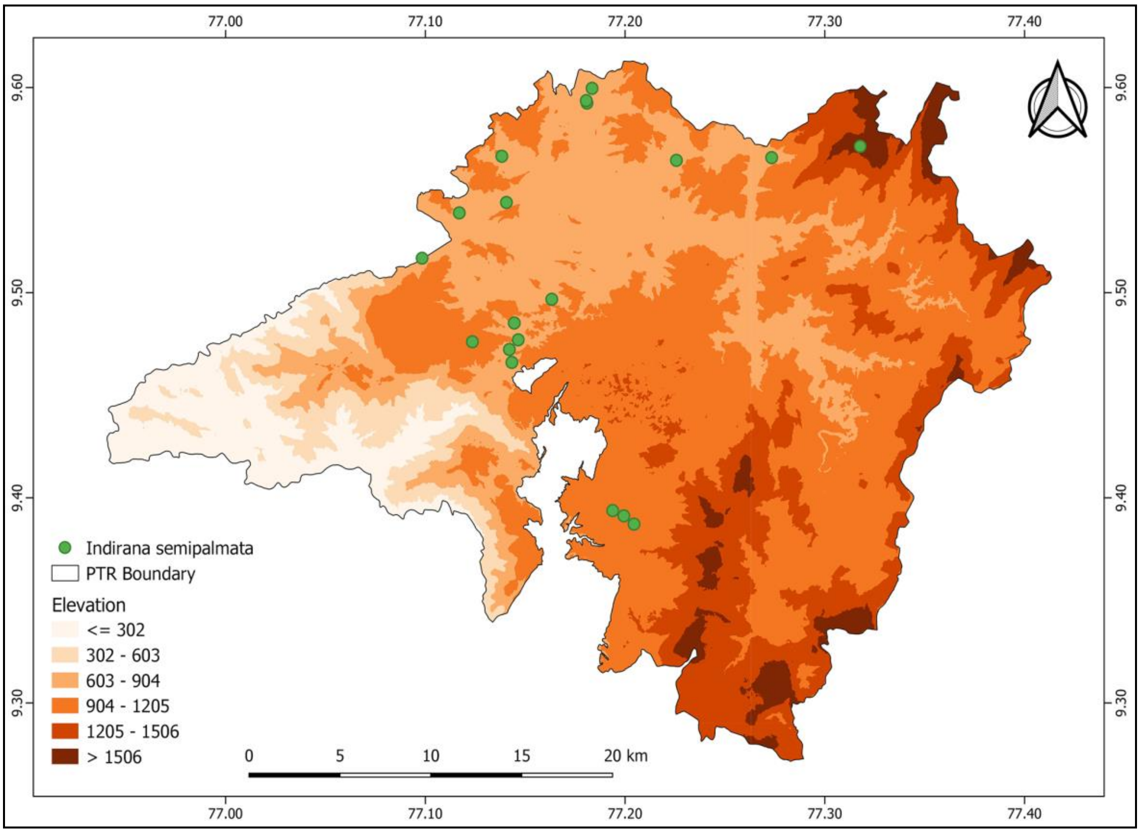

Fig. 5. 20 Distribution map of *Indirana semipalmata*

Clinotarsus curtipes **(Jerdon, 1853),** Bicoloured Frog

Order: Anura

Family: Ranidae

IUCN Category: Near Threatened

Endemism: Western Ghats

Wildlife Protection Act, 1972: Schedule IV

CITES: Not listed

Distribution of the species in Periyar as per the present observation is in Fig. 5.21

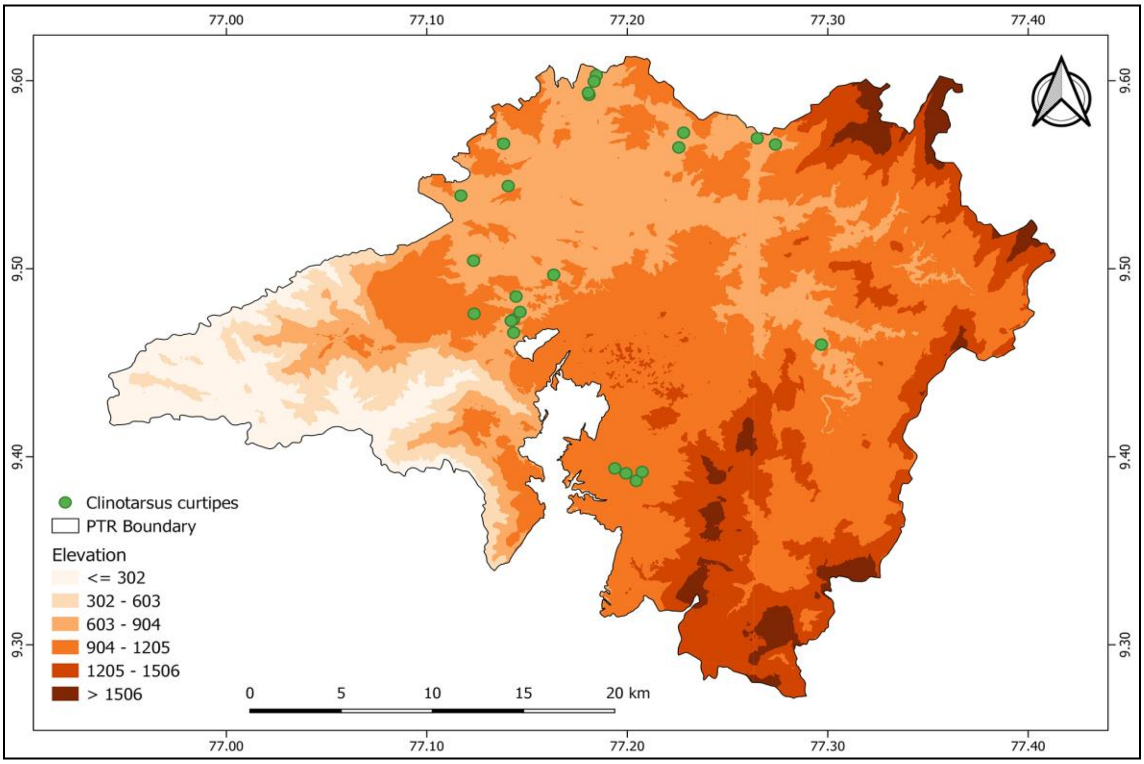

Fig. 5. 21 Distribution map of *Clinotarsus curtipes*

Indosylvirana sreeni **(Biju, Garg, Mahony, Wijayathilaka, Senevirathne and Meegaskumbura, 2014),** Sreeni's Golden-backed Frog

Order: Anura

Family: Ranidae

IUCN Category: Not Evaluated

Endemism: Western Ghats

Wildlife Protection Act, 1972: Not listed

CITES: Not listed

Distribution details from the present study are in Fig. 5.22.

Polypedates maculatus **(Gray, 1834),** Common Indian Tree Frog

Order: Anura

Family: Rhacophoridae

IUCN Category: Least Concern

Endemism: Widely distributed

Wildlife Protection Act, 1972: Not listed

CITES: Not listed

Distribution in Periyar as per the present study is given in Fig. 5.23.

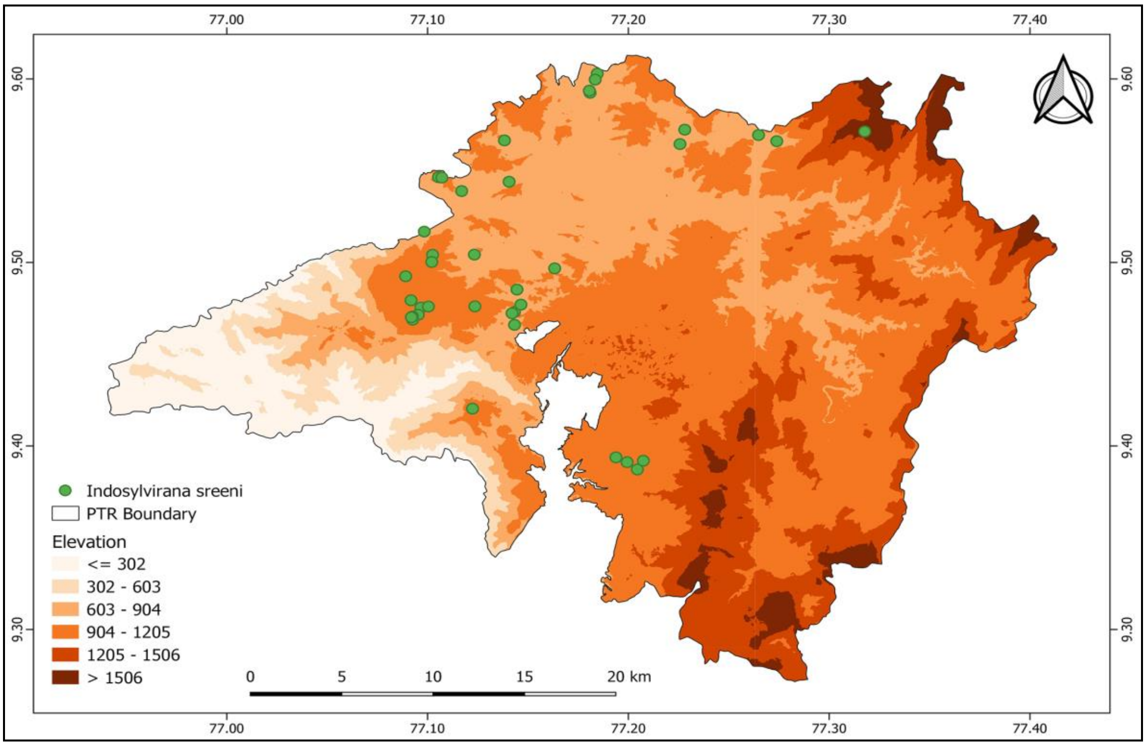

Fig. 5. 22 Distribution map of *Indosylvirana sreeni*

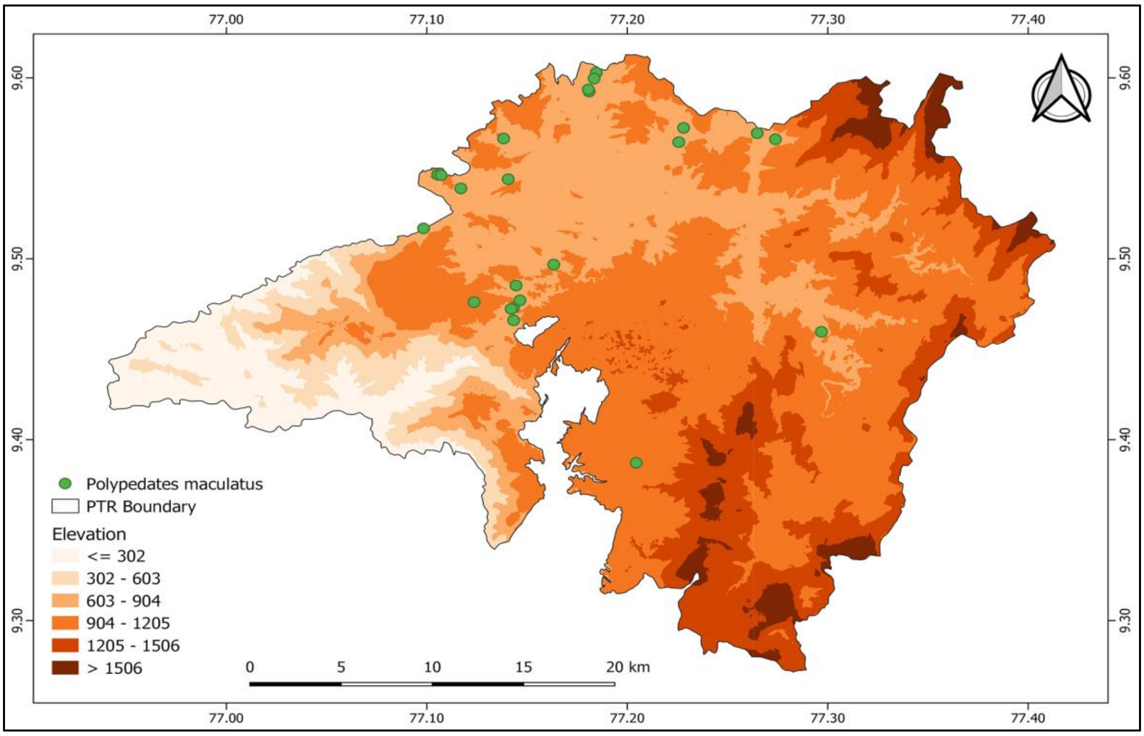

Fig. 5. 23 Distribution map of *Polypedates maculatus*

Polypedates occidentalis **(Das and Dutta, 2006),** Charpa Tree frog

Order: Anura

Family: Rhacophoridae

IUCN Category: Data Deficient

Endemism: Western Ghats

Wildlife Protection Act, 1972: Not listed

CITES: Not listed

Distribution of the species in Periyar is given in Fig. 5.24.

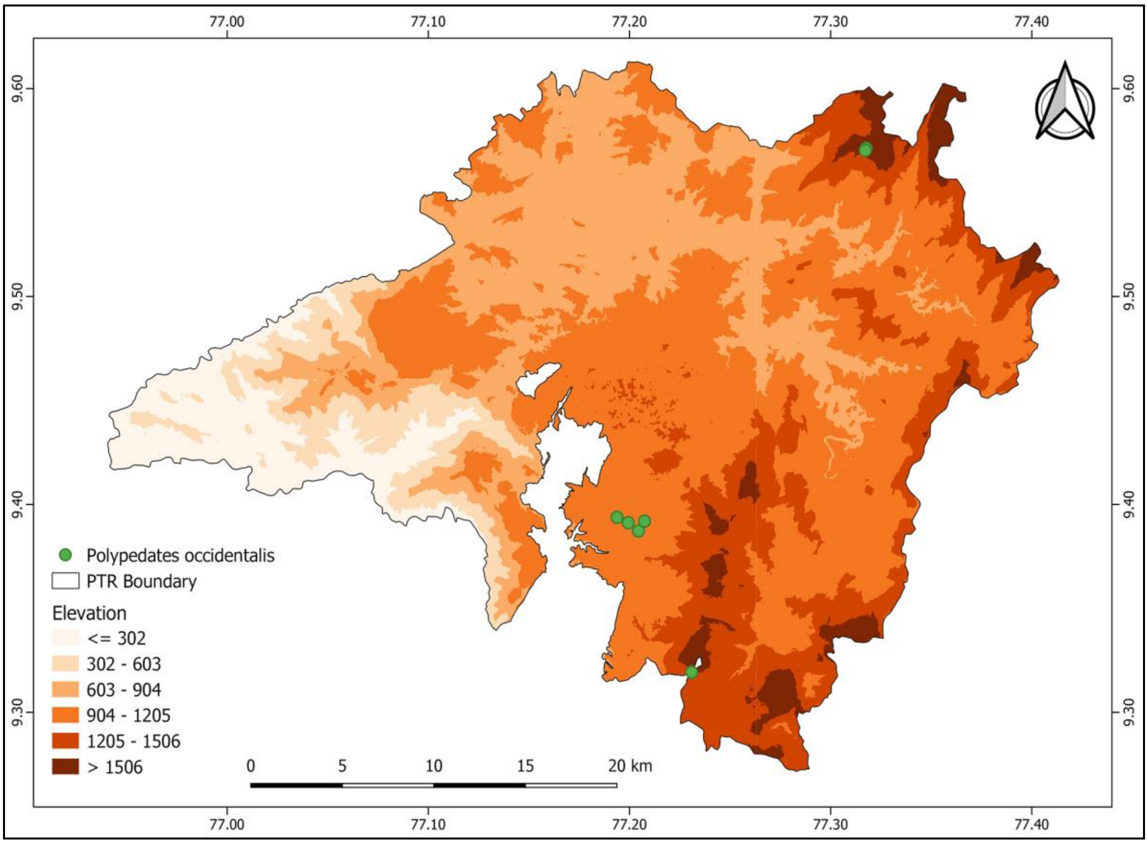

Fig. 5. 24 Distribution map of *Polypedates occidentalis*

Pseudophilautus wynaadensis **(Jerdon, 1853),** Jerdon's Bush Frog

Order: Anura

Family: Rhacophoridae

IUCN Category: Endangered

Endemism: Western Ghats

Wildlife Protection Act, 1972: Not listed

CITES: Not listed

Distribution of the species as observed from the present study is in Fig/ 5.25.

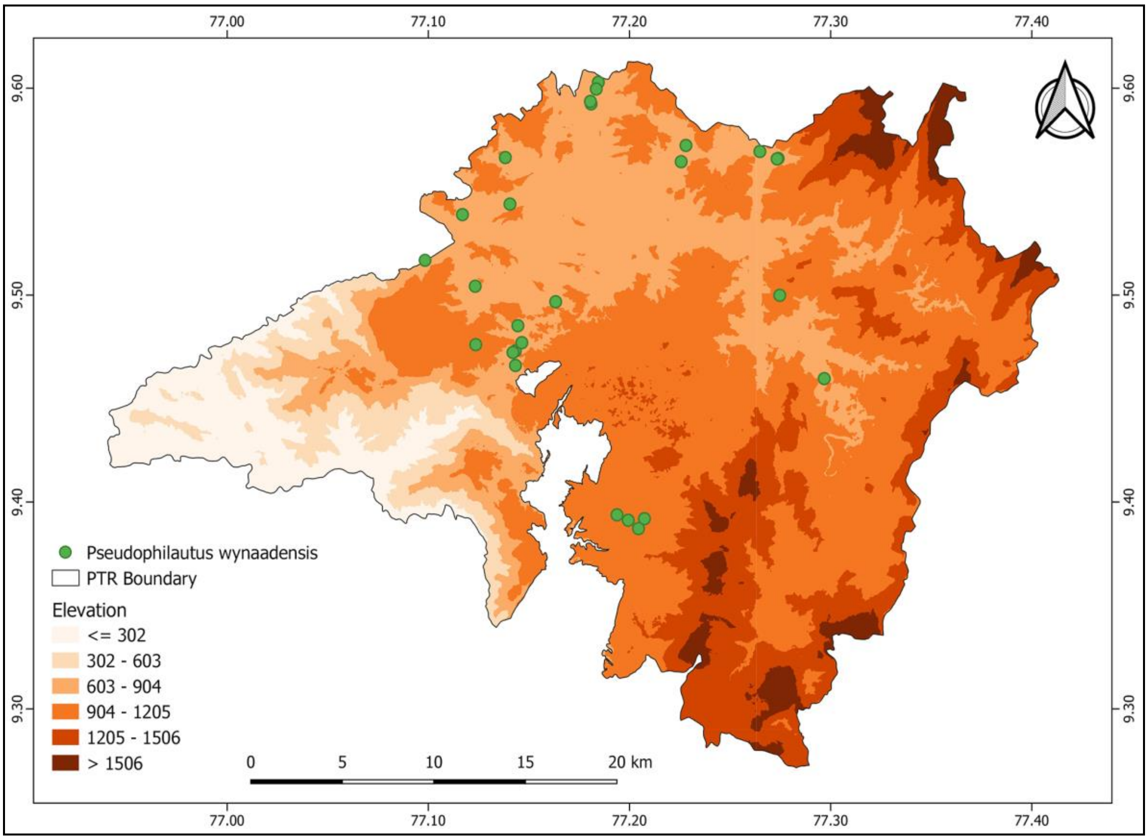

Fig. 5. 25 Distribution map of *Pseudophilautus wynaadensis*

***Raorchestes akroparallagi* (Biju and Bossuyt, 2009),** Variable Bush Frog

Order: Anura

Family: Rhacophoridae

IUCN Category: Least Concern

Endemism: Western Ghats

Wildlife Protection Act, 1972: Not listed

CITES: Not listed

Distribution details from the present study are in Fig. 5.26.

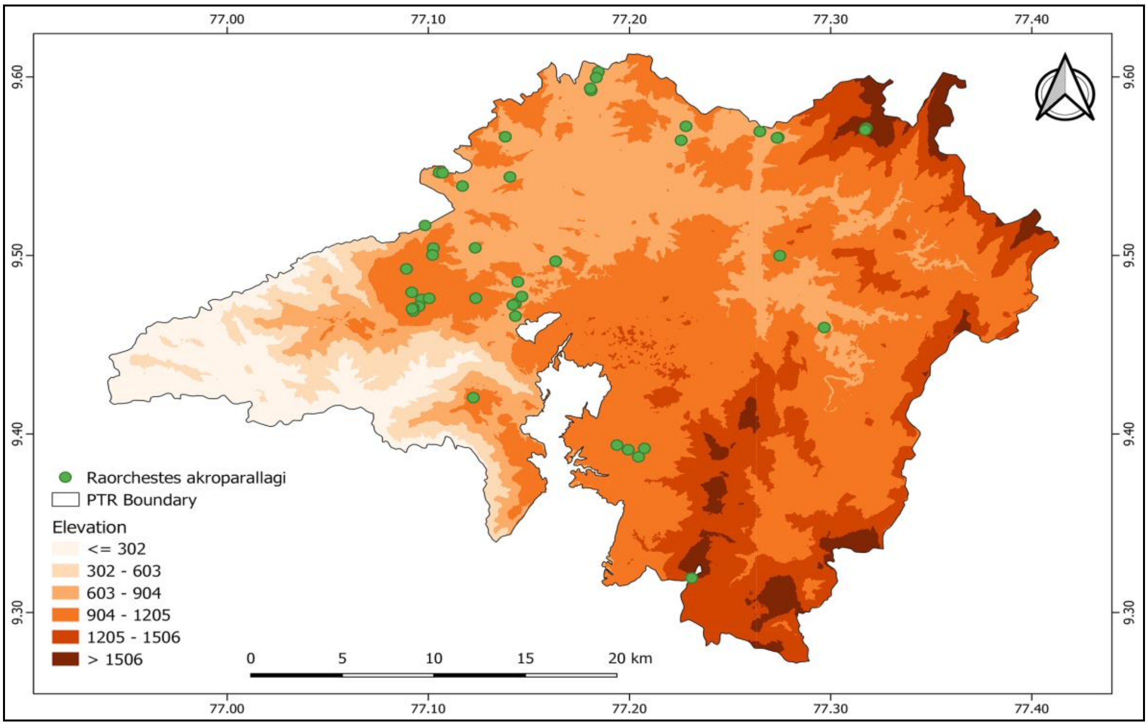

Fig. 5. 26 Distribution map of *Raorchestes akroparallagi*

***Raorchestes anili* (Biju and Bossuyt, 2009),** Anil's Bush Frog

Order: Anura

Family: Rhacophoridae

IUCN Category: Least Concern

Endemism: Western Ghats

Wildlife Protection Act, 1972: Not listed

CITES: Not listed

Distribution in Periyar as obtained from the present study is given in Fig. 5.27.

***Raorchestes beddomii* (Gunther, 1876),** Beddome's Bush Frog

Order: Anura

Family: Rhacophoridae

IUCN Category: Near Threatened

Endemism: Western Ghats

Wildlife Protection Act, 1972: Not listed

CITES: Not listed

Distribution details from the present study are in Fig. 5.28.

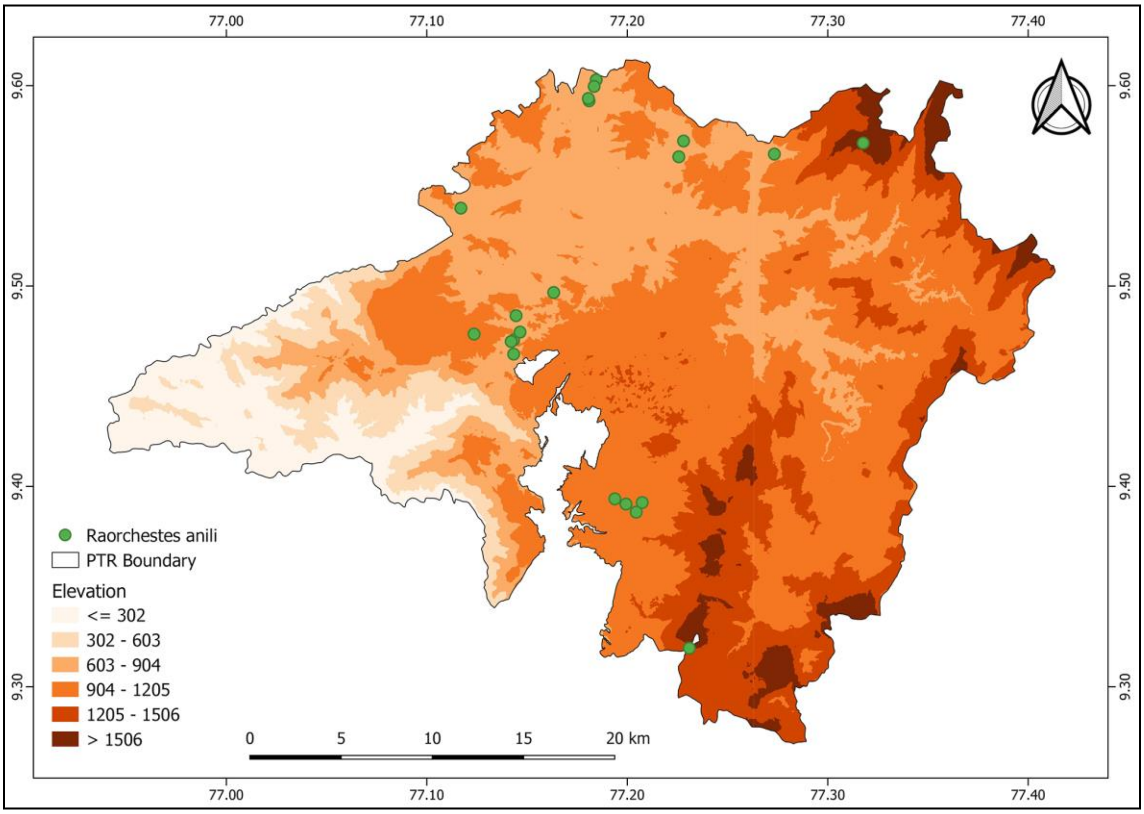

Fig. 5. 27 Distribution map of *Raorchestes anili*

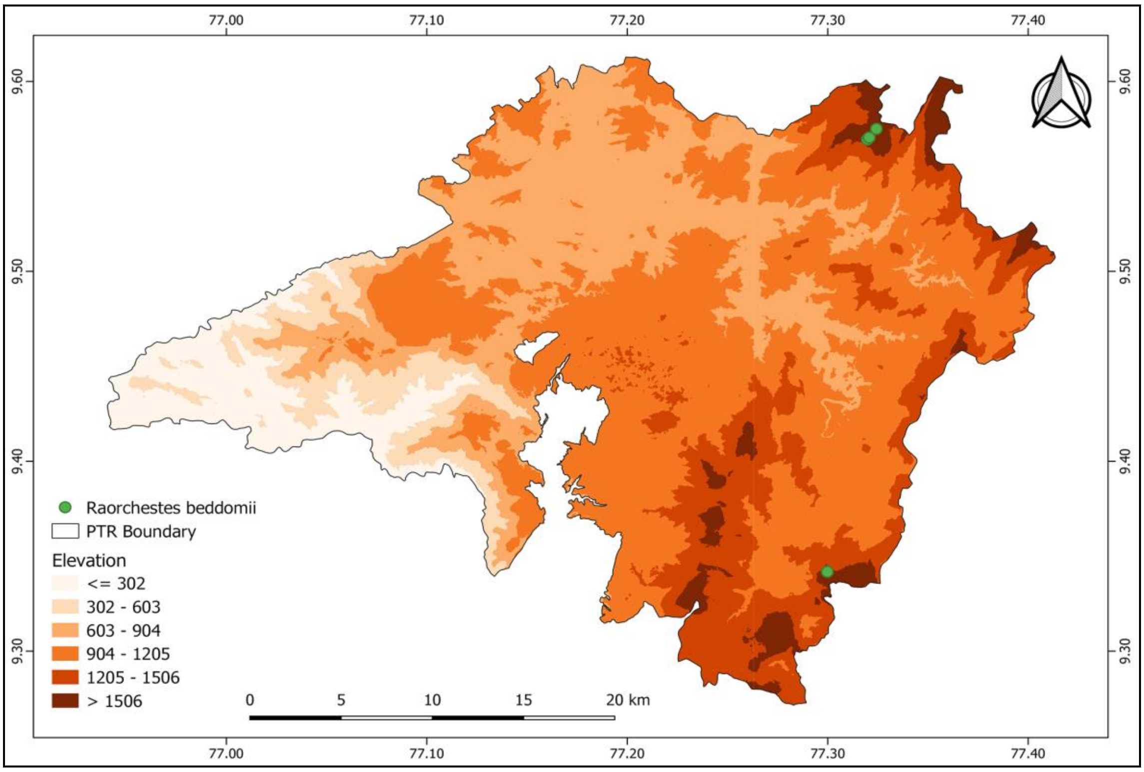

Fig. 5. 28 Distribution map of *Raorchestes beddomii*

***Raorchestes chlorosomma* (Biju and Bossuyt, 2009),** Green-eyed Bush Frog

Order: Anura

Family: Rhacophoridae

IUCN Category: Critically Endangered

Endemism: Western Ghats

Wildlife Protection Act, 1972: Not listed

CITES: Not listed

Distribution details from the present study are in Fig. 5.29.

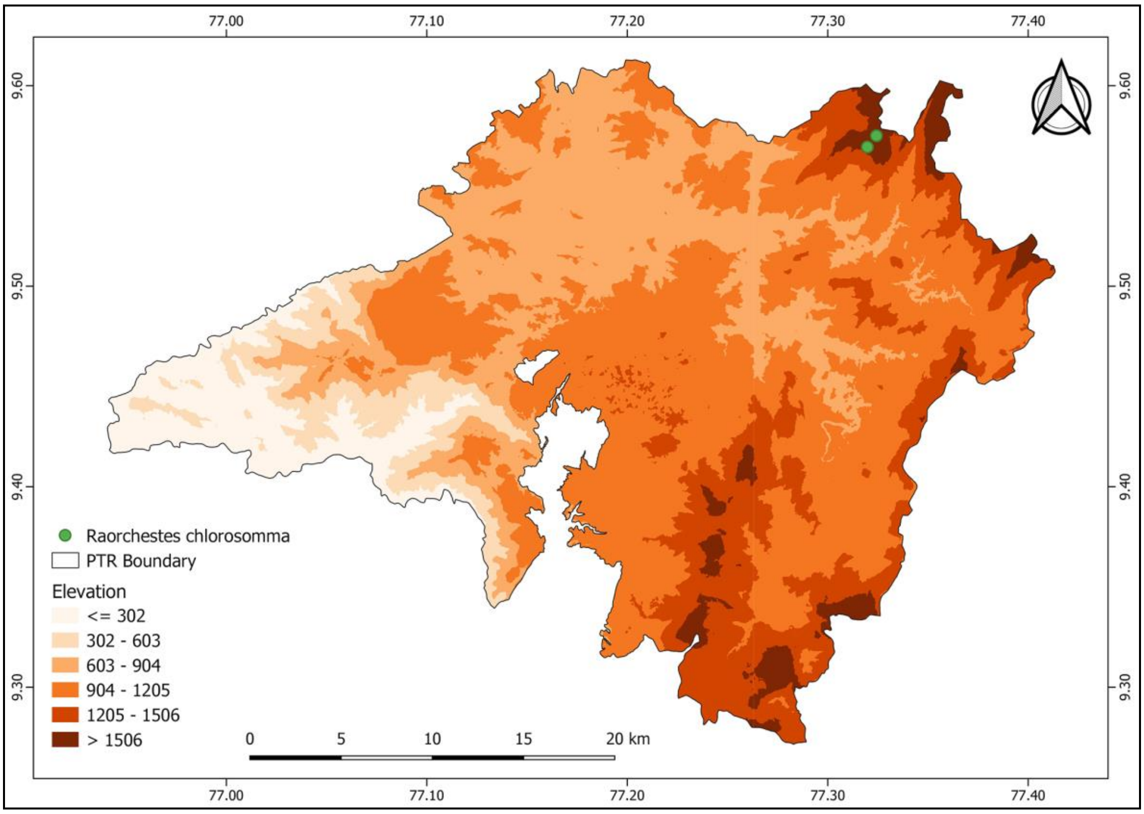

Fig. 5. 29 Distribution map of *Raorchestes chlorosomma*

***Raorchestes ochlandrae* (Gururaja, Dinesh, Palot, Radhakrishnan and Ramachandra, 2007),** Ochlandrae Reed Bush Frog

Order: Anura

Family: Rhacophoridae

IUCN Category: Data Deficient

Endemism: Western Ghats

Wildlife Protection Act, 1972: Not listed

CITES: Not listed

Distribution details as observed in the present study are in Fig. 5.30.

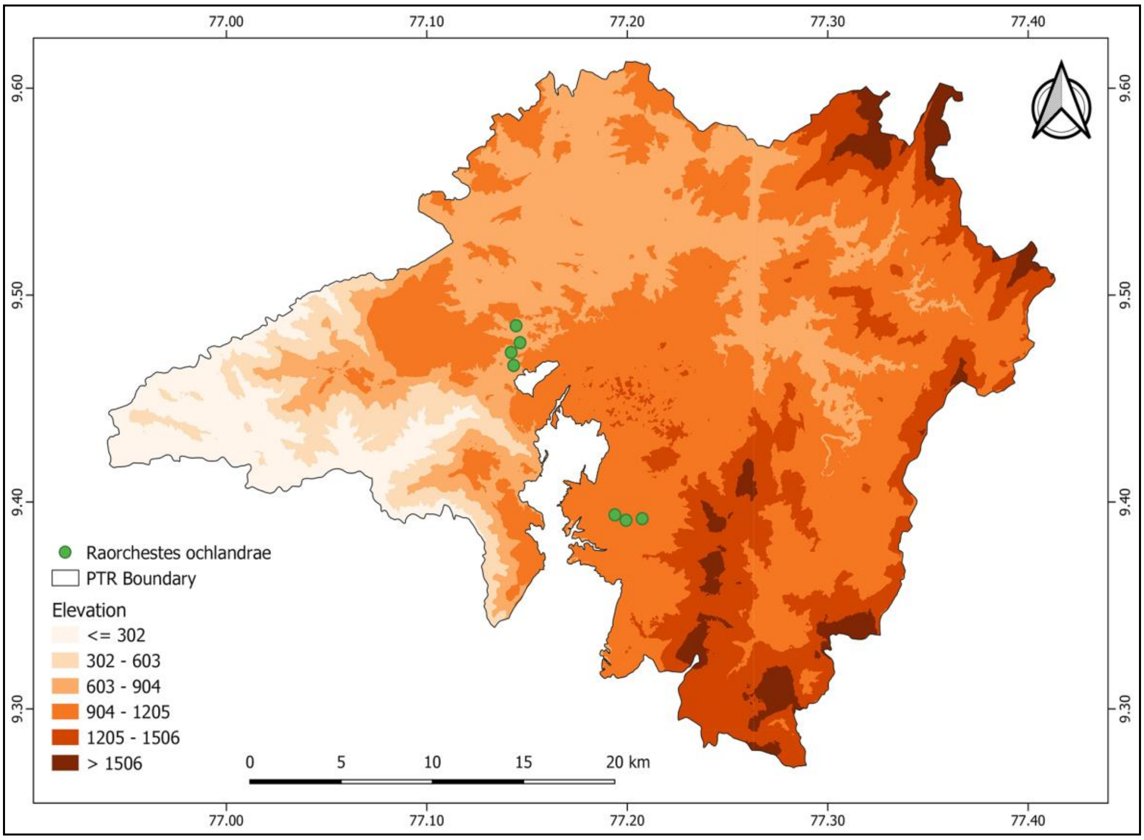

Fig. 5. 30 Distribution map of *Raorchestes ochlandrae*

***Raorchestes ponmudi* (Biju and Bossuyt, 2005),** Large Ponmudi Bush Frog

Order: Anura

Family: Rhacophoridae

IUCN Category: Critically Endangered

Endemism: Western Ghats

Wildlife Protection Act, 1972: Not listed

CITES: Not listed

Distribution of the species from the present study is in Fig. 5.31.

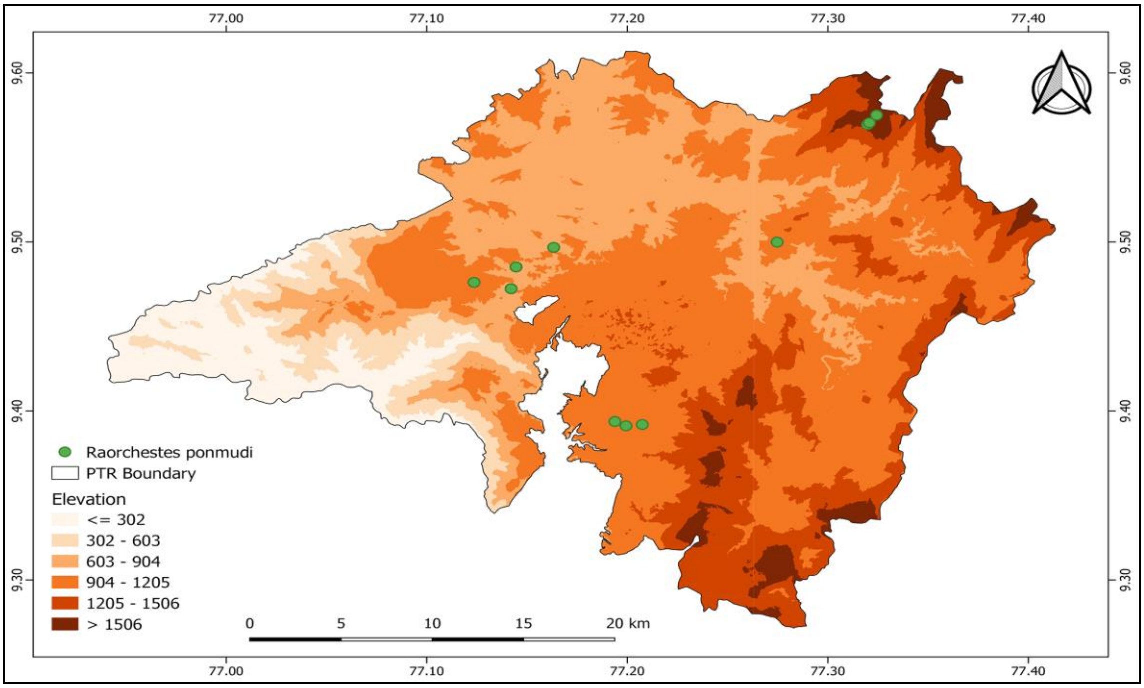

Fig. 5. 31 Distribution map of *Raorchestes ponmudi*

Raorchestes uthamani **(Zachariah, Dinesh, Kunhikrishnan, Das, Raju, Radhakrishnan, Palot and Kalesh, 2011),** Uthaman's Reed Bush Frog

Order: Anura

Family: Rhacophoridae

IUCN Category: Not Evaluated

Endemism: Western Ghats

Wildlife Protection Act, 1972: Not listed

CITES: Not listed

Distribution of the species from the present study is in Fig. 5.32.

Raorchestes keirasabinae **(Garg, Suyesh, Das, Bee and Biju, 2021)**

Order: Anura

Family: Rhacophoridae

IUCN Category:

Endemism: Western Ghats

Wildlife Protection Act, 1972: Not listed

CITES: Not listed

Distribution of the species from the present study is in Fig. 5.33.

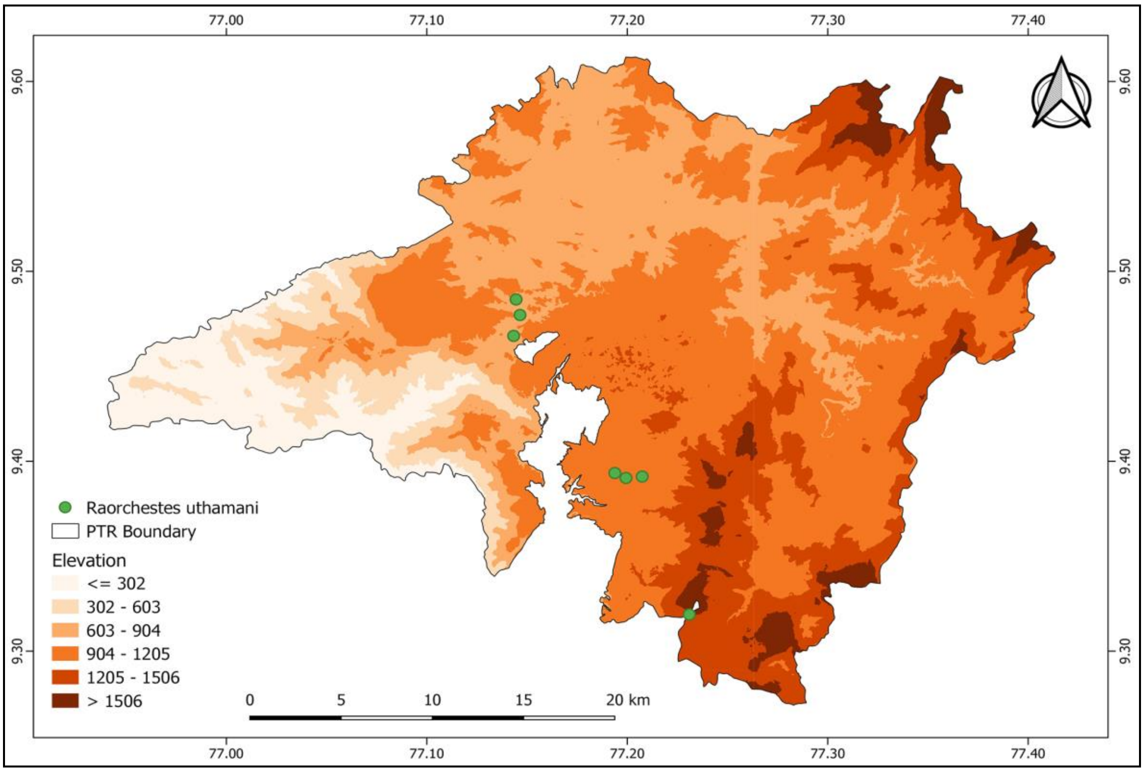

Fig. 5. 32 Distribution map of *Raorchestes uthamani*

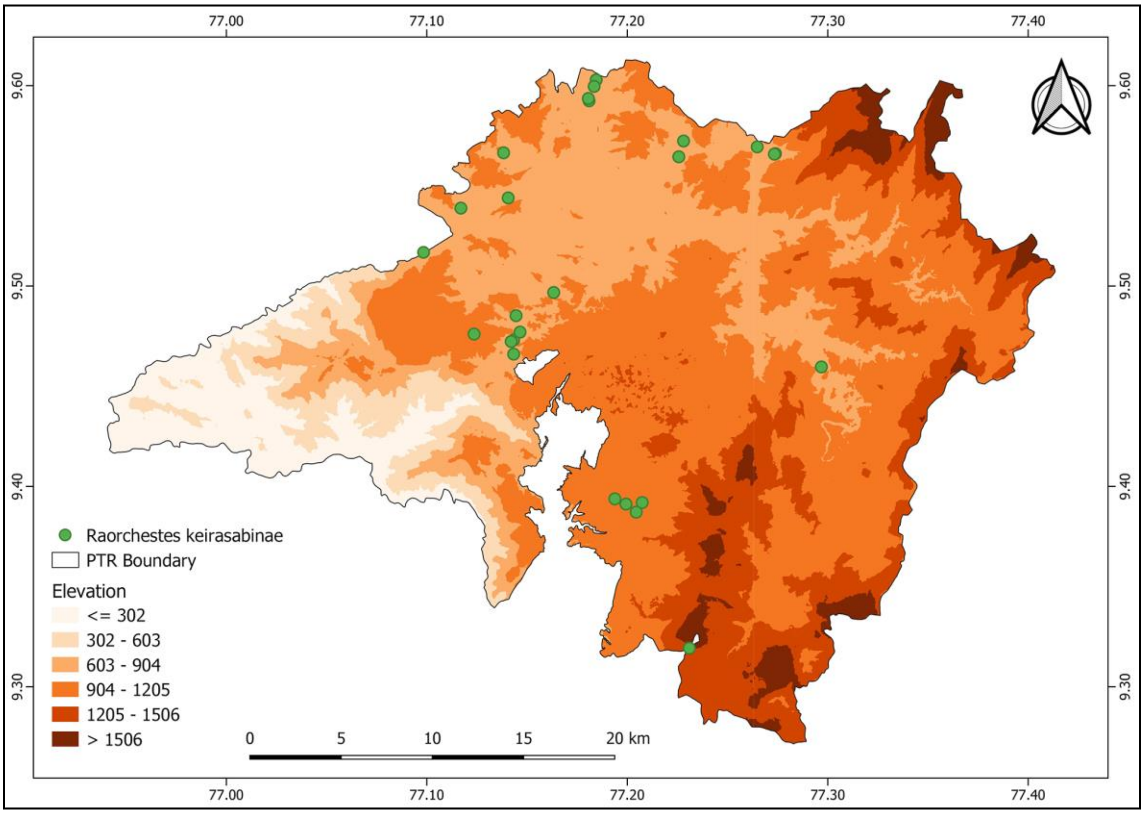

Fig. 5. 33 Distribution map of *Raorchestes keirasabinae*

***Raorchestes travancoricus* (Boulenger, 1891),** Travancore Bush Frog

Common name: Travancore Bush Frog

Order: Anura

Family: Rhacophoridae

IUCN Category: Endangered

Endemism: Western Ghats

Wildlife Protection Act, 1972: Not listed

CITES: Not listed

Distribution of the species in Periyar from the present study is in Fig. 5.34

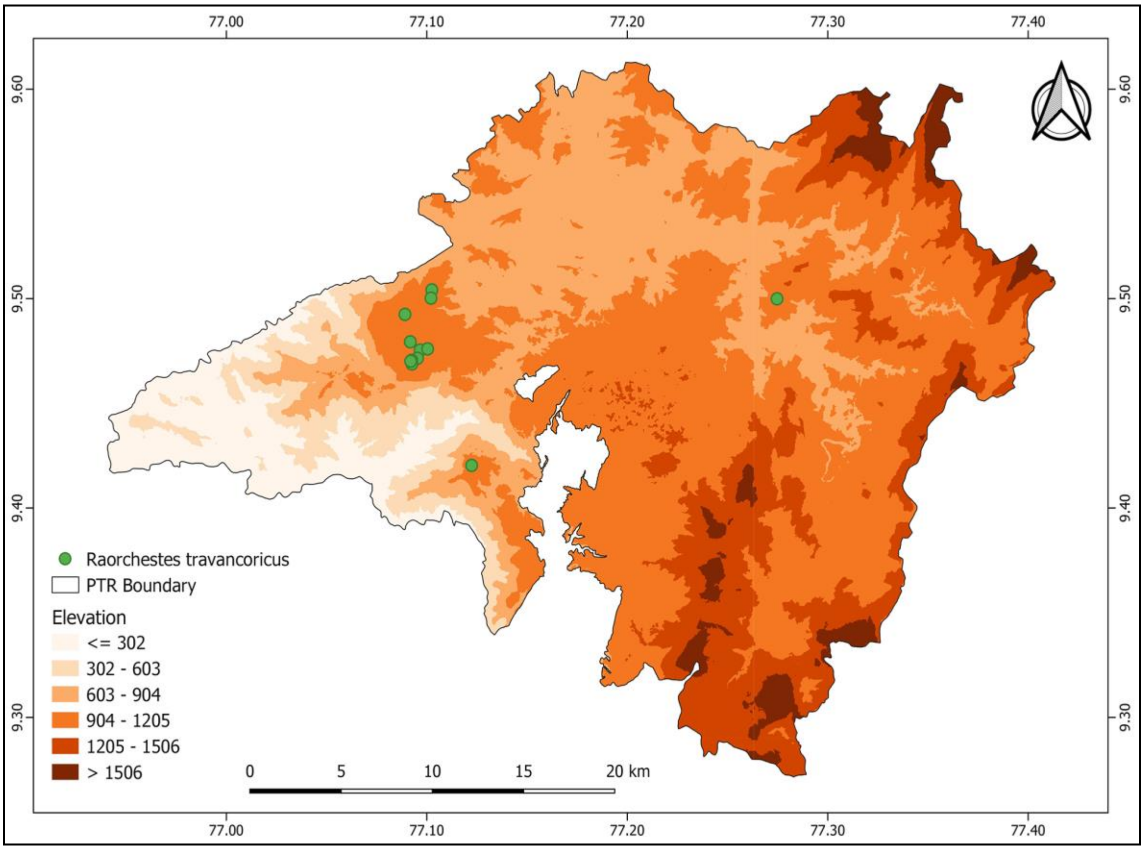

Fig. 5. 34 Distribution map of *Raorchestes travancoricus*

***Raorchestes jayarami* (Biju and Bossuyt, 2009),** Jayaram's Bush Frog

Order: Anura

Family: Rhacophoridae

IUCN Category: Not Evaluated

Endemism: Western Ghats

Wildlife Protection Act, 1972: Not listed

CITES: Not listed

Distribution of the species from the present study is in Fig. 5.35

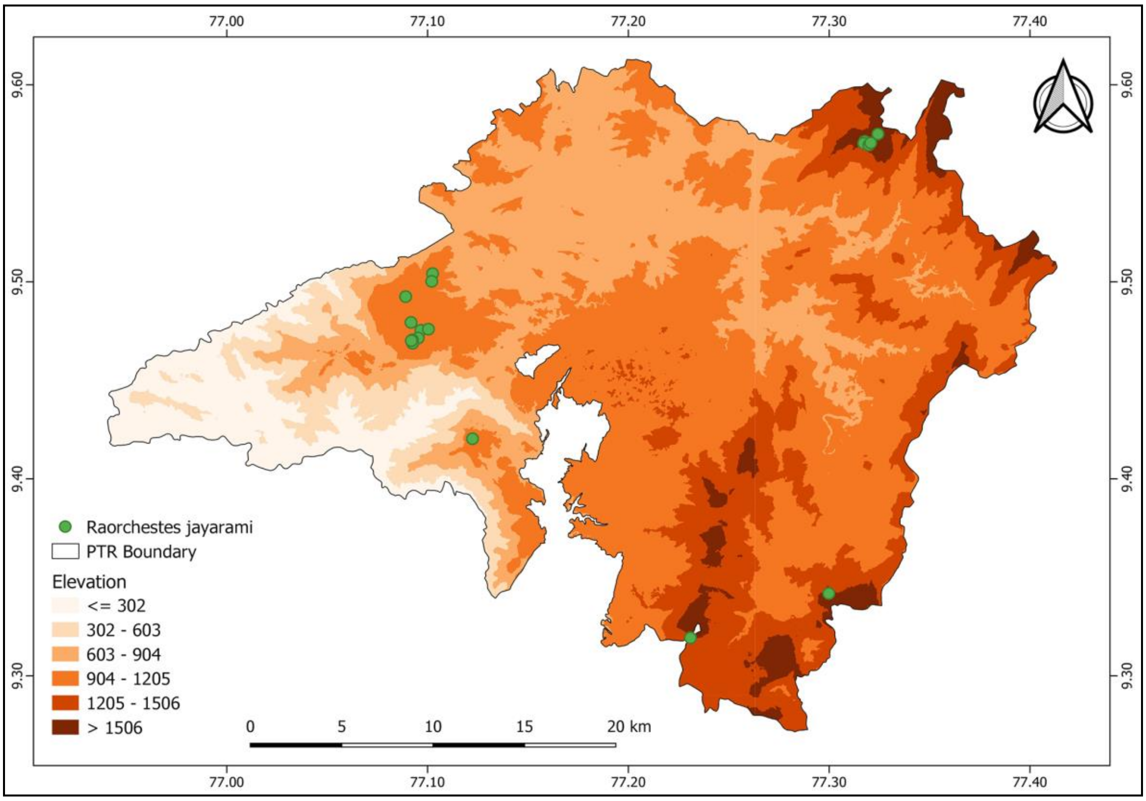

Fig. 5. 35 Distribution map of *Raorchestes jayarami*

***Raorchestes griet* (Bossuyt, 2002),** Griet's Bush Frog

Order: Anura

Family: Rhacophoridae

IUCN Category: Critically Endangered

Endemism: Western Ghats

Wildlife Protection Act, 1972: Not listed

CITES: Not listed

Distribution of the species in Periyar from the present study is in Fig. 5.36

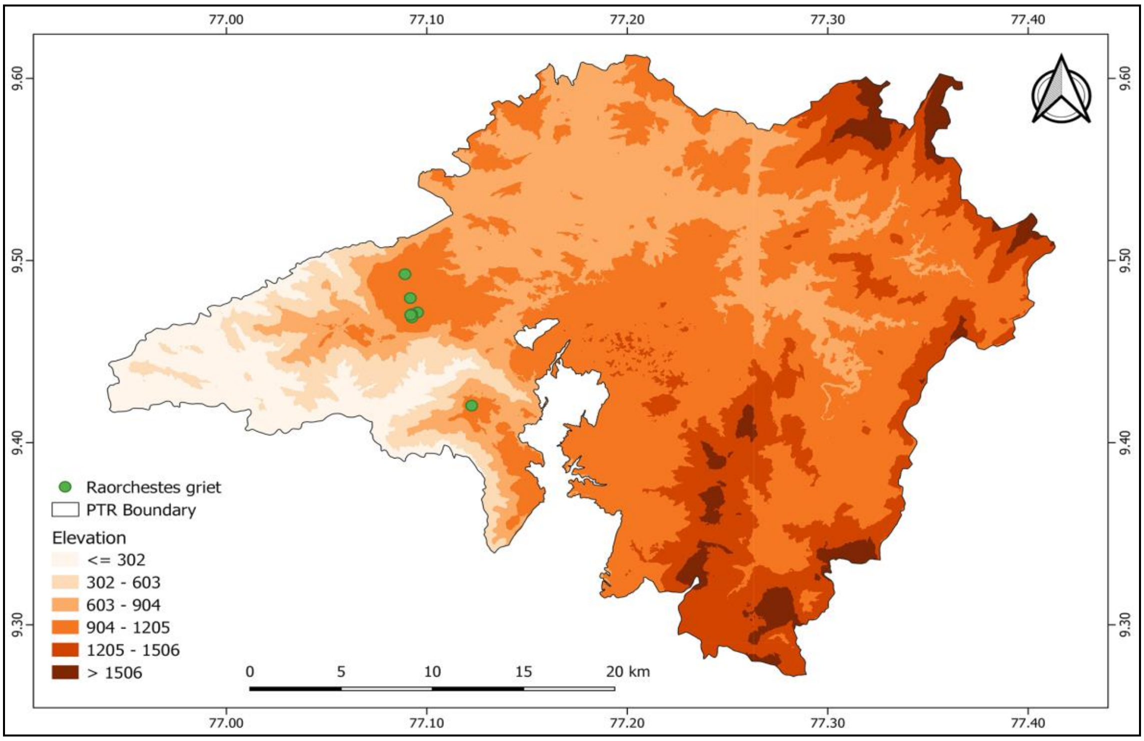

Fig. 5. 36 Distribution map of *Raorchestes griet*

***Rhacophorus malabaricus* (Jerdon, 1870),** Malabar Gliding Frog

Order: Anura

Family: Rhacophoridae

IUCN Category: Least Concern

Endemism: Western Ghats

Wildlife Protection Act, 1972: Not listed

CITES: Not listed

Distribution of the species from the present study is in Fig. 5.37

***Rhacophorus pseudomalabaricus* (Vasudevan and Dutta, 2000),** Malabar False Tree frog

Order: Anura

Family: Rhacophoridae

IUCN Category: Critically Endangered

Endemism: Western Ghats

Wildlife Protection Act, 1972: Not listed

CITES: Not listed

Distribution of the species from the present study is in Fig. 5.38

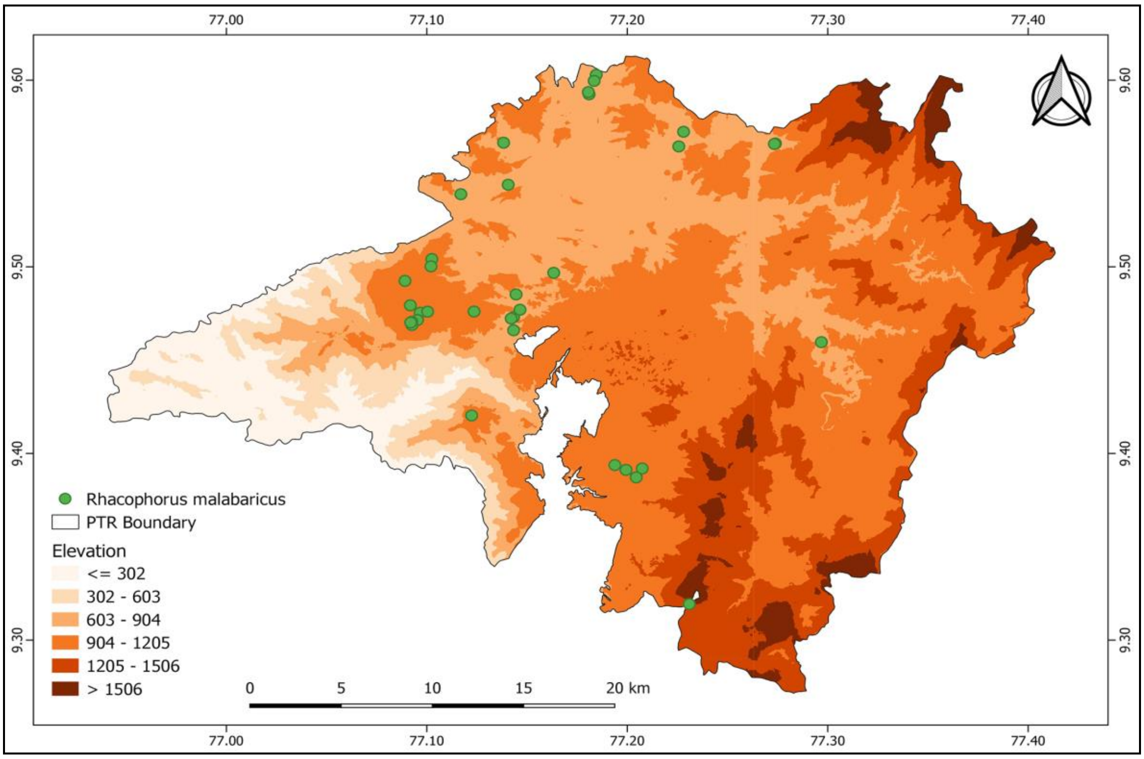

Fig. 5. 37 Distribution map of *Rhacophorus malabaricus*

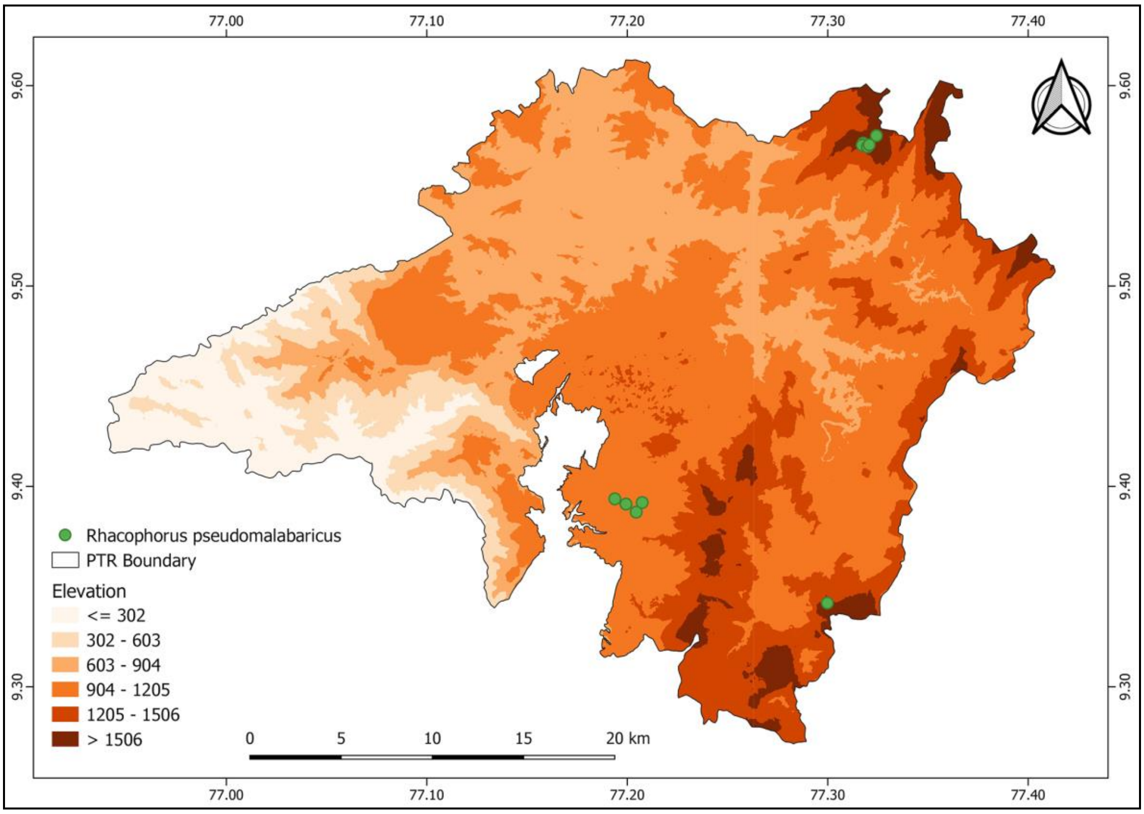

Fig. 5. 38 Distribution map of *Rhacophorus pseudomalabaricus*

***Rhacophorus calcadensis* (Ahl, 1927),** Kalakad Tree Frog

Order: Anura

Family: Rhacophoridae

IUCN Category: Endangered

Endemism: Western Ghats

Wildlife Protection Act, 1972: Not listed

CITES: Not listed

Distribution of the species in Periyar from the present study is in Fig. 5.39

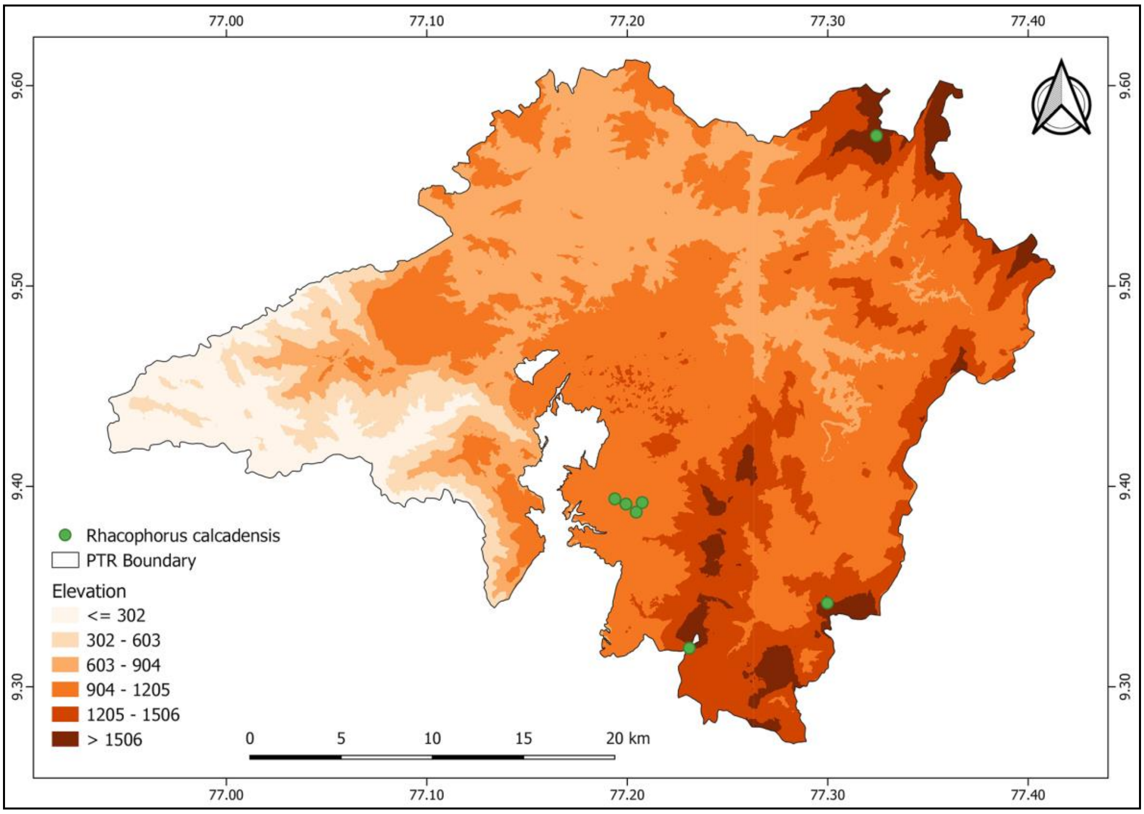

Fig. 5. 39 Distribution map of *Rhacophorus calcadensis*

Ichthyophis beddomei (Peters, 1870), Beddome's Caecilian

Order: Gymnophiona

Family: Ichthyophidae

IUCN Category: Least Concern

Endemism: Western Ghats

Wildlife Protection Act, 1972: Not listed

CITES: Not listed

Distribution of the species from the present study is in Fig. 5.40

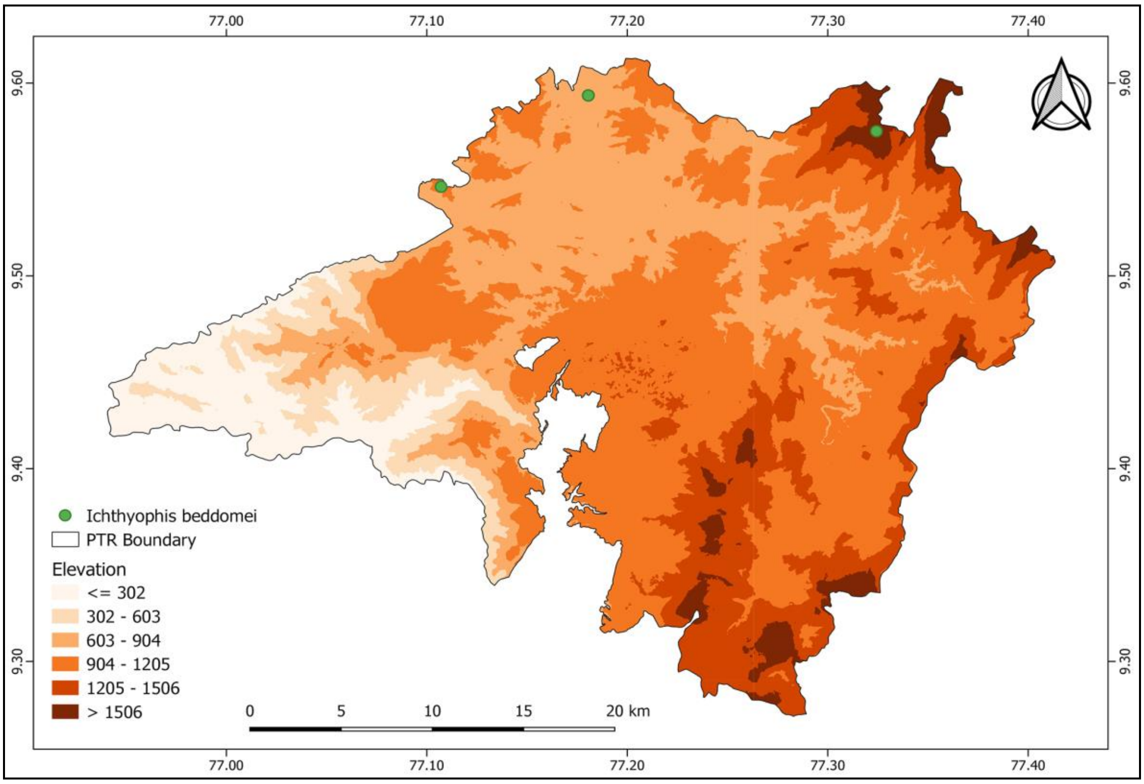

Fig. 5. 40 Distribution map of *Ichthyophis beddomei*

5.3.3.2 The description of Reptiles recorded from the area

Melanochelys trijuga **(Schweigger, 1812),** Indian Black Turtle

Common name: Indian Black Turtle

Order: Testudines

Family: Geoemydidae

IUCN Category: Near Threatened

Endemism: Widely distributed

Wildlife Protection Act, 1972: Not listed

CITES: Appendix II

Distribution of the species from the present study is in Fig.5.41

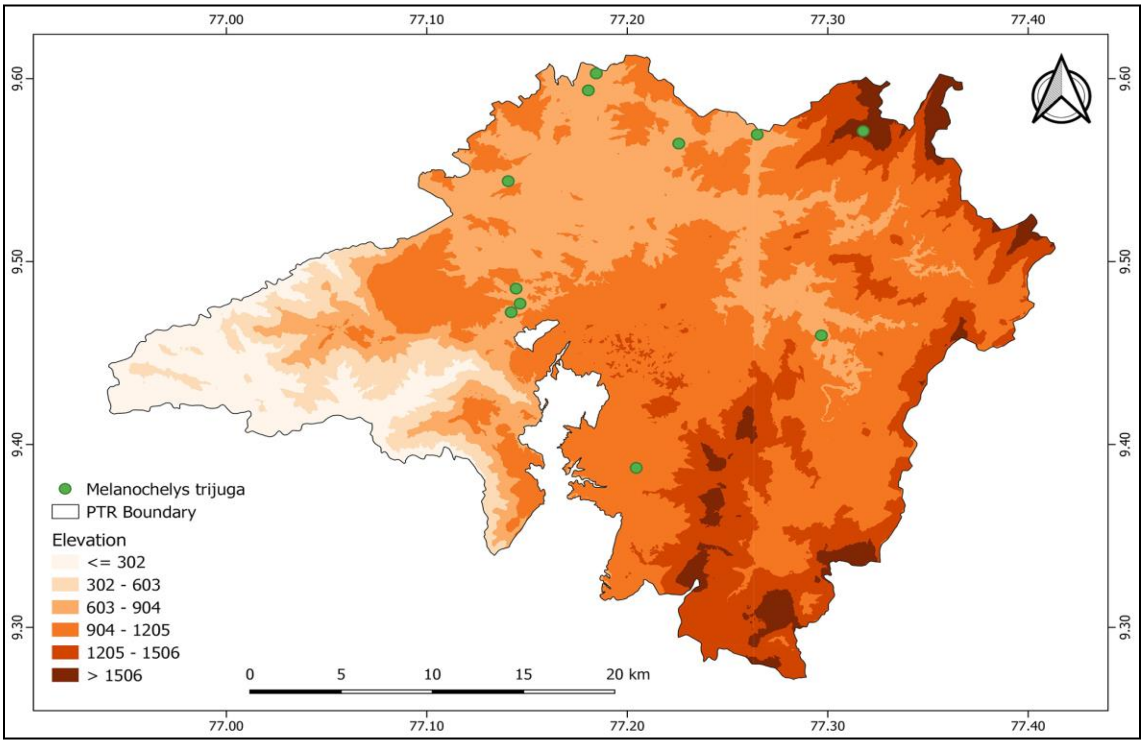

Fig. 5. 41 Distribution map of *Melanochelys trijuga*

Indotestudo travancorica **(Boulenger, 1907),** Travancore Tortoise

Common name: Travancore Tortoise

Order: Testudines

Family: Testudinidae

IUCN Category: Vulnerable

Endemism: Western Ghats

Wildlife Protection Act, 1972: Schedule IV

CITES: Appendix II

Distribution of the species from the present study is in Fig. 5.42

Monilesaurus ellioti **(Günther, 1864),** Elliot's Forest Lizard

Common name: Elliot's Forest Lizard

Order: Squamata

Family: Agamidae

IUCN Category: Least Concern

Endemism: Western Ghats

Wildlife Protection Act, 1972: Not listed

CITES: Not listed

Distribution of the species from the present study is in Fig. 5.43

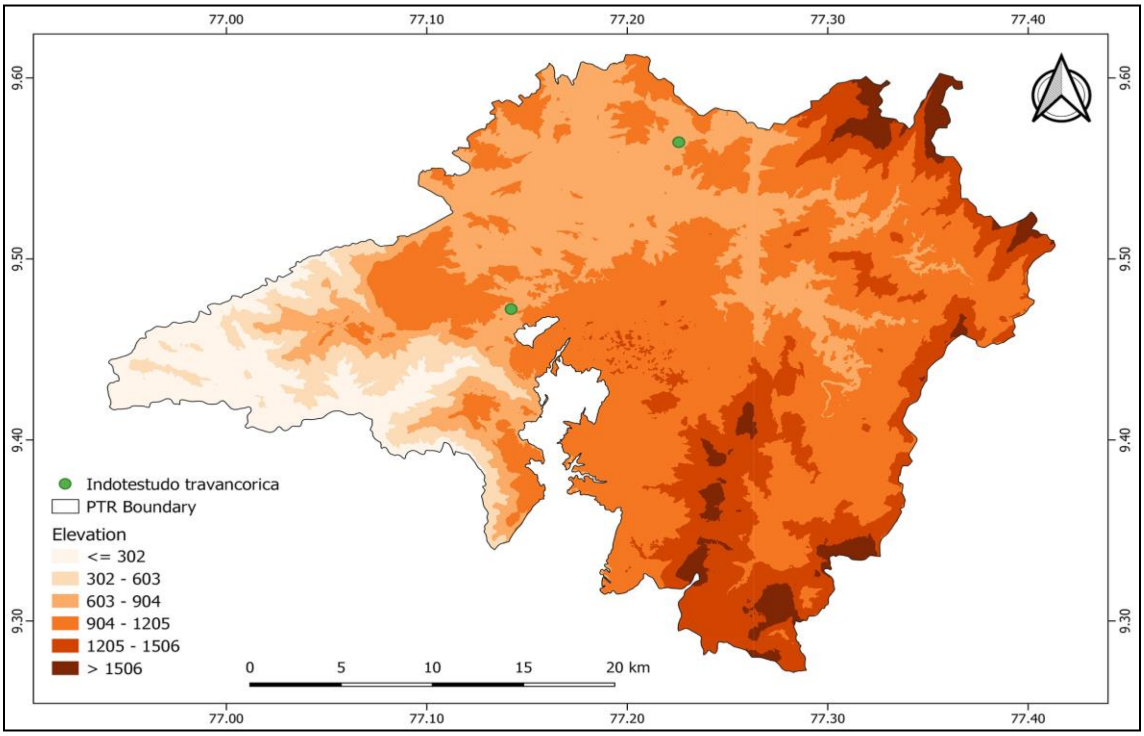

Fig. 5. 42 Distribution map of *Indotestudo travancorica*

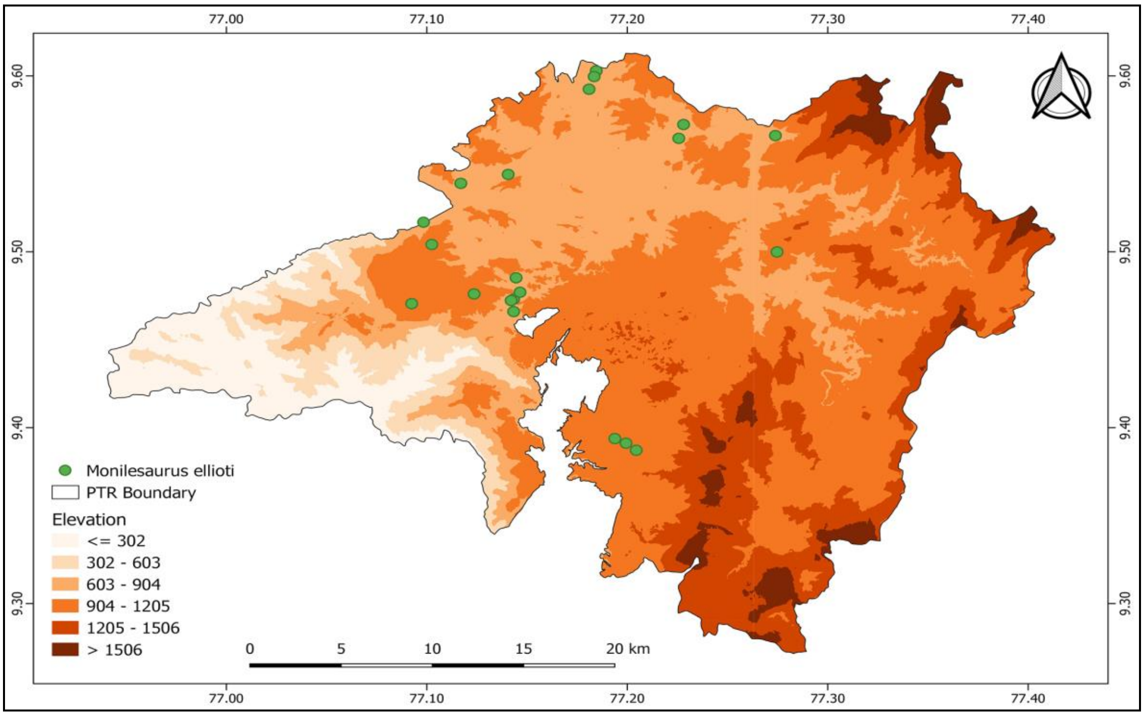

Fig. 5. 43 Distribution map of *Monilesaurus ellioti*

***Monilesaurus rouxii* (Duméril and Bibron, 1837),** Roux's Forest Lizard

Order: Squamata

Family: Agamidae

IUCN Category: Least Concern

Endemism: Widely distributed

Wildlife Protection Act, 1972: Not listed

CITES: Not listed

Distribution of the species from the present study is in Fig. 5.44

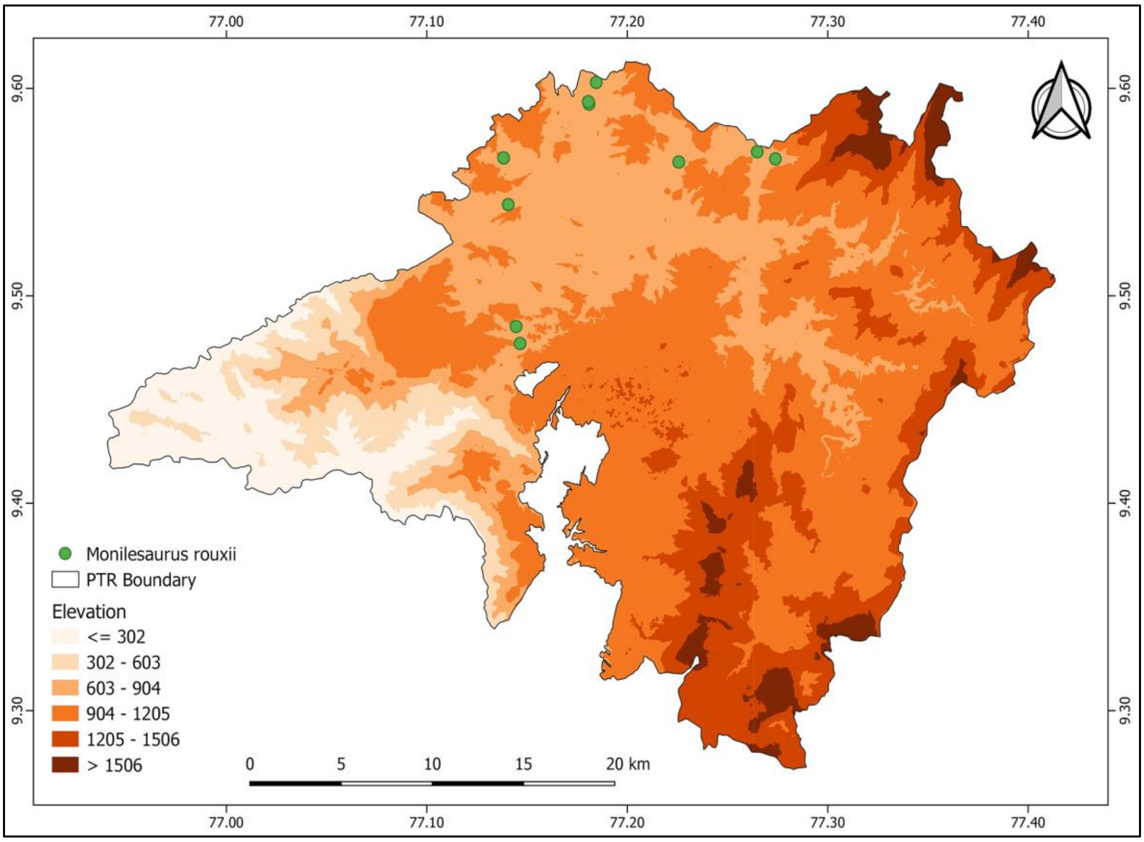

Fig. 5. 44 Distribution map of *Monilesaurus rouxii*

***Calotes calotes* (Linnaeus, 1758),** Common Green Forest Lizard

Order: Squamata

Family: Agamidae

IUCN Category: Not Evaluated

Endemism: Western Ghats

Wildlife Protection Act, 1972: Not listed

CITES: Not listed

Distribution of the species from the present study is in Fig. 5.45

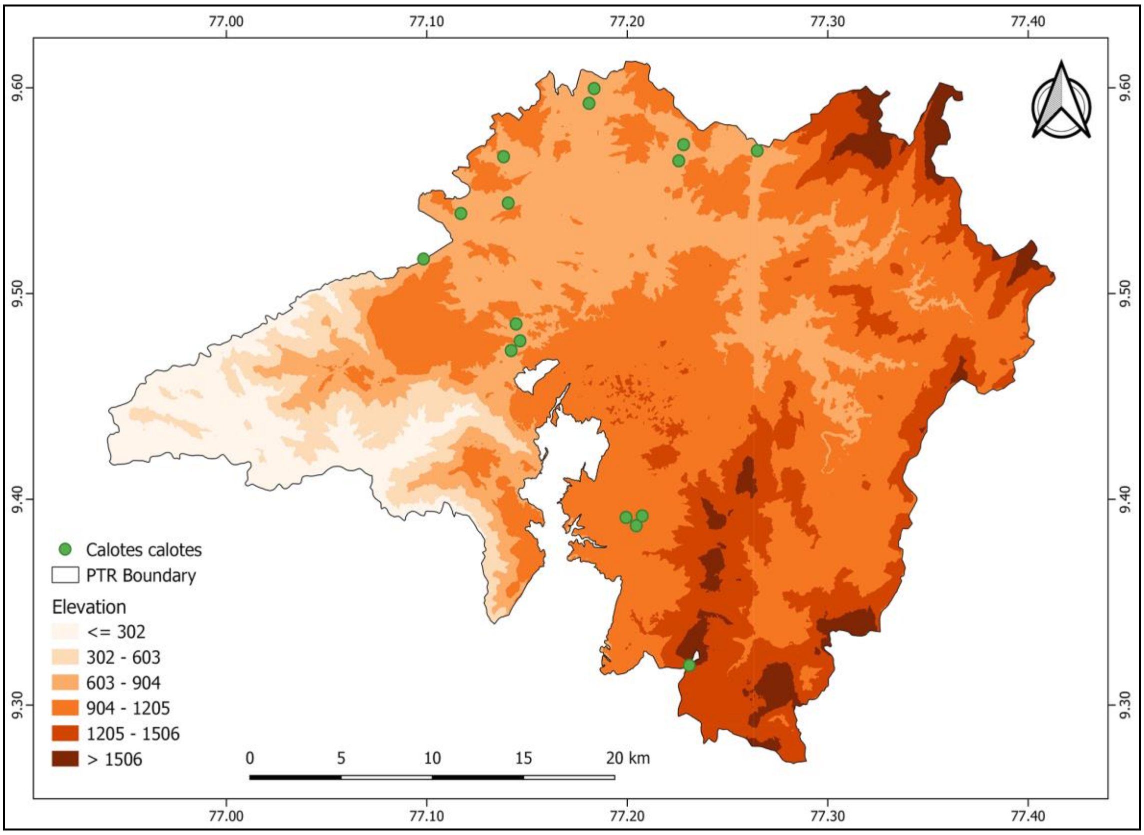

Fig. 5. 45 Distribution map of *Calotes calotes*

Calotes grandisquamis **(Gunther, 1875),** Large-scaled Forest Lizard

Order: Squamata

Family: Agamidae

IUCN Category: Least Concern

Endemism: Western Ghats

Wildlife Protection Act, 1972: Not listed

CITES: Not listed

Distribution of the species from the present study is in Fig. 5.46

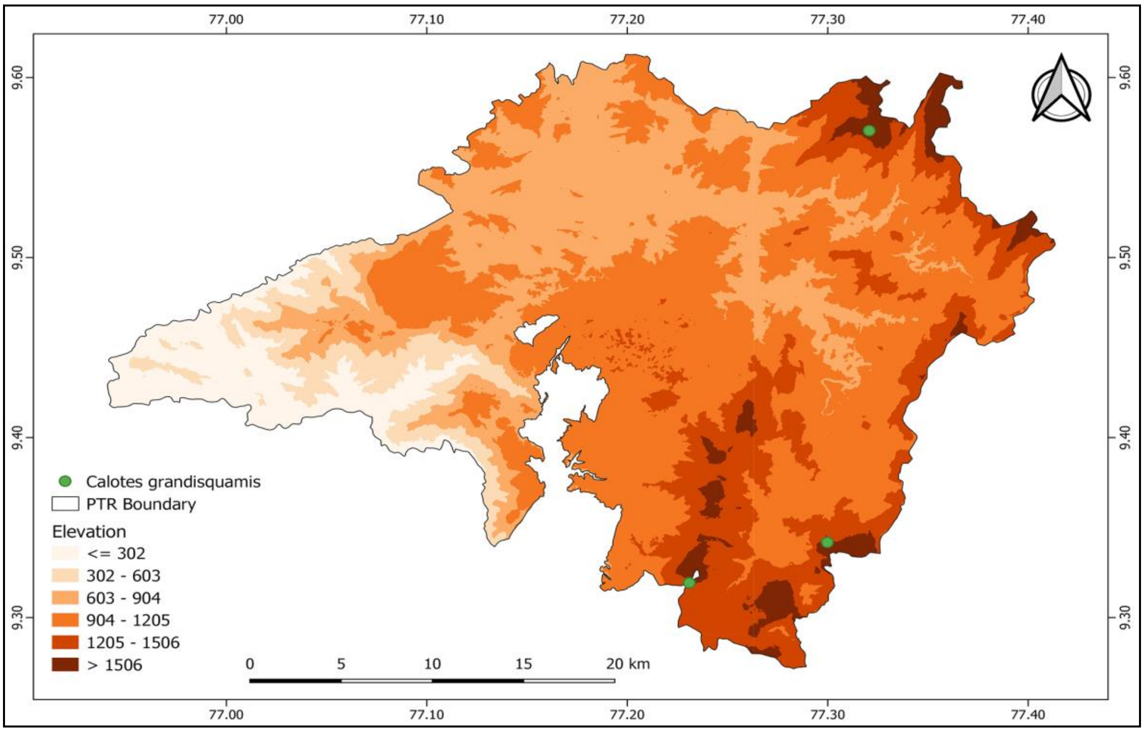

Fig. 5. 46 Distribution map of *Calotes grandisquamis*

Calotes versicolor **(Daudin, 1802),** Indian Garden Lizard

Order: Squamata

Family: Agamidae

IUCN Category: Not Evaluated

Endemism: Widely distributed

Wildlife Protection Act, 1972: Not listed

CITES: Not listed

Distribution of the species from the present study is in Fig. 5.47

Cnemaspis wynadensis **(Beddome, 1870),** Wayanad Day Gecko

Order: Squamata

Family: Gekkonidae

IUCN Category: Endangered

Endemism: Kerala

Wildlife Protection Act, 1972: Not listed

CITES: Not listed

Distribution of the species from the present study is in Fig. 5.48

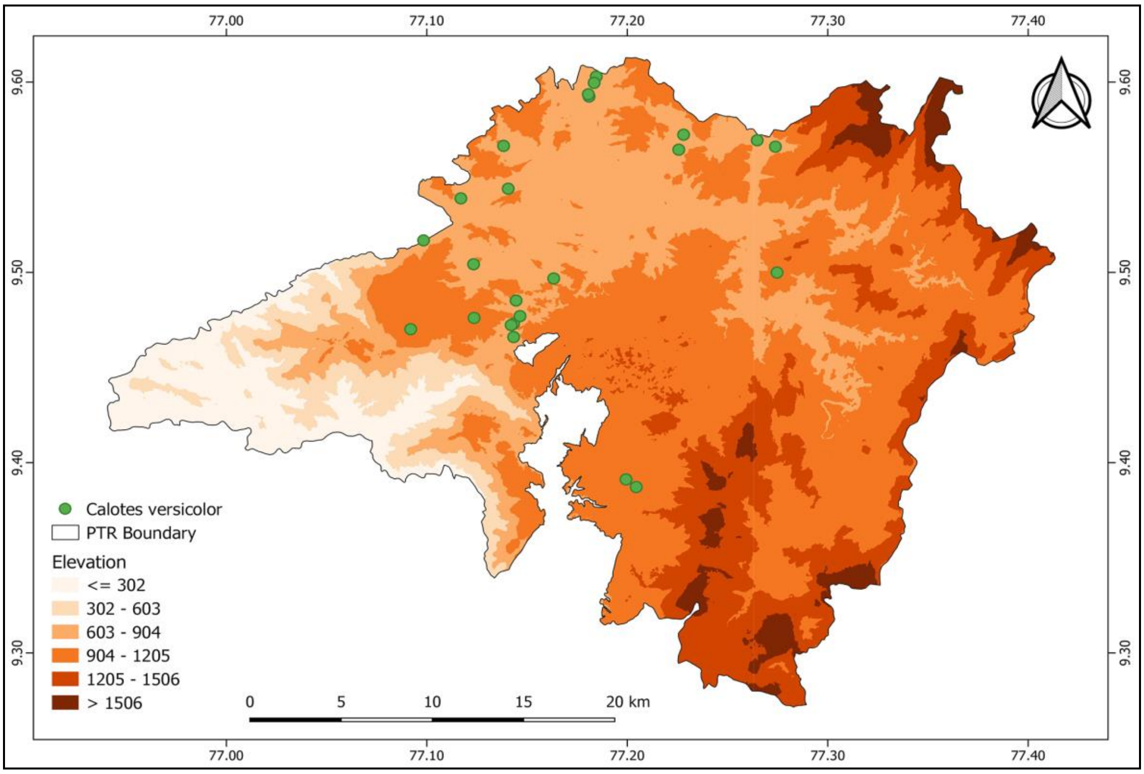

Fig. 5. 47 Distribution map of *Calotes versicolor*

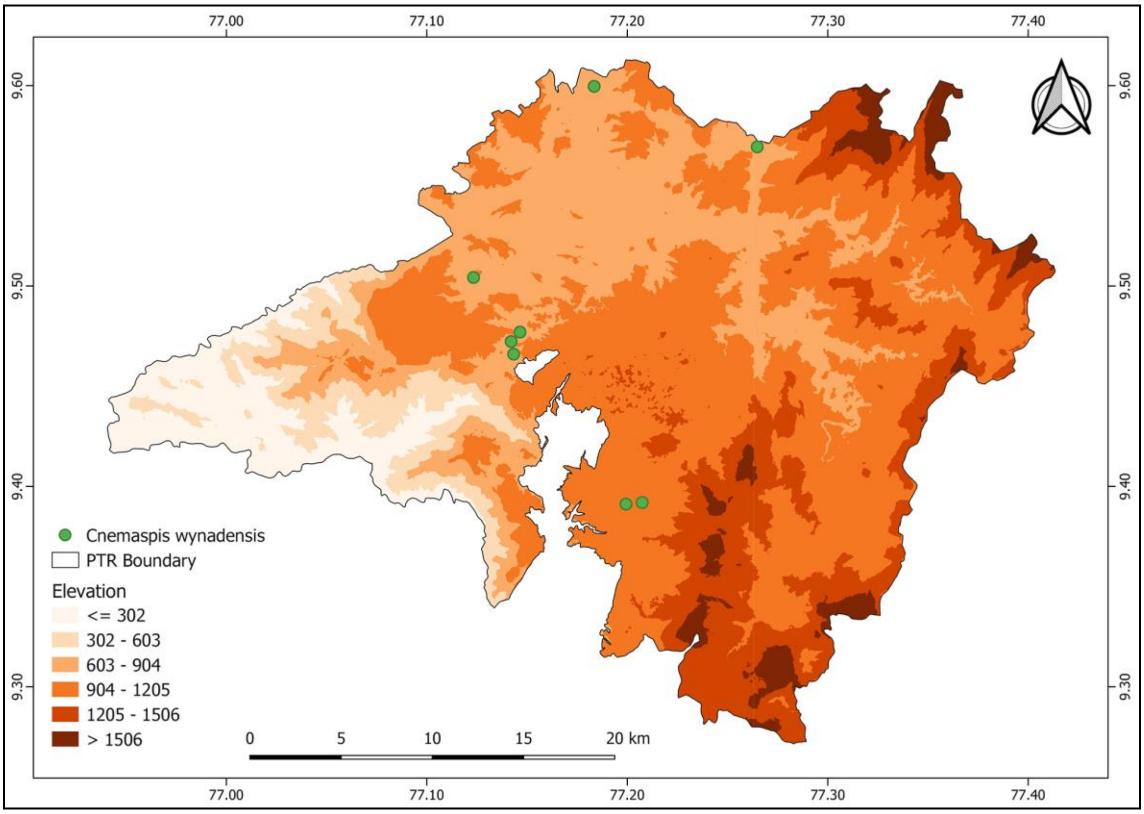

Fig. 5. 48 Distribution map of *Cnemaspis wynadensis*

***Dravidogecko* sp.**

Order: Squamata

Family: Gekkonidae

IUCN Category:

Endemism: Western Ghats

Wildlife Protection Act, 1972:

CITES:

Distribution of the species from the present study is in Fig. 5.49

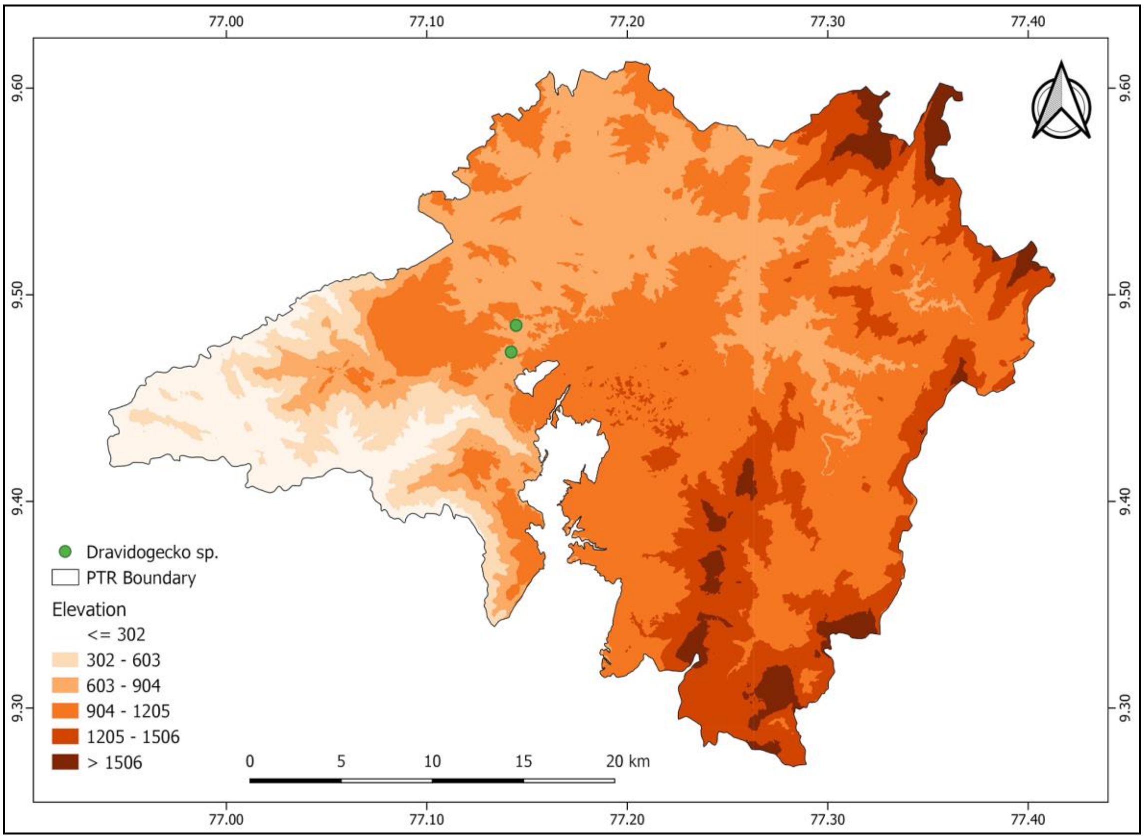

Fig. 5. 49 Distribution map of *Dravidogecko* sp.

***Hemidactylus cf. parvimaculatus* (Deraniyagala, 1953),** Spotted House Gecko

Order: Squamata

Family: Gekkonidae

IUCN Category: Not Evaluated

Endemism: NA

Wildlife Protection Act, 1972: Not listed

CITES: Not listed

Distribution of the species from the present study is in Fig. 5.50

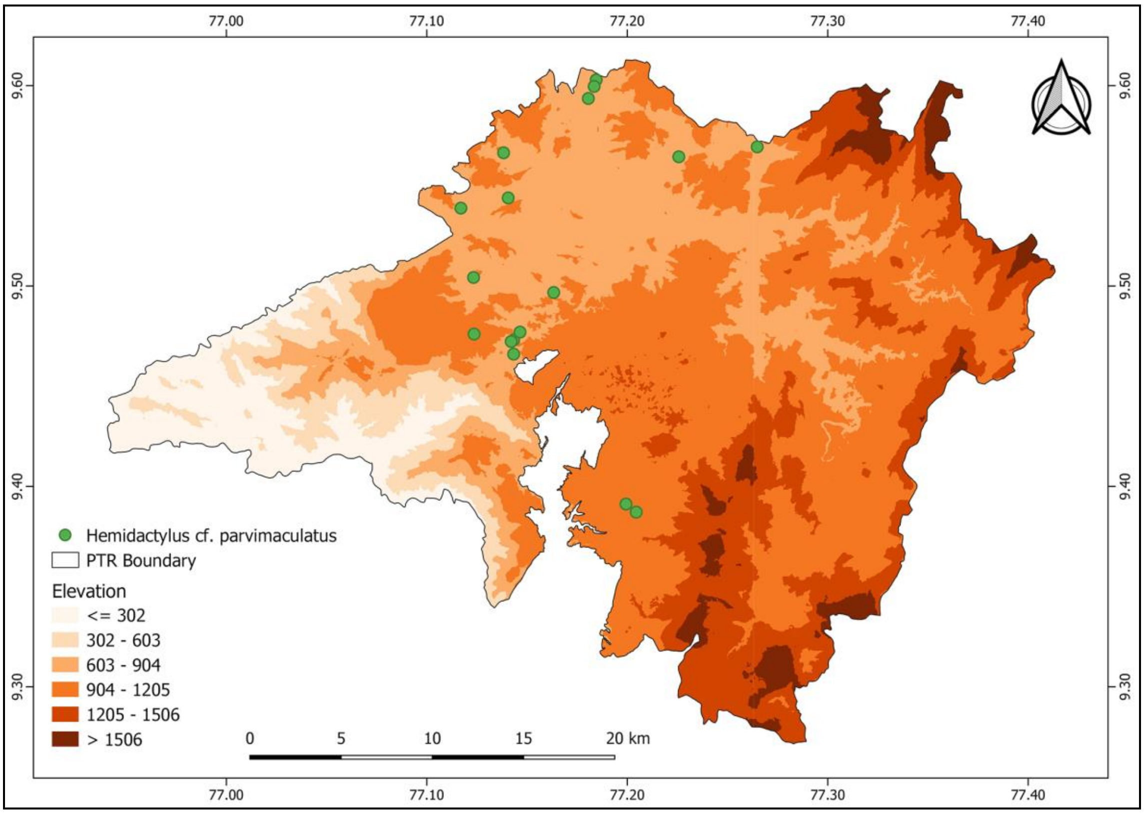

Fig. 5. 50 Distribution map of *Hemidactylus cf. parvimaculatus*

***Hemidactylus frenatus* (Schlegel, 1836),** Asian House Gecko

Order: Squamata

Family: Gekkonidae

IUCN Category: Least Concern

Endemism: NA

Wildlife Protection Act, 1972: Not listed

CITES: Not listed

Distribution of the species from the present study is in Fig. 5.51

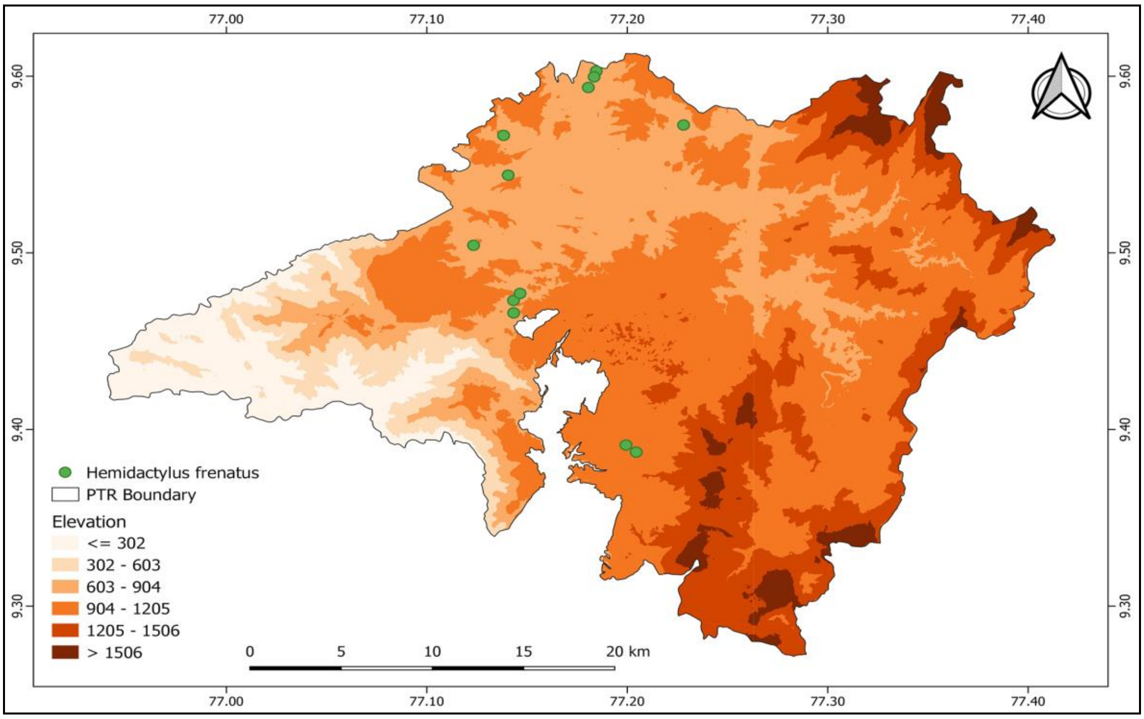

Fig. 5. 51 Distribution map of *Hemidactylus frenatus*

***Hemidactylus leschenaultii* (Duméril and Bibron, 1836),** Bark Gecko

Order: Squamata

Family: Gekkonidae

IUCN Category: Least Concern

Endemism: NA

Wildlife Protection Act, 1972: Not listed

CITES: Not listed

Distribution of the species from the present study is in Fig. 5.52

***Hemidactylus* sp.**

Order: Squamata

Family: Gekkonidae

IUCN Category:

Endemism: NA

Wildlife Protection Act, 1972:

CITES:

Distribution of the species from the present study is in Fig. 5.53

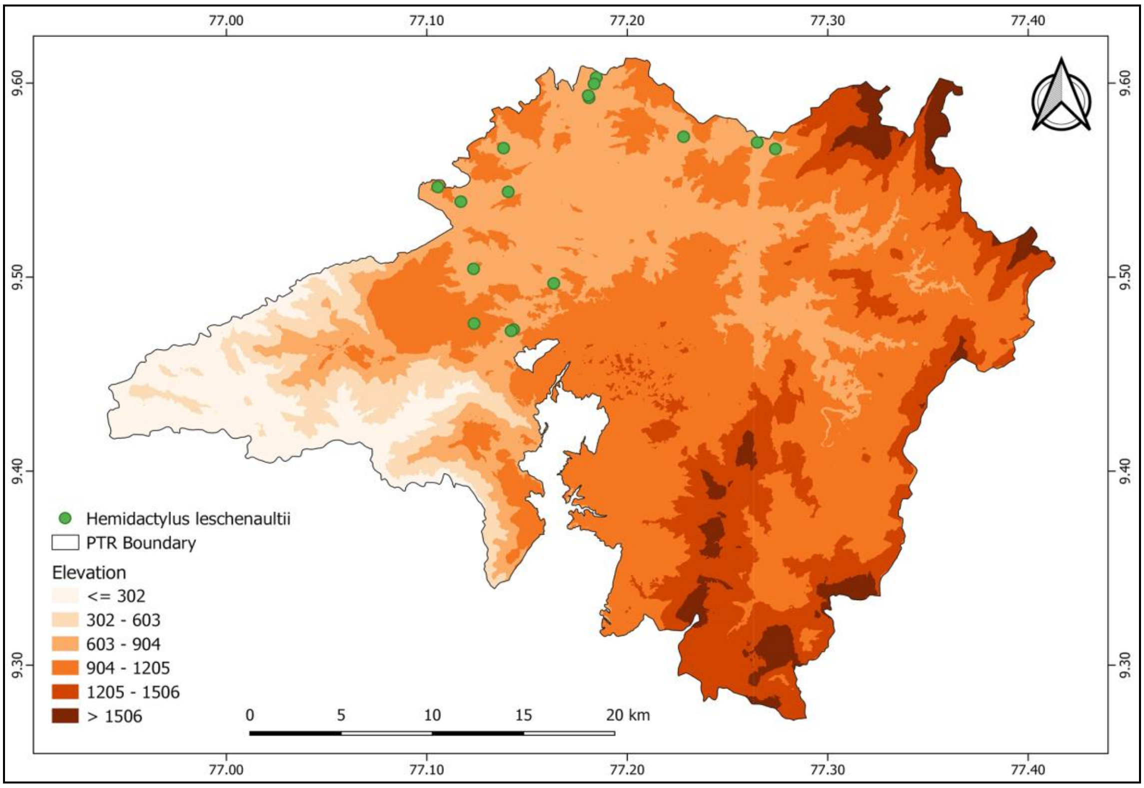

Fig. 5. 52 Distribution map of *Hemidactylus leschenaultii*

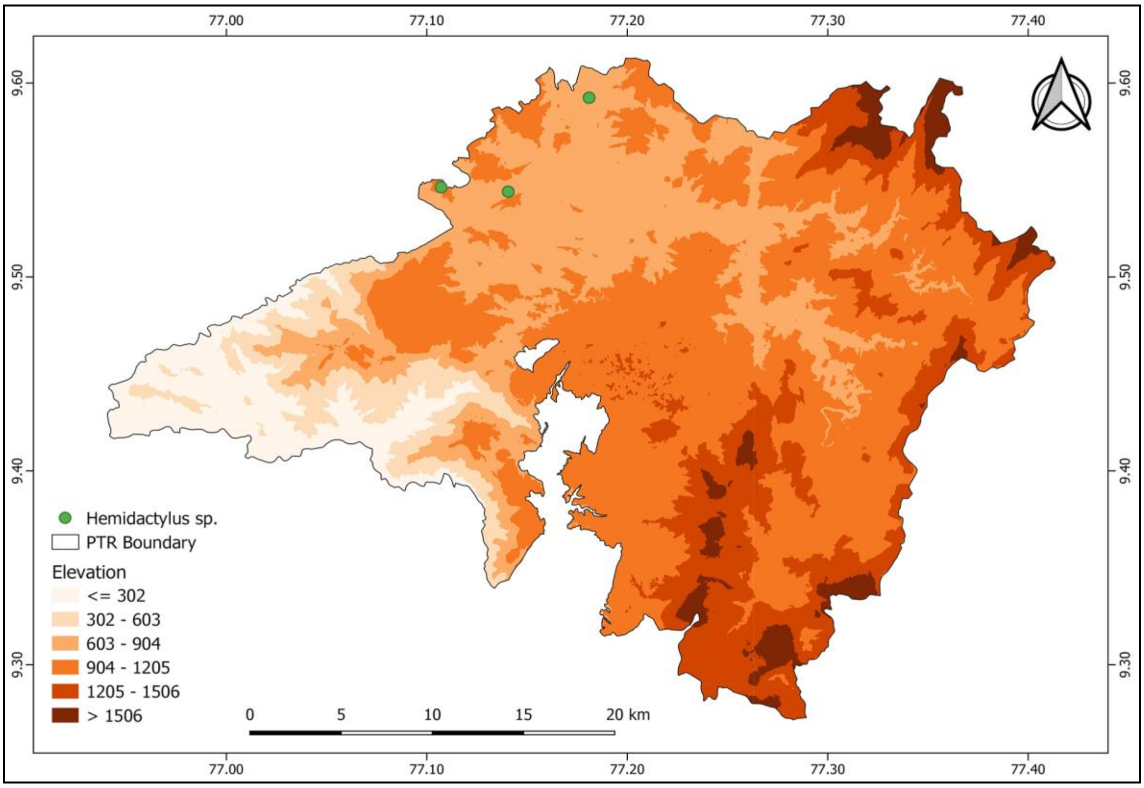

Fig. 5. 53 Distribution map of *Hemidactylus* sp.

***Eutropis carinata* (Schneider, 1801),** Common Keeled Skink

Order: Squamata

Family: Scincidae

IUCN Category: Least Concern

Endemism: NA

Wildlife Protection Act, 1972: Not listed

CITES: Not listed

Distribution of the species from the present study is in Fig. 5.54

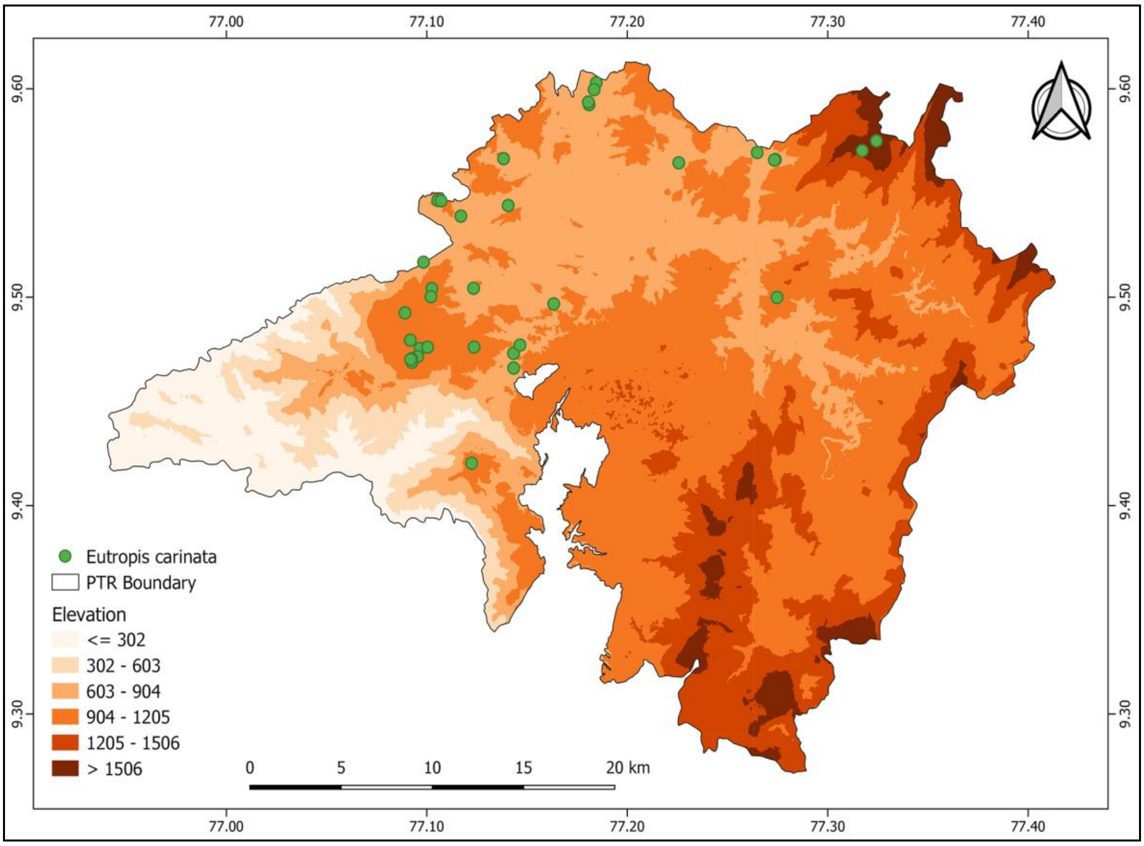

Fig. 5. 54 Distribution map of *Eutropis carinata*

***Eutropis macularia* (Blyth, 1853),** Bronze Grass Skink

Order: Squamata

Family: Scincidae

IUCN Category: Not Evaluated

Endemism: NA

Wildlife Protection Act, 1972: Not listed

CITES: Not listed

Distribution of the species from the present study is in Fig. 5.55

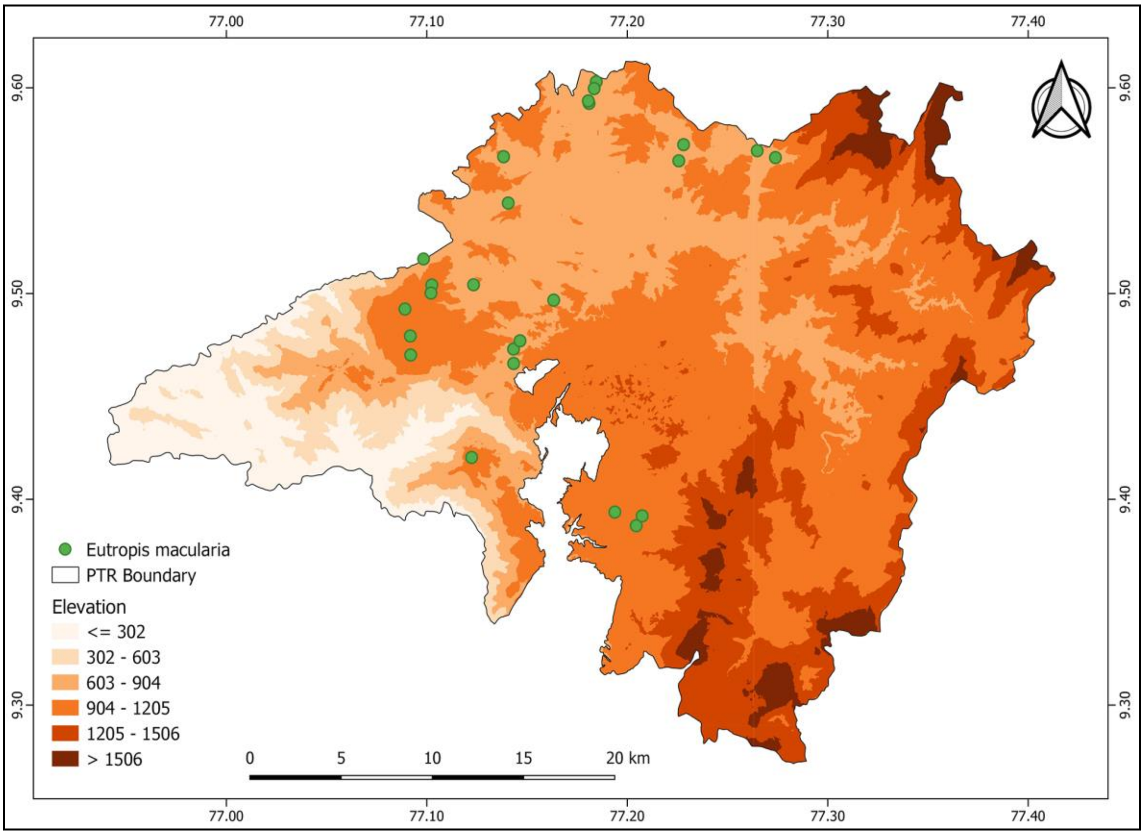

Fig. 5. 55 Distribution map of *Eutropis macularia*

Kaestlea laterimaculata **(Boulenger, 1887),** Side-spotted Ground Skink

Order: Squamata

Family: Scincidae

IUCN Category: Vulnerable

Endemism: Western Ghats

Wildlife Protection Act, 1972: Not listed

CITES: Not listed

Distribution of the species from the present study is in Fig. 5.56

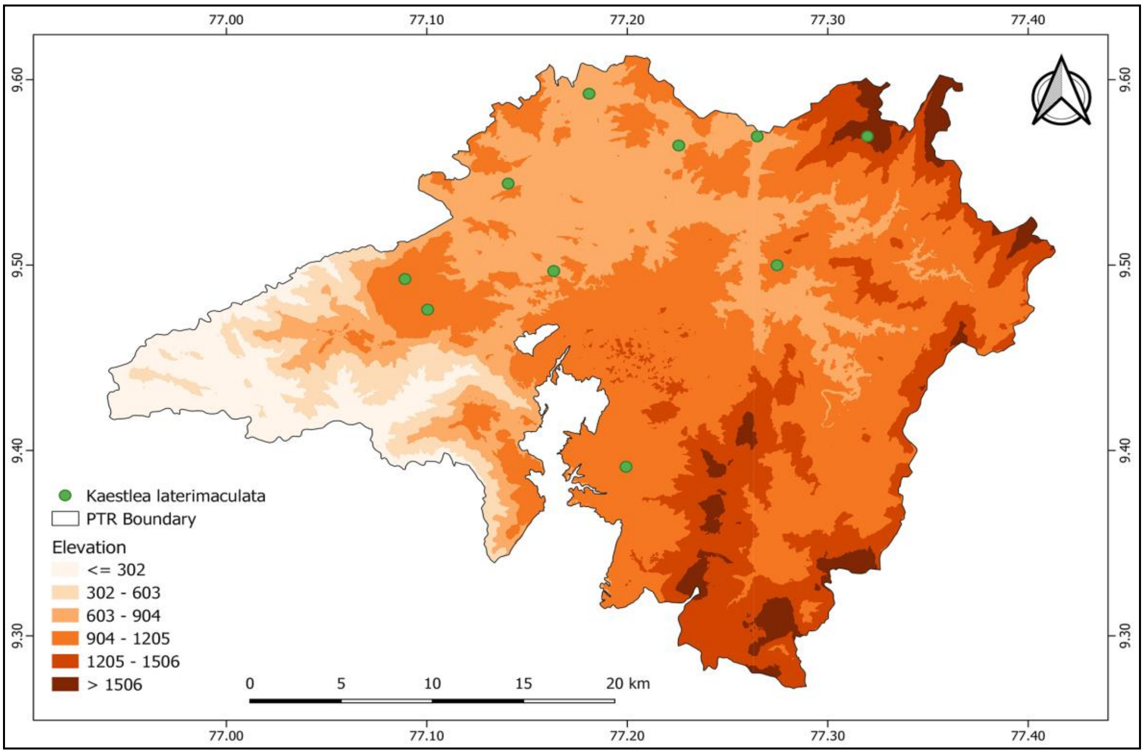

Fig. 5. 56 Distribution map of *Kaestlea laterimaculata*

***Varanus bengalensis* (Daudin, 1802),** Bengal Monitor

Order: Squamata

Family: Varanidae

IUCN Category: Least Concern

Endemism: NA

Wildlife Protection Act, 1972: Schedule I

CITES: Appendix I

Distribution of the species from the present study is in Fig. 5.57

***Indotyphlops braminus* (Daudin, 1803),** Brahminy Worm Snake

Order: Squamata

Family: Typhlopidae

IUCN Category: Not Evaluated

Endemism: NA

Wildlife Protection Act, 1972: Schedule IV

CITES: Not listed

Distribution of the species from the present study is in Fig. 5.58

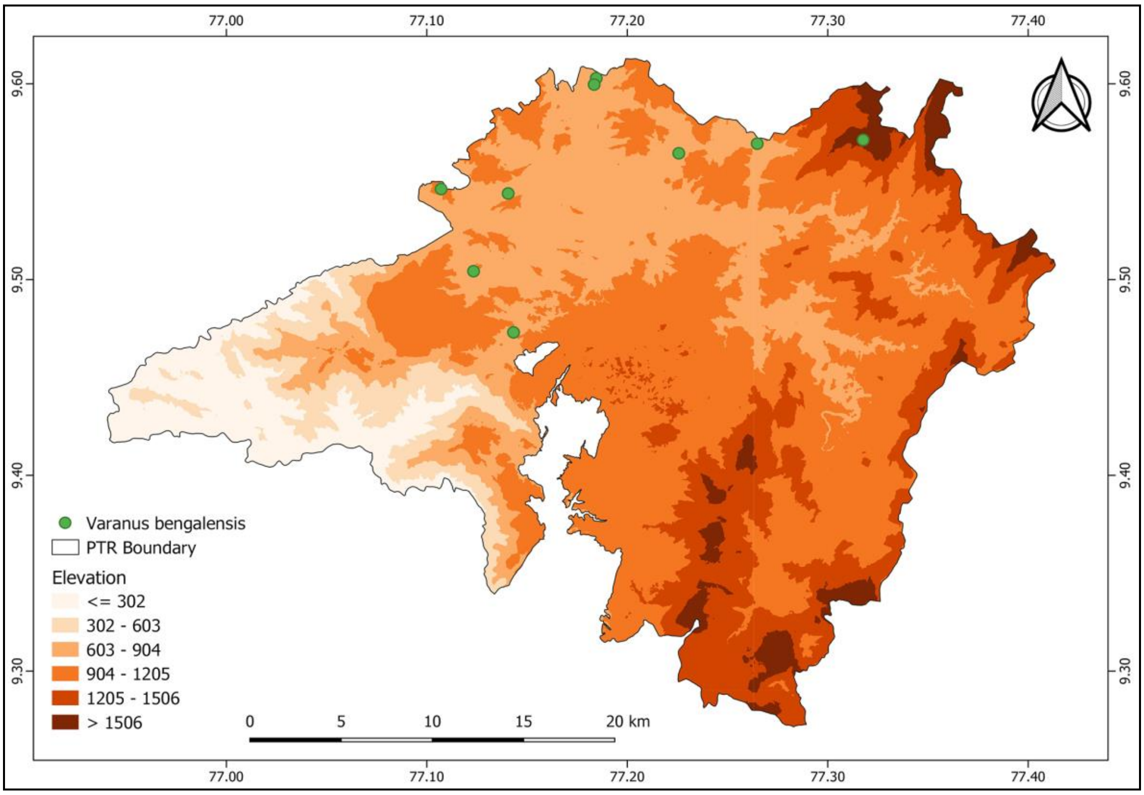

Fig. 5. 57 Distribution map of *Varanus bengalensis*

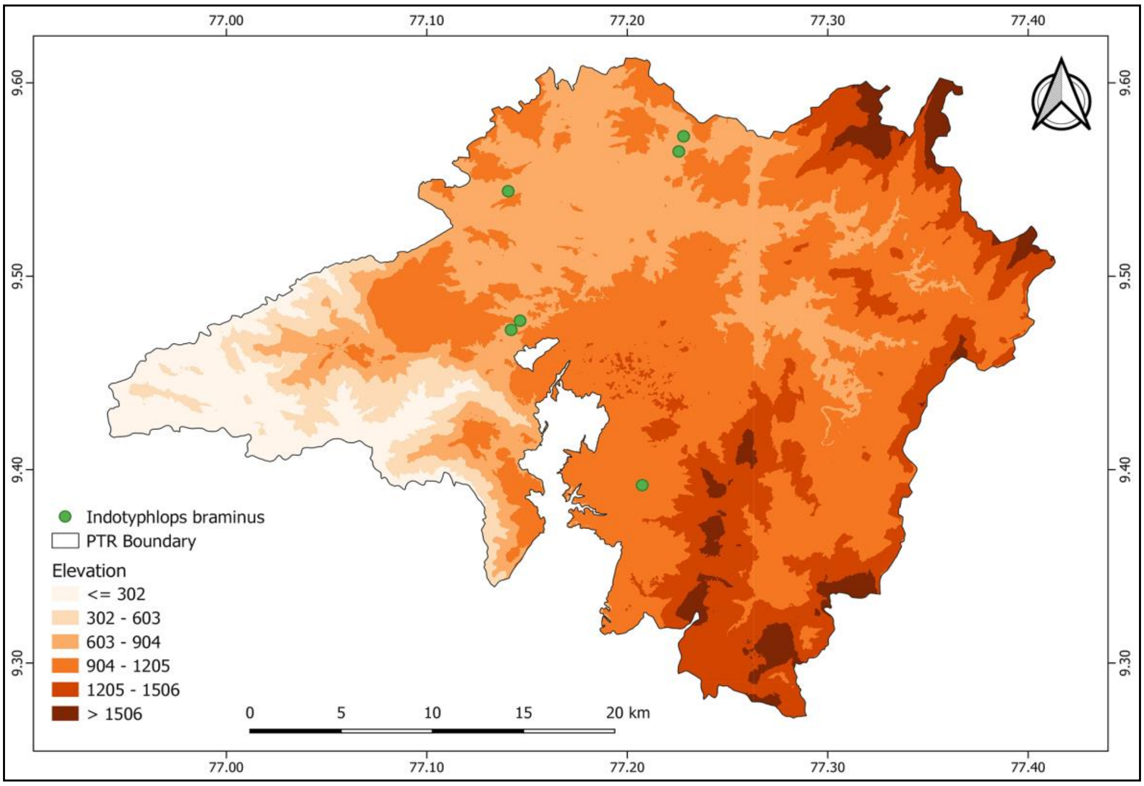

Fig. 5. 58 Distribution map of *Indotyphlops braminus*

Grypotyphlops acutus **(Dumeril and Bibron, 1844),** Beaked Worm Snake

Order: Squamata

Family: Typhlopidae

IUCN Category: Least Concern

Endemism: NA

Wildlife Protection Act, 1972: Schedule IV

CITES: Not listed

Distribution of the species from the present study is in Fig. 5.59

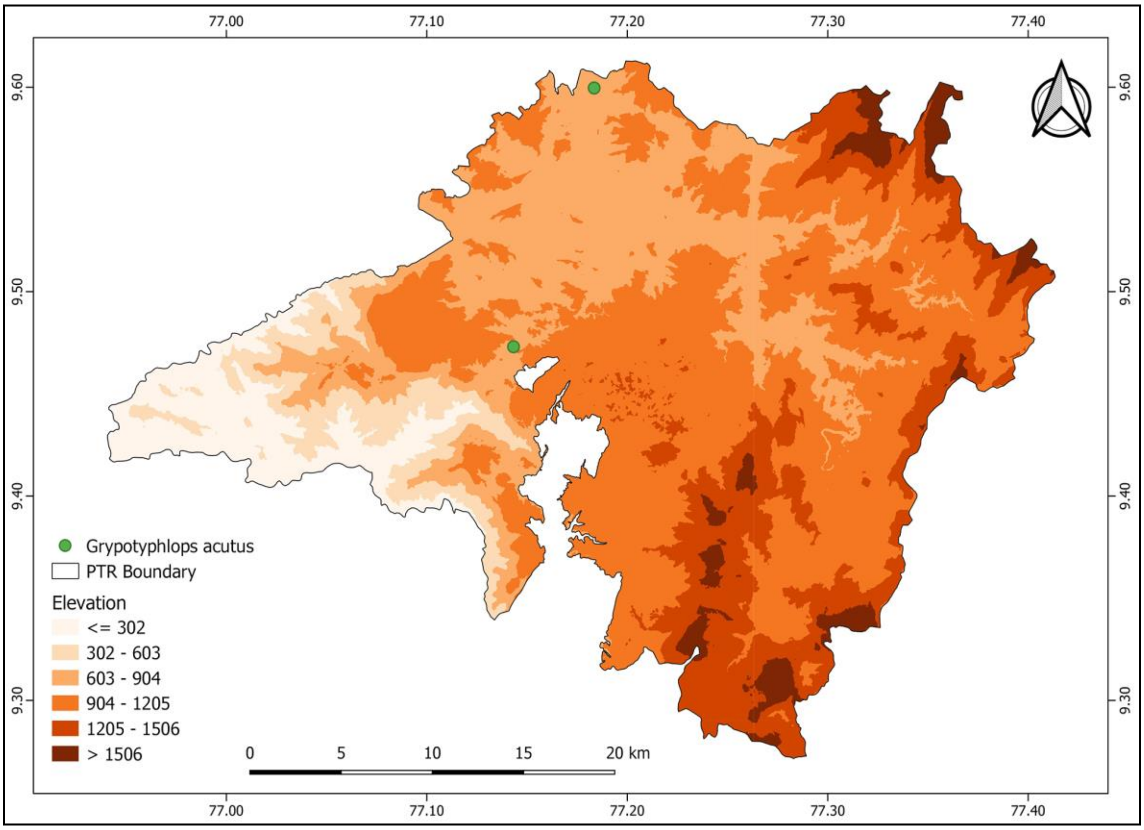

Fig. 5. 59 Distribution map of *Grypotyphlops acutus*

Melanophidium punctatum **(Beddome, 1871),** Pied-belly Shieldtail

Order: Squamata

Family: Uropeltidae

IUCN Category: Least Concern

Endemism: Western Ghats

Wildlife Protection Act, 1972: Schedule IV

CITES: Not listed

Distribution of the species from the present study is in Fig. 5.60

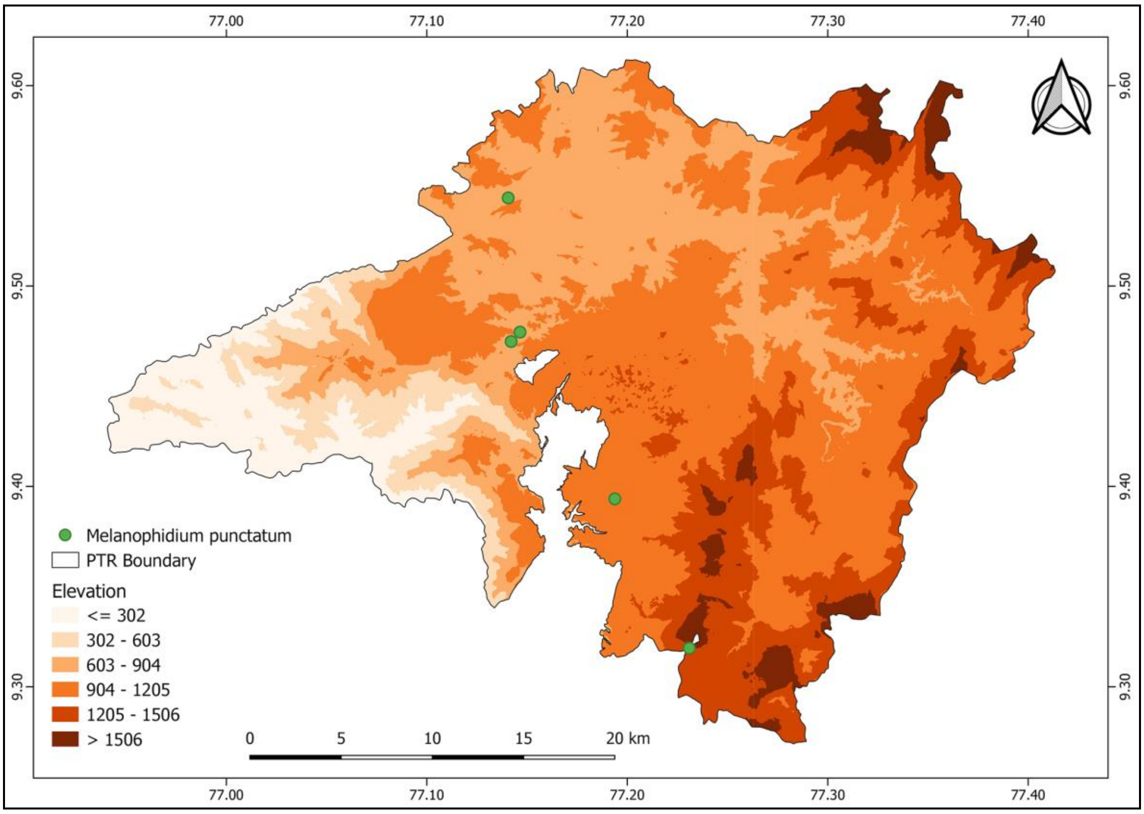

Fig. 5. 60 Distribution map of *Melanophidium punctatum*

Python molurus **(Linnaeus, 1758),** Indian Rock Python

Order: Squamata

Family: Pythonidae

IUCN Category: Least Concern

Endemism: NA

Wildlife Protection Act, 1972: Schedule I

CITES: Appendix I

Distribution of the species from the present study is in Fig. 5.61

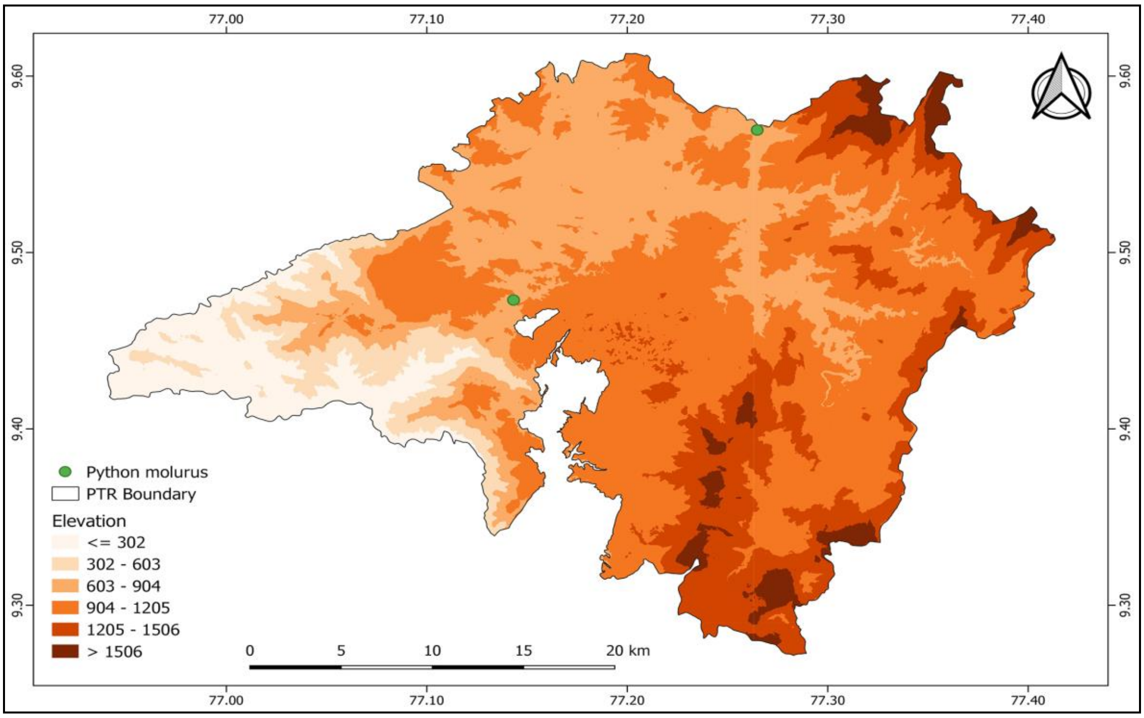

Fig. 5. 61 Distribution map of *Python molurus*

***Ptyas mucosa* (Linnaeus, 1758),** Indian Rat Snake

Order: Squamata

Family: Colubridae

IUCN Category: Not Evaluated

Endemism: NA

Wildlife Protection Act, 1972: Schedule II

CITES: Not listed

Distribution of the species from the present study is in Fig. 5.62

***Oligodon arnensis* (Shaw, 1802),** Common Kukri Snake

Order: Squamata

Family: Colubridae

IUCN Category: Not Evaluated

Endemism: NA

Wildlife Protection Act, 1972: Schedule IV

CITES: Not listed

Distribution of the species from the present study is in Fig. 5.63

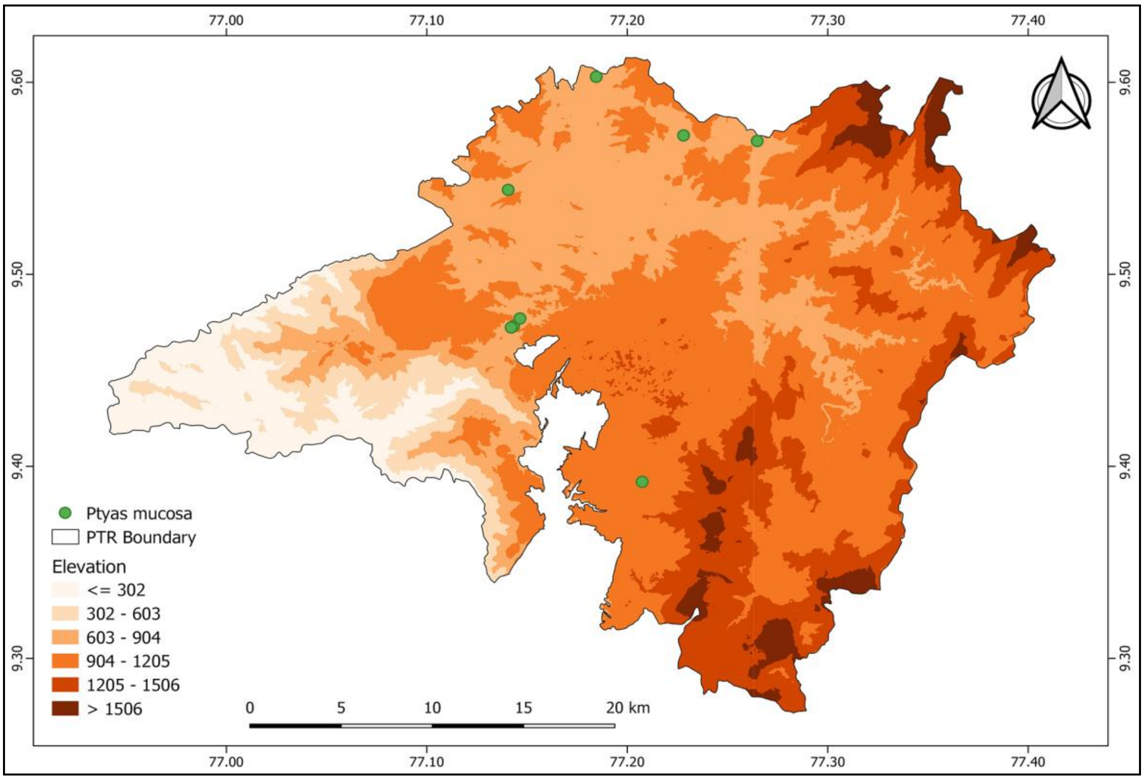

Fig. 5. 62 Distribution map of *Ptyas mucosa*

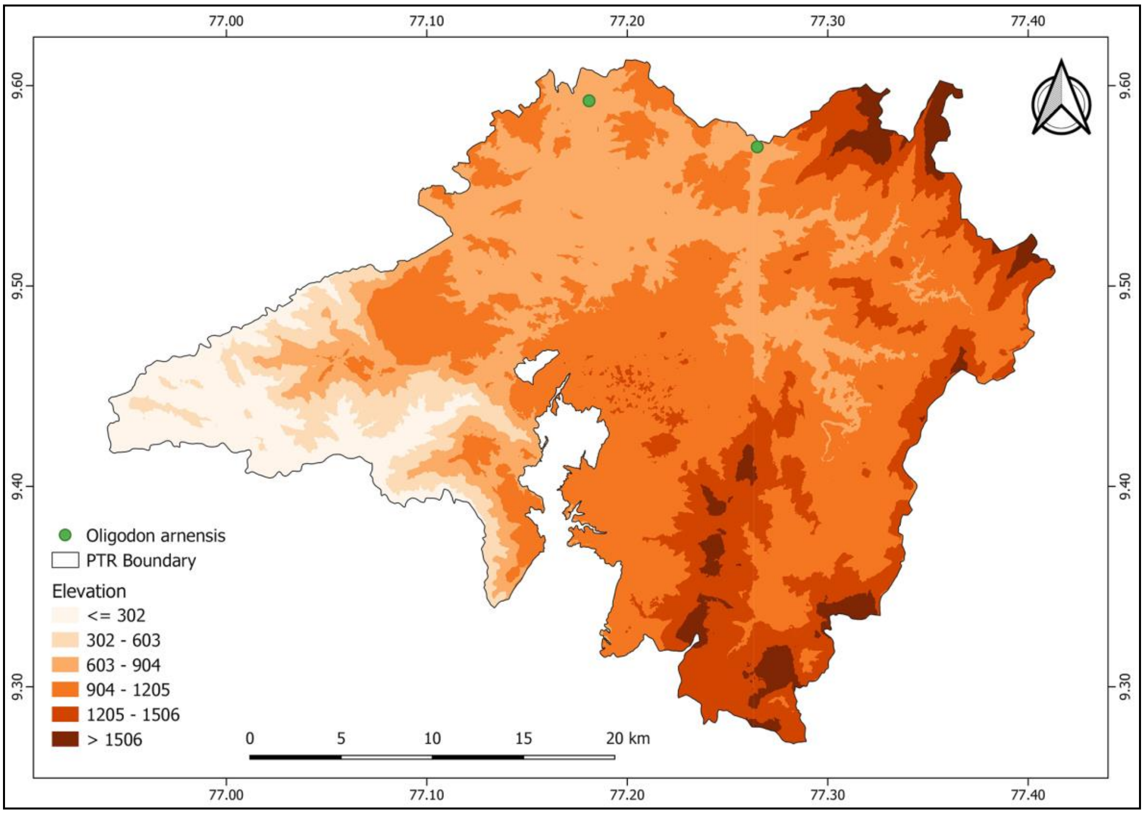

Fig. 5. 63 Distribution map of *Oligodon arnensis*

***Lycodon aulicus* (Linnaeus, 1754),** Common Wolf Snake

Order: Squamata

Family: Colubridae

IUCN Category: Not Evaluated

Endemism: NA

Wildlife Protection Act, 1972: Schedule IV

CITES: Not listed

Distribution of the species from the present study is in Fig. 5.64

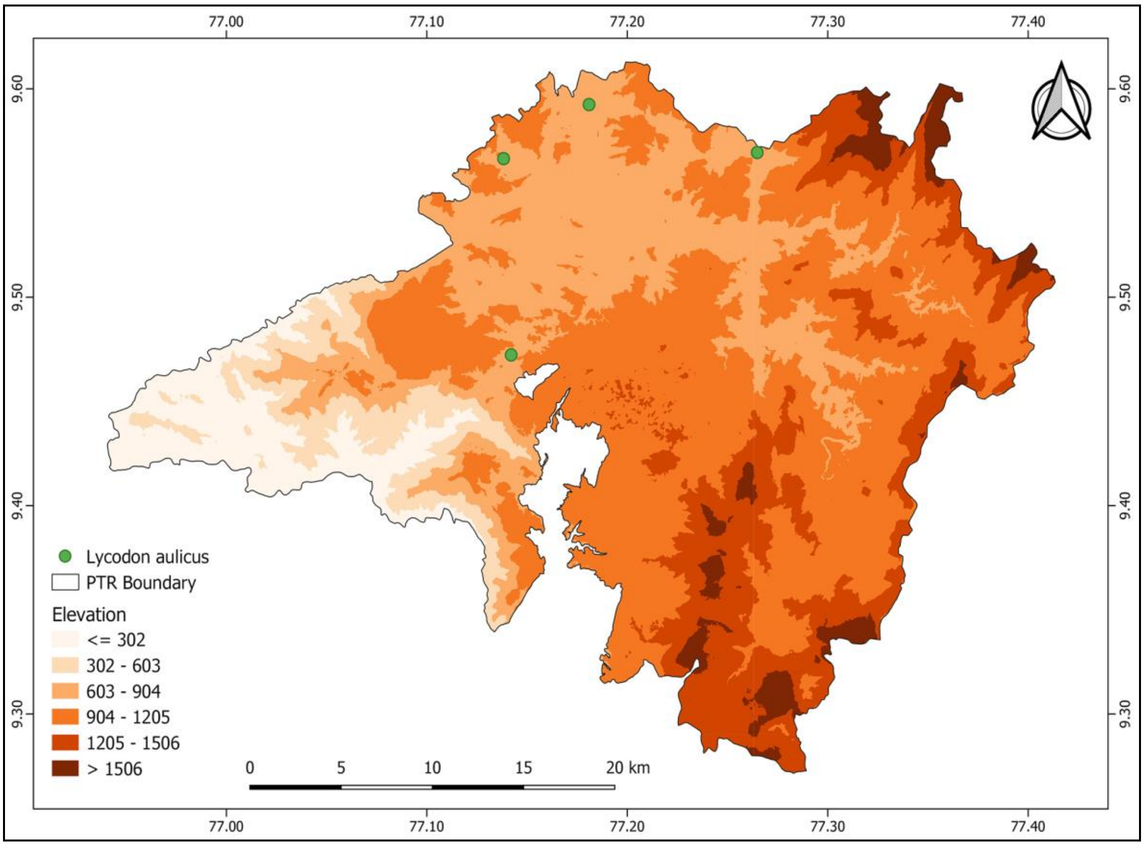

Fig. 5. 64 Distribution map of *Lycodon aulicus*

***Lycodon travancoricus* (Beddome, 1870),** Travancore Wolf Snake

Order: Squamata

Family: Colubridae

IUCN Category: Least Concern

Endemism: NA

Wildlife Protection Act, 1972: Schedule IV

CITES: Not listed

Distribution of the species from the present study is in Fig. 5.65

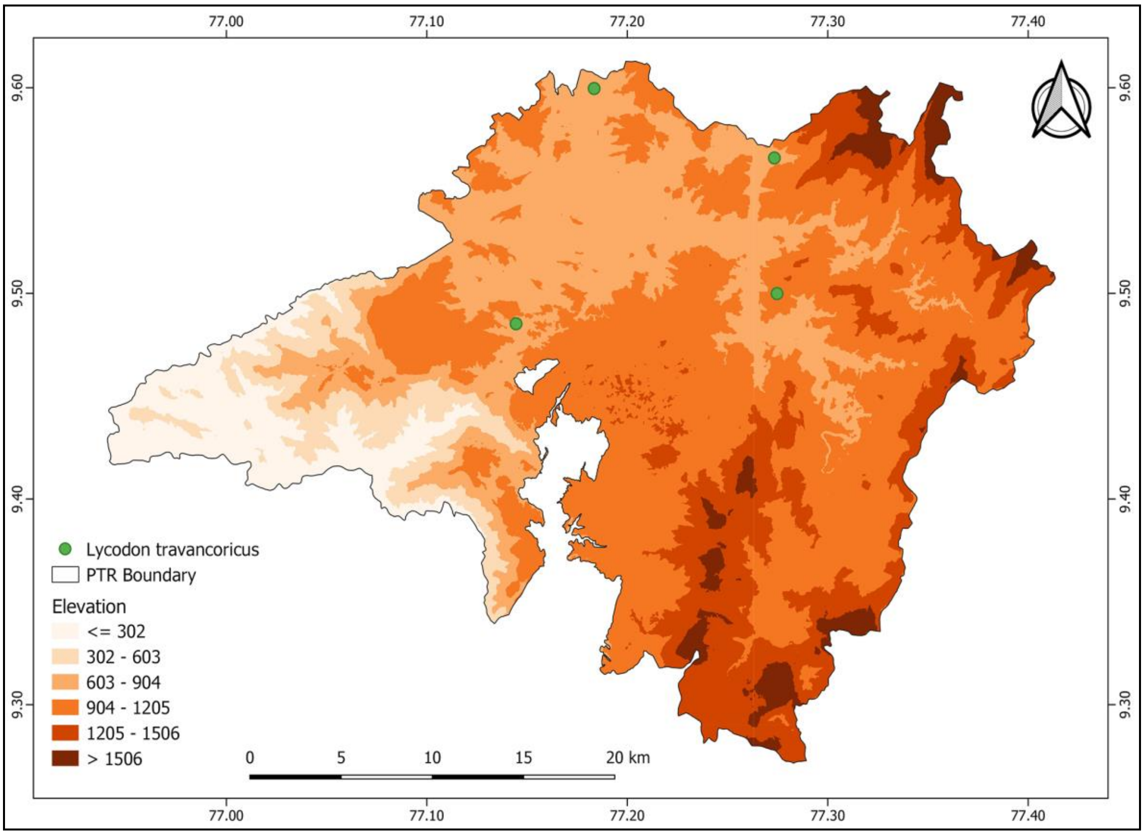

Fig. 5. 65 Distribution map of *Lycodon travancoricus*

Ahaetulla isabellina **(Mallik, Srikanthan, Pal, D'Souza, Shanker and Ganesh, 2020)**

Order: Squamata

Family: Colubridae

IUCN Category: Not Evaluated

Endemism: Western Ghats

Wildlife Protection Act, 1972: Not listed

CITES: Not listed

Distribution of the species from the present study is in Fig. 5.66

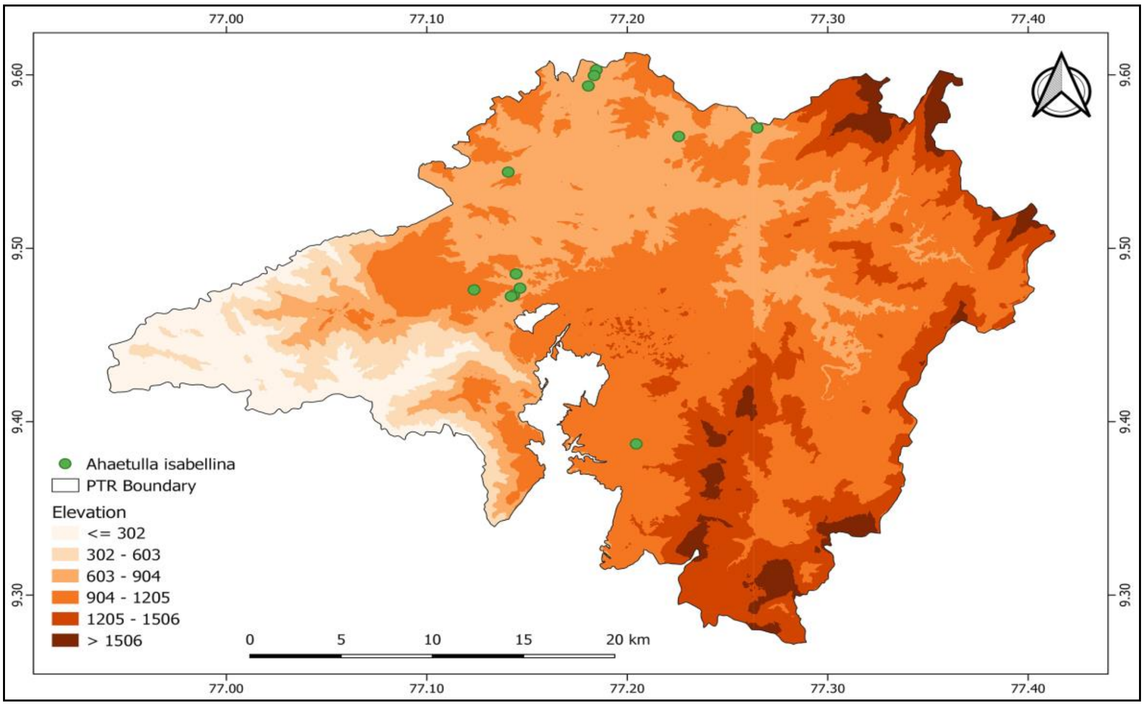

Fig. 5. 66 Distribution map of *Ahaetulla isabellina*

Ahaetulla dispar **(Gunther, 1864),** Gunther's Vine Snake

Order: Squamata

Family: Colubridae

IUCN Category: Near Threatened

Endemism: Western Ghats

Wildlife Protection Act, 1972: Schedule IV

CITES: Not listed

Distribution of the species from the present study is in Fig. 5.67

Boiga thackerayi **(Giri, Deepak, Captain, Pawar and Tillack, 2019),** Thackeray's Cat Snake

Order: Squamata

Family: Colubridae

IUCN Category:

Endemism: Western Ghats

Wildlife Protection Act, 1972: Not listed

CITES: Not listed

Distribution of the species from the present study is in Fig. 5.68

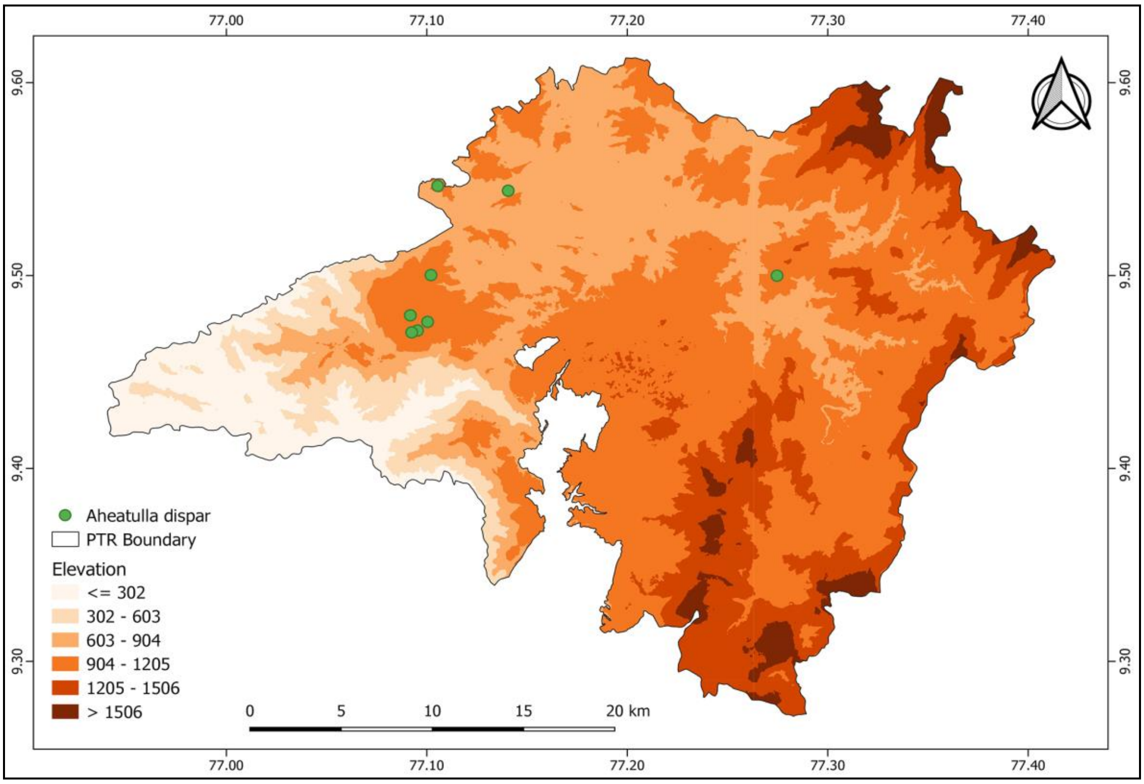

Fig. 5. 67 Distribution map of *Ahaetulla dispar*

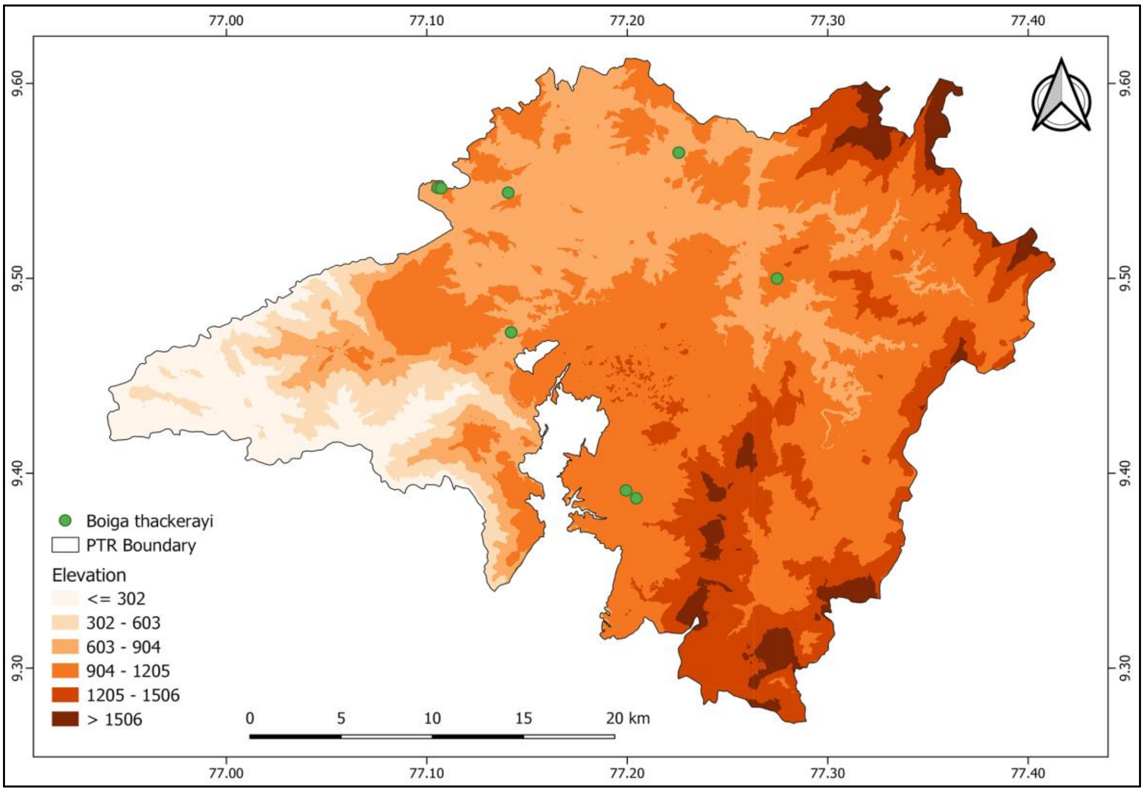

Fig. 5. 68 Distribution map of *Boiga thackerayi*

***Hebius beddomei* (Günther, 1864),** Beddome'sKeelback

Order: Squamata

Family: Natricidae

IUCN Category: Least Concern

Endemism: Western Ghats

Wildlife Protection Act, 1972: Schedule IV

CITES: Not listed

Distribution of the species from the present study is in Fig. 5.69

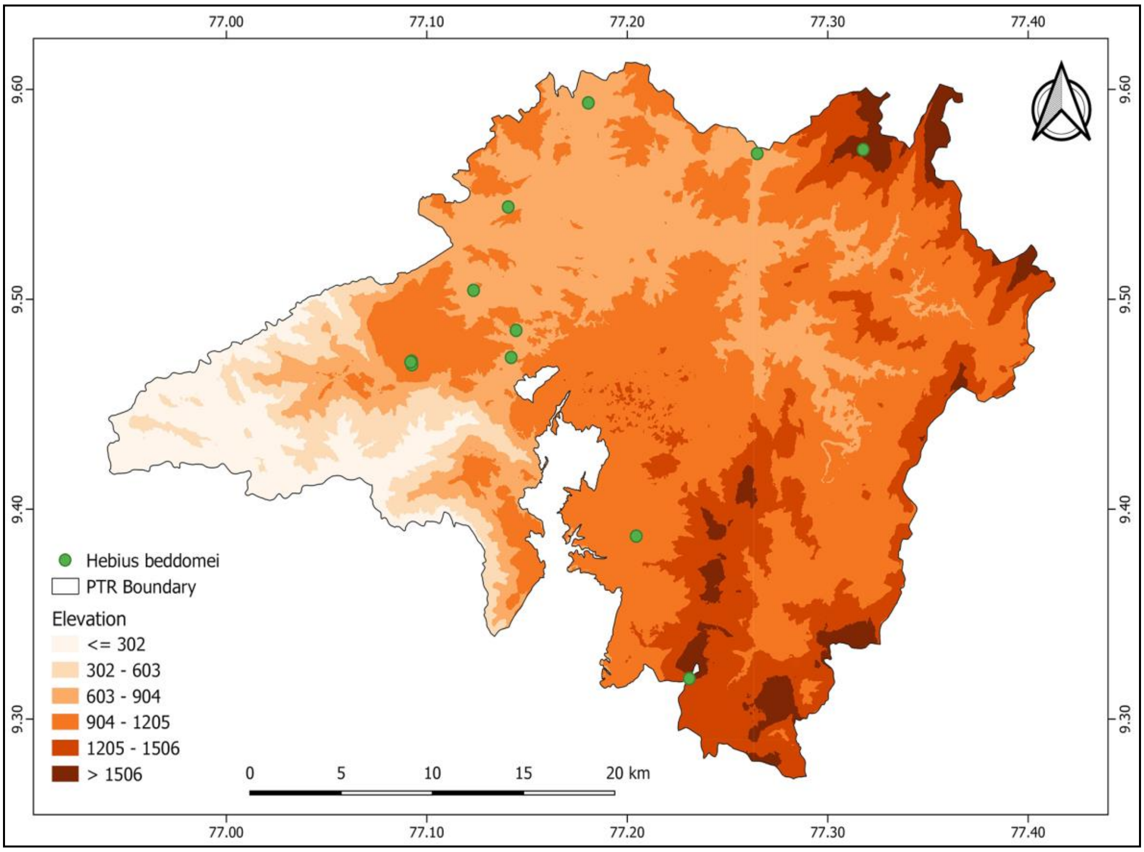

Fig. 5. 69 Distribution map of *Hebius beddomei*

***Hebius monticola* (Jerdon, 1852),** Hill Keelback

Order: Squamata

Family: Natricidae

IUCN Category: Least Concern

Endemism: Western Ghats

Wildlife Protection Act, 1972: Schedule IV

CITES: Not listed

Distribution of the species from the present study is in Fig. 5.70

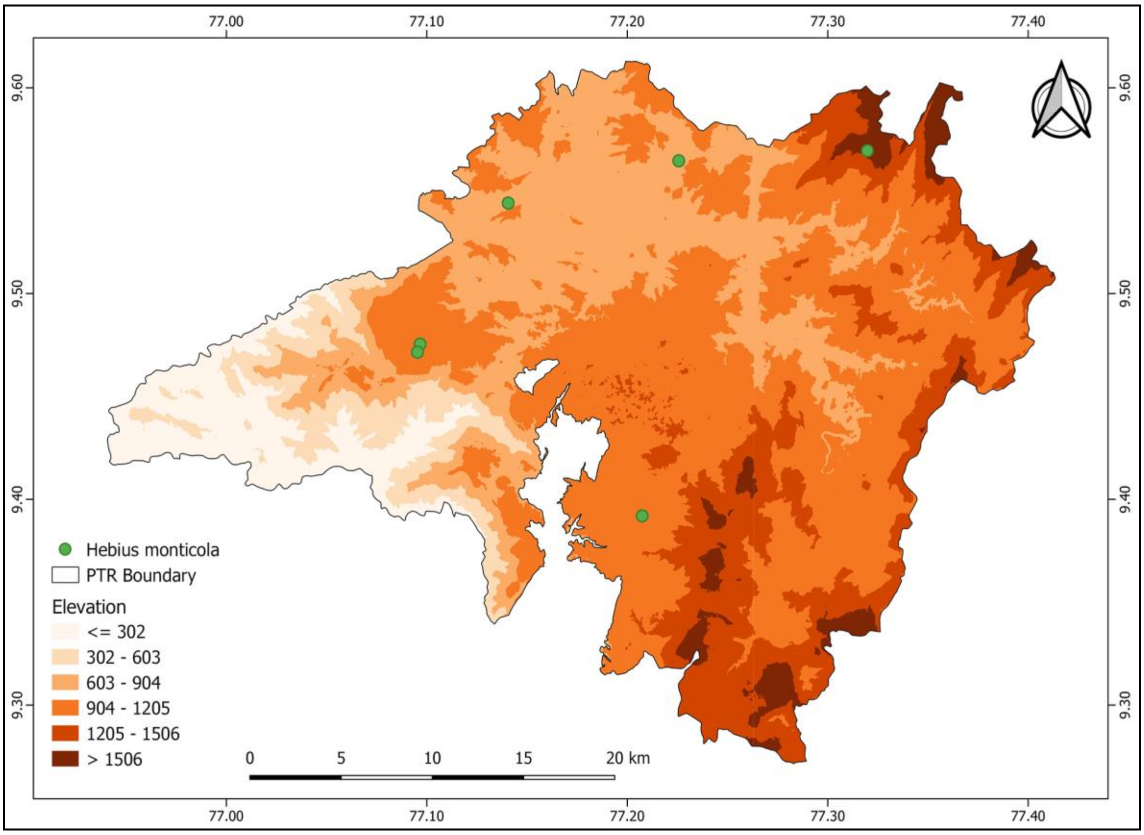

Fig. 5. 70 Distribution map of *Hebius monticola*

***Fowlea piscator* (Schneider, 1799),** Checkered Keelback

Order: Squamata

Family: Natricidae

IUCN Category: Not Evaluated

Endemism: NA

Wildlife Protection Act, 1972: Schedule II

CITES: Appendix III

Distribution of the species from the present study is in Fig. 5.71

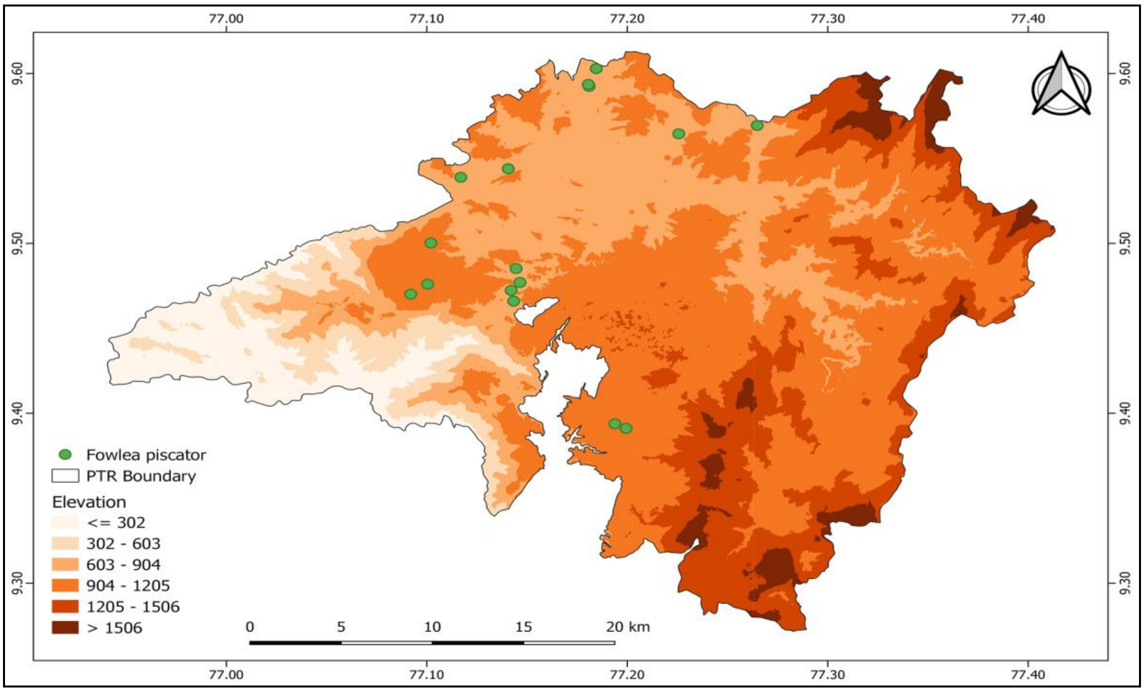

Fig. 5. 71 Distribution map of *Fowlea piscator*

Calliophis nigrescens **(Gunther, 1862),**

Common name: Striped Coral Snake

Order: Squamata

Family: Elapidae

IUCN Category: Least Concern

Endemism: Western Ghats

Wildlife Protection Act, 1972: Schedule IV

CITES: Not listed

Distribution of the species from the present study is in Fig. 5.72

Craspedocpehalus macrolepis **(Mallik, Srikanthan, Ganesh, Vijayakumar, Campbell, Malhotra and Shanker, 2021),**

Order: Squamata

Family: Viperidae

IUCN Category:

Endemism: Western Ghats

Wildlife Protection Act, 1972: Not listed

CITES: Not listed

Distribution of the species from the present study is in Fig. 5.73

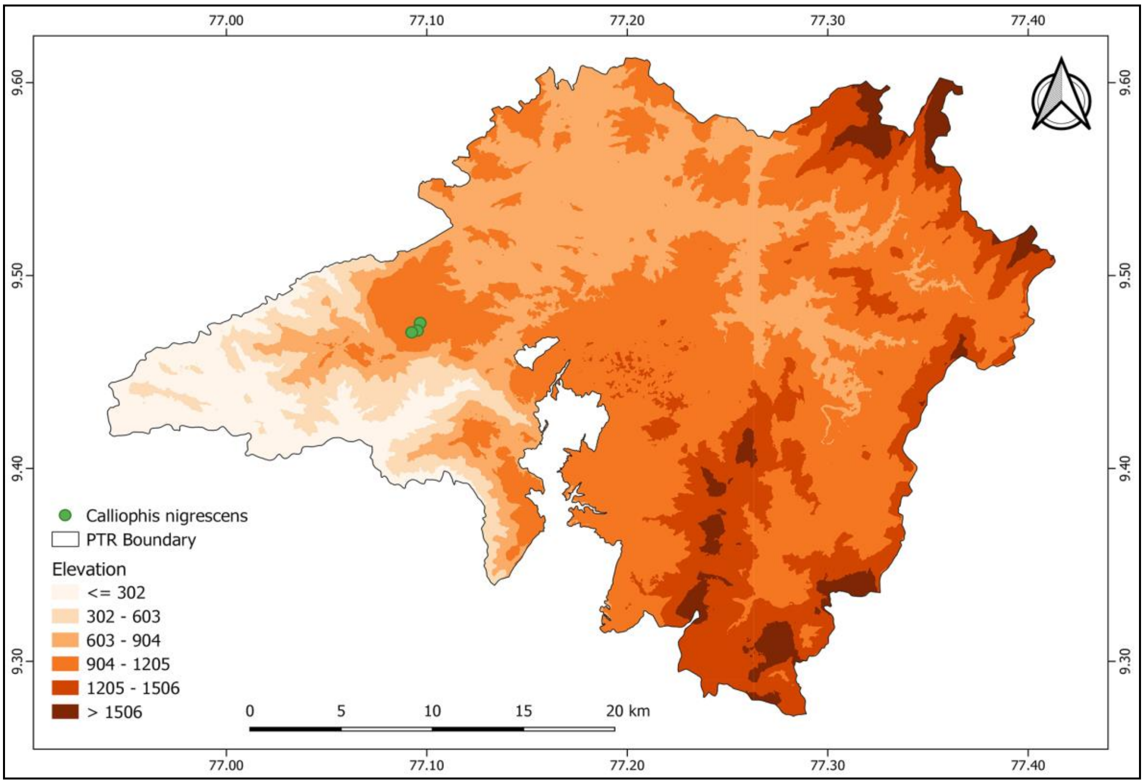

Fig. 5. 72 Distribution map of *Calliophis nigrescens*

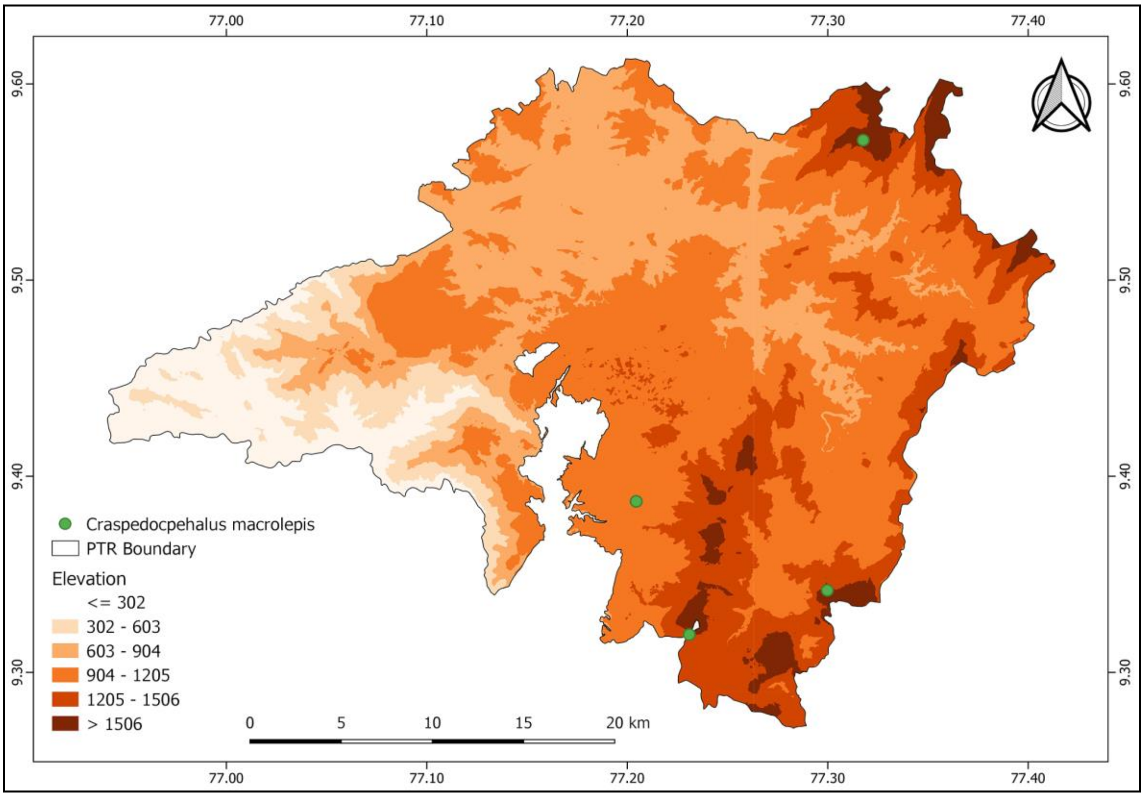

Fig. 5. 73 Distribution map of *Craspedocpehalus macrolepis*

Craspedocephalus anamallensis **(Mallik, Srikanthan, Ganesh, Vijayakumar, Campbell, Malhotra and Shanker, 2021),**

Order: Squamata

Family: Viperidae

IUCN Category: Not Evaluated

Endemism: Western Ghats

Wildlife Protection Act, 1972: Not listed

CITES: Not listed

Distribution of the species from the present study is in Fig. 5.74

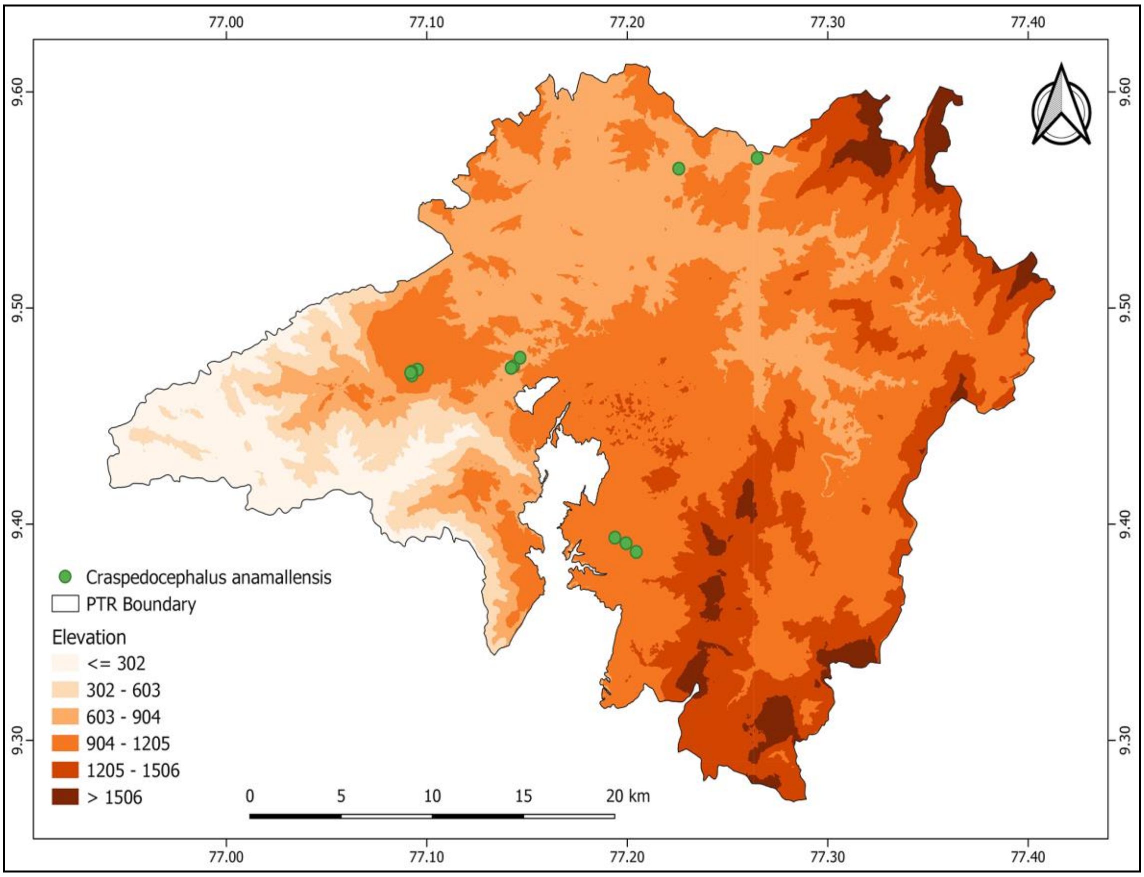

Fig. 5. 74 Distribution map of *Craspedocephalus anamallensis*

5.3.4 Family Wise Herpetofaunal Contribution

5.3.4.1 Amphibians

An analyses of family wise contribution of amphibians recorded from vayals and its immediate surrounding vegetation show that the family Rhacophoridae has more number of species followed by Nyctibatrachidae and Dicroglossidae (Fig. 5.75). The species contribution in vayal and in the surrounding vegetation show that the amphibians from eight out of nine families recorded were having same number of species contribution in both the vayals and in the surrounding vegetation. The family of tree frogs (Rhacophoridae) has more species representation in the surrounding vegetation (17 species) than vayals (13 species) (Table 5.1). The species *Polypedates maculatus, P. occidentalis, Pseudophilautus wynaadensis, Raorchestes akroparallagi, R. anili, R. beddomii, R. griet, R. jayarami, R. keirasabinae, R. travancoricus, Rhacophorus calcadensis, R. malabaricus,* and *R. pseudomalabaricus* were recorded from both vayal and its immediate surrounding vegetation and the species *Raorchestes chlorosomma, R. ochlandrae, R. ponmudi, and R. uthamani* were only recorded from the surrounding vegetation. From all other eight families the species recorded from vayal and surrounding vegetation are same and the species are *Nyctibatrachus* sp., *N. gavi, N. Periyar* and *N. manalari* from Nyctybatrachidea family, *Euphlyctis cyanophlyctis*, *Euphlyctis cyanophlyctis* and *Minervarya keralensis* from Dicroglossidae family. The family Bufonidae and Ranidae has two species each and the species are *Duttaphrynus melanostictus*, *D. parietalis* and *Clinotarsus curtipes*, *Indosylvirana sreeni* respectively. Rest of the four families like Micrixalidae, Microhylidae, Ranixalidae and Icthyophidae has one species representation and the species are *Micrixalus adonis*, *Uperodon montanus*, *Indirana semipalmata* and *Ichthyophis beddomei* respectively.

Table 5. 1 List of amphibians recorded during the study in vayals and surrounding areas

No	Species	Inside vayal	Surrounding vegetation
1	*Duttaphrynus melanostictus*	✓	✓
2	*Duttaphrynus parietalis*	✓	✓
3	*Euphlyctis cyanophlyctis*	✓	✓
4	*Hoplobatrachus tigerinus*	✓	✓
5	*Minervarya keralensis*	✓	✓
6	*Micrixalus adonis*	✓	✓
7	*Uperodon montanus*	✓	✓
8	*Nyctibatrachus* sp.	✓	✓
9	*Nyctibatrachus gavi*	✓	✓
10	*Nyctibatrachus manalari*	✓	✓
11	*Nyctibatrachus periyar*	✓	✓
12	*Indirana semipalmata*	✓	✓
13	*Clinotarsus curtipes*	✓	✓
14	*Indosylvirana sreeni*	✓	✓
15	*Polypedates maculatus*	✓	✓
16	*Polypedates occidentalis*	✓	✓
17	*Pseudophilautus wynaadensis*	✓	✓
18	*Raorchestes akroparallagi*	✓	✓
19	*Raorchestes anili*	✓	✓
20	*Raorchestes beddomii*	✓	✓
21	*Raorchestes chlorosomma*	×	✓
22	*Raorchestes griet*	✓	✓
23	*Raorchestes jayarami*	✓	✓
24	*Raorchestes keirasabinae*	×	✓
25	*Raorchestes ochlandrae*	✓	✓
26	*Raorchestes ponmudi*	×	✓
27	*Raorchestes travancoricus*	✓	✓
28	*Raorchestes uthamani*	×	✓
29	*Rhacophorus calcadensis*	✓	✓
30	*Rhacophorus malabaricus*	✓	✓
31	*Rhacophorus pseudomalabaricus*	✓	✓
32	*Ichthyophis beddomei*	✓	✓

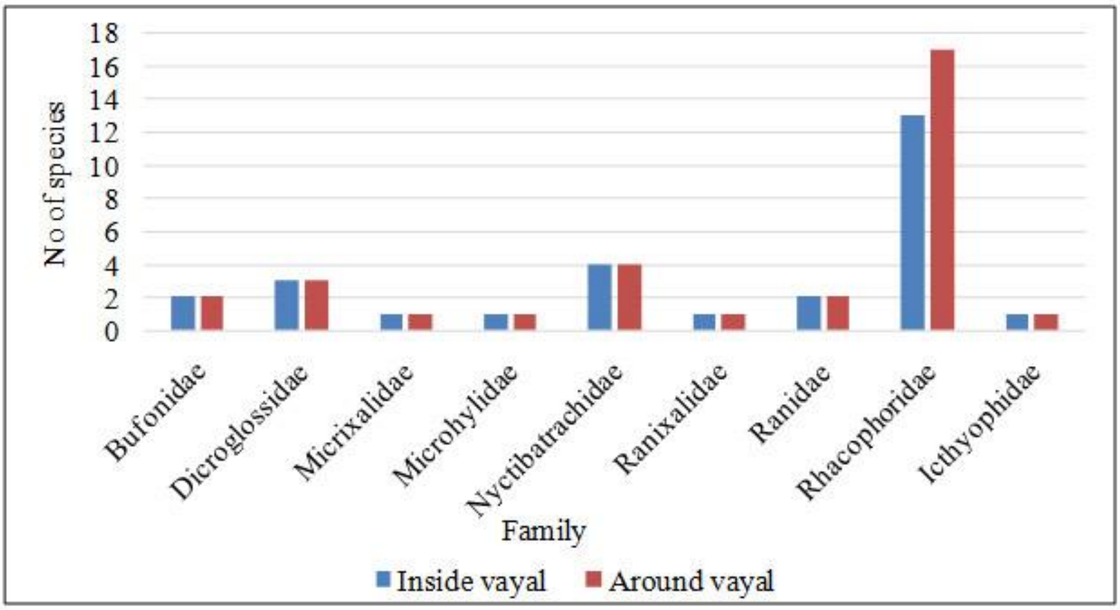

Fig. 5. 75 Family wise contribution of amphibians from vayal and its surroundings

5.3.4.2 Reptiles

In reptiles, species from the family Testudinidae and Pythonidae were recorded only from surrounding vegetation and the families of lizards (Agamidae and Gekkonidae) and one family of snake (Colubridae) showed difference in species contribution in vayals and in its immediate surroundings (Fig. 5.76). The family Colubridae had more number of species representation with seven species. Of these, three species (*Lycodon aulicus*, *L. travancoricus* and *Oligodon arnensis*) were not recorded from vayals. The other Colubrids (*Ahaetulla isabellina*, *A. dispar*, *Boiga thackerayi* and *Ptyas mucosa*) were recorded from both vayal and surrounding vegetation. The other families with highest species representations were from the lizard families Gekkonidae (6 species) and Agamidae (5 species). Out of the six species recorded from the family Gekkonidae, four species (*Cnemaspis wynadensis*, *Dravidogecko* sp., *Hemidactylus cf. parvimaculatus* and *H. leschenaultia*) were recorded only from the surrounding vegetation and the *Hemidactylus frenatus* and *H. cf. parvimaculatus* were recorded from both vayals and surrounding vegetation. From the family Agamidae, *Calotes versicolor* and *Monilesaurus ellioti* were recorded from both vayals and surrounding vegetation and rest of the species (*Calotes calotes*, *C. grandisquamis* and *Monilesaurus rouxii*) were recorded only from the surrounding vegetation. The family Scincidae and Natricidae contributed three species each from both vayals and surrounding vegetation and the species are *Eutropis carinata, E.* macularia and Kaestlea *laterimaculata* from the former and *Fowlea piscator, Hebius beddomei*and *H. monticola* from family Natricidae. The family Typhloidae and Viperidae has two species representations (*Indotyphlops braminus* and *Grypotyphlops acutus*) from both vayals and surrounding vegetation *Craspedocpehalus malabaricus* and *Craspedocpehalus macrolepis* were recorded from the family Viperidae. Rest of the four families *viz*. Geoemydidae, Varanidae, Uropeltidae and Elapidae had one species each. These were *Indotestudo travancorica, Varanus bengalensis, Melanophidium punctatum* and *Calliophis nigrescens* respectively. Out of these, *Indotestudo travancorica* was recorded only from the surrounding vegetation.

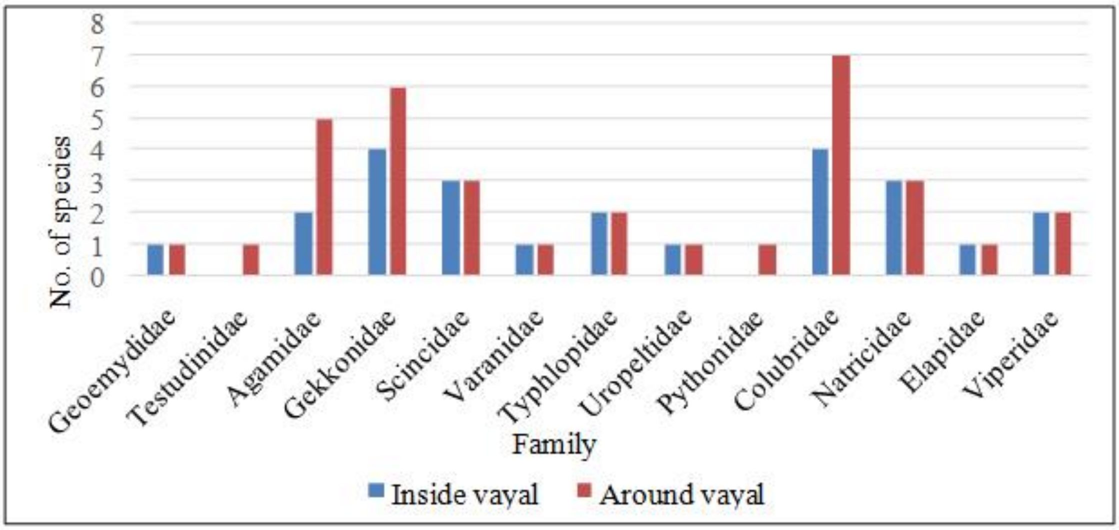

Fig. 5. 76 Family wise contribution of reptiles

Table 5. 2 List of reptiles recorded during the study

No	Species	Inside vayal	Surrounding vegetation
1	*Melanochelys trijuga*	✓	✓
2	*Indotestudo travancorica*	×	✓
3	*Monilesaurus ellioti*	✓	✓
4	*Monilesaurus rouxii*	×	✓
5	*Calotes calotes*	×	✓
6	*Calotes grandisquamis*	×	✓
7	*Calotes versicolor*	✓	✓
8	*Cnemaspis wynadensis*	✓	✓
9	*Dravidogecko* sp.	✓	✓
10	*Hemidactylus cf. parvimaculatus*	✓	✓
11	*Hemidactylus frenatus*	×	✓
12	*Hemidactylus leschenaultii*	✓	✓
13	*Hemidactylus maculatus*	×	✓
14	*Eutropis carinata*	✓	✓
15	*Eutropis macularia*	✓	✓
16	*Kaestlea laterimaculata*	✓	✓
17	*Varanus bengalensis*	✓	✓
18	*Indotyphlops braminus*	✓	✓
19	*Grypotyphlops acutus*	✓	✓
20	*Melanophidium punctatum*	✓	✓
21	*Python molurus*	×	✓
22	*Ptyas mucosa*	✓	✓
23	*Oligodon arnensis*	×	✓
24	*Lycodon aulicus*	×	✓
25	*Lycodon travancoricus*	×	✓
26	*Ahaetulla isabellina*	✓	✓
27	*Aheatulla dispar*	✓	✓

28	*Boiga thackerayi*	✓	✓
29	*Hebius beddomei*	✓	✓
30	*Hebius monticola*	✓	✓
31	*Fowlea piscator*	✓	✓
32	*Calliophis nigrescens*	✓	✓
33	*Craspedocpehalus malabaricus*	✓	✓
34	*Craspedocpehalus macrolepis*	✓	✓

5.3.5 Family Wise Endemic Species Contribution

About 86% of amphibians and 38% of reptiles recorded during the study are endemic to the Western Ghats (Fig. 5.77 and Fig. 5.78). *Duttaphrynus melanostictus, Euphlyctis cyanophlyctis, Hoplobatrachus tigerinus* and *Polypedates maculatus* has wider distribution and the rest 28 species are restricted to the Western Ghats. All the species recorded from the families Micrixalidae, Microhylidae, Nyctibatrachidae, Ranixalidae, Ranidae and Ichthyophidae during the study are endemic to the Western Ghats (Fig. 5.77). Out of the 34 reptile species recorded, 13 are endemic to the Western Ghats. These are *Indotestudo travancorica*, *Monilesaurus ellioti*, *Calotes grandisquamis*, *Cnemaspis wynadensis*, *Dravidogecko* sp., *Kaestlea laterimaculata*, *Melanophidium punctatum*, *Aheatulla dispar*, *Hebius beddomei*, *H. monticola*, *Calliophis nigrescens*, *Craspedocpehalus malabaricus* and *C. macrolepis*. All the reptile species recorded from the families Testudinidae, Uropeltidae, Elapidae and Viperidae during the study are endemic to the Western Ghats (Fig. 5.78). Apart from this, 67% of species recorded from the family Natricidae and 40% of the species recorded from family Agamidae are endemic to Western Ghats followed by Gekkonidae and Scincidae with 33% and Colubridae with 14% endemics (Fig. 5.78).

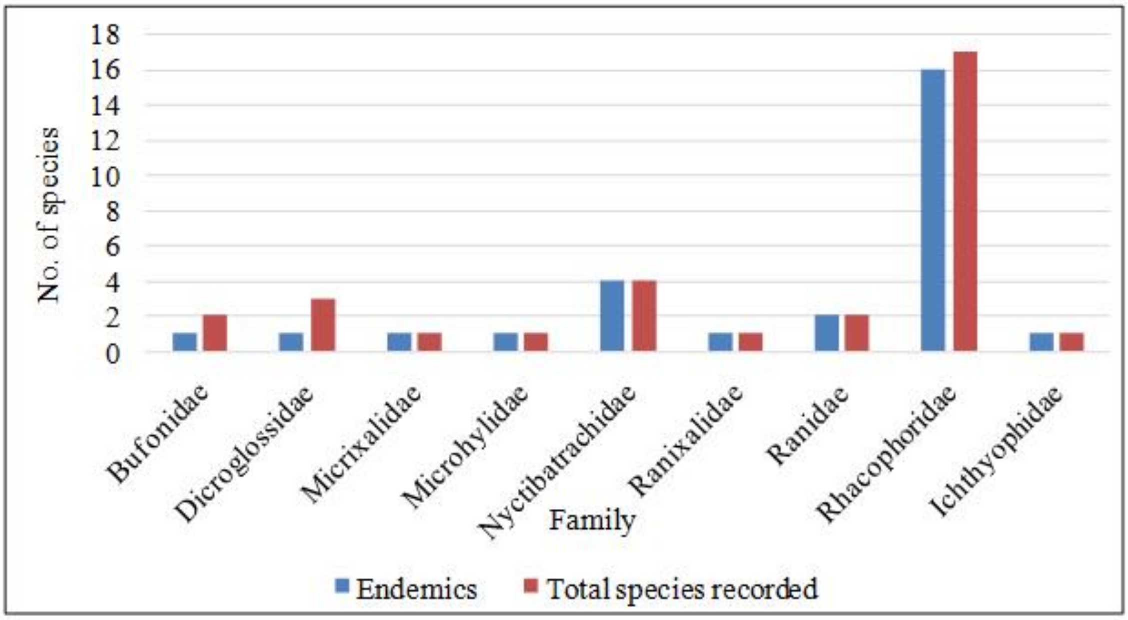

Fig. 5. 77 Western Ghats endemic amphibians recorded from different family

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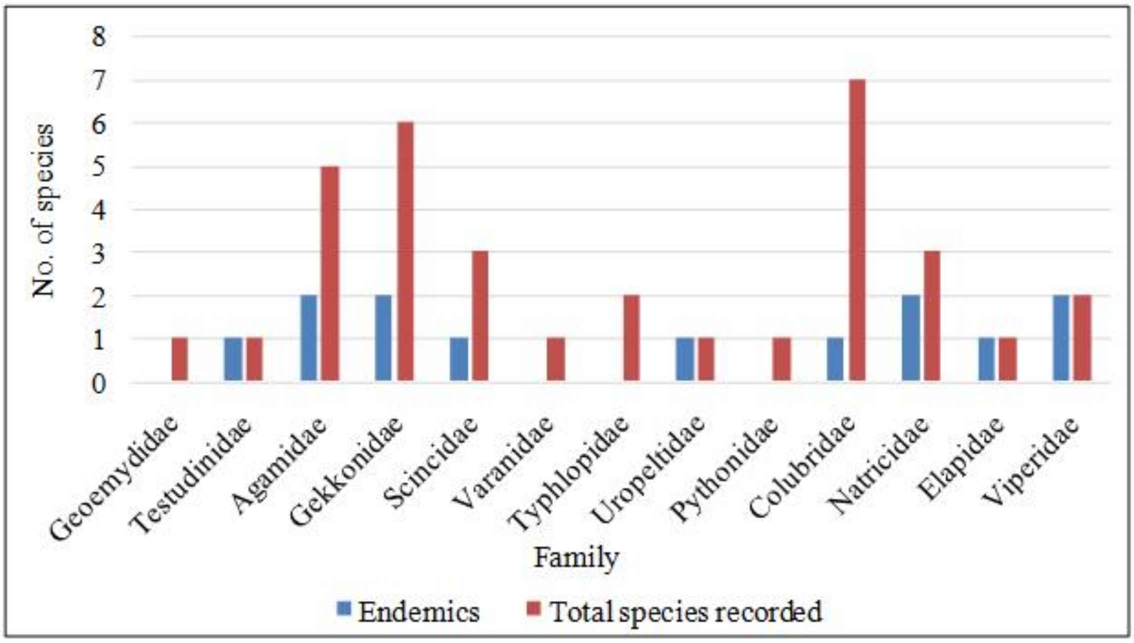

Fig. 5. 78 Western Ghats endemic reptiles recorded from different family

5.3.6 IUCN Status of Amphibians and Reptiles Recorded

Out of the 32 species of amphibians recorded 38% (12 species) fall under different threatened categories (Fig. 5.79). Four species of tree frogs, the *Raorchestes* *chlorosomma, R. griet, R. ponmudi*and *Rhacophorus pseudomalabaricus*are Critically Endangered and other four species of tree frogs like *Pseudophilautus wynaadensis, Raorchestes keirasabinae, R. travancoricus* and *Rhacophorus calcadensis* fall under the Endangered category. Other four species of frogs are Near Threatened and the species are *Duttaphrynus parietalis, Uperodon montanus, Clinotarsus curtipes* and *Raorchestes beddomii*. Out of the 34 species of reptiles recorded six species fall under different IUCN threatened categories (Fig. 5.79). Three of the threatened species are Near Threatened (*Dravidogecko* sp., *Ahaetulla dispar*, *Craspedocpehalus macrolepis*). The *Indotestudo travancorica* and *Kaestlea laterimaculata* are Vulnerable and the *Cnemaspis wynadensis* is Endangered.

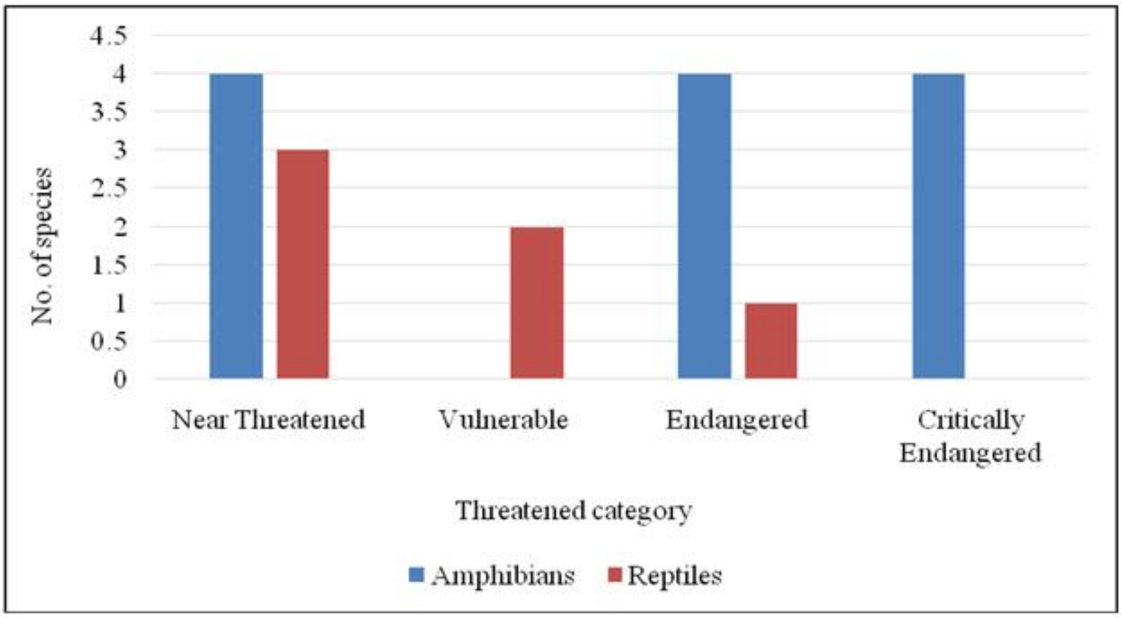

Fig. 5. 79 Amphibians and reptiles falling under different IUCN threatened categories

5.3.7 Monthly Herpetofaunal Richness in Relation to Surrounding Vegetation

The monthly amphibians and reptile richness from vayals in different habitats like evergreen, semi-evergreen, grassland, plantation and vayals bordered with both evergreen and plantation were plotted and the amphibian richness in all the habitats were found to show similar kind of monthly changes (Fig. 5.80). The species richness in all the habitats are less than four species from November to April. In May, the richness goes up to 11 to 13 species, in June it reaches to a maximum of 15 species and then gradually reduces and till October the richness is around 8 before it touches the lowest during November to April (Fig. 5.80). The reptile richness is different across habitats and not showing specific pattern with months (Fig. 5.81). The richness is lowest in the grassland ecosystems and the highest recorded richness was four during December - January followed by October (3). The highest recorded species richness was from semi-evergreen (10) in May followed by plantation and evergreen-plantation with eight species in September and October in plantation and March in evergreen-plantation (Fig. 5.81).

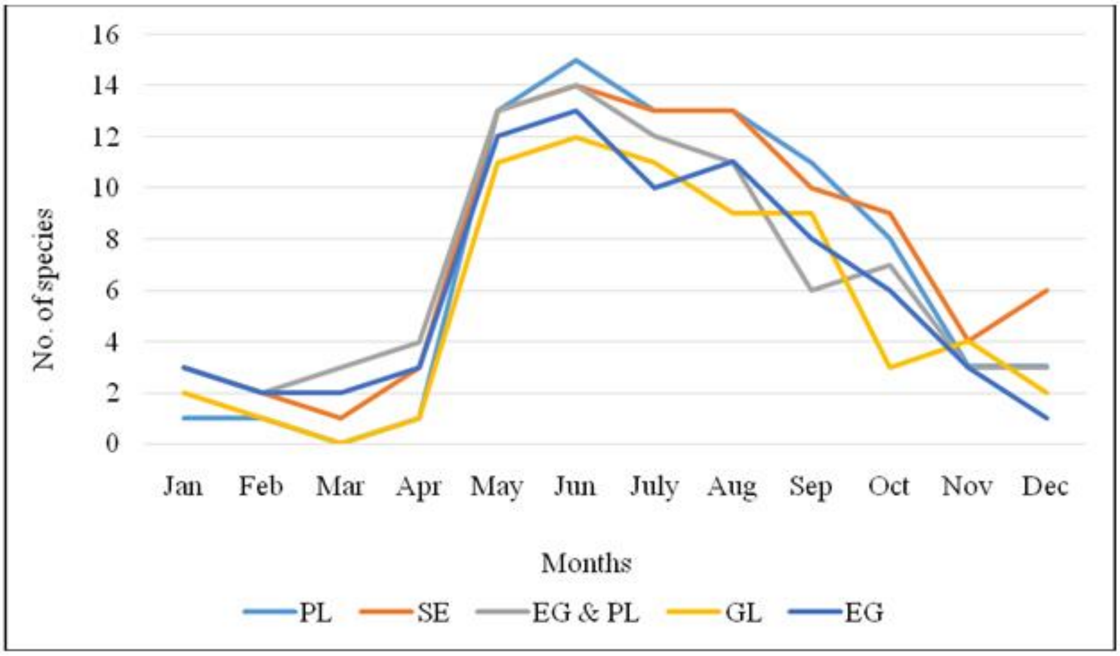

Fig. 5. 80 Monthly amphibian richness across different habitats

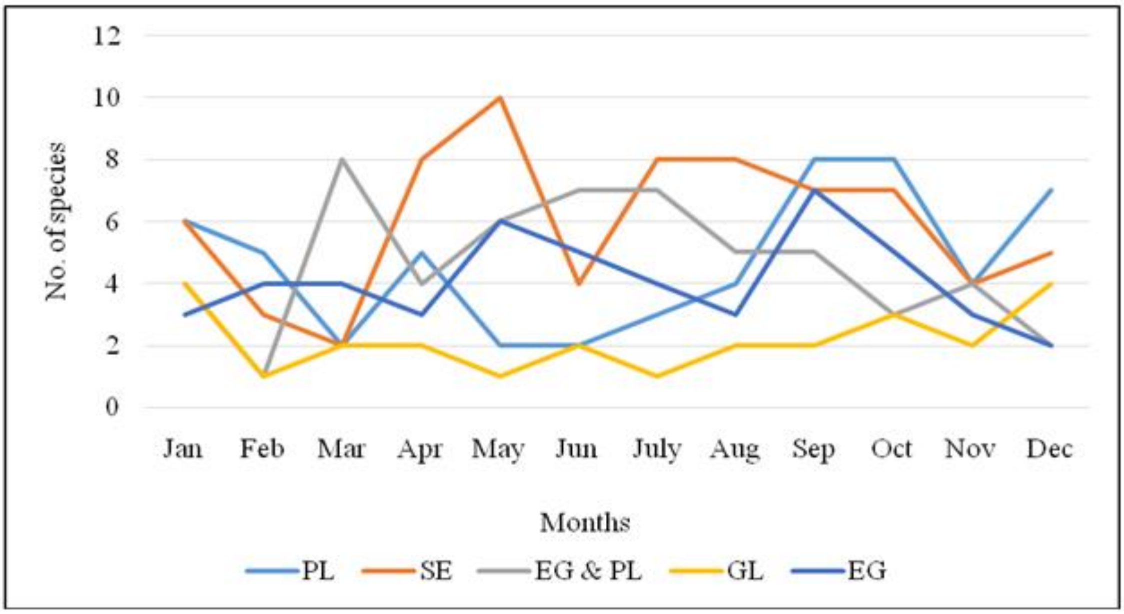

Fig. 5. 81 Monthly reptile richness across different habitats

5.3.8 Monthly Herpetofaunal Richness in Relation to Environmental Variables

The amphibian and reptile richness from all the five habitats around the vayals were combined and plotted against the monthly mean temperature, average humidity and rainfall (Fig. 5.82). The lowest amphibian richness was recorded during February - March with four species each and the highest species richness was recorded during June with 25 species. Reptile richness was high during January and August (14) and low in February and June (6 and 8). The mean temperature is high during March, April, May and November months when it goes above 24ºC. The amphibian richness is low during these periods. The lowest mean temperature was recorded during December and January.The average humidity ranges between 77% (April) to 89% (June). The average humidity is above 80% in almost all the months and it goes below 80% during the summer months in February, March and April. During the monsoon the average humidity reaches the maximum and from June to December the humidity goes above 84% and the highest amphibian richness was recorded during this period (Fig. 5.83).

July receives the highest amount of rainfall of more than 550mm. Periyar receives less rainfall during December to May when the average rainfall is 75mm (Fig. 5.84). During the south west and north east monsoon seasons, the average rainfall goes around 356mm.

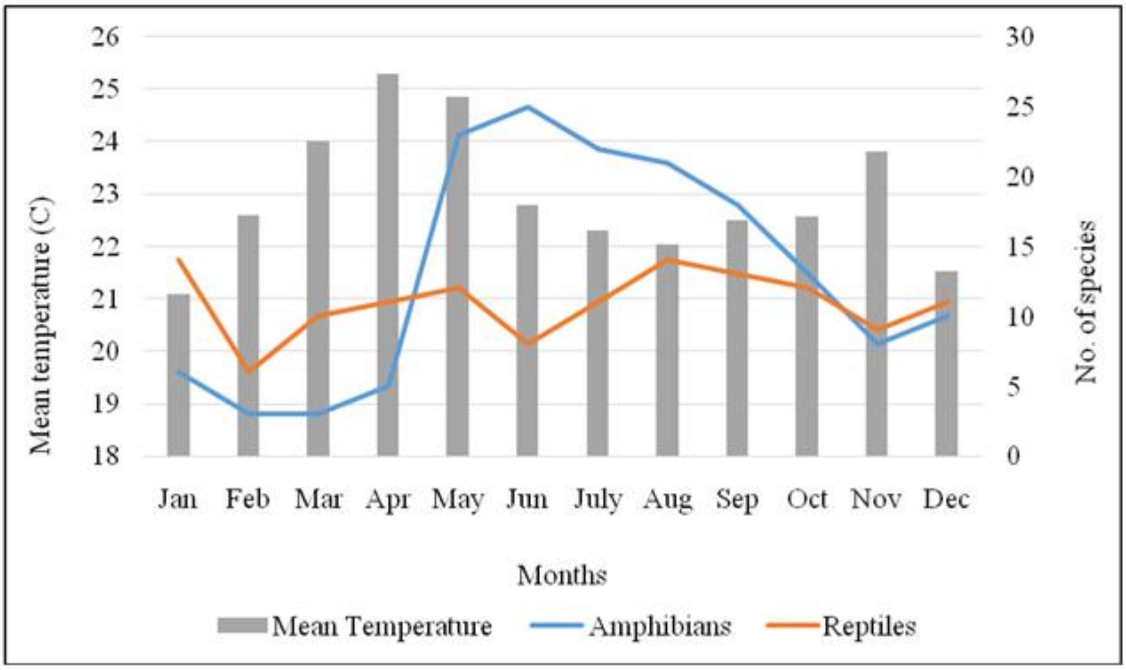

Fig. 5. 82 Monthly mean temperature and amphibian and reptile total richness

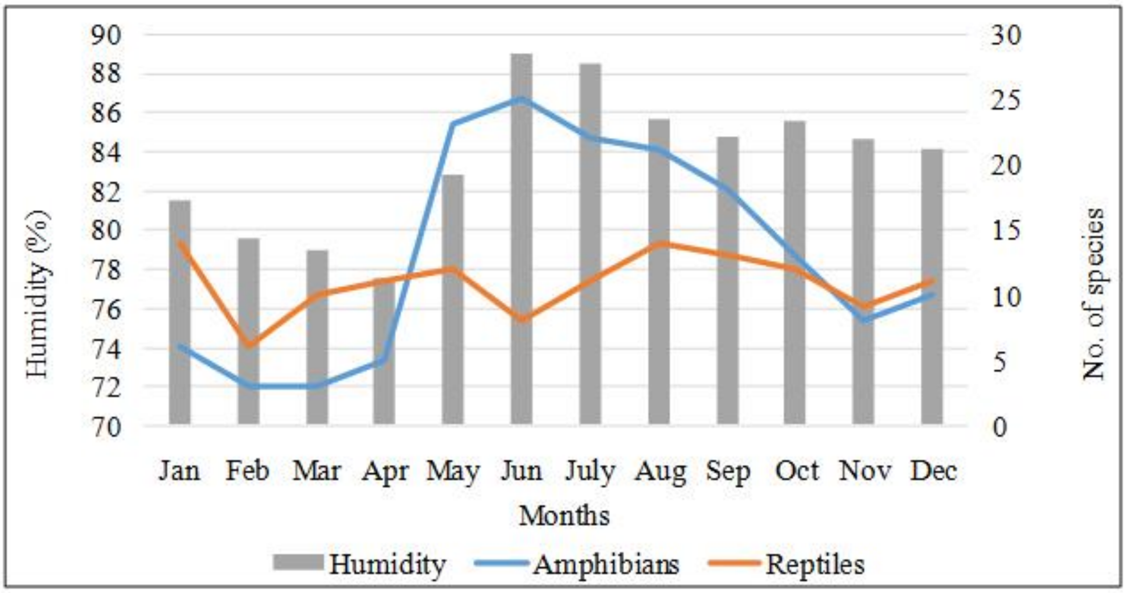

Fig. 5. 83 Monthly average humidity and amphibian and reptile total richness

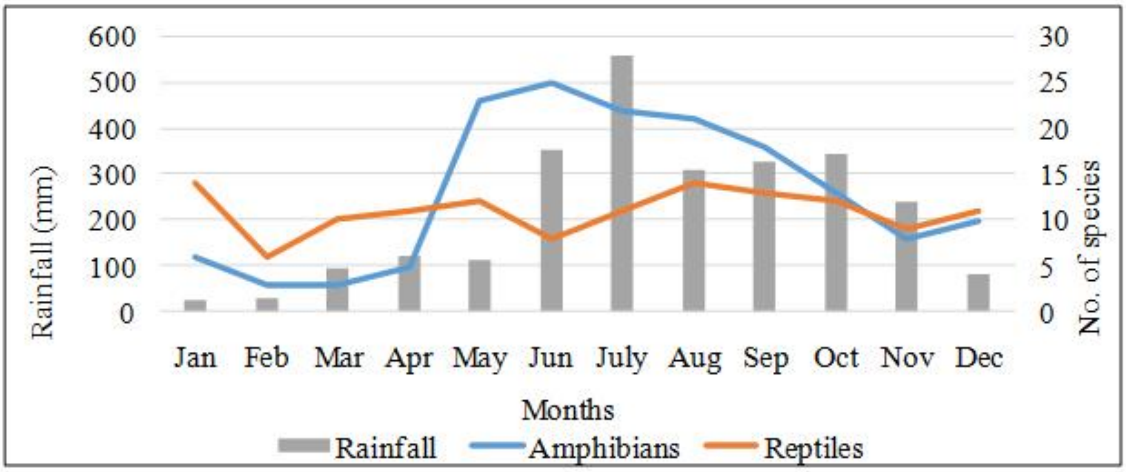

Fig. 5. 84 Monthly average rainfall and amphibian and reptile total richness

5.3.9 Monthly Herpetofaunal Abundance in Relation to Environmental Variables

Monthly mean temperature, humidity and rainfall were plotted against abundance of amphibians and reptiles recorded each month (Fig. 5.85 - 5.87). May, June and July were the amphibian abundant months. In May and July, around 350 individuals of amphibians were recorded and in June it went up to 450 individuals. The reptile abundance was not showing much difference and it ranged between 13 and 34. The lowest reptile abundant month was February (13) and the highest was May (34).

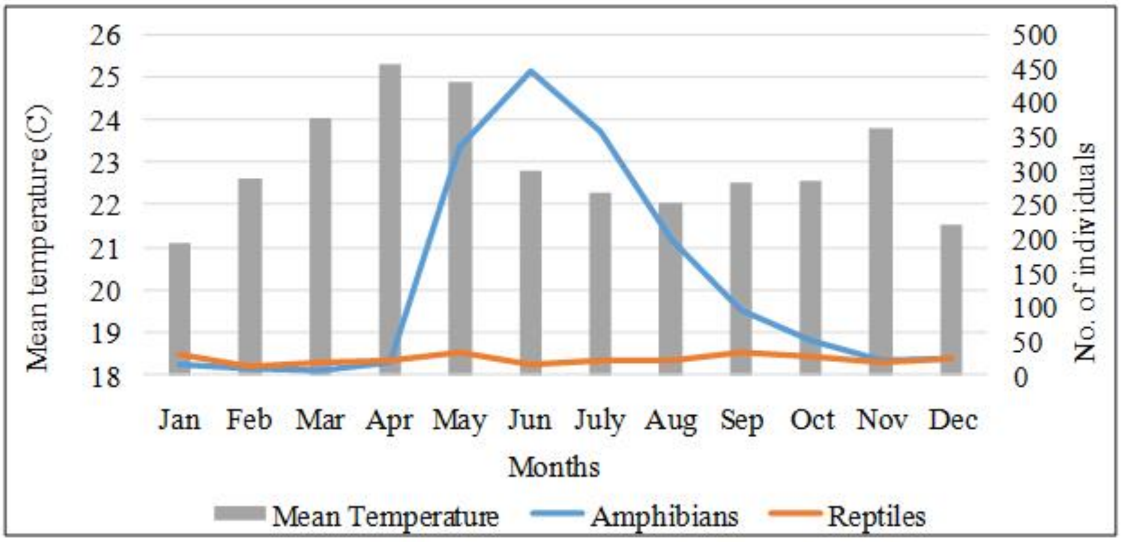

Fig. 5. 85 Monthly mean temperature and amphibian and reptile

abundance

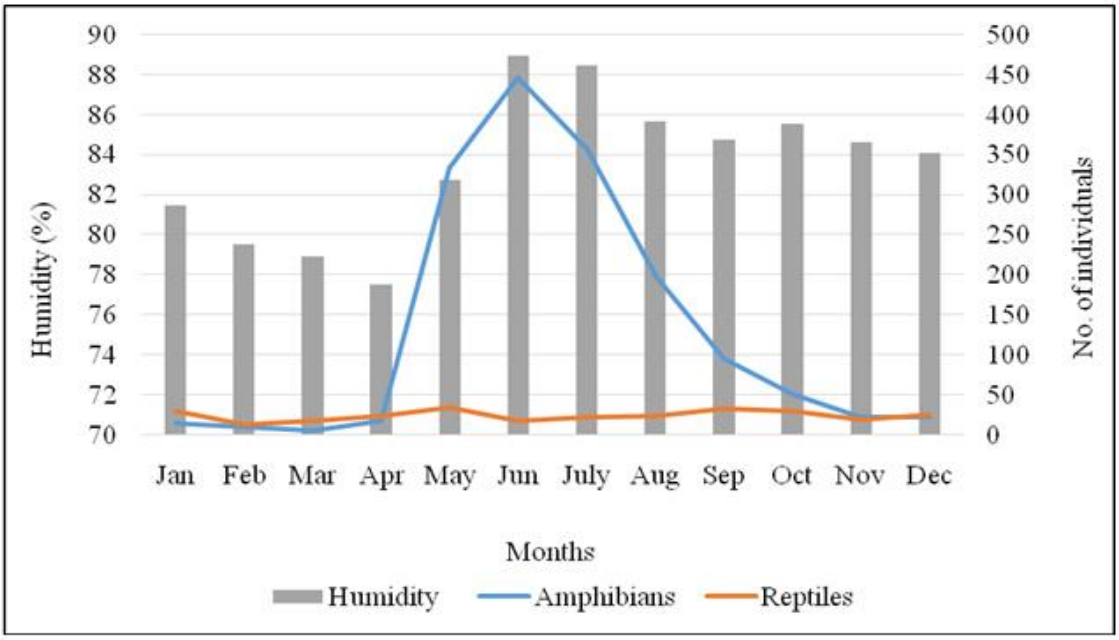

Fig. 5. 86 Monthly humidity and amphibian and reptile abundance

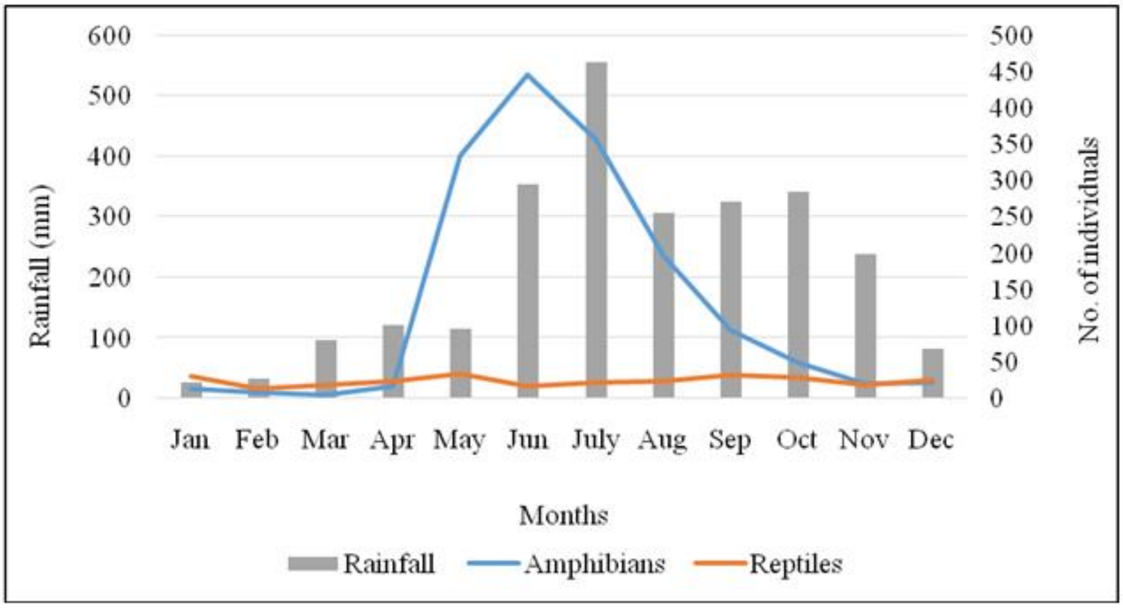

Fig. 5. 87 Monthly rainfall and amphibian and reptile abundance

5.3.10 Monthly Herpetofaunal Diversity in Relation to Environmental Variables

Monthly mean temperature, humidity and rainfall were plotted against the monthly diversity indices (H) of amphibians and reptiles (Figs. 5.88 – 5.90). The amphibian diversity was very high from May to December and the average diversity (H) is 2.487 with the highest in May (H=2.829). Amphibian diversity is lowest during January, February, March and April with an average diversity (H) of 1.250. The lowest recorded diversity was in March 0.950 (H).

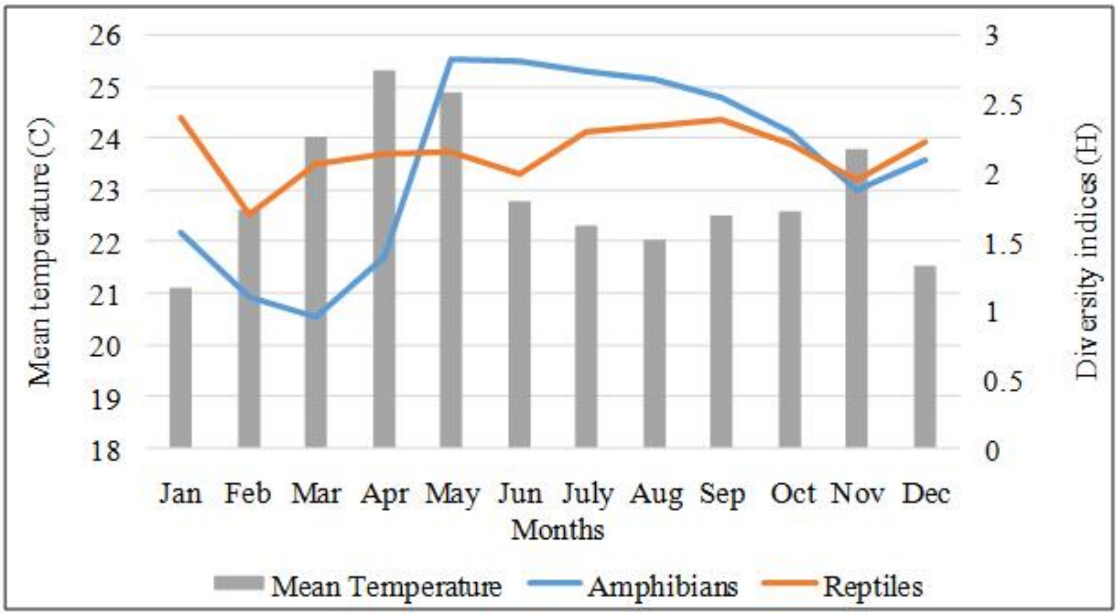

Fig. 5. 88 Monthly mean temperature and amphibian and reptile diversity (H)

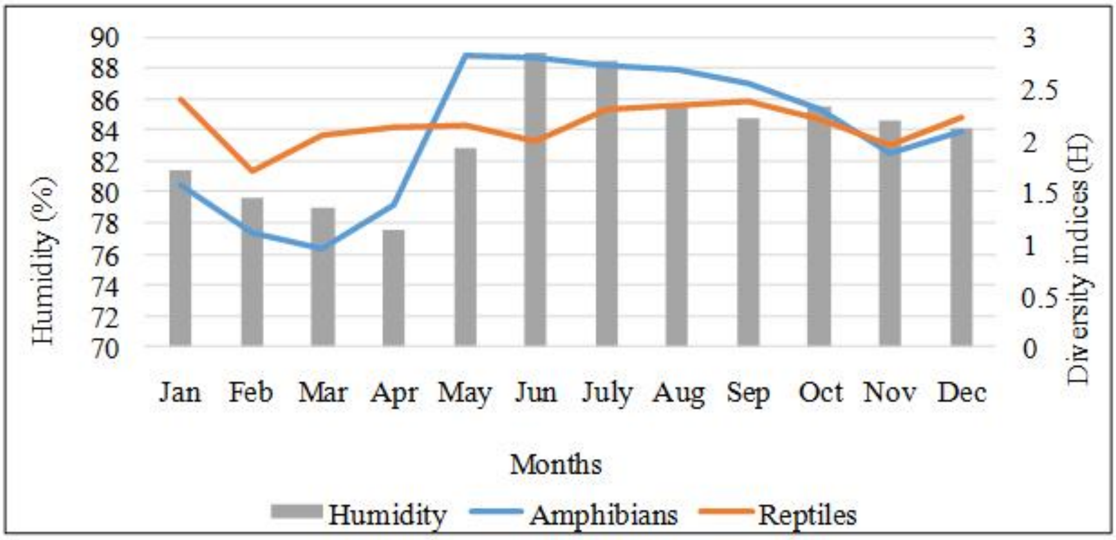

Fig. 5. 89 Monthly humidity and amphibian and reptile diversity (H)

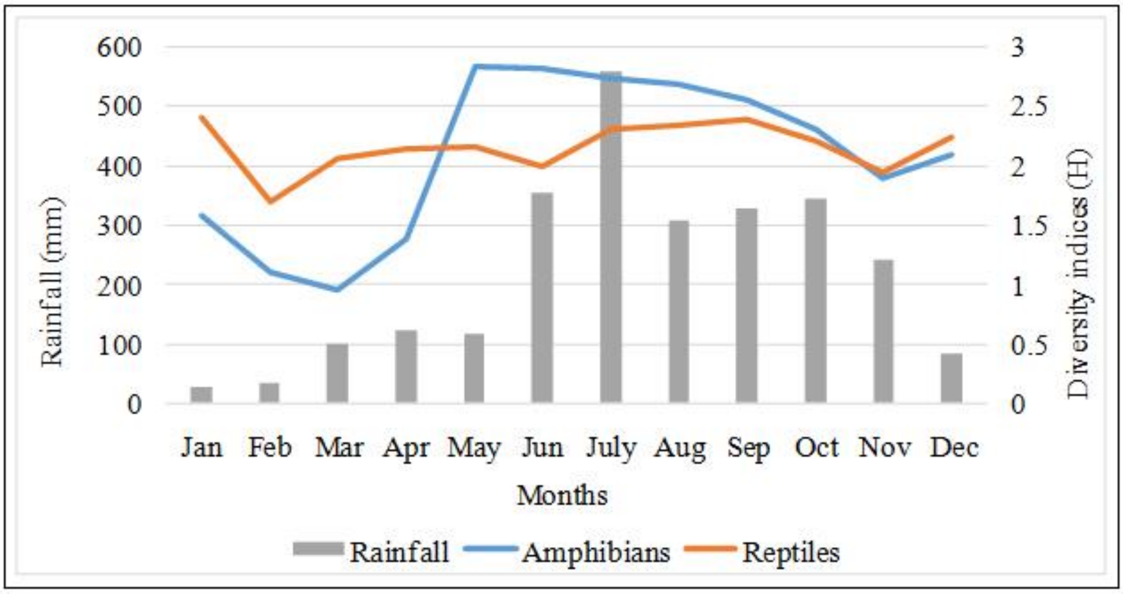

Fig. 5. 90 Monthly rainfall and amphibian and reptile diversity (H)

5.3.11 Herpetofaunal Diversity in Vayals and its Surroundings

Diversity indices for amphibians and reptiles in every sampling unit were derived and it was done for vayals and surrounding vegetation separately. The amphibian diversity was more or less similar in vayals and its surrounding vegetation in most of the sampling units (Table 5.3). The highest diversity inside vayals was recorded in Randanamukku I vayal (H=2.746) and the diversity (H) in its surrounding vegetation was 2.682. Second highest diversity was recorded in Randanamukku II vayal with 2.622 (H) followed by Randanamukku 5th Chappath vayal with 2.545 (H) and the diversity in the surrounding vegetation was 2.692 and 2.834 respectively. The Kumarikulam Trek Path vayal has lowest amphibian diversity inside the vayal (H=1.220) and the diversity in the surrounding vegetation of Kumarikulam Trek Path was 1.294 (H). The Randanamukku 5th Chappath vayal had the highest amphibian diversity in the surrounding vegetation (H=2.834) followed by Randanamukku II vayal and Randanamukku I vayal with diversity indices (H) 2.692 and 2.682 respectively.

Diversity inside these vayals were 2.545, 2.611 and 2.746 (H) respectively. The lowest amphibian diversity was recorded from the Kizhangupara II vayal and the diversity indices (H) was 0.868. The reptile diversity in vayal and the surrounding vegetation was considerably different in many of the sampling units (Table 5.4).The highest reptile diversity from vayals was recorded from Poomaram vayal (H=2.434) followed by Poovarashu vayal and Pothukandam vayal with 2.278 and 2.233 (H) respectively whereas the reptile diversity in the surrounding vegetation was 2.577, 2.377 and 2.679 (H) respectively. The lowest reptile diversity was recorded from the Seethakkulam Zero Point vayal (H=0.562) and diversity in the surrounding vegetation was 0.693 (H). The highest reptile diversity in the surrounding vegetation was recorded from Pothukandam vayal (H=2.679) followed by Mavadi and Poomaram vayal with 2.588 and 2.577 (H) respectively. The diversity inside the vayal was 2.233, 2.020 and 2.434 (H) respectively. The lowest reptile diversity was recorded from Uppupara Thavalam vayal (H=0.500).

A comparison of the amphibian diversity indices inside vayals and its surrounding vegetation indicate only minor difference in values in most of the sampling units. However, the values for reptiles changed considerably in many sampling units (Table 5.3 and Table 5.4). Therefore a diversity t-test was carried out to check whether changes are significant or not. The amphibian diversity inside vayal and its surrounding vegetation in Pachakkanam Bit I vayal (p=0.009) and Uppupara Thavalam vayal (p=0.017) showed a significant difference in diversity. In all other sampling units, the p value was more than 0.05. The diversity t-test in reptiles showed a significant difference in the diversity inside vayal and its surrounding vegetation in 10 sampling units. These vayals are Pothukandam (p=0.010), Kokkara II Gate II (p=0.018), Kokkara Watch Tower I (p=0.045), Kokkara Watch Tower II (p=0.027), Thondiyar Main (p=0.029), Uppupara Thavalam II (p=0.040), Kizhangupara II (p=0.017), Mavadi (p=0.038), Poosinikakuchi (p=0.046) and Karimala II vayal (p=0.017) (Table 5.4).

Table 5. 3 Shannon diversity indices (H) for amphibians recorded from vayal and its immediate surrounding vegetation and t-value and p-value for diversity t-test between diversity in and around vayal ecosystem

No	Vayal Name	H - Inside	H - Around	t – value	p - value
1	Pothukandam Vayal	2.403	2.290	1.240	0.217
2	Quarter Palam Vayal	2.270	2.364	-0.561	0.577
3	Circle Road Vayal	2.018	1.997	0.125	0.901
4	Pachakkanam Bit - II	2.451	2.337	1.049	0.298
5	Pachakkanam Bit - I	2.320	2.597	-2.636	0.009
6	85 Plantation Bit - I	1.679	1.295	1.242	0.231
7	85 Plantation Bit - II	1.817	1.642	0.687	0.501
8	Paravalavu Vayal	2.371	2.512	-0.732	0.468
9	Randanamukku Bit - I	2.746	2.682	0.387	0.701
10	Randanamukku Bit - II	2.611	2.692	-0.417	0.678
11	Randanamukku Vayal	2.245	2.568	-1.496	0.140
12	5th Chappath Vayal	2.545	2.834	-1.858	0.067
13	Kokkara II Gate Bit - I	2.324	2.269	0.488	0.627
14	Kokkara II Gate Bit - II	2.348	2.333	0.123	0.902
15	Kokkara Watch Tower Bit – I	2.489	2.383	0.863	0.390
16	Kokkara Watch Tower Bit – II	2.415	2.320	0.737	0.463
17	Poovarashu Vayal	2.378	2.369	0.090	0.928
18	Zero Point Vayal	2.175	2.217	-0.306	0.761
19	Thondiyar Main Vayal	2.323	2.087	0.985	0.330
20	Thondiyar Small Vayal	2.085	2.034	0.223	0.825
21	Uppupara Kalungu Bit - I	1.867	1.848	0.117	0.907

22	Uppupara Kalungu Bit – II	1.866	1.827	0.218	0.828
23	Uppupara Thavalam	2.074	1.794	2.413	0.017
24	Uppupara Tower Bit - I	2.050	1.836	1.559	0.122
25	Uppupara Tower Bit - II	2.061	1.757	1.944	0.055
26	Pachakkanam Vayal	2.397	2.407	-0.066	0.948
27	Campshed Vayal	2.304	2.267	0.239	0.812
28	Poomaram Vayal	2.501	2.596	-1.212	0.227
29	Kozhikkanam Checkdam	2.445	2.542	-0.893	0.373
30	Second Mile Vayal	1.818	1.679	0.567	0.576
31	Second Mile Top Vayal	1.946	1.654	1.275	0.209
32	Seethakkulam Bit - I	2.155	1.929	1.494	0.139
33	Seethakkulam Bit - II	2.008	1.928	0.426	0.672
34	Seethakkulam Zero Point	1.837	1.698	0.753	0.455
35	Uppupara Thavalam	1.968	1.831	0.977	0.331
36	65 Plantation Vayal	2.095	1.905	0.822	0.416
37	Kalvarithodu Vayal	2.014	1.836	0.808	0.424
38	Kizhangupara Bit - I	2.120	1.579	1.826	0.077
39	Kizhangupara Bit - II	1.673	0.868	2.155	0.054
40	Kumrikulam Trek Path	1.220	1.294	-0.332	0.742
41	Manikkamala Vayal	2.192	2.371	-0.945	0.350
42	Mavadi Vayal	2.078	1.992	0.706	0.482
43	Palod Vayal	1.494	1.477	0.054	0.957
44	Poosinikkakuchi Vayal	1.667	1.560	0.315	0.757
45	Thavalakkulam Vayal	1.851	2.165	-1.606	0.114
46	Karimala Bit - I	1.736	1.986	-1.149	0.259
47	Karimala Bit - II	1.824	1.810	0.062	0.951

Table 5. 4 Shannon diversity indices (H) for reptiles recorded from vayals and its immediate surrounding vegetations and t-value and p-value for diversity t-test between diversity in and around vayal ecosystem

No	Vayal Name	H - Inside	H - Around	t - value	p - value
1	Pothukandam Vayal	2.233	2.679	-2.645	0.010
2	Quarter Palam Vayal	1.386	1.748	-0.907	0.388
3	Circle Road Vayal	1.748	1.846	-0.299	0.769
4	Pachakkanam Bit - II	2.038	2.475	-1.958	0.058
5	Pachakkanam Bit - I	2.038	2.183	-0.502	0.619
6	85 Plantation Bit – I	0.693	1.099	-0.834	0.445
7	85 Plantation Bit - II	1.099	0.693	0.834	0.445
8	Paravalavu Vayal	1.609	1.386	0.535	0.606
9	Randanamukku Bit - I	1.609	2.303	-1.961	0.077
10	Randanamukku Bit - II	1.040	1.386	-0.803	0.445
11	Randanamukku Vayal	1.099	1.561	-1.076	0.319
12	5th Chappath Vayal	1.386	1.834	-1.166	0.274
13	Kokkara II Gate Bit - I	1.767	2.250	-1.920	0.064
14	Kokkara II Gate Bit - II	1.494	2.303	-2.613	0.018
15	Kokkara Watch Tower Bit - I	1.386	2.246	-2.473	0.045
16	Kokkara Watch Tower Bit – II	1.099	2.274	-3.064	0.027
17	Poovarashu Vayal	2.278	2.377	-0.440	0.662
18	Zero Point Vayal	1.040	1.609	-1.443	0.181
19	Thondiyar Main Vayal	0.693	2.146	-3.543	0.029
20	Thondiyar Small Vayal	1.099	1.792	-1.631	0.149
21	Uppupara Kalungu Bit – I	0.693	0.562	0.284	0.789
22	Uppupara Kalungu Bit – II	0.693	1.099	-0.834	0.445
23	Uppupara Thavalam	1.040	1.040	0.000	1.000
24	Uppupara Tower Bit - I	1.040	1.581	-1.290	0.224

25	Uppupara Tower Bit - II	0.637	0.562	0.175	0.866
26	Pachakkanam Vayal	1.494	1.677	-0.534	0.601
27	Campshed Vayal	1.386	1.677	-0.748	0.474
28	Poomaram Vayal	2.434	2.577	-0.723	0.473
29	Kozhikkanam Checkdam	1.475	1.941	-1.339	0.202
30	Second Mile Vayal	0.000	0.693	-1.961	0.189
31	Second Mile Top Vayal	0.693	0.693	0.000	1.000
32	Seethakkulam Bit - I	0.000	0.637	-2.108	0.126
33	Seethakkulam Bit - II	0.000	0.000	0.000	1.000
34	Seethakkulam Zero Point	0.562	0.693	-0.284	0.789
35	Uppupara Thavalam	1.311	0.500	2.400	0.040
36	65 Plantation Vayal	1.386	1.386	0.000	1.000
37	Kalvarithodu Vayal	0.000	0.693	0.000	0.000
38	Kizhangupara Bit - I	0.693	0.693	0.000	1.000
39	Kizhangupara Bit - II	0.000	0.693	-3.921	0.017
40	Kumrikulam Trek Path	0.000	1.906	-7.906	0.000
41	Manikkamala Vayal	0.693	1.792	-2.491	0.062
42	Mavadi Vayal	2.020	2.588	-2.183	0.038
43	Palod Vayal	0.000	0.000	0.000	0.000
44	Poosinikkakuchi Vayal	0.000	1.099	-3.296	0.046
45	Thavalakkulam Vayal	0.673	0.693	-0.099	0.924
46	Karimala Bit – I	0.693	0.693	0.000	1.000
47	Karimala Bit – II	0.000	0.693	-3.921	0.000

For confirming the diversity t-test results, a perMANOVA test was done using Bray-Curtis similarity index. The data was relativized by maximum before conducting the test. The results showed that the amphibian diversity inside vayals and in the surrounding vegetation are not significantly different (p=0.1145) but the reptile diversity is significantly different (p=0.0001).

5.4. Discussion

Standardized visual encounter surveys are recommended for diversity studies (Crump and Scott, 1994; Rodel and Ernst, 2004; Minh, 2007; Dodd, 2009; Murali and Raman, 2012; Rathod and Rathod, 2013; Dodd, 2016; Das *et al*., 2020). Estimated species richness obtained from our study also shows a higher precision of documenting the diversity using VES than other two methods.

The high-elevation hill ranges of the Western Ghats act as a core area for diversification of Rhacophorids (Vijayakumar *et al*., 2016) and it is the most diverse family of amphibians in the Western Ghats and also in India (Aravind and Gururaja, 2011). Studies on amphibian diversity from the Western Ghats shows that the family Rhacophoridae has more species contribution (Aravind and Gururaja, 2011; Dinesh *et al*., 2013; Rathod and Rathod, 2013; Easa and Sivaram, 2014; Das *et al*., 2015; Rajkumar *et al*., 2018; Das *et al*., 2019a; Das *et al*., 2019b; Das *et al*., 2020) and it is the most diverse family of amphibians in the Western Ghats and also in India (Aravind and Gururaja, 2011). The present study also recorded the highest number of species from the family Rhacophoridae both inside the vayals (13) and its surrounding vegetation (17). Western Ghats harbour highest endemism in amphibians and reptiles. More than 90% of the amphibians and 59% of reptiles known from Kerala are endemic to the Western Ghats (Nameer *et al*., 2015). About 86% of amphibians and 38% of reptiles recorded during the present study are endemic to the Western Ghats.

Species from the family Rhacophoridae are adapted to live in all the smaller possible microhabitats and microclimates (Vijayakumar *et al*., 2016). *Raorchestes griet* recorded from the vayals in the grasslands are mainly found on grasses just above the ground and the *R. keirasabinae* found on the tree canopy layer around 30m. About 58% of the reptiles recorded from Kerala were snakes (Palot, 2015). Considering Periyar as a cross section of the herpetofaunal habitat in Kerala, the current study also found more snakes (50%) than turtles and lizards.

Frogshave been always associated with water, rain, or aquatic habitats and are believed to be the animal that brings rain and announce the forthcoming rain in different cultures in almost all the continents (Wells, 2007). Influence of precipitation on the activity patterns and reproductive behavior of anurans have been stressed by several authors (Prado *et al*., 2005; Vasconcelos and Rossa-Feres 2005; Richter-Boix *et al*., 2007; Hirschfeld and Rodel, 2011). Further, the importance of water rich areas like wetlands in amphibian species richness and abundance have been reported in earlier studies in different areas (Easa, 1998; Pope *et al.,* 2000; Vasudevan *et al.,* 2001; Guerry and Hunter, 2002; Wells, 2007). The influence of forest patches around wet lands in determining species richness have been highlighted (Franzem *et al.* 2017; Land and Verboom, 1990; Guerry and Hunter, 2002). Similarly, humidity also plays an important role in defining their activity. Amphibians are reported to be highly associated with higher relative humidity (Wells, 2007). Temperature and light intensity are also two prime factors for amphibians that control their activities. When the temperature goes up, amphibians control their activity and stay mostly inactive. When the temperature increases the ambient humidity will decrease and this will lead to a higher degree of evaporative water loss and which will threaten their life to avoid this they partition their temporal activity daily and seasonally (Wells, 2007). Similarly, the animal exposed to direct sunlight will tend to lose more water content from their body through evaporation, and to prevent this mostly amphibians prefer humid nighttime.

The activity of amphibians recorded from the current study was also highly influenced by mean temperature, humidity, and rainfall. Their activity is regulated by temperature, humidity, and rainfall (Duellman, 1995; Bevier, 1997; Bertoluci and Rodrigues, 2002; Saenz *et al*., 2006; Wells, 2007; Vit and Caldwell, 2014; Heinermann *et al*., 2015; Schalk and Saenz, 2016). Thus most of the species breeds during the monsoon season (Aichinger, 1987; Arzabe, 1999; Rodrigues and Bertoluci, 2002). In the present study, the richness was observed to be very low during the winter and summer months (from December to April) whereas it was high during the rainy season (from May to November). The rainy season also recorded higher humidity. The highest activity of amphibians is observed when the rainfall goes above 300mm and the humidity is higher than 80%, from May to September. The results from the present study suggest that both factors together have more influence than one factor alone. May with low rainfall (close to 100 mm) but with humidity of 80% recorded higher richness. Similarly, the humidity recorded from September to December was higher than 80%, which generally supports amphibian activity but the amphibian activity goes low during these months because the rainfall was comparatively low after October. Both the factors together have more influence on amphibians activity than independently.

The four species of amphibians (*Raorchestes chlorosomma*, *R. ochlandrae*, *R. ponmudi*, and *R. uthamani*) not seen in the vayals are bush frogs. Of these, two are reported very specific to reed habitat (Gururaja *et al*., 2007; Zachariah *et al*., 2011; Seshadri *et al*., 2014). Reeds are only seen on in the surrounding vegetation of vayals and not seen inside. The absence of their preferred microhabitat inside the vayal is the reason why these two frogs were not recorded from vayals. The other two frogs are known to be using bushes like *Lantana camera* and *Chromolaena odorata* thickets (Biju and

Bossuyt, 2009). But the current observations were not from bushes and thickets but was from tree saplings. Frogs were sighted from an average height of 2-3 meters in the surrounding vegetation of these two vayals.

Out of the 10 species of reptiles that were not seen in vayals, the *Indotestudo travancorica* was known to be using vayals (Deepak*et al*., 2016) for feeding during the dry season and as a refuge during a forest fire. The current two sightings were not from the vayal habitat. Current sightings were from semi-evergreen forests and eucalypts plantations. Both the area are situated at almost the same elevation range, around 900msl. The forest floor and the vegetation in Periyar are not dry as in Parambikulam Tiger Reserve and Anamalai Tiger Reserve areas where Deepak and Vasudevan (2014) studied *I. travancorica*. Deepak and Vasudevan (2014) identified forest fire as a threat to the animal. Here in Periyar, the fire incidents were very low compared to the other drier parts of Kerala. Therefore lack of forest fire may be the reason for their absence during the study in vayals and there could be other factors that influence their distribution in Periyar. Long terms studies are required to find out the possible reason behind this.

Among the remaining nine species of reptiles not recorded from vayal, three species of agamids (*Calotes calotes*, *C. grandisquamis*, and *Monilesaurus rouxii*) are semi-arboreal to arboreal species and they prefer tree trunks to bushes or grasses as seen in the vayals (Pal *et al*., 2018). Lack of preferred microhabitat could have limited them to use microhabitats inside vayals. The other three lizards (*Hemidactylus frenatus* and *H.* cf. *parvimaculatus*. *H. frenatus*) that were not seen inside vayals are not a highly habitat-specific species and havewider distribution all over the world (Javed *et al*., 2010; Bansal and Karanth, 2010; Frenkel, 2006). These species are mostly seen near human settlements, using buildings and in forests prefering tree trunks (Javed *et al*., 2010; Heckard *et al*., 2013). The present observations from the surrounding vegetations of vayals were from tree trunks, under tree bark, and inside tree cavities around 1-4 m above ground. Lack of preferred microhabitats seem to be the reason for the absence of sightings of these species in vayals.

Python molurus was sighted from the forested areas around the vayals during surveys in the monsoon season. The individuals were young ones with an average length of 60-70 cm. Literature suggests that these young ones could be hatchlings from the same breeding season (Whitaker and Captain, 2004; Ramesh and Bhupathy, 2010). The species is known to be preferring marshes (Ramesh and Bhupathy, 2010) since only two observations were there during the present study, it is not possible to arrive at any conclusion regarding the preferred habitat. The other three species that were not recorded from vayals are snakes belonging to the family Colubridae. These snakes are known to be preferring forest floors, rotting logs and stones mainly, and are active among the leaf litter (Ganesh *et al*., 2020). The lack of these microhabitats could be the limitation for these species to use the vayal habitats.

The species that are restricted to certain habitats are highly prone to extinction. A better understanding of distribution and microhabitat requirements is essential for their conservation (Block and Morrison, 1998; Wyman, 1990). With the current global environmental changes and local habitat changes, diseases can very easily push the range-restricted species to extinction (Pineda and Halffter, 2004; Hoffmeister *et al*., 2005; Wake and Vredenburg, 2008). Smaller habitats can only support fewer species and the movement between such suitable habitats may be restricted due to distance, fragmentation, geographical barriers, etc. and this will act as a bottleneck (Wyman, 1990; Gibbs, 1993). Vayals are considered to be smaller ecosystem units without connectivity with similar vayal ecosystem, restricting species to choose only the available microhabitats inside vayals. There could be vayal associated microorganisms since vayal is unique from the surroundings and the area available is enough for the microorganisms to complete their life cycle. Results from the perMANOVA analysis show that there are not much differences in the amphibian diversity in the vayals and their surrounding vegetation ($p=0.1145$) indicating the absence of any vayal habitat-specific amphibians, which could increase the probability of survival chances in the long run. The surrounding vegetation of vayals has higher species richness than vayals with additionally four species of amphibians and 10 species of reptiles. When comparing the species richness obtained with the recent study on herpetofaunal assemblage in Periyar Tiger Reserve by Rajkumar *et al*. (2018) about 50% of the amphibians and reptiles present in Periyar are seen in vayals or its immediate surrounding vegetation.

In reptiles, the perMANOVA results show a significant difference in diversity inside vayals and their surroundings ($p=0.0001$). The surrounding vegetation was observed to have more reptile richness and diversity than in the vayals. The reptile fauna of the area also was seen dominated by snakes and the surrounding forested vegetation provides larger number of micro habitats. These factors along with presence of more number of snakes would have contributed to the reptile species richness in the surrounding vegetation. According to Abramsky *et al*. (2002) species prefer habitats that provide better shelter, more food, and protection from negative inter and intra-specific interactions. Lack of these services in vayals could have limited certain amphibians and reptiles in using these ecosystems.

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Chapter 6

Influence of Extent, Surrounding Vegetation, Plant Composition and Altitude of Vayals on Herpetofauna

Chapter 6. Influence of Extent, Surrounding Vegetation, Plant Composition and Altitude of Vayals on Herpetofauna

6.1 Introduction

Tropical regions are complex habitats, well known for their highest species richness and diversity across different taxa (Myers *et al*., 2000; Bohm *et al*., 2013; Upton, 2015). Documenting the species diversity of an area is an important aspect in the conservation of an ecosystem (Diaz *et al*., 2006; Worm *et al*., 2006; Chakraborty *et al*, 2015) and thereby the ecosystem services (Loreau *et al*., 2001; Diaz *et al*., 2006; Worm *et al*., 2006; Cardinale *et al*., 2012; Roth-Monzon *et al*., 2018). Recent studies from the tropics suggest that this region is a treasure of amphibians and reptiles that are new to science (Biju, 2003; Biju and Bossuyt, 2005a; Biju and Bossuyt, 2005b; Biju and Bossuyt, 2006; Tri and Bauer, 2008; Biju and Bossuyt, 2009; Biju *et al*., 2010; Biju *et al*., 2011; Malhotra *et al*., 2011; Catenazzi *et al*., 2013; Biju *et al*., 2014; Vijayakumar *et al*., 2014; Vassilieva *et al*., 2014; Rojas *et al*., 2015; Garg and Biju, 2016; Garg and Biju, 2017; Garg *et al*., 2017; Giri *et al*., 2017; Pal *et al*., 2018; Biju *et al*., 2019; Chaitanya *et al*., 2019; Garg *et al*., 2019; Al-Razi *et al*., 2020; Deepak *et al*., 2020; Mallik *et al*., 2020; Garg *et al*., 2021; Mallik *et al*., 2021). This region also has the highest number of threatened and data deficient amphibians and reptiles (Bohm *et al*., 2013). More than 50% of the amphibians known from the Western Ghats are described in the last 20 years (Harikrishnan *et al*., 2018). With the advancement of science, taxonomic tools and better survey efforts, many widespread amphibians and reptiles are now split into different species with narrow distribution range (Vijayakumar *et al*., 2014; Garg and Biju, 2017; Garg *et al*., 2017; Chaitanya *et al*., 2019; Mallik *et al*., 2020; Garg *et al*., 2021; Mallik *et al*., 2021). The species with restricted distribution range is highly vulnerable to threats (Wake and Vredenburg, 2008). Hundreds of species are going extinct every year (Ceballos *et al*., 2015) and the tropical regions are expected to witness the highest species loss (Ricketts *et al*., 2005).

The Western Ghats is a hotspot of species richness and diversity and may become a hotspot for species loss too. A better understanding of community ecology is essential for examining the threats and the resultant species loss (Upton, 2015). Stiling (2012) has opined that communities with high species richness are better in terms of functioning than communities with low species richness. Identifying and understanding such communities will help us channel our limited time and resources to the most appropriate targeted species (Upton, 2015). A study by Rickets *et al*. (2005) suggests that about 423 species of amphibians (408) and reptiles (15) may soon go extinct, if site specific actions are not taken on time. Therefore, detailed community ecology studies are essential for conservation.

Forming a single larger reserve or two or more smaller ones with an equal total area was a difficult question during the 1970s (Humphreys and Kitchener, 1982) and many researchers tried to address this (Humphreys and Kitchener, 1982; Blake and Karr, 1984). Humphreys and Kitchener (1982) studied lizards, passerine birds and mammals from 21 smaller and larger nature reserves in Western Australia to address this question. Their study recorded highest species richness in these three different taxa from two smaller nature reserves compared to a single larger nature reserve with the same extent. These species were also using the surrounding vegetation of the nature reserve. Blake (1983) studied breeding birds in forest areas in Illinois that differ in size and found that omnivorous birds were the dominant group in smaller forest areas and that they used the surrounding vegetation for foraging, whereas the abundance of ground, bark and foliage insectivores increased with the extent of forest area. This finding indicates the strong association of abundance with the guilds and the food resources vary with the size of the forest. Blake and Karr (1984) made a comparison of the bird species composition in small and larger forest patches in Illinois. The results showed that the resident birds and short-distance migrant birds favoured two or more smaller forest patches whereas the long-distance migrants and the species that depend on a wide range of microhabitats preferred a single larger forest patch. The study also found that many of the species that prefer smaller forest areas were using the surrounding vegetation of forest areas. Therefore the protection of smaller forest areas is suitable for resident birds and short-distance migrant birds.

The study of Franzem *et al*. (2017) on the amphibian abundance in the constructed vernal pools stress the importance of habitat quality in determining species abundance. They also found that the vernal pools in the forest patches hold more species than the vernal pools in the center of large meadows. The results of a study by Laan and Verboom (1990) showed that the distance from the woodland is an important factor for species richness. Importance of small wetlands for the protection of the local population of turtles, small birds and mammals has been revealed by Gibbs (1993). Gibbs' study also suggested that the animals with low densities and low population growth, like turtles and birds, are highly vulnerable to the disappearance of small wetlands and the species with high density and population growth, like amphibians, were least affected.

The study by Pope *et al*. (2000) suggested that the surrounding vegetation of ponds was highly associated with the Leopard Frog density. The distribution of amphibians in a mosaic of farmlands, forest areas and ponds was highly associated with the distance to the nearest forest area and few species were associated with the distance to the pond (Guerry and Hunter, 2002). Guerry and Hunter (2002) argue that both the forest and open areas are equally important for amphibians and the conservation strategies should be species-specific. Breeding success of amphibians in the vernal pools was highly associated with the surrounding vegetation, canopy cover, and other terrestrial characteristics and the surrounding vegetation also supported the water quality of pools (Calhoun *et al*., 2003). Similarly, Snyder (2020) also reported that the amphibian distribution and abundance had a significant association with distance from the surrounding vegetation to the vernal pool. Study by Vallan *et al*. (2004) in the rainforests in Madagascar could not establish any correlation between selective felling and amphibian diversity and found an increase in abundance of arboreal amphibians.

Although there are studies conducted on amphibians and reptiles across the Western Ghats, their association with habitat size, habitat type, and plant composition were not well investigated. Most of the studies were inventory studies with checklists (Zacharias and Bharadwaj 1996; Abraham *et al*., 1999; Thomas *et al*., 2012; Ganesh *et al*., 2013; Chaitanya *et al*., 2018) while some studies mentioned the habitat or microhabitat (Thomas and Easa 1997; Zacharias, 1997; Andrews *et al*., 2005; Chandramouli and Ganesh, 2010; Aravind and Gururaja, 2011). There are a few other studies which addressed the variation in species richness, diversity and abundance according to the different habitats (Guerry and Hunter, 2002; Krishnamurthy, 2003; Rathod and Rathod, 2013; Thompson *et al*., 2016; Leyte-Manrique *et al*., 2019; Sankararaman *et al*., 2021).
In 1998, Easa studied the amphibians and reptiles in the Nilgiri Biosphere Reserve and found that the forest floor dwelling amphibian species were abundant across different habitats and showed a strong association with water bodies. The turtles recorded were

also associated with the water bodies. The study also reported the microhabitat and habitat preferences of several amphibians and reptiles. Vasudevan *et al*. (2001) also reported association of forest floor amphibian abundance with water bodies in the Kalakad–Mundanthurai Tiger Reserve. Similarly, Srinivas and Bhupathy (2013) found strong association of the amphibian species richness with the habitat and water bodies in Meghamalai hills. Krishnamurthy (2003) studied amphibians in disturbed and undisturbed areas in the central Western Ghats and reported habitat as the key factor that influences the diversity and distribution of amphibians. Some of the species that use a wide range of habitats were found in both distributed and undisturbed habitats. About 50% of the amphibians recorded during the study of Krishnamurthy (2003) were habitat-specific and were recorded only from undisturbed areas indicating the high vulnerability of such species to habitat degradation. Krishna *et al*. (2005) compared the amphibian abundance in streams inside the forest and nearby coffee and cardamom plantations and found a significant difference in species abundance and composition between habitats. However, a few species did not show much difference between habitats whereas some other stream and forest floor dwelling species showed a significant difference. According to Vasudevan *et al*. (2006), the amphibian assemblage varies considerably between the hill ranges and the species turnover also varies within the streams in a hill range. The results of the study on amphibian and reptile assemblages in five different habitats in dry forest mosaic at Agasthyamalai hills showed the relation between amphibian richness and abundance and riparian vegetation (Vijayakumar *et al*., 2006) while reptile richness and abundance was related to dry deciduous forest . Naniwadekar and Vasudevan (2007) reported that the amphibian richness was high in the elevation gradient between 1200-1300m in Kalakkad, Agasthyamalai.

Bhupathy and Sathishkumar (2013) attributed the highest reptile species richness in Meghamalai hills to the availability of different climatic conditions, elevation range, and the presence of suitable microhabitats. They also mentioned that the reptiles in the Western Ghats were highly vulnerable to threats because more than 50% of the reptiles recorded from the Western Ghats were restricted to not more than two biogeographic zones in India. The canopy cover and leaf-litter volume played a crucial role in determining the species richness and abundance, according to the study on herpetofauna in the human modified landscape in Agumbe by Balaji *et al.* (2014). A study by Sankararaman *et al.* (2021) on the amphibian richness and abundance in arecanut, rubber and coffee plantations in the Western Ghats showed the highest amphibian richness and abundance in coffee plantations. The presence of water bodies like streams and ponds has a strong association with species richness and the other two habitats were more degraded than the coffee plantations. This study also highlight the importance of conservation of microhabitats even in human-modified landscapes. Easa and Sivaram (2014) found highest amphibian species richness in shola forests, the highest diversity from evergreen forests and the least species richness and diversity from the grassland habitat in Agasthyamala Biosphere Reserve areas. The study by Jins *et al*. (2020) on the influence of elevation and bioclimatic variables on reptile richness in the Agasthyamalai Biosphere Reserve reported a monotonic decline in the reptile species richness with the temperature. In the current world scenario with the pace of climate change, the range-restricted reptiles are highly vulnerable due to the temperature association.

The extent, surrounding vegetation, and the plant composition of vayals vary considerably but no studies have been conducted on the community ecology of vayals. In our study, we consider vayals as a separate habitat unit and investigate the influence of vayal extent, surrounding vegetation of vayals, and the plant composition inside the vayals on amphibians and reptiles richness, abundance and diversity. Since the altitude range of vayals varies considerably, we have also included the elevation of vayals for statistical analyses.

6.2 Methods

The data collection was started in January 2015 and continued till November 2017. Time-constrained Visual Encounter Survey (Chapter 4) was conducted in the selected 47 vayals spending 15 minutes for search each vayal. All the microhabitats like tree barks, shrubs, grass clumps, boulders, leaf litter, fallen logs and stones were searched to document amphibians and reptiles. Care was taken to follow the same pace. Night surveys and daytime surveys were conducted to locate diurnal and nocturnal species. The night surveys were done with the help of trained forest trackers using powerful torch lights. Daytime surveys were carried out between 08:00 and 18:00 hours and night surveys between 18:00 and 01:00 hours. More than one sampling was done in larger vayals. For that, a location away from the earlier one was chosen to avoid recounting of animals that might have moved out from the earlier sampled area. All the animals found during the survey were captured and put in separate polythene zip lock bags and the fast-moving animals were closely observed for its identification. The captured ones were identified and released back to the same location after confirming the identification.

6.2.1 Statistical analysis

The data collected following the visual encounter survey were used for analyzing the diversity. The diversity of amphibians and reptiles in all the vayals was estimated. Based on these two analyses, the dataset for further analysis were selected.

Venn diagrams were prepared using Microsoft Office PowerPoint and MS Excel to identify the species overlap. Common species found in all the habitats were also identified.

Rank abundance curve was prepared using PAST 4.03 to identify the abundant species in each habitat. Habitat-wise rank abundance curves were prepared using relative abundance to identify the most and the least abundant species.

Cluster analysis was performed using PAST 4.03 to identify vayals with similar plant composition rank and size class in terms of amphibian and reptile diversity. Plant composition rank 5 represents vayals with only vayal-specific plant species and rank 1 represents vayals that are highly degraded with less than 20% of vayal-specific species. Habitat similarity clusters were also prepared to identify the most similar habitats.

Non-Metric Multidimensional Scaling (NMDS) analysis was done using R to identify and test the factors that influence amphibians and reptiles in the vayals in different habitat surroundings, extent of vayal, elevation and plant composition rank.

6.3 Results

A total of 47 vayals were selected, mapped and its extent calculated. The smallest vayal recorded was the Seethakkulam Zero Point Vayal (0.15 ha) in Azhutha Forest Range and the largest was the Poovarashu Vayal (30.08 ha) in Thekkady Forest Range (Table 6.1). The vayal situated at the lowest altitude was the 65 Plantation vayal in Vallakadavu Forest Range and the vayal at the highest altitude is the Karimala I vayal in Periyar Forest Range (Table 6.1).

6.3.1 Amphibian and reptile diversity in different vayals

The highest amphibian diversity was recorded from the Randanamukku Bit – I vayal (2.746) and the highest reptile diversity from Poomaram vayal (2.434) (Table 6.1). The lowest amphibian diversity was recorded from Kumrikulam Trek Path Vayal and no reptiles were recorded from the Kumrikulam Trek Path Vayal, Palod Vayal, Poosinikkakuchi Vayal, Kizhangupara Bit – II Vayal, Second Mile Vayal, Karimala Bit – II Vayal, Seethakkulam Bit – II Vayal, Kalvarithodu Vayal, and Seethakkulam Bit – I Vayal (Table 6.1). The lowest reptile diversity was recorded from Seethakkulam Zero Point vayal (0.562) (Table 6.1).

Table 6. 1 Shannon diversity indices (H') for amphibians and reptiles recorded from vayals with altitude and extent of each vayal

No.	Vayal Name	Amphibian (H')	Reptile (H')	Extent (Hectare)	Altitude (msl)
1	Pothukandam Vayal	2.403	2.233	16.39	920
2	Quarter Palam Vayal	2.27	1.386	1.06	870
3	Circle Road Vayal	2.018	1.748	2.24	981
4	Pachakkanam Bit – II	2.451	2.038	0.33	916
5	Pachakkanam Bit – I	2.32	2.038	4.93	926
6	85 Plantation Bit – I	1.679	0.693	0.16	1069
7	85 Plantation Bit – II	1.817	1.099	0.48	1076
8	Paravalavu Vayal	2.371	1.609	0.19	928
9	Randanamukku Bit – I	2.746	1.609	0.2	1041
10	Randanamukku Bit – II	2.611	1.04	0.61	1044
11	Randanamukku Vayal	2.245	1.099	6.51	1042
12	5th Chappath Vayal	2.545	1.386	1.15	1043
13	Kokkara II Gate Bit – I	2.324	1.767	6.46	893
14	Kokkara II Gate Bit – II	2.348	1.494	5.83	894
15	Kokkara Watch Tower Bit - I	2.489	1.386	6.17	884

16	Kokkara Watch Tower Bit - II	2.415	1.099	4.8	889
17	Poovarashu Vayal	2.378	2.278	30.8	889
18	Zero Point Vayal	2.175	1.04	2.98	891
19	Thondiyar Main Vayal	2.323	0.693	9.68	885
20	Thondiyar Small Vayal	2.085	1.099	1.97	880
21	Uppupara Kalungu Bit - I	1.867	0.693	0.76	1201
22	Uppupara Kalungu Bit - II	1.866	0.693	0.34	1198
23	Uppupara Thavalam	2.074	1.04	1.36	1195
24	Uppupara Tower Bit – I	2.05	1.04	0.52	1193
25	Uppupara Tower Bit – II	2.061	0.637	1.03	1201
26	Pachakkanam Vayal	2.397	1.494	0.96	923
27	Campshed Vayal	2.304	1.386	1.44	1188
28	Poomaram Vayal	2.501	2.434	1.8	918
29	Kozhikkanam Checkdam	2.445	1.475	1.7	905
30	Second Mile Vayal	1.818	0	3.31	1125
31	Second Mile Top Vayal	1.946	0.693	2.09	1118
32	Seethakkulam Bit – I	2.155	0	1.11	1110
33	Seethakkulam Bit – II	2.008	0	1.86	1111
34	Seethakkulam Zero Point	1.837	0.562	0.15	1196
35	Uppupara Thavalam	1.968	1.311	1.95	1192
36	65 Plantation Vayal	2.095	1.386	0.28	861
37	Kalvarithodu Vayal	2.014	0	1.96	929
38	Kizhangupara Bit – I	2.12	0.693	0.37	1632
39	Kizhangupara Bit – II	1.673	0	0.86	1636
40	Kumrikulam Trek Path	1.22	0	0.76	1139
41	Manikkamala Vayal	2.192	0.693	0.29	1583
42	Mavadi Vayal	2.078	2.02	2.5	911
43	Palod Vayal	1.494	0	5.62	960
44	Poosinikkakuchi Vayal	1.667	0	0.17	1494
45	Thavalakkulam Vayal	1.851	0.673	0.52	1629
46	Karimala Bit – I	1.736	0.693	0.79	1647
47	Karimala Bit – II	1.824	0	0.18	1635

6.3.2 Diversity in vayals with different surrounding vegetation

Twenty eight species of amphibians and 24 species of reptiles were recorded from the surveys conducted inside the vayal habitats surrounded by the five different vegetation categories *viz*., evergreen, semi-evergreen, grasslands, eucalypts plantations, and vayals surrounded by both evergreen and eucalypts plantations.

6.3.2.1 Diversity of amphibians in vayals with different surrounding vegetation

Among all the habitats, vayals in the evergreen habitats was found to hold more amphibian with 25 species followed by vayals in eucalypts plantation with 16 species and the lowest species richness was recorded in the vayals in grasslands with 14 species (Fig. 6.1). The vayals surrounded by evergreen forest, by both evergreen and eucalypts plantations, semi-evergreen forest, and eucalypts plantation were sharing 15 species of amphibian in common followed by the vayals in evergreen forest and semi-evergreen forest with 13 species in common (Fig. 6.1). Vayals in eucalypts plantation and grassland shared eight species of amphibians in common and vayals surrounded by grassland and by both evergreen forest and eucalypts plantation recorded only six species in common (Fig. 6.1). The vayals surrounded by evergreen forest, semi-evergreen forest, and both evergreen forest and eucalypts plantation shared 14 species of amphibians in common and the same number of species was shared in common by the vayals in evergreen forest, semi-evergreen forest, and eucalypts plantations. Vayals surrounded by evergreen forest, semi-evergreen forest, plantation, and both evergreen forest and plantation shared 14 species in common. Seven species are common in all other combinations of habitats (Fig. 6.1).

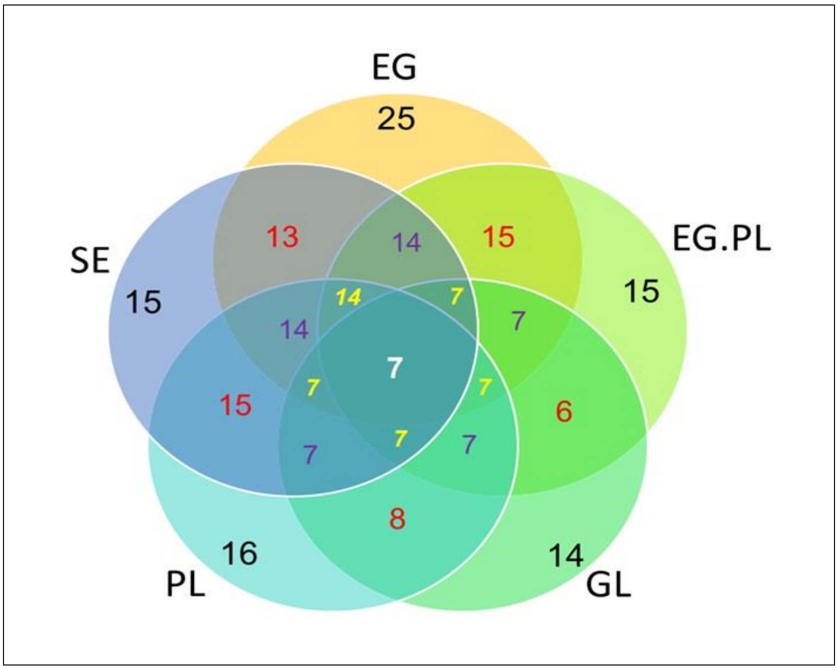

Fig. 6. 1 Venn-Diagram showing the amphibian species overlap between habitats

6.3.2.2 Diversity of reptiles in vayals with different surrounding vegetation

Among the vayals in all five different vegetation types, vayals surrounded by semi-evergreen forests was found to hold more reptile species (18), followed by the vayals surrounded by both evergreen forest and eucalypts plantation (17), and followed by evergreen forest with 16 species. The vayals in eucalypts plantations and grasslands had 14 and 10 species of reptiles (Fig. 6.2). Vayals in evergreen forest and semi-evergreen forest share 14 species followed by the vayals in eucalypts plantation and semi-evergreen forest with 12 species and vayals in evergreen forest and vayals surrounded by both evergreen forest and eucalypts plantation with 12 species (Fig. 6.2). Vayals surrounded by both evergreen forest and eucalypts plantation and grasslands were holding only seven species in common and the vayals in grassland and eucalypts plantations also had seven species in common (Fig. 6.2). A total of 11 species of reptiles were common in vayals in semi-evergreen forests, evergreen forests, and vayals surrounded by both evergreen forests and eucalypts plantations (Fig. 6.2). The vayals in eucalypts plantations, semi-evergreen forests and evergreen had 10 species of reptiles in common. Vayals in the semi-evergreen forest, eucalypts plantations and grasslands had six species in common, and the vayals in eucalypts plantations, grasslands, and vayals in both evergreen forests and eucalypts plantations shared six species. The vayals in grasslands, evergreen forest and by both evergreen forest and eucalypts plantations shared six common species. Five species of reptiles were common in all the habitats (Fig. 6.2).

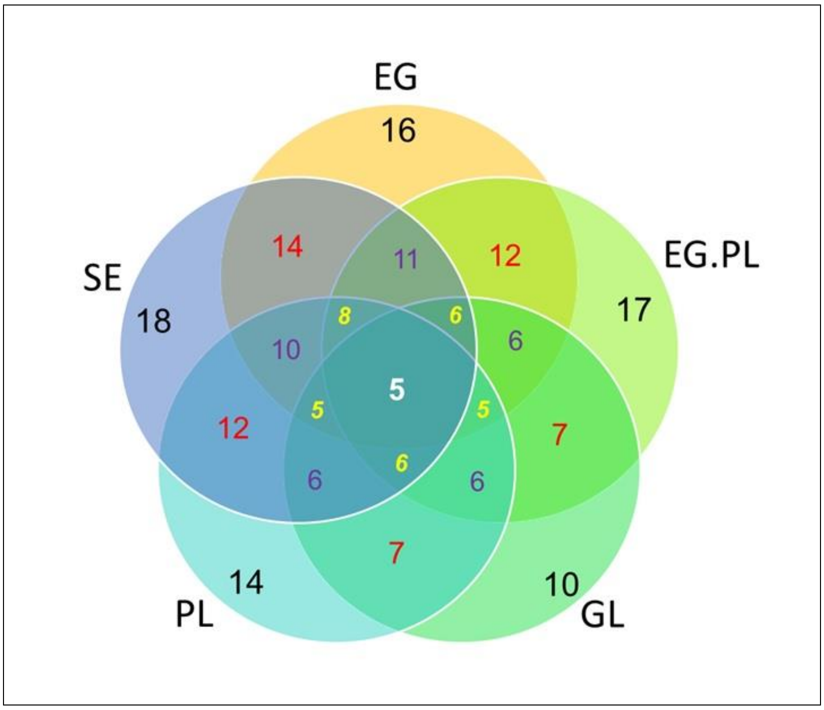

Fig. 6. 2 Venn-Diagram showing reptile species overlap between habitats

6.3.3 Rank Abundance Estimation

The Species recorded from the vayals are given species codes for analysis for rank abundance (Tables 6.2 and 6.3).

Table 6. 2 List of amphibians with species code used for Rank Abundance Curve and Non-metric Multidimensional Scaling ordination analyses

Species Code	Scientific name
Sp1	*Duttaphrynus melanostictus*
Sp2	*Duttaphrynus parietalis*
Sp3	*Euphlyctis cyanophlyctis*
Sp4	*Hoplobatrachus tigerinus*
Sp5	*Zakerana keralensis*
Sp6	*Micrixalus adonis*
Sp7	*Uperodon montanus*
Sp8	*Nyctibatrachus* sp.
Sp9	*Nyctibatrachus manalari*
Sp10	*Nyctibatrachus gavi*
Sp11	*Nyctibatrachus periyar*
Sp12	*Indirana semipalmata*
Sp13	*Clinotarsus curtipes*
Sp14	*Indosylvirana sreeni*
Sp15	*Polypedates maculatus*
Sp16	*Polypedates occidentalis*
Sp17	*Pseudophilautus wynaadensis*
Sp18	*Raorchestes akroparallagi*
Sp19	*Raorchestes anili*
Sp20	*Raorchestes beddomii*
Sp21	*Raorchestes keirasabinae*
Sp22	*Raorchestes travancoricus*
Sp23	*Raorchestes jayarami*
Sp24	*Raorchestes griet*
Sp25	*Rhacophorus malabaricus*
Sp26	*Rhacophorus pseudomalabaricus*
Sp27	*Rhacophorus calcadensis*
Sp28	*Ichthyophis beddomei*

Table 6. 3 List of reptiles with species code used for Rank Abundance Curve and Non-metric Multidimensional Scaling ordination

Species Code	Scientific Name
Sp1	*Melanochelys trijuga*
Sp2	*Monilesaurus ellioti*
Sp3	*Calotes versicolor*
Sp4	*Cnemaspis wynadensis*
Sp5	*Dravidogecko sp.*
Sp6	*Hemidactylus cf. parvimaculatus*
Sp7	*Hemidactylus leschenaultii*
Sp8	*Eutropis carinata*
Sp9	*Eutropis macularia*
Sp10	*Kaestlea laterimaculata*
Sp11	*Varanus bengalensis*
Sp12	*Indotyphlops braminus*
Sp13	*Grypotyphlops acutus*
Sp14	*Melanophidium punctatum*
Sp15	*Ptyas mucosa*
Sp16	*Hebius beddomei*
Sp17	*Hebius monticola*
Sp18	*Fowlea piscator*
Sp19	*Ahaetulla isabellina*
Sp20	*Aheatulla dispar*
Sp21	*Boiga thackerayi*
Sp22	*Calliophis nigrescens*
Sp23	*Craspedocephalus anamallensis*
Sp24	*Craspedocpehalus macrolepis*

6.3.3.1 Rank Abundance Estimation in vayals with Evergreen surrounding

6.3.3.1.1 Amphibians

The vayals in evergreen forests were the most amphibian species-rich among all the different habitats. A total of 25 species were recorded with a total of 378 individual sightings. *Pseudophilautus wynaadensis* (Sp17) was the most abundant species (Relative Abundance – RA 10.84%) followed by *Raorchestes akroparallagi* (Sp18) and *Duttaphrynus parietalis* (Sp2) with 8.99% and 8.73% relative abundance respectively. Dominance of these three species are evident from the rank abundance curve with a steep curve and rest of the species recorded showed a relatively even distribution with a shallow curve (Fig. 6.3). *Nyctibatrachus manalari* (Sp9) and *Nyctibatrachus periyar* (Sp11) were recorded only on four occasions during the study with RA 1.05% (Fig. 6.3).

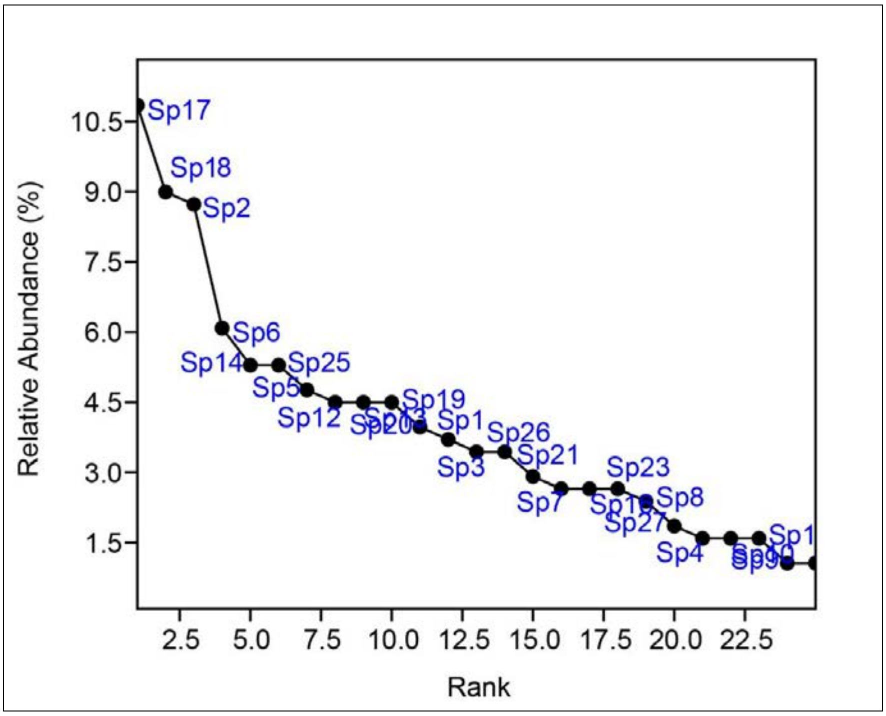

Fig. 6. 3 Amphibian species rank abundance curve in vayals in evergreen habitat

6.3.3.1.2 Reptiles

Sixteen species of reptiles were recorded from the vayals in evergreen forests with a total of 43 individual sightings. Among the 43 sightings, *Calotes versicolor* (Sp3) was the most abundant species with RA 20.93%, followed by *Eutropis macularia* (Sp9) and *Monilesaurus ellioti* (Sp2) (Fig. 6.4) with RA 18.60% and 11.63% respectively (Fig. 6.4). Dominance of these two species are evident from the steep curve of the rank abundance curve. *Hemidactylus* cf. *parvimaculatus* (Sp6), *Hemidactylus leschenaultii* (Sp7), *Kaestlea laterimaculata* (Sp10), *Indotyphlops braminus* (Sp12), *Hebius monticola* (Sp17), *Fowlea piscator* (Sp18), *Ahaetulla isabellina* (Sp19) and *Boiga thackerayi* (Sp21) were recorded only once during the surveys in evergreen habitat with RA 2.33%.

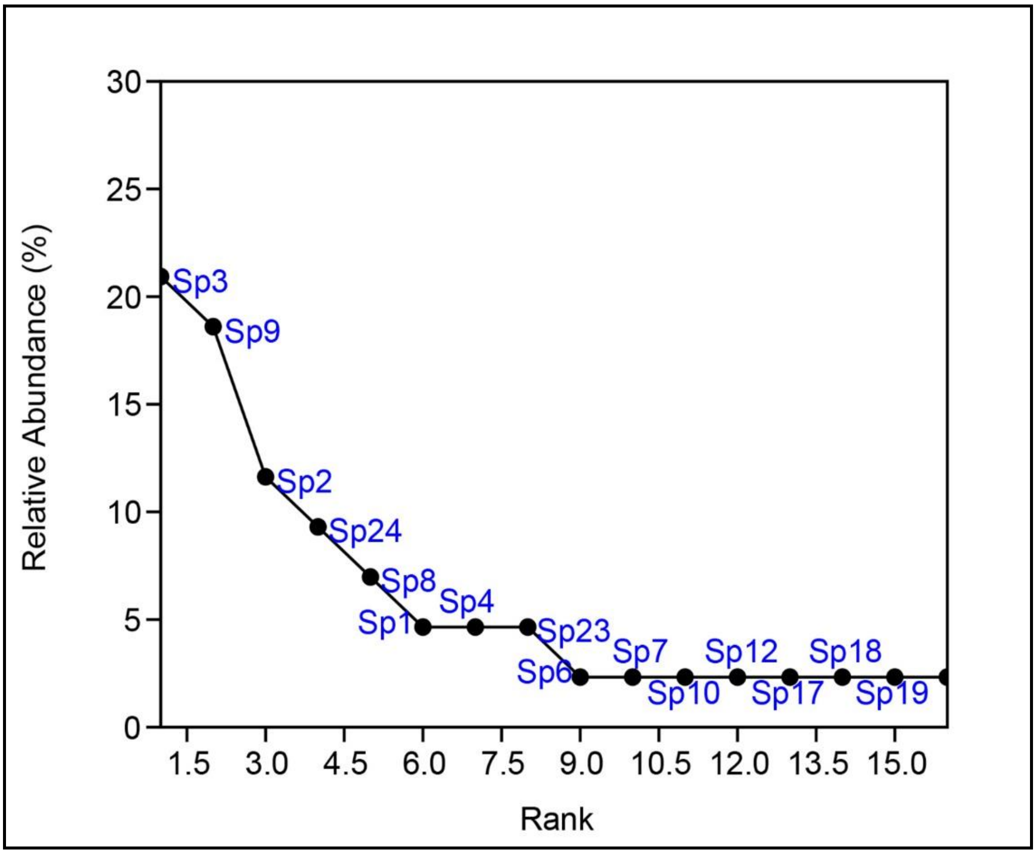

Fig. 6. 4 Reptile species rank abundance curve in vayals in evergreen habitat

6.3.3.2 Rank Abundance Estimation in vayals with Semi-evergreen surrounding

6.3.3.2.1 Amphibians

Out of the 28 species of amphibians recorded from vayals, 15 species of amphibians with 454 individual sightings were recorded from vayals in the semi-evergreen forest. *Pseudophilautus wynaadensis* (Sp17) was the most abundant species with RA 16.08%, followed by *Hoplobatrachus tigerinus* (Sp4) and *Indosylvirana sreeni* (Sp14) (Fig. 6.5) with 12.78% RA each. The rank abundance curve shows a relatively shallow curve. *Uperodon montanus* (Sp7) was recorded twice and *Ichthyophis beddomei* (Sp32) only once during the surveys in vayals with RA 0.44% and 0.22% respectively.

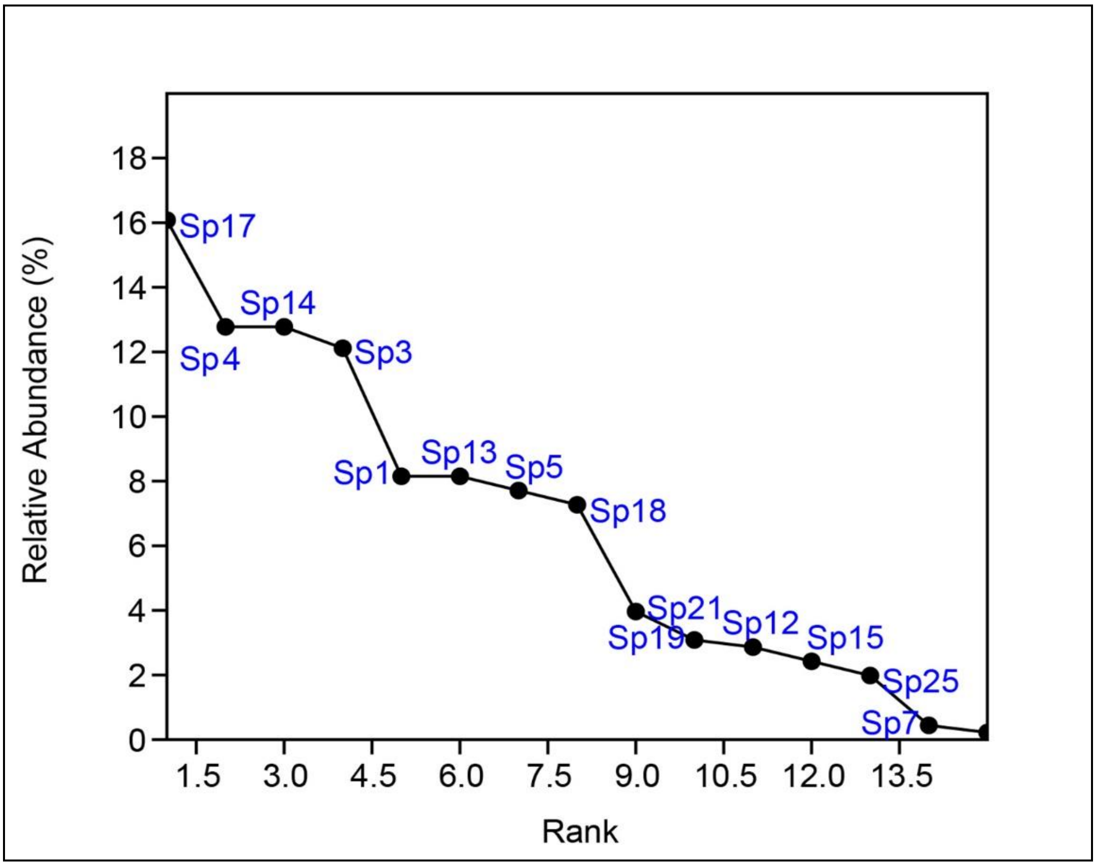

Fig. 6. 5 Amphibian species rank abundance curve in vayals in semi-evergreen habitats

6.3.3.2.2 Reptiles

Out of the 24 species of reptiles recorded from all the vayals, the ones in semi-evergreen forests had the highest numsber with 69 sightings of 18 species. Among these, *Eutropis macularia* (Sp9) was the most abundant species with RA 21.74% followed by *Eutropis carinata* (Sp8) and *Calotes versicolor* (Sp3) (Fig. 6.6) with 17.39% and 13.04% RA respectively. The rank abundance curve shows a steep curve with high dominance.

Cnemaspiswynadensis (Sp4), *Hemidactylus* cf. *parvimaculatus* (Sp6), *Hemidactylus leschenaultii* (Sp7), *Indotyphlops braminus* (Sp12), *Grypotyphlops acutus* (Sp13), *Hebius beddomei* (Sp16), *Hebius monticola* (Sp17) and *Craspedocephalus anamallensis* (Sp23) were recorded only once during the surveys in semi-evergreen habitat with RA 1.45%.

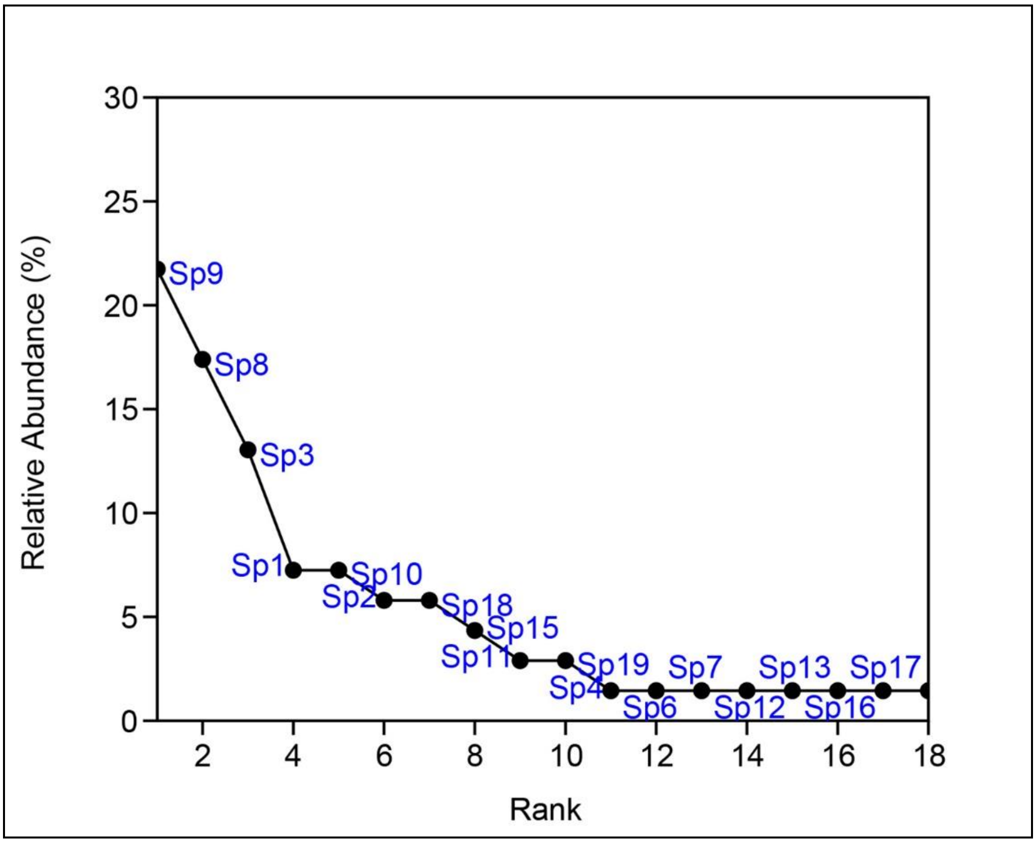

Fig. 6. 6 Reptile species rank abundance curve in vayals in semi-evergreen habitats

6.3.3.3 Rank Abundance Estimation in vayals within grasslands

6.3.3.3.1 Amphibians

From grasslands, a total of 14 species of amphibians with 459 individual sightings were recorded. Among the 14 species recorded, *Raorchestes travancoricus* (Sp22) was found to be the most abundant species with RA 21.13%, followed by *Raorchestes akroparallagi* (Sp18) and *Indosylvirana sreeni* (Sp14) (Fig. 6.7) with RA 17.86% and 13.51% respectively. The rank abundance shows a relatively shallow curve. *Uperodon montanus* (Sp7) and *Clinotarsus curtipes* (Sp13) were sighted twice (RA 0.44%) and *Polypedates maculatus* (Sp15) was sighted once (RA 0.22%) during the surveys from grasslands with.

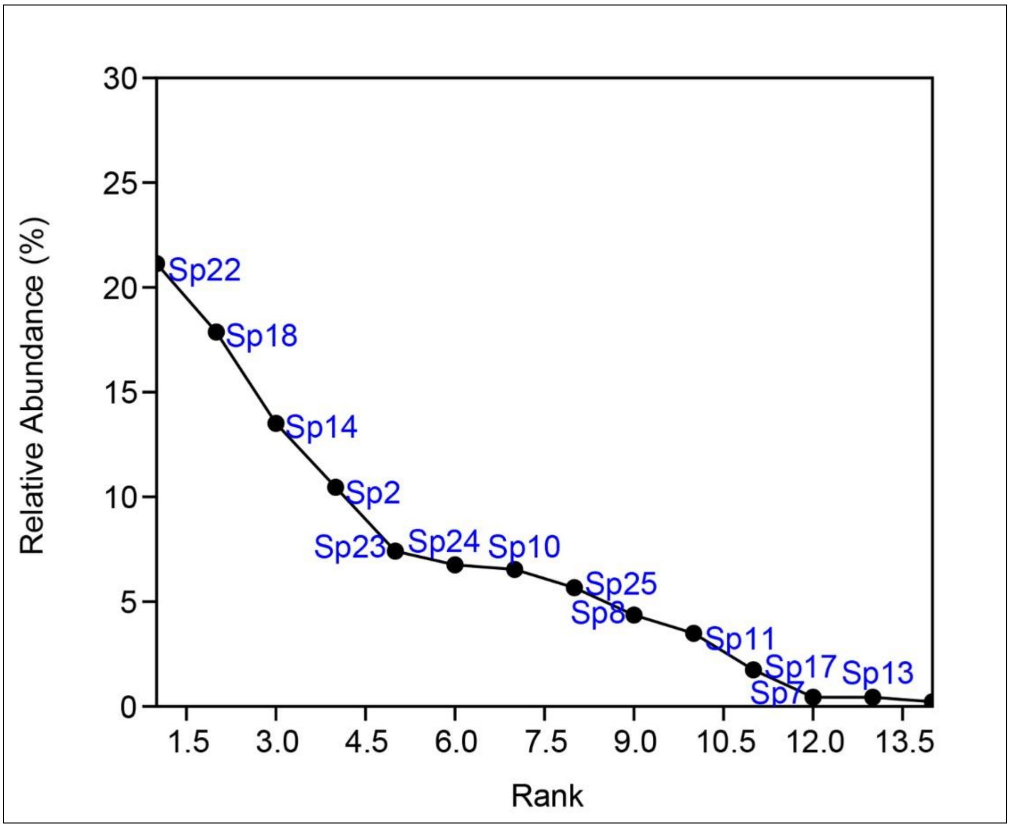

Fig. 6. 7 Amphibian species rank abundance curve in grassland habitat

6.3.3.3.2 Reptiles

Vayals in grassland had the lowest reptile species richness with a total of 36 sightings of 10 species. Among the 36 sightings, *Eutropis macularia* (Sp9) was the most abundant species with 11 sightings (RA 30.56%) followed by *Eutropis carinata* (sp8) and *Aheatulla dispar* (Sp20) (Fig. 6.8) with RA 19.44% and 13.89% respectively. The abundance curve shows the dominance of these three species. The *Melanochelys trijuga* (Sp1), *Hebiusbeddomei* (Sp16), *Hebius monticola* (Sp17), and *Calliophis nigrescens* (Sp22) were sighted only once (RA 2.78%) during the study from the vayals in grasslands.

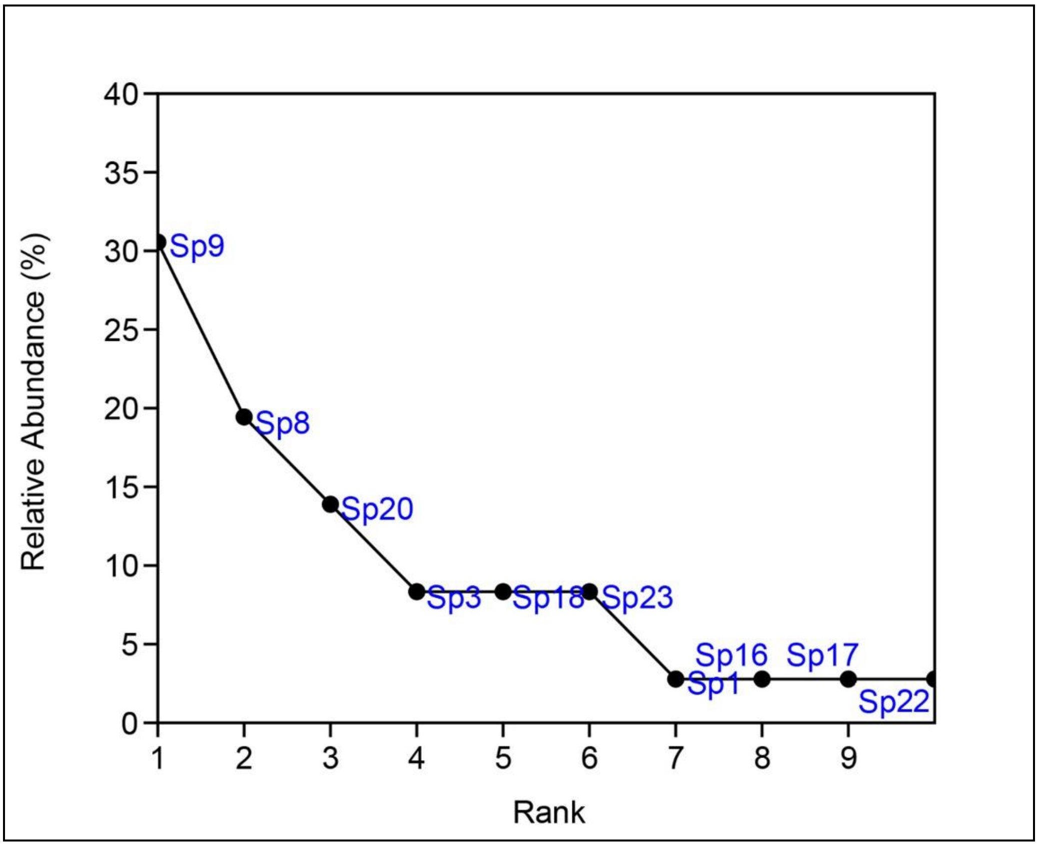

Fig. 6. 8 Reptile species rank abundance curve in grassland habitat

6.3.3.4 Rank Abundance Estimation in vayals within Eucalypts plantation

6.3.3.4.1 Amphibians

A total of 16 species of amphibians were recorded with 413 sightings from the vayals in eucalypts plantations. Among the 16 species, *Pseudophilautus wynaadensis* (Sp17) was found to be the most abundant species with RA 14.04%, followed by *Indosylvirana sreeni* (Sp14) and *Euphlyctis cyanophlyctis* (Sp3) (Fig. 6.9) with RA 13.56% and 10.90% respectively. The rank abundance curve shows a relatively even distribution of species with shallow curve. The least abundant species includes *Raorchestes anili* (Sp19) with RA 1.21%, *Uperodon montanus* (Sp7) and *Nyctibatrachus anamallaiensis* (Sp8) with RA 0.97% each and *Ichthyophis beddomei* (Sp28) with RA 0.24%.

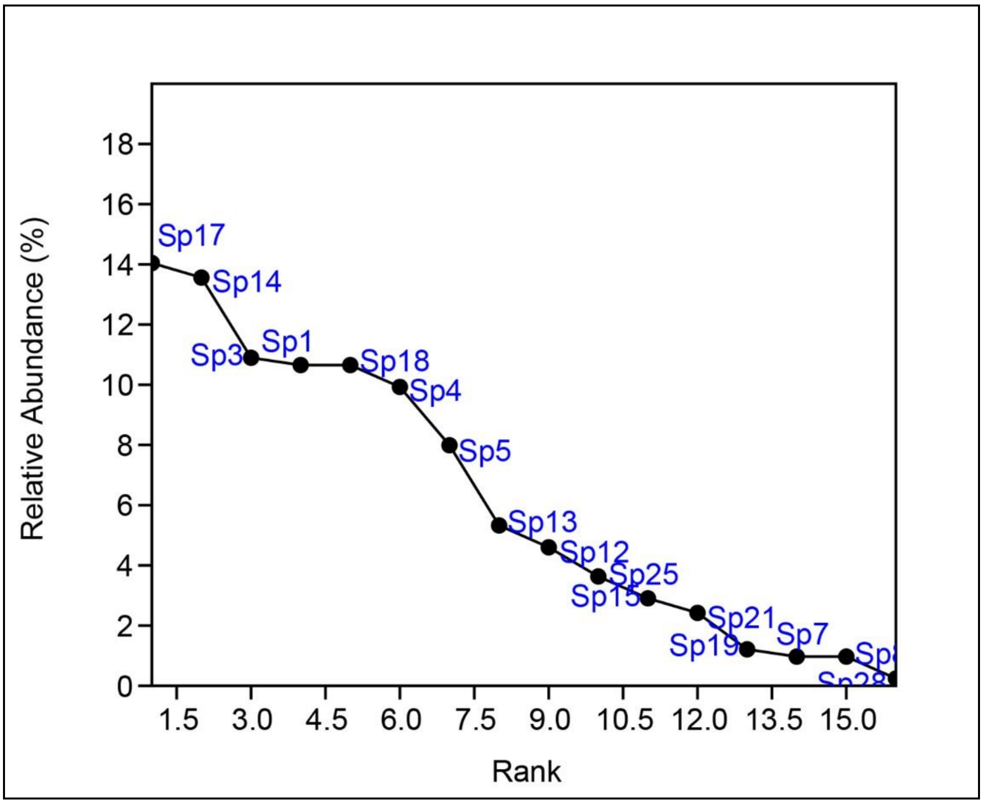

Fig. 6. 9 Amphibian species rank abundance curve in eucalypts plantations

6.3.3.4.2 Reptiles

Fourteen species of reptiles were recorded from the vayals in eucalypts plantations. Of these, *Eutropis carinata* (Sp8) was found to be the most abundant species with RA 21.25% followed by *Eutropis macularia* (Sp9) and *Calotes versicolor* (Sp3) with RA 16.25% and 15.0% respectively (Fig. 6.10). The curve was relatively shallow with a high even distribution of reptiles. Among the least abundant species, *Cnemaspis wynadensis* (Sp4), *Kaestlea laterimaculata* (Sp10), *Hebius beddomei* (Sp16), and *Aheatulla dispar* (Sp20) were recorded twice with RA 2.5% and the *Boiga thackerayi* (Sp21) only once with RA 1.25% during the surveys.

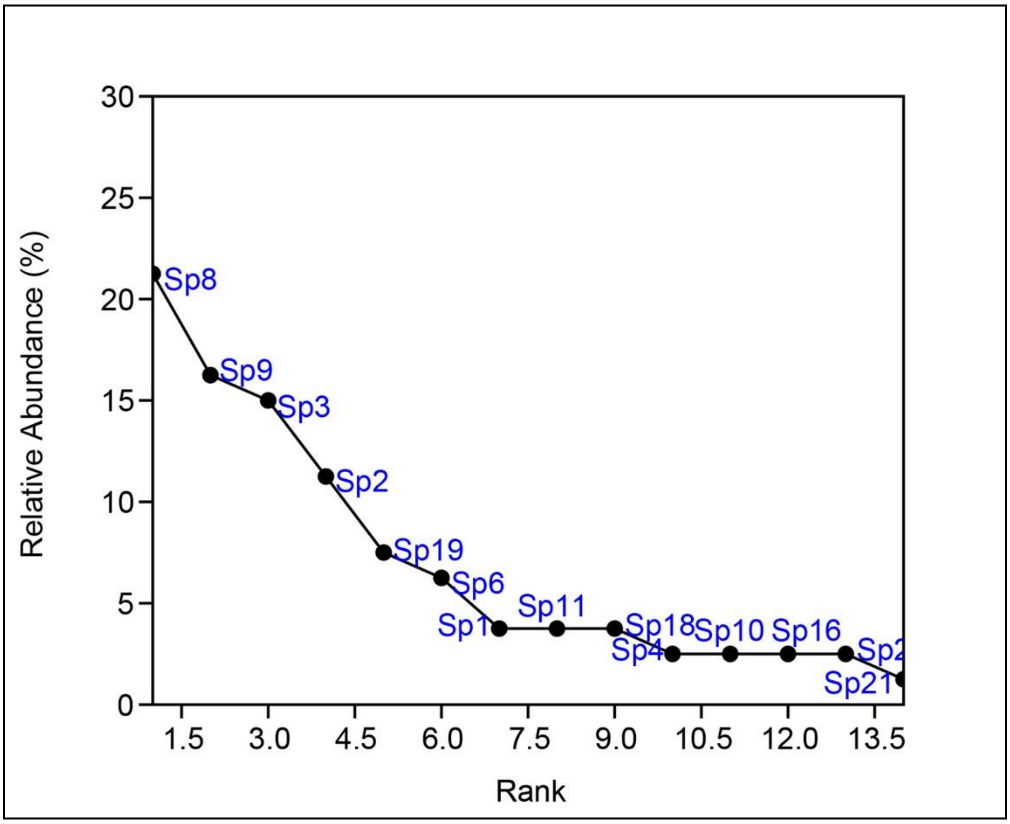

Fig. 6. 10 Reptile species rank abundance curve in eucalypts plantations

6.3.3.5 Rank Abundance Estimation in vayals surrounded by Evergreen and Eucalypts plantation

6.3.3.5.1 Amphibians

From the vayals that were covered with both evergreen forest and eucalypts plantation, a total of 15 species of amphibians with 284 sightings were recorded. Of these, *Pseudophilautus wynaadensis* (Sp17) was found to be the most abundant with RA 16.90%, followed by *Euphlyctis cyanophlyctis* (Sp3) and *Indosylvirana sreeni* (Sp14) (Fig. 6.11) with RA 11.62% and 11.27% respectively. The shallow curve of rank abundance shows a relatively even distribution of amphibians. The least abundant species includes the *Hoplobatrachus tigerinus* (Sp4) and *Micrixalus adonis* (Sp6) with RA 2.82% each and *Uperodon montanus* (Sp7) with RA 1.76%.

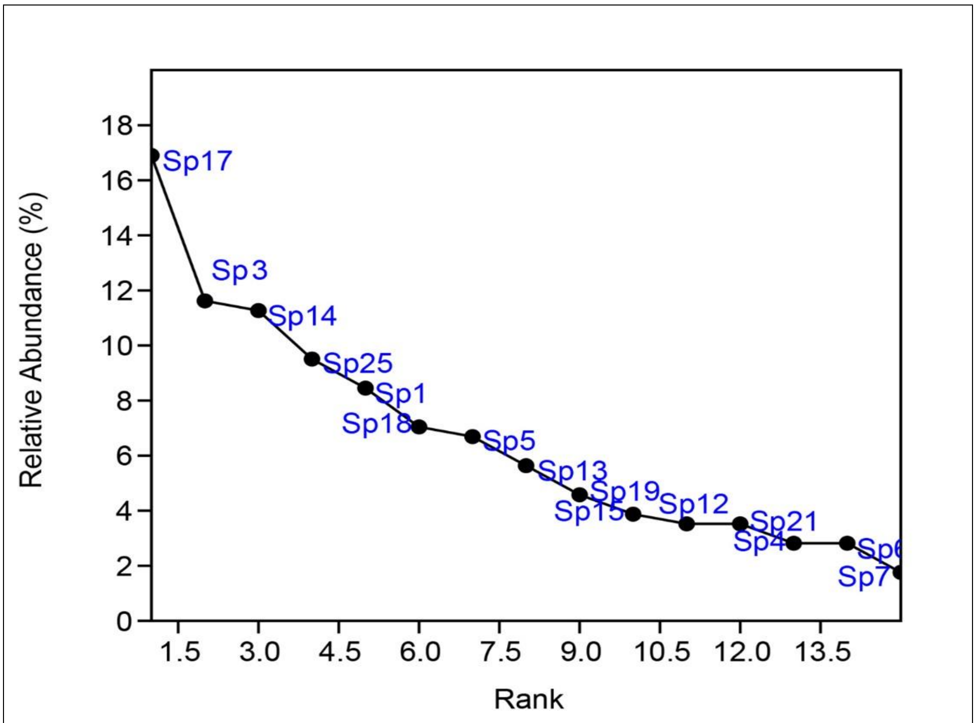

Fig. 6. 11 Amphibian species rank abundance curve in vayals surrounded by both evergreen and eucalypts plantation

6.3.3.5.2 Reptiles

Out of the 24 species of reptiles recorded during the study, 17 species were recorded from the vayals that were surrounded by both evergreen forest and eucalypts plantations with a total of 52 sightings. Among the 52 sightings, *Calotes versicolor* (Sp3) was found to be the most abundant species with RA 21.15%, followed by *Monilesaurus ellioti* (Sp2) and *Fowlea piscator* (Sp18) (Fig. 6.12) with RA 11.54% and 9.62% respectively. The steep curve followed by shallow curve represents dominance of these three species and relatively even distribution of rest of the species. *Indotyphlops braminus* (Sp12), *Grypotyphlops acutus* (Sp13), *Melanophidiumpunctatum* (Sp14), *Hebius beddomei* (Sp16), and *Boiga thackerayi* (Sp21) were the least abundant species with RA 1.92%.

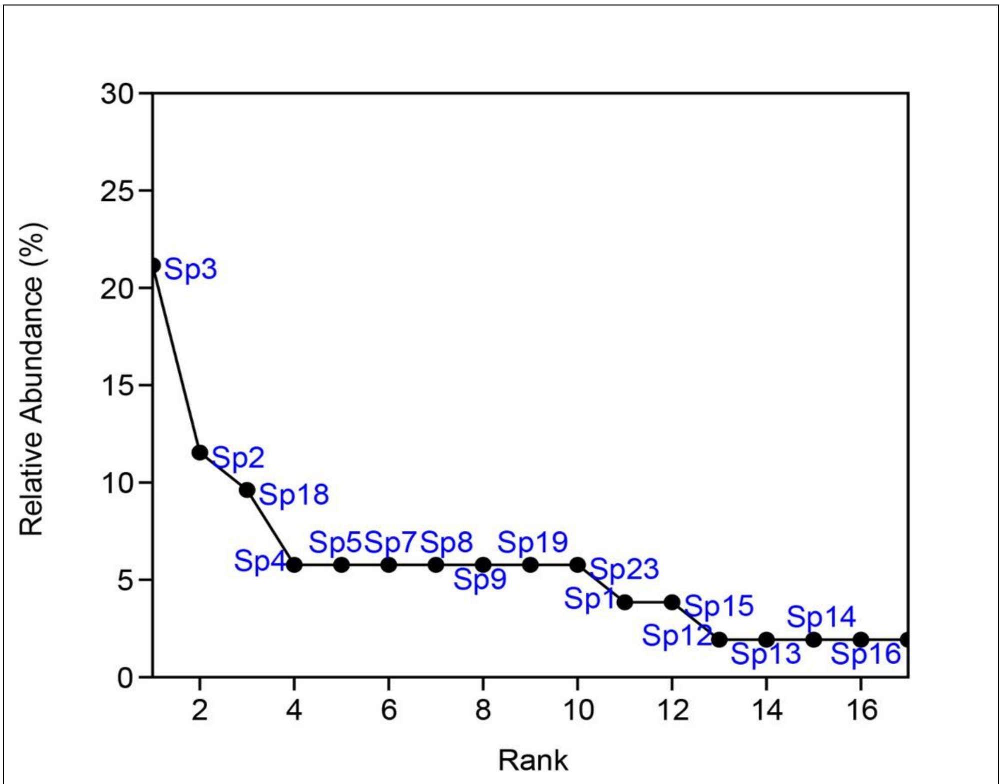

Fig. 6. 12 Reptile species rank abundance curve in vayals surrounded by both evergreen and eucalypts plantation

6.3.4 Species diversity in different elevation classes

6.3.4.1 Amphibians

A total of 21 vayals were identified and mapped from the altitude range 801-1000 msl. From the 21 vayals, 17 species of amphibians were recorded with a total of 1177 sightings. Among the 17 species, the bush frog *Pseudophilautus wynaadensis* was found to be the most abundant species with 189 sightings followed by *Indosylvirana sreeni* and *Euphlyctis cyanophlyctis* with 143 and 134 sightings respectively. In this altitude class, *Micrixalus adonis*, *Nyctibatrachus anamallaiensis*, and *Ichthyophis beddomei* were the least abundant species with eight, four and one sightings respectively. From altitude class 1001-1200 msl, a total of 17 vayals were recorded from which a total of 25 species of amphibians were recorded. Among the 25 species, *Raorchestes akroparallagi* was sighted 97 times followed by *Raorchestes travancoricus* and *Indosylvirana sreeni* with 71 and 67 sightings respectively. *Uperodon montanus* and *Ichthyophis beddomei* were sighted twice and once respectively.

From the altitude class 1201-1400 msl (two vayals), ten species of amphibians were recorded. *Raorchestes travancoricus* was found to be the most abundant species with 26 sightings in this altitude class. This was followed by *Indosylvirana sreeni*, *Duttaphrynus parietalis* and *Raorchestes akroparallagi* with 16, 11 and 10 sightings respectively. *Nyctibatrachus periyar* and *Raorchestes jayarami* were recorded four and two times respectively.

Two vayals were recorded from the altitude class 1401-1600 msl and five vayals from 1601-1800 msl. The vayals at altitude class 1401-1600 msl had a total of 13 amphibian species. Of these, *Duttaphrynus parietalis* and *Micrixalus adonis* were found to be the most abundant species with six sightings each followed by *Raorchestes akroparallagi* with four sightings. *Uperodon montanus*, *Raorchestes beddomii*, *Raorchestes keirasabinae* and *Rhacophorus pseudomalabaricus* were recorded only once., A total of 15 species were recorded from five vayals in the 1601-1800 msl altitude class, of which *Duttaphrynus* parietalis, *Raorchestes beddomii* and *Micrixalus adonis* were abundant with 27, 14 and 10 sightings respectively. Only one sighting was recorded in the case of *Duttaphrynus melanostictus*, *Raorchestes anili* and *Rhacophorus calcadensis*.

The vayals located between 801-1000 msl and 1001-1200 msl were more similar in terms of amphibian diversity (Fig. 6.13). This forms a separate cluster from other altitude classes. Vayals located between 1401-1600 msl and 1601-1800 msl were similar and this cluster was more related to the vayals at 1201-1400 m.

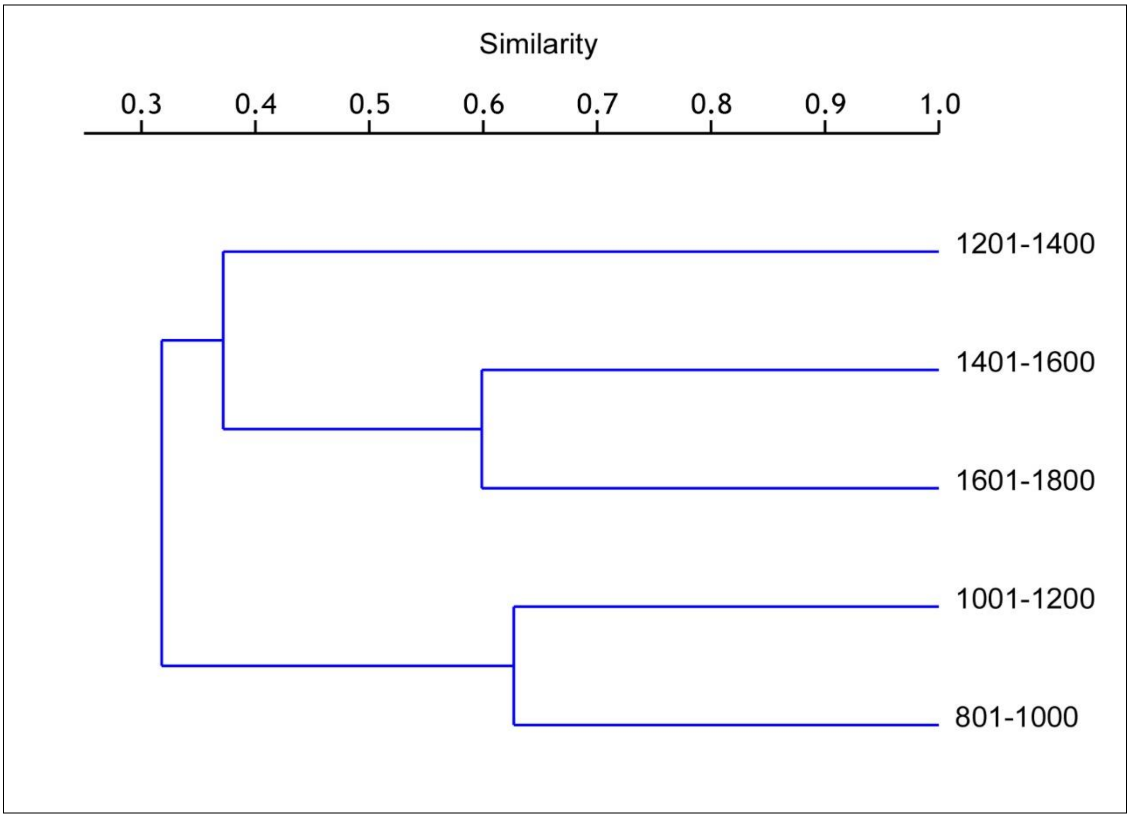

Fig. 6. 13 Amphibian species richness in vayals in different altitude classes

6.3.4.2 Reptiles

From the 21 vayals recorded within the altitude class 801-1000 msl, a total of 22 species of reptiles were recorded. Of these, *Eutropis macularia*, *Calotes versicolor* and *Eutropis carinata* were found to be the abundant species with 35, 33 and 32 sightings respectively. *Melanophidium punctatum*, *Hebius monticola*, *Aheatulla dispar*, and *Boiga thackerayi* were recorded only once from the altitude class. From the 17 vayals in the 1001-1200 msl altitude class, a total of 16 species of reptiles were recorded. Of these, *Eutropis macularia* was found to be the most abundant species with 15 sightings followed by *Eutropis carinata* and *Aheatulla dispar* with seven and six sightings respectively. *Melanochelys trijuga*, *Monilesaurus ellioti*, *Hemidactylus cf. parvimaculatus*, *Varanus bengalensis*, *Indotyphlops braminus*, *Calliophis nigrescens*, and *Craspedocpehalus macrolepis* were sighted only once during the surveys in this altitude class.

From the altitude class 1201-1400msl, a total of three species of reptiles were recorded of which *Eutropis carinata* was sighted three times and *Hebius beddomei* and *H. monticola* only once. Two species of reptiles were recorded from the two vayals in the altitude class 1401-1600 msl, *Craspedocpehalus macrolepis* and *Monilesaurus ellioti*, with two and one sightings respectively. From the five vayals in the altitude class 1601-1800 msl, a total of four species of reptiles, *Monilesaurus ellioti* (eight), *Melanochelys trijuga* (one), *Hebius monticola* (one) and *Craspedocpehalus macrolepis* (one) were recorded.

The reptile diversity was more similar in vayals in altitude class 801-1000 and 1001-1200 msl (Fig. 14). Vayals in 1401-1600 and 1601-1800 msl form another related cluster in terms of reptile diversity. These two clusters form a separate cluster with the vayals in 1201-1400 msl class.

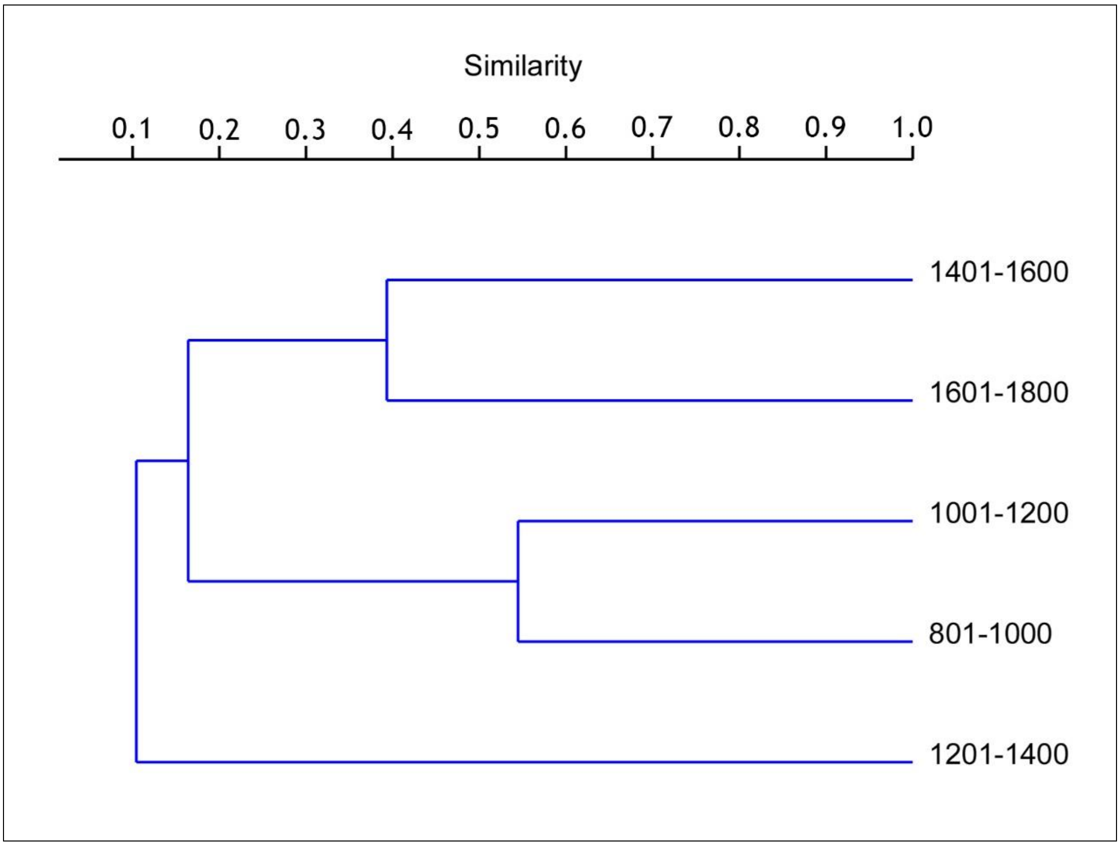

Fig. 6. 14 Reptile species richness in vayals in different altitude classes

6.3.5 Species diversity in vayals of different plant composition rank

6.3.5.1 Amphibians

Five vayals fall under the plant composition rank 1. Twenty four species of amphibians were recorded from these five vayals. Ofthese, *Pseudophilautus wynaadensis* was found to be the most abundant species with 34 sightings followed by *Indosylvirana sreeni* and *Euphlyctis cyanophlyctis* with 23 and 21 sightings respectively. From the four vayals under the plant composition rank 2, 15 species of amphibians were recorded. Among the 15 species, *Pseudophilautus wynaadensis* was the most abundant with 30 sightings followed by *Euphlyctis cyanophlyctis* and *Raorchestes akroparallagi* with 22 and 21 sightings respectively. *Uperodon montanus* and *Micrixalus adonis* were found to be the least abundant species with three and two sightings respectively. Ten vayals come under the plant composition rank 3. From the 10 vayals, 23 species of amphibians were recorded of which *Pseudophilautus wynaadensis* was found to be the most abundant with 42 sightings followed by *Indosylvirana sreeni* and *Raorchestes akroparallagi* with 37 and 34 sightings respectively. Eighteen vayals fall under the plant composition rank 4 and a total of 25 species of amphibians were recorded from the vayals. Among these, *Pseudophilautus wynaadensis* was found to be the most abundant species with 117 sightings followed by *Indosylvirana sreeni* and *Raorchestes akroparallagi* with 110 and 86 sightings respectively. *Rhacophorus pseudomalabaricus* and *Rhacophorus calcadensis* were found to be the least abundant species with five and four sightings respectively. Ten vayals come under the plant composition rank 5 and 15 species of amphibians were recorded from these vayals. Of these, *Raorchestes akroparallagi* was found to be the most abundant species with 60 sightings followed by *Raorchestes travancoricus* and *Indosylvirana sreeni* with 59 and 40 sightings respectively. Among the 15 species of amphibians recorded, *Raorchestes beddomii*, *Rhacophorus pseudomalabaricus*, and *Rhacophorus calcadensis* were the least abundant with a single sighting each.

The amphibians seen in vayals with plant composition rank 1 and 3 were closely similar and form a cluster (Fig. 15). This cluster forms another cluster with the amphibians in plant composition rank 2. These 1, 3, and 2 forms cluster with the vayals in rank 4. The vayals in rank 5 show very little similarity and so forms weaker cluster with 1, 2, 3 and 4.

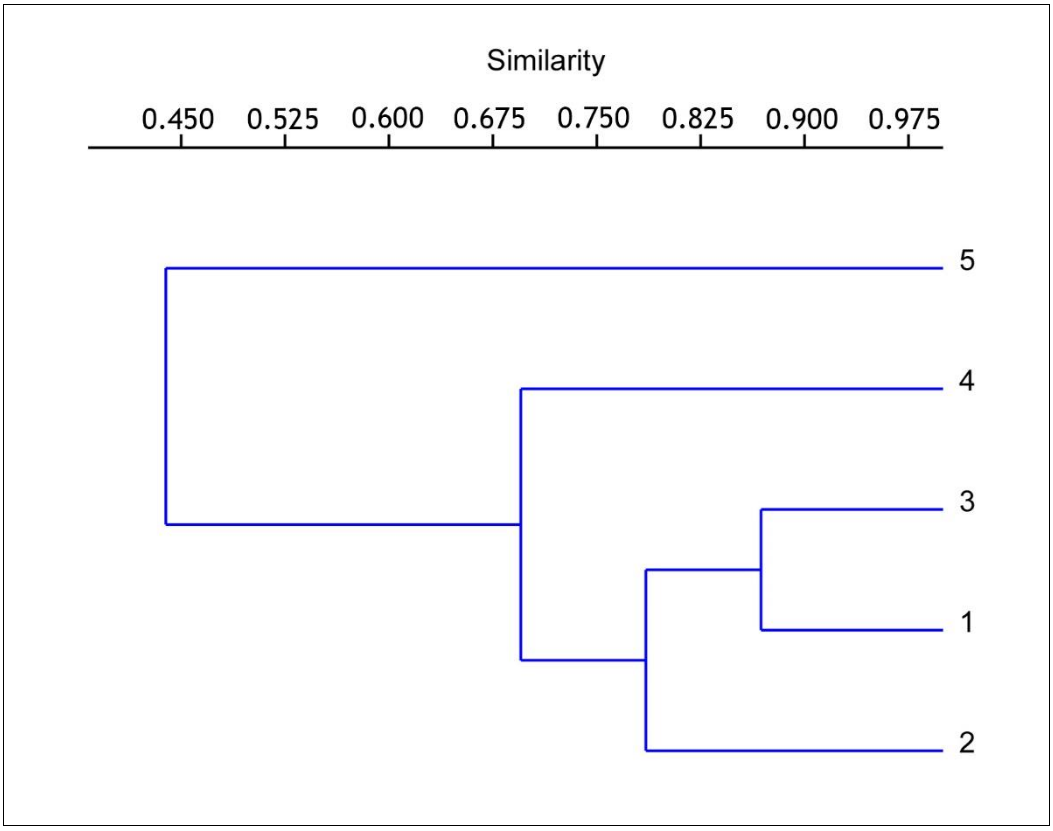

Fig. 6. 15 Amphibian species richness in vayals in different plant composition category

6.3.5.2 Reptiles

Eighteen species of reptiles were recorded from the five vayals that come under the plant composition rank 1. Of these, *Calotes versicolor* was the most abundant species with nine sightings followed by *Monilesaurus ellioti* and *Cnemaspis wynadensis* with five and four sightings respectively. Among the 18 species of reptiles, *Eutropis carinata*, *Kaestlea laterimaculata*, *Melanophidium punctatum*, *Ptyas mucosa*, *Hebius monticola*, *Ahaetulla isabellina* and *Boiga thackerayi* were recorded only once from the five vayals. From the four vayals under the plant composition rank 2, 11 species of reptiles were recorded. Of these, *Calotes versicolor* and *Fowlea piscator* were recorded three times and *Eutropis carinata* were recorded twice. All other species, i.e. *Melanochelys trijuga*, *Monilesaurus ellioti*, *Dravidogecko sp.*, *Hemidactylus cf. parvimaculatus*, *Hemidactylus leschenaultii*, *Eutropis macularia*, *Kaestlea laterimaculata* and *Ahaetulla isabellina* were recorded only once from the four vayals.

The ten vayals in the plant composition rank 3 had 14 species of reptiles. Among these 14 species, *Eutropis carinata* and *Calotes versicolor* were the most abundant species with 11 sightings each. This was followed by *Eutropis macularia* with nine sightings. *Hemidactylus leschenaultii*, *Varanus bengalensis*, *Grypotyphlops acutus*, *Ptyas mucosa*, *Fowlea piscator*, *Aheatulla dispar*, *Boiga thackerayi*, and *Craspedocephalus anamallensis* were sighted only once from the 10 vayals. From the 18 vayals that fall under the plant composition rank 4, 21 species of reptiles were recorded. Of these, *Eutropis macularia* was the most abundant species with 26 sightings followed by *Eutropis carinata* and *Calotes versicolor* with 24 and 18 sightings respectively. Four species of reptiles, *Hemidactylus leschenaultii*, *Indotyphlops braminus*, *Grypotyphlops acutus* and *Boiga thackerayi* were recorded only once from the 18 vayals. Ten vayals were ranked 5 from which nine species of reptiles were recorded. Of these, *Eutropis macularia* was the most abundant species with 11 sightings followed by *Eutropis carinata* with four sightings and *Calotes versicolor* and *Aheatulla dispar* with three sightings each. *Hebius beddomei*, *Calliophis nigrescens* and *Craspedocpehalus macrolepis* were recorded only once from the 10 vayals.

The reptile diversity in plant composition rank 3 and 4 show more similarity than other plant composition ranks and therefore forms a cluster. This cluster in turn forms another cluster with the vayals in plant composition rank 1 (Fig. 16) thereby forming a separate cluster with the vayals with plant composition rank 2. The entire cluster forms a weaker cluster with the vayals in plant composition rank 5.

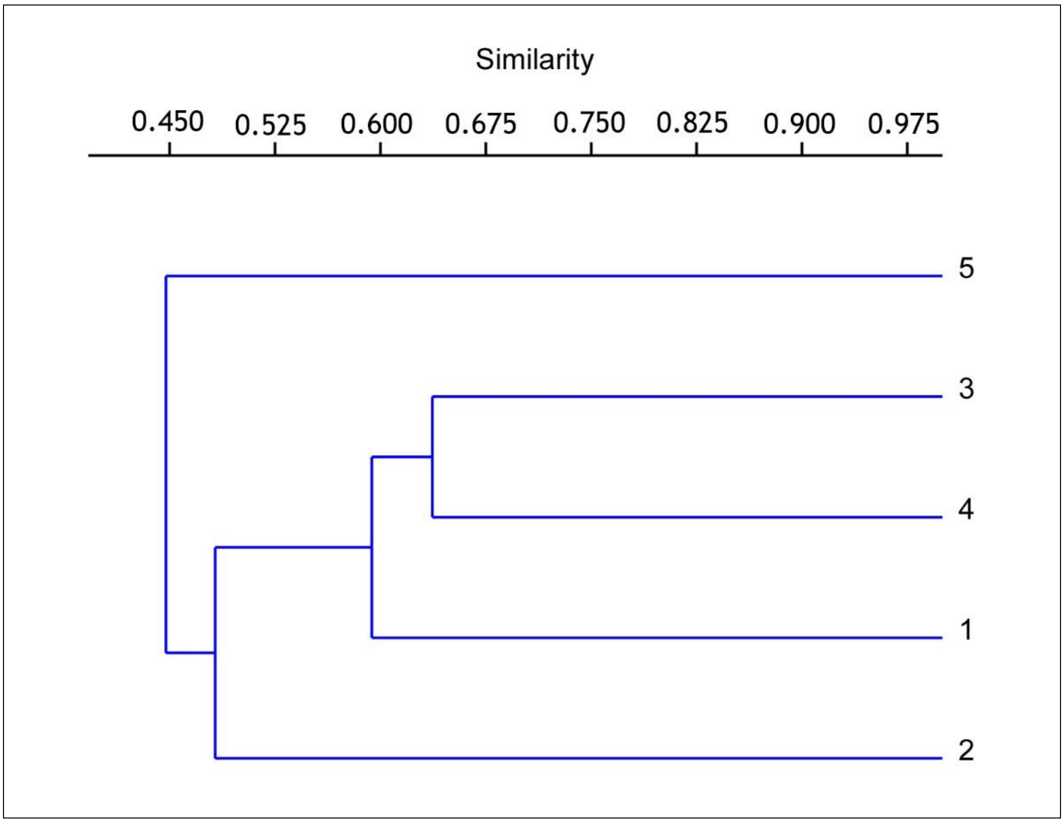

Fig. 6. 16 Reptile species richness in vayals in different plant composition category

6.3.6 Species diversity and extent of vayal

6.3.6.1 Amphibians

Twenty vayals recorded from the vayal size class 0-1ha had 28 species of amphibians of which *Raorchestes akroparallagi* was the most abundant species followed by *Indosylvirana sreeni* and *Duttaphrynus parietalis* with 55 and 53 sightings respectively. *Nyctibatrachus manalari* and *Ichthyophis beddomei* were the least abundant species with four and one sightings respectively. From the 13 vayals that fall under the vayal size class 1.01-2ha, 22 species of amphibians were recorded. Among these, *Raorchestes akroparallagi* was the most abundant species with 84 sightings followed by *Indosylvirana sreeni* and *Pseudophilautus wynaadensis* with 75 and 69 sightings respectively. *Uperodon montanus* was the least abundant with six sightings in this size class. From the three vayals under the 2.01-3ha vayal size class category, a total of 11 species of amphibians were recorded. Of these, *Hoplobatrachus tigerinus, Pseudophilautus wynaadensis* and *Indosylvirana sreeni* were the most abundant species with 18, 16 and 15 sightings respectively. *Nyctibatrachus periyar* was the least abundant species with only one sighting. Two vayals come under the vayal size class 3.01-4ha, from which a total of 15 species of amphibians were recorded. Among these 15 species, *Pseudophilautus wynaadensis* and *Raorchestes akroparallagi* were the most abundant species with eight sightings each and *Nyctibatrachus anamallaiensis*, *Raorchestes keirasabinae, Rhacophorus pseudomalabaricus* and *Rhacophorus calcadensis* sighted only once from the two vayals.

From the two vayals that fall under the size class category 4.01-5ha, 13 species of amphibians were recorded. Of these, *Indosylvirana sreeni* and *Pseudophilautus wynaadensis* were the most abundant with 17 sightings each followed by *Hoplobatrachus tigerinus* and *Euphlyctis cyanophlyctis* with 14 and 13 sightings respectively. *Polypedates maculatus* and *Ichthyophis beddomei* were the least abundant with three and one sightings respectively. Two vayals come under the vayal size class 5.01-6ha with 13 species of amphibians. Among these, *Pseudophilautus wynaadensis* and *Indosylvirana sreeni* were found to be the abundant species with 15 and nine sightings respectively and *Raorchestes anili* was f the least abundant with only one sighting.Two vayals falling under the vayal size class 6.01-7ha recorded14 species of amphibians. Of these 14 species, *Indosylvirana sreeni* was the most abundant species with 20 sightings followed by *Pseudophilautus wynaadensis* with 19 sightings and *Euphlyctis cyanophlyctis* and *Hoplobatrachus tigerinus* with 15 sightings each. Among the 14 species, *Polypedates maculatus* (3), *Rhacophorus malabaricus* (3), and *Uperodon montanus* (2) were the least abundant. .

The amphibian diversity in vayal size class 4.01-5 and 6.01-7ha show highest similarity with each other and form a cluster (Fig. 17), followed by the diversity of amphibians in 0-1 and 1.01-2ha size class. The diversity of amphibians in the 4.01-5 and 6.01-7ha cluster showed similarity with the diversity in the size class 5.01-6ha. This cluster shows similarity with the size class 2.01-3ha. This entire cluster group forms a cluster with the 0-1 and 1.01-2ha cluster, which stands separately and is far different from the diversity of amphibians in the 3.01-4ha vayal size class.

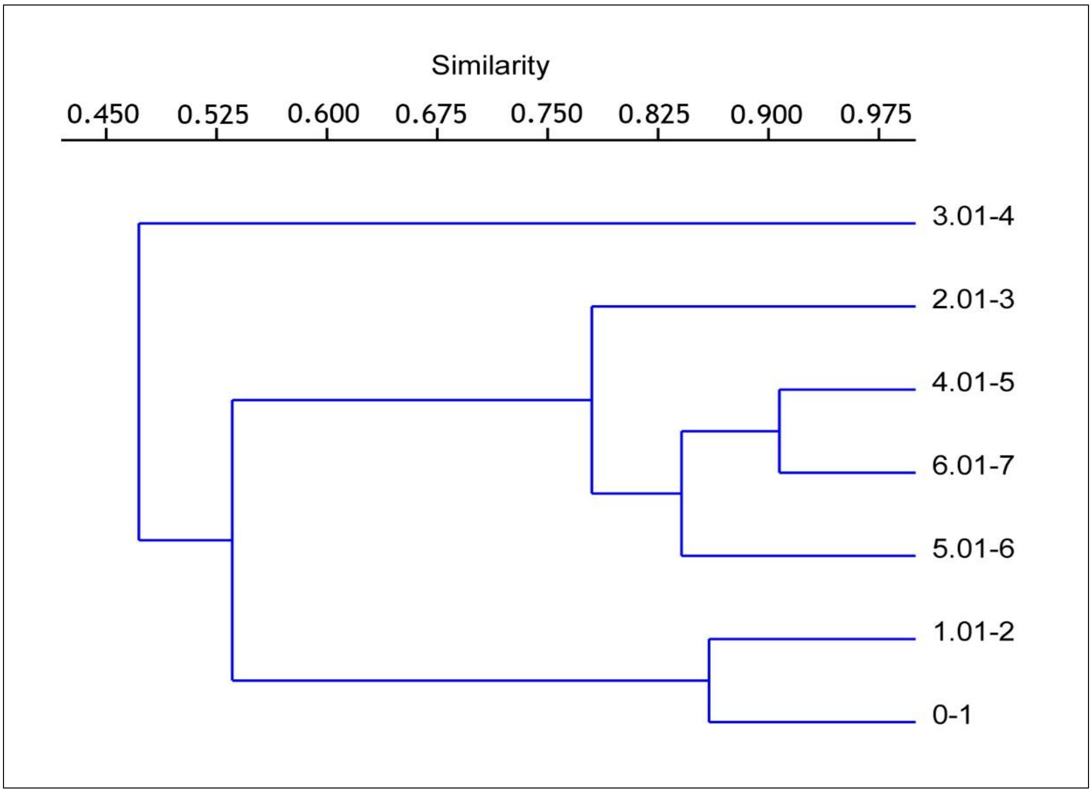

Fig. 6. 17 Amphibian species richness in different vayal extent category

6.3.6.2 Reptiles

Fifteen species of reptiles were recorded from the 20 vayals belonging to the vayal size class 0-1ha. Of these, *Eutropis macularia, Eutropis carinata* and *Calotes versicolor* were the abundant ones with 13, 12 and 10 sightings respectively and *Varanus bengalensis* was sighted only once from the 20 vayals. From the 13 vayals in the size class 1.01-2ha, a total of 21 species of reptiles were recorded. Out of the 21 species, *Calotes versicolor*, *Eutropis macularia* and *Eutropis carinata* were the most abundant with 15, 10 and 9 sightings respectively. *Kaestlea laterimaculata*, *Varanus bengalensis*, *Indotyphlops braminus*, *Melanophidium punctatum*, *Ptyas mucosa*, *Aheatulla dispar*, *Boiga thackerayi* and *Calliophis nigrescens* were recorded only once from the 13 vayals.

Ten species of reptiles were recorded from the vayal size class category 2.01-3ha. Among the 10 species, *Eutropis macularia* was the most abundant with five sightings. Among the remaining nine species, three were sighted twice and the rest of the six species were sighted only once. From the two vayals in the size class 3.01-4ha, three species of reptiles were recorded. Among these, *Eutropis macularia* was sighted two times and the *Cnemaspis wynadensis* and *Indotyphlops braminus* was sighted only once from the vayals. The vayal size class 4.01-5ha had a total of 10 species of reptiles. Among the 10 species, *Calotes versicolor*, *Eutropis carinata* and *Eutropis macularia* were the most abundant with four sightings each and the *Hemidactylus leschenaultii*, *Grypotyphlops acutus*, *Ptyas mucosa*, *Fowlea piscator*, *Ahaetulla isabellina* and *Craspedocephalus anamallensis* were the least abundant with only one sighting each.

From the two vayals belonging to the size class 5.01-6ha, six species of reptiles were recorded. Among the six species, *Calotes versicolor* and *Eutropis macularia* were recorded three and two times respectively and the remaining four species were recorded only once. Ten species of reptiles were recorded from the two vayals belonging to the size class 6.01-7ha. Of these, *Eutropis macularia* and *Eutropis carinata* were the abundant species with five and four sightings respectively. *Melanochelys trijuga*, *Monilesaurus ellioti*, *Hemidactylus leschenaultii*, *Kaestlea laterimaculata*, *Varanus bengalensis* and *Ahaetulla isabellina* were recorded only once. .

Reptile diversity in vayal size classes 4.01-5 and 6.01-7ha were more similar than any other size class category (Fig. 6.18). This cluster is more similar to the reptile diversity in the vayal size class 2.01-3ha and this whole cluster forms another cluster with the diversity of reptiles in the vayal size class 5.01-6ha. After the cluster 4.01-5 and 6.01-7ha, the cluster 0-1 and 1.01-2ha is the most similar size class. This cluster forms a cluster with the whole clusters mentioned above. The 3.01-4ha class is very less similar to the whole size classes and forms a weaker cluster.

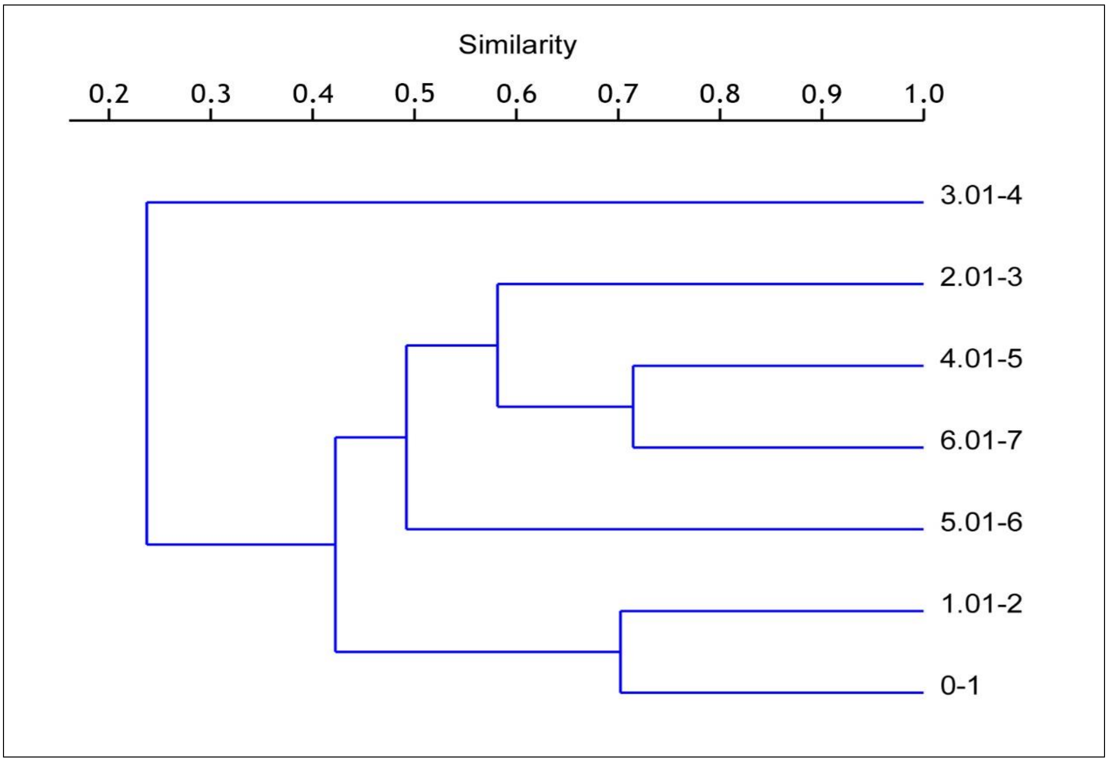

Fig. 6. 18 Reptile species richness in vayals in different vayal extent category

6.3.7 Non-metric Multidimensional Scaling ordination (NMDS)

6.3.7.1 Amphibians

Non-metric Multidimensional Scaling ordination (NMDS) result for amphibians (stress value is 0.12) shows that the amphibians were more associated with surrounding vegetation (p=0.001) of vayals, altitude (p=0.001) and plant composition (p=0.001) and not significantly associated with extent (p= 0.05) of vayals (Fig. 6.19).

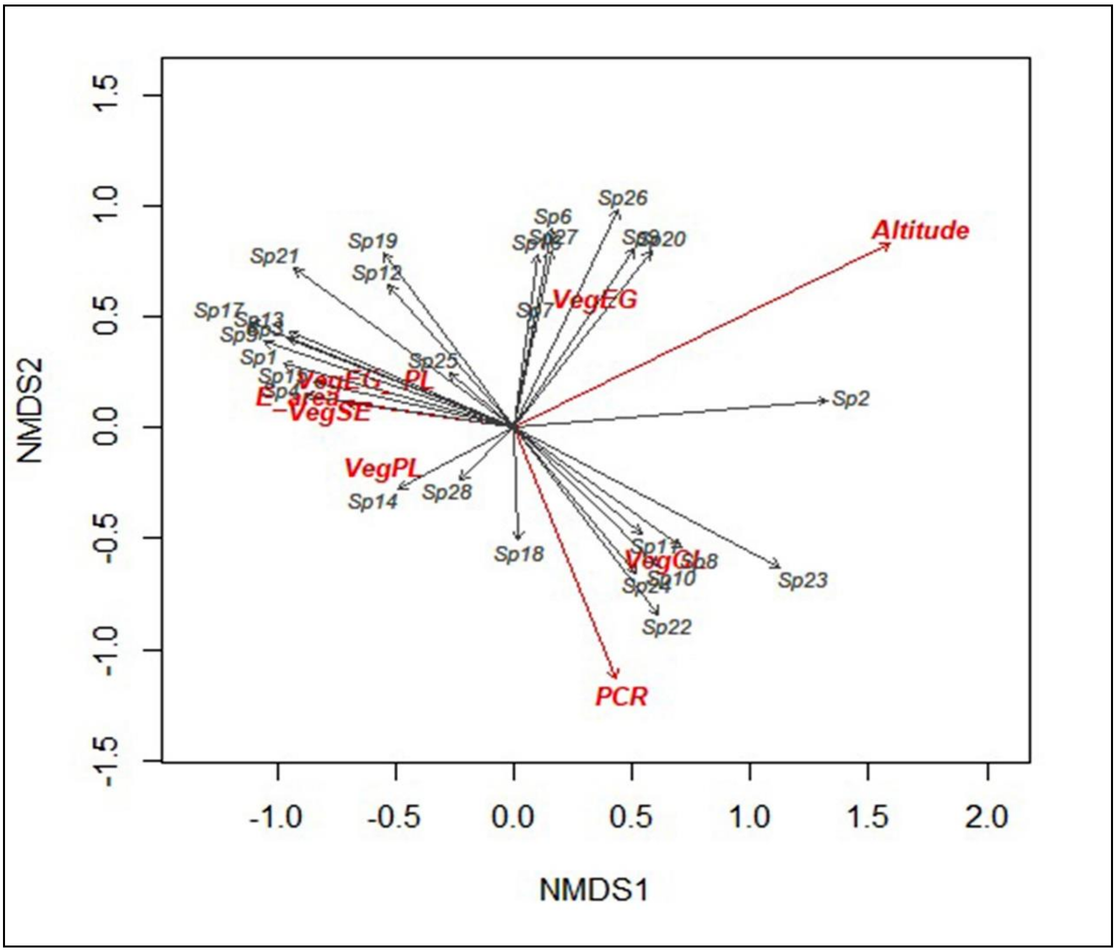

Fig. 6. 19 Non-metric Multidimensional Scaling ordination (NMDS) biplot results of amphibians. VegEG – Evergreen Forest; VegSE – Semi-evergreen forest; VegGL – Grassland; VegPL – EucalyptsEucalypts Plantation; VegEG_PL – vayals surrounded by both Evergreen forest and eucalyptseucalypts plantation, PCR – Plant Composition Rank, E_Area – Extent of vayal, Altitude – Altitude of vayal.

The Sp6, Sp7, Sp9, Sp16, Sp20, SP26 and Sp27 are strongly associated with evergreen forests. The Sp18 shows association with grassland and eucalypts plantations. The Sp8, Sp10, Sp11, Sp22 and Sp24 show strong association with vayals in the grassland ecosystem and plant composition of vayals. The Sp2 shows a strong association with the surrounding vegetation, evergreen forests and grassland and also with the elevation. It was recorded only from vayals in the evergreen and grassland ecosystems. *Duttaphrynus parietalis* (Sp2) was recorded 33 times from vayals in the evergreen forest, which are at an altitude of 1601-1800msl and 48 times from the vayals in grassland which are above 1001-1200msl. The Sp9 and Sp20 are recorded only from vayals in the evergreen forest. The Sp22 and Sp24 are recorded from grassland alone.

6.3.7.2 Reptiles

The NMDS result for reptiles (stress value is 0.14) shows a strong association of reptile with the altitude (p=0.001) vayals and surrounding vegetation of vayals (p=0.003) and not significantly associated with plant composition (p=0.1) and extent (p=0.7) (Fig. 6.20). The Sp24 shows a strong association with vayals in evergreen forests. The Sp20 shows association with grasslands and eucalypts plantation. The Sp17 shows strong association with elevation and the Sp22 is strongly associated with eucalypts plantation. Most of the species show association with the surrounding vegetation. Sp24 was recorded from only vayals in the evergreen forest. The Sp20 was recorded only from the vayals in grassland and eucalypts plantation, with five and two sightings respectively. The Sp22 was recorded only once from the vayals surrounded by grassland.

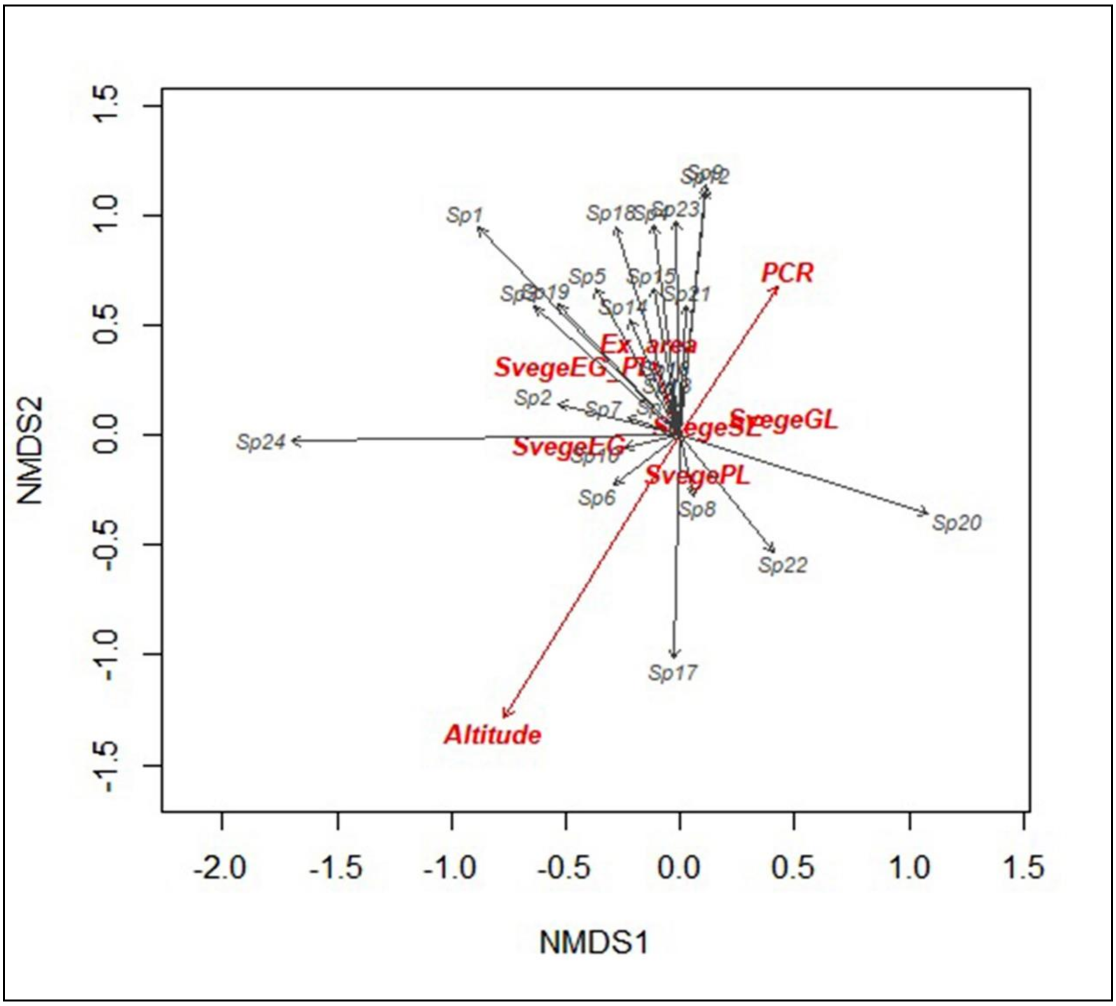

Fig. 6. 20 Non-metric Multidimensional Scaling ordination (NMDS) biplot results of reptiles. SvegeEG – Evergreen Forest; SvegeSE – Semi-evergreen forest; SvegeGL – Grassland; SvegePL – Eucalypts Plantation; SvegeEG_PL – vayals surrounded by both Evergreen forest and eucalypts plantation, PCR – Plant Composition Rank, Ex_Area – Extent of vayal, Altitude – Altitude of vayal.

6.4 Discussion

The herpetofaunal species richness was observed to be high in vayals surrounded by evergreen, semi-evergreen forests and evergreen-eucalypts plantation combination. Amphibian species richness was high in vayals surrounded by evergreen vegetation whereas reptile species richness was high in the vayals surrounded by semi-evergreen forest. Vayals with Grasslands in the surroundings had very low amphibian and reptile species richness.

There were individual differences in the abundance of species in vayals depending on the surrounding vegetation types. Among the amphibians, seven species *viz. Uperodon montanus*, *Clinotarsus curtipes*, *Indosylvirana sreeni*, *Polypedates maculatus*, *Pseudophilautus wynaadensis*, *Raorchestes akroparallagi* and *Rhacophorus malabaricus* seem to be broadly niched and were recorded from vayals in all the five habitat types. *Pseudophilatus wynaadensis* was the most abundant amphibian in four out of the five habitats, i.e. in the evergreen forests, semi-evergreen forests, eucalypts plantation and vayals surrounded by both evergreen forest and eucalyptus plantation. A few of the amphibians (*Raorchestes travancoricus, R. griet, Duttaphrynus parietalis, Polypedates occidentalis*, *Rhacophorus pseudomalabaricus* and *R. calcadensis* were found to be limited to the vayals with specific vegetation around. *Raorchestes travancoricus* was found to be the most abundant species in vayals in grasslands. *Raorchestes travancoricus* and *R. griet* were recorded only from vayals surrounded by grasslands. *Duttaphrynus parietalis* was only recorded from the vayals surrounded by evergreen forests and grasslands. *Polypedates occidentalis*, *Rhacophorus pseudomalabaricus* and *R. calcadensis* were recorded only from the vayals in evergreen forests.

Among the reptiles, five species (*Melanochelys trijuga*, *Calotes versicolor*, *Eutropis carinata*, *Eutropis macularia*, and *Fowlea piscator*) were found to use niches in all the five different habitat types. Out of these, *E. macularia* was the most commonly sighted reptile species with 50 sightings, followed by *C. versicolor* and *E. carinata* with 44 and 42 sightings respectively.The snake, *Craspedocpehalus macrolepis* was recorded only from the vayals surrounded by evergreen forest. Species wise, *Calotes versicolor* was the most abundant in vayals surrounded by evergreen. *Eutropis macularia* was observed to be the most abundant species in vayals in semi-evergreen as well as grasslands. *Eutropis carinata* was abundant in vayals surrounded by eucalypts and lizards abundant in vayals in evergreen.

The cluster anlysis with altitude classes for amphibians showed similarity between 801-1000msl and 1001-1200msl. Seventeen species of amphibians were recorded from 801-1000msl and 16 from the 1001-1200msl altitude class. The results also indicate that the most abundant amphibian recorded during the study was abundant in the altitude class 801-1000 msl followed by 1001-2000 msl. Sixteen amphibian species were common in both the elevation classes. Eleven amphibians were common in 1400-1600 msl and 1600-1800 msl classes. The cluster of amphibians in 1201-1400 msl was a standalone class with very little similarity with all other altitude classes. The vayals in1001-1200 msl class had the highest amphibian species richness with 25 species. Vayals in grasslands were mostly frequented in the altitude class 1001-1200 msl with six grassland specific species like *Duttaphrynus parietalis*, *Nyctibatrachus gavi*, *N. periyar*, *Raorchestes travancoricus*, *R. jayarami*, and *R. griet*. This would explain the higher species richness in this altitude class.

The cluster analysis for reptiles in different altitude classes showed higher species richness in the 801-1000 msl class with 22 species and this class also was had highest abundance of reptiles. The highest reptile species richness, abundance, diversity were recorded from Poomaram vayal followed by Pothukandam and Poovarashu vayal and these were at an elevation of 918 msl, 920 msl and 889 msl. Fourteen reptile species were common in 801-1000msl and 1001-1200msl whereas only two were common in 1400-1600 and 1600-1800 msl class.

The vayals with higher habitat quality were also the ones with higher diversity and abundance of amphibians. However, species like *Pseudophilaustus wynaadensis* was seen to occupy habitats of varying degree of quality in terms of abundance. And the fourth-highest amphibian diversity and abundance was in highly degraded vayals with plant composition rank 1. The highest reptile species richness, abundance, diversity was recorded from plant composition rank 1, 4, and 4. The most abundant reptile was seen abundant in all 5 categories of habitat quality. But the reptile abundance was higher in the Rank 4 habitats with better plant composition.

The amphibian species richness in vayals of varying sizes did not follow a pattern. The highest amphibian species richness in vayals of 0.2ha area, the smallest vayals. The second highest amphibian species-rich vayals was 0.17ha. The lowest value in richness was recorded for the vayals with 5.62 ha, 0.76 ha, 0.17ha and 0.86 ha. Vayals under one hectare was also seen to have more species abundance. However, the vayals with an area between 1 ha and 7 ha also recorded higher abundance.

The reptile richness and abundance were also observed to follow a pattern similar to amphibians. Higher species richness and abundance was seen in almost all vayals irrespective of the area of vayals. The highest reptile abundance was in vayals with smaller extent.

The results of Non-metric Multidimensional Scaling ordination (NMDS) analysis for amphibians (stress value is 0.12) showed that the amphibians were more associated with surrounding vegetation (p=0.001) of vayals, altitude (p=0.001) and plant composition (p=0.001) and not significantly associated with extent (p= 0.05) of vayals. The NMDS result for reptiles (stress value is 0.14) indicated a strong association of reptile with the altitude (p=0.001) and surrounding vegetation of vayals (p=0.003) and not significantly associated with plant composition (p=0.1) and extent (p=0.7).

The amphibian and reptile species with wider distribution have been reported to occupy different vegetation types at different elevations (Biju and Bossuyt, 2009; Srinivasalu *et al*., 2014; Gopalan *et al*., 2016; Pal *et al*., 2018; Harikrishnan *et al*., 2018; Rajkumar *et al*., 2018; Das *et al*., 2019a and 2019b; Das *et al*., 2020; Wogan *et al*., 2021; Vyas, 2021; Cota *et al*., 2021). There a few species with habitat specificity limiting their distribution (eg. *Raorchestes travancoricus* and *R. griet*). The breeding requirement of certain species limit their abundance in the distributional rang as in the case of *Rhacophorus malabaricus,* which build foam nests and lay eggs (Kadadevaru and Kanamadi, 2000).

Apart from the widely distributed species, there are altitude-specific and habitat-specific species like the *Rhacophorus pseudomalabaricus* and *R. calcadensis*. These two species were only recorded from vayals surrounded by evergreen forest mostly above 1000msl up to 1700msl. Plant composition ranks of these vayals were 1, 3, 4, and 5, and the size of vayals ranges from 0.17 to 3.35ha. Here, even the habitat-specific species were found using natural to highly degraded vayals and the extent also varied from small to medium size.

The observations of the present study also show a correlation of the substrate types and possibly with the forested surroundings. Further, the presence of perennial and seasonal streams in vayals is a driving factor for their distribution in vayals in all five habitat types.

Whitaker *et al.* (1973) defined the habitat of a species as the portion of a multi-dimensional hyperspace occupied by a given species. This hyperspace is defined by a number of habitat factors. Multiple factors influence the habitat choice, which is a complex decision (Graeter, 2005). Litter fall rates, mast fruiting, breeding habitat constraints, heterogeneity, topography, altitude and precipitation are reported to have profound influence on the amphibian species diversity and abundance (Allmon, 1991; Duellman, 1999).

Amphibians reportedly show a preference for forested habitat over open disturbed habitat (Rothermel and Semlitsch, 2002; Vasconcelos and Calhoun 2004). However, this preference differs by species and among studies. Species distribution is partly determined by habitat preference, which is based on physical structure, prey availability, nest sites, refuges from inclement weather and predators (Bellows *et al*., 2001; Smith and Ballinger, 2001). The preferred habitat extend higher fitness to such species adapted to the preferred habitat (Jaenike and Holt, 1991). Heterogeneous microhabitat support higher diversity (Purushotham *et al*., 2011).

Vayals are ecosystem units that may be waterlogged for some time or not necessarily filled with water or standing water. But with a sufficient amount of water/moisture content in the soil that supports the growth of hydrophytes and other grasses and sedges that prefer high soil moisture (Keeley and Zedler, 1998). A comparison between vayals in Periyar shows that these habitats vary in their plant composition and moisture content thereby offering heterogenous micrhabitats. The difference in the surrounding vegetation also contributes to this variations. The results of the present study suggest that the amphibian and reptile richness, abundance, and diversity in the vayal ecosystems do not change with respect to the increase in extent of the vayals. This result was similar to that of studies on wetland amphibians by Richter and Azous (1995) and Babbitt (2005), in which they found that there was no significant relationship between amphibian richness and size of the wetland. The highest species richness was observed from smaller wetlands. Richter and Azous (1995) had also reported that the plant composition and the amphibian richness were not significantly associated.

In the current study, the NMDS result shows that plant composition has significant association with amphibian. Studies on higher taxa suggest that vegetation has influenced species richness (MacArthur and MacArthur, 1961; MacArthur *et al*., 1966).

A study by Gibbs (1993) suggests that conserving smaller wetlands will reduce the extinction risk of animals with low density and low population growth like turtles. According to his study, amphibians were less prone to extinction due to their high density and population growth. Smaller areas will not support species with larger area requirements (Humphrey and Kitchener, 1982). Studies on birds suggest that smaller forest fragments are used by short-distance migrant birds and resident birds and larger forest fragments are used by long-distance migrant birds (Blake and Karr, 1984). This study suggests that conserving one larger forest fragment is better than conserving two or more smaller fragments because long-ranging species tend to use all different microhabitats and the smaller fragments may not provide that for a longer period. While in the case of our study, for amphibians and reptiles, the extent of vayal does not matter for their richness, abundance, and diversity. This could be because these animals are restricted to very smaller areas that provide more resources like food, protection from predators, and less interspecific competition (Abramsky *et al*., 2002) when compared to highly moving vertebrates like birds and mammals. Further area-specific studies from these smaller to larger vayals will shed more light on this aspect. Studies on vernal pools suggest that the hydroperiod was the key factor which supports amphibian species richness (Snodgrass *et al*., 2000; Paton and Crouch, 2002; Babbitt, 2005; Baldwin *et al*., 2006; Tournier *et al*., 2017). In the current study, influence of the hydroperiod of vayals on the richness and abundance of amphibians was not examined. This needs to be further investigated, especially in the current scenario of global temperature rise and biodiversity loss.

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Chapter 7

Status, distribution and behavior of Raorchestes travancoricus

Chapter 7. Status, distribution and behavior of *Raorchestes travancoricus*

7.1. Introduction

Amphibians are smaller in size compared to other vertebrates and their home ranges are also very small (Wells, 2007; Vitt and Caldwell, 2014). Therefore, their movement and utilization of home range vary considerably compared to birds and mammals or even reptiles (Wells, 2007; Vitt and Caldwell, 2014). Many of the amphibians show site fidelity (Wells, 2007; Vitt and Caldwell, 2014) and studies have reported that many species use the same home range for years (Marvin, 2001; Rebelo and Leclair, 2003; Wells, 2007). Their elusive nature has made it difficult to study the movement patterns (Wells, 2007). The daily and seasonal movements define their behaviour like breeding, territorial, inter and intraspecific interactions and acoustics (Wells, 2007; Vitt and Caldwell, 2014). Tropical arboreal amphibians show higher heterozygosity, which represents their higher adaptations to live in diverse microhabitats (Wells, 2007).

Till the 1950s, there was no published information on sexual selection, especially the female choice (Cronin, 1992). Darwin's attributes of a sense of beauty in animals, like in humans, were followed till then. Research on sexual selection has now become the backbone of evolutionary biology and behavioural ecology study (Andersson, 1994). Though the amphibians communicate through visual, tactile and chemical senses, acoustic communication is the prime method in anurans (Vitt and Caldwell, 2014). The acoustic communication system in anurans is well developed. Each species has a very unique vocalization, which helps them to even identify individuals (Bee *et al.,* 2013a and 2013b; Vitt and Caldwell, 2014; Garg *et al.,* 2021). Four types of calls are identified in anurans; advertisement call, reciprocation call, release call and distress call. The advertisement calls were thought to be mating calls, or which were produced as part of sexual selection but also serve several other functions too. Hence, advertisement calls are further categorized into three *viz*. territorial call (to establish and defend its territory), encounter call (encounter with another male) and as believed earlier, the courtship call (to attract conspecific gravid female) (Vitt and Caldwell, 2014).

Many species, which are considered to be endangered or gone extinct have a better population in several fragments (Pal *et al.,* 2010). This finding calls for species-specific and community studies for implementing better management and conservation strategies to protect the habitat and the species. Most of the species-specific studies on home range, acoustics and other behavioural aspects began after the 1950s. Wells (1980) studied ecology, social organization and vocalization of *Colostethus inguinalis*. This study revealed their elaborate courtship and agonistic behaviour. Females were holding smaller territories and not all the females have dry season territories. The females that hold dry season territories were found to be active during dry seasons. Wet season territories of males were seen to be ten times bigger than their dry season territories. This species was also observed to have seasonal changes in social organization. Tuttle and Ryan (1982) investigated the impacts of negative interaction (prey-predator) by bat species, *Trachops cirrhosus* on frog species, *Smilisca sila* during their breeding season like how it affects breeding behaviour, acoustic activity, ability to synchronize their calls with neighbours' calls, the complexity of calls and niche selection. These frogs were seen using visual cues to detect bats, which will lead to a reduction in the rate and complexity of calls and choosing a location to hide from bats. Bats chose frog vocalization that is away from the surrounding noises like a waterfall. The study by Ryan (1983) suggested that different components of an advertisement call in *Physalaemus pustulosus* are associated with different functions. Rand (1985) suggested that male-female interactions like sexual selection are the major driving factors of anuran acoustic evolution.

Lopez *et al*. (1988) studied the differences in frequency and pulses of advertisement calls and aggressive calls by field playback method. Ryan and Rand (1990) studied females' preferences in sexual selection in *Physalaemus pustulosus* and found that the preexisting details of sexual traits are the females' sexual selection criteria. A study by Ryan and Wilczynski (1991) on the variation in the acoustics of *Acris crecpitans* reported variation in all the variables in advertisement call within a population. Gerhardt (1991) investigated the importance of static and acoustic variables in mate selection by female tree frogs. Roy and Elepfandt (1993) studied breeding calls of three frog species from Assam and Meghalaya. Study by Das (1996) on spatial, temporal and trophic resource partitioning in a community of eight frogs on the southeast coast of Sothern India. He reported that larger species chose more microhabitats and different types of food while smaller species chose smaller prey but the number of prey fed is higher than larger species. Smaller species are resource specialists than their sympatric larger generalists. Lillywhite *et al*. (1998) found that *Polypedates maculatus* selected microhabitats to avoid overheating and related disruption of lipid barrier and body water loss through sweating. Luddecke *et al*. (2000) reported spatial and temporal niche partitioning in anurans from the study on acoustic activity partitioning in anuran communities in the Neotropical highlands. Bridges and Dorcas (2000) suggested acoustic behaviour and temporal variation studies as a standard method to monitor anuran communities. Bastos and Haddad (2002) studied acoustic and other breeding behaviour in *Scinax rizibilis* found in Brazil. Hatano *et al.* (2002) studied the effects of light intensity, temperature, relative humidity, and photoperiod influencing the acoustic activity of *Hylodes phyllodes*. The study concluded that the species is active by day and most active between 07:00 to 08:00 hours and acoustically between 10:00 to 13:00 hours. Light intensity was found to be positively correlated with acoustic activity and the mean temperature is negatively correlated with acoustic activity. Precipitation had no effect on the species activity. Wycherley *et al*. (2002) compared acoustic characters of *Rana lessonae* between populations. Gottsberger and Gruber (2004) studied niche partitioning among anurans in Guiana. They found that patterns in rain are the main triggering factor behind breeding and the females reached the breeding site even before males started to call. Direct developing frogs were active during the beginning of the monsoon and the species with terrestrial oviposition and parental care were continuously active. Based on the reproductive mode, the anurans are temporally partitioning their niches.

Canavero *et al*. (2008) studied acoustic activity patterns in anuran communities in Uruguay with temperature and rainfall. According to the study, photoperiod is the major driving factor of acoustic activity in anurans than temperature and rainfall. Page and Ryan (2008) investigated the preference of bats on simple and complex acoustic characters of *Physalaemus pustulosus* frogs and found that bats prefer complex acoustic characters to simple characters. So the complex calls are considered to be a threat to the anurans. Hillers (2008), based on a study on assemblages of frogs and toads in the West African forests, reported that habitat degradation affects the canopy opening and microhabitats thereby affecting the assemblage of anurans.

Several species have gone locally extinct and altogether species richness reduced due to fragmentation. Hamer and Organ (2008) studied the ecology of endangered species *Litoria raniformis* in Melbourne and observed that the species showed clustered population and were mostly found on the submerged vegetation in the water body. This vegetation provides oviposition sites for the species and also protection for tadpoles from predators. They recorded a reduction in population size compared to previous years and attributed to the the human population growth and related habitat modification and fragmentation. Steelman and Dorcas (2010) reported that air temperature and relative humidity positively associated with the activity while precipitation has no significant association with acoustic activity of frogs. Urbina-Cardona and Flores-Villela (2010) studied 222 amphibians and 371 reptiles from Mexico with the help of niche-based distribution models. They suggested new areas for conservation of herpetofauna in Mexico which can cover 80% of the herpetofauna present in Mexico. Samarasinghe (2011) published a detailed call description of *Pseudophilautus popularis*. Sinsch *et al.* (2012) studied the species richness using morphological, molecular and acoustic tools and also niche partitioning by amphibians in wetlands in Rwanda. They reported very low niche breadth, low interspecific overlap and acoustic niche partitioning. Dayananda and Wickramsinghe (2014) reported up and down movement during the most active period of *Pseudophilautus popularis*. This study suggested that the protection of vegetation is the prime factor for species conservation.

Gingras *et al*. (2013), based on the study on advertisement calls of 90 species of anurans, suggested that several acoustic characters are associated with phylogenetic signals. Bee *et al*. (2013a) reported two types of calls and the note types and that complexity varied within an individual according to their social environment in *Raorchestes graminirupes*.

Bee *et al*. (2013b) reported two types of calls in *Pseudophilautus kani*. Larger males produced faster pulses within a short period. Sabino-Pinto *et al*. (2014) described an advertisement call of three sympatric leaf litter frogs in the rain forests of Madagascar. Rowley *et al*. (2014) studied and described the advertisement call of *Limnonectes dabanus* and its breeding behaviour. Padhye *et al*. (2015) reported the distribution and aspects of the ecology of *Raorchestes tuberohumerus*. They have calculated its Extent of Occurrence (EOO) and Area of Occupancy (AOO) and suggested a new IUCN category. Thomas *et al*. (2014) studied only one type of call in the endangered fossorial *Nasikabatrachus sahyadrensis*. In 2016, Goutte *et al*. (2016) found change in the acoustic characters with changes in habitat. Goutte *et al*. (2018) observed that the temporal acoustic characters did not show any changes according to changes in the habitat.

Weaver *et al*. (2020) studied temporal and spatial acoustic characters of six Australian frog calls using calls submitted through the FrogID citizen science project. They found that the acoustic characters within a species vary in connection with the geographic area of recording, the time difference (intra-annual) between recordings and the number of individuals recorded. They also suggested that minimum of 20 individuals should be recorded for studying the variation in advertisement calls. Cutajar *et al*. (2020) reported the presence of *Megophrys jingdongensis* from Vietnam for the first time with a description of its advertisement call. Callaghan and Rowley (2021), from a study on the temporal patterns in the acoustic behaviour of frogs in Australia, suggested that the relationship between acoustic activity and time of the day is conserved through evolution. Das *et al*. (2020) studied the distribution and vocalization of *Raorchestes resplendens* in Munnar landscape. They recorded this species from 38 locations and described its call for the first time and calculated its extent of occurrence and area of occupancy which covered an area of 289km^2 and 84km^2. Abhijith and Mukherjee (2020) observed laying of eggs by four bush frogs in the wet soil during the southwest monsoon season. They also reported the clutch size (55 eggs) and the development took around 21 days. Garg *et al*. (2021) did a comprehensive study on all the bush frogs belonging to the genus *Raorchestes* from the Western Ghats and grouped them into 16 based on molecular tools, morphological characters and acoustic parameters.

After 2005, species distribution model studies got more attention (Pearson *et al.,* 2007; Siqueira *et al.,* 2009; Singh *et al.,* 2015). Similarly after 2010, more studies on acoustics were reported (Bee *et al.,* 2013a and 2013b; Gingras *et al.,* 2013; Sabino-Pinto *et al.,* 2014; Thomas *et al.,* 2014; Padhye *et al.,* 2015; Rajkumar *et al.,* 2016) and formed a crucial part of species description (Vijayakumar *et al.,* 2014; Zachariah *et al.,* 2016; Garg *et al.,* 2017; Garg and Biju, 2017; Garg *et al.,* 2021).

There are mainly two types of anuran assemblages in the tropics; arboreal and leaf litter or forest floor anurans (Wells, 2007). In the Kerala part of Western Ghats, more than 35% of amphibians belong to the first category and the number continues to increase through new descriptions (Vijayakumar *et al.,* 2014; Zachariah *et al.,* 2016; Garg *et al.,* 2021). The genus Raorchestes is one among them, which is evolved and diversified in peninsular

India (Vijayakumar *et al.,* 2016). This genus holds the highest diversity and endemism (Jiang et al., 2020; Garg et al., 2021). Moreover, these species are mostly range-restricted. This necessitates specific studies in the Western Ghats. Like diversity study and community ecology study, species-specific and area-specific studies are also a very important part of conservation. *Raorchestes travancoricus* is one such arboreal frog endemic to the Western Ghats. *R. travancoricus* was recorded during the reconnaissance surveys in 2014 from Periyar, mostly from vayal associated habitats (Rajkumar, 2016). *Raorchestes travancoricus* was collected by Ferguson and described by Boulenger (1891). The description was based on a single gravid female specimen and the collection location mentioned was the foot of the hills of Bodinayakanur (Boulenger, 1891). After the description, there was no sighting of this species for a long time and was considered extinct till2004 (Rajkumar, 2016). After more than 110 years, it was spotted in 2004 during an expedition (Biju and Bossuyt, 2009). They spotted and collected individuals from two locations, Vagamon and Vandiperiyar. Even after its rediscovery, the species was listed as extinct in the IUCN Red List assessment (Srinivas and Bhupathy, 2013). In the present study, the niche preference, acoustic activity pattern, temporal and spectral patterns of vocalization and morphometrics of the species were investigated in detail.

7.2. Methods

The Travancore Bush Frog (*Raorchestes travancoricus*) was recorded during the reconnaissance surveys in 2014. Like any other bush frogs in the Western Ghats, this species is also active during the monsoon season. The methods chosen for this study were as detailed in chapter 3 (General Methods). Two methods; visual encounter surveys (3.2) and audio strip transects (3.4) were chosen. The surveys were done in three monsoon seasons *viz*. the last week of May to the end of July in 2015, 2016 and 2017. In the 2014 monsoon season, we found the frog from eight locations in Periyar Tiger Reserve. Using this information, we did niche modeling to predict the suitable areas for getting a better result for our distribution surveys.

7.2.1. Visual encounter surveys – Niche partitioning

Visual encounter surveys were done for the distribution range and niche partitioning of *R. travancoricus* and its sympatric frog species. Time-constrained visual encounter surveys were done with 15 minutes for each sampling. The survey was carried out between 18:00 to 06:00 hours. Whenever a *R. travancoricus* or its sympatric species was encountered, the height of their occupied niche was recorded using a measuring tape. The snout-vent length measurements of males, females and juveniles observed during the survey was recorded using INSIZE digital caliper and a digital SLR camera was used to photograph.

7.2.2. Audio strip transects – Acoustic activity partitioning/pattern

Audio strip transects were done for studying the acoustic activity pattern. *Raorchestes travancoricus* was active mostly during the night. Therefore surveys were from dusk (18:00 h) to dawn (06:00 h) irrespective of sunrise and sunset. The survey was carried out in Anathodu. Four 30 meter transects with 1meter width on either side were marked. In every two hours, two strip transects which maintained a minimum of 30m distance from the other was walked and the calling *R. travancoricus* and its sympatric species frogs were counted. Each transect was walked within a maximum of 5 minutes. The survey was repeated till 06:00 h. The very next day, the survey was started at 19:00

hours and continued till 05:00 hours. The survey was conducted during the peak southwest monsoon season in May, June and July.

7.2.3. Niche modelling

During the surveys conducted in 2014, *Raorchestes travancoricus* was recorded from eight locations. Using that location details and already known locations like Vagamon and Vandiperiayar and the type locality, we ran a niche model. The modeling was performed with the help of MaxEnt and QGIS with the help of ~30 arc seconds data for altitude, average temperature, and precipitation and the 19 bioclimatic variables available at the WorldClim website (http://www.worldclim.org/). Ground-truthing surveys were conducted in the predicted very high, high, medium, and low priority areas to find out its distribution range. Whenever a *R. travancoricus* was found from a new area, the geographical coordinates were recorded using a Garmin eTrex 30 GPS Device. The extent of occurrence (EOO) was calculated by overlaying the hexagonal layer over the niche-based prediction map and counting the grids with at least some prediction. Each hexagonal grid is approximately 100 km^2 (Padhye *et al.,* 2015). The extent of occurrence and area of occupancy (AOO) of the final distribution was calculated with the help of GeoCat (http://geocat.kew.org).

7.2.4. Call description

The calls were recorded during night time between 17:00 to 00:00 hours, when the males are most actively vocalizing. The call was recorded using Zoom H4n handy recorder by holding it approximately 0.5m away from the vocalizing individual. The calls were recorded from two locations in Periyar Tiger Reserve viz., Uppupara and

Anathodu. The calls were monitored using a JBL headphone in real-time and the recorder gain setting was set to get better signals with less noise before recording the calls. Temperature and humidity at the time of the recording were noted and snout-vent length was measured using a digital caliper to the nearest 0.1mm for all the individuals that were recorded.

Temporal call and pulse properties and dominant frequency (spectral property) of calls were measured using the software Raven Pro 1.6 (Cornell Laboratory of Ornithology, Ithaca, NY, USA). The measurements of calls were described based on Bee *et al.* (2013a and 2013b). Call properties like call duration (ms) (time between the start of first pulse and the end of last pulse in a call), call rise time (ms) (time between the start of first pulse and the pulse with maximum amplitude) call fall time (ms)(time between the pulse with maximum amplitude and end of last pulse), inter-call interval(time between end of a call to the start of the next call), note repetition rate {(notes per call – 1)/call duration} and overall dominant frequency were analyzed for the current study.

7.2.5. Morphometric measurements

Morphometric measurements were taken using a digital caliper to the nearest 0.1mm. Biju and Bossuyt (2009) was followed for measurements and terminology. The measurements were snout-vent length (SVL), head width measured at the angle of the jaws (HW), head length measured from the rear of the mandible to the tip of the snout (HL), snout length measured from the tip of the snout to the anterior orbital border of the eye (SL), eye length - the horizontal distance between the bony orbital borders of the eye (EL), inter upper eyelid width - the shortest distance between the upper eyelids (IUE), maximum upper eyelid width (UEW), forelimb length measured from the elbow to the base of the outer palmar tubercle (FLL), hand length measured from the base of the outer palmar tubercle to the tip of the third finger (HAL), shank length (ShL), thigh length (TL) and foot length measured from the base of the inner metatarsal tubercle to the tip of the fourth toe (FOL). The Natural History Museum, London was visited to examine the type specimen of *R. travancoricus*. The type specimen was photographed using Nikon D3200 digital SLR camera.

7.3 Results

A total of 43 Visual encounter surveys yielded 268 sightings of *Raorchestes travancoricus* from the grasslands at Anathodu. Apart from *R. travancoricus*, sympatric frogs like *Pseudophilautus wynaadensis, Raorchestes akroparallagi and R. griet* were also recorded with 76, 202 and 120 sightings respectively. A total of 117 audio strip transects were done and recorded 190 sightings of *R. travancoricus* followed by 137 sightings of *R. akroparallagi*, 86 sightings of *R. griet* and 51 sightings of *P. wynaadensis*.

7.3.1. Niche partitioning

Visual encounter surveys were done during the monsoon, starting from the end of May to July. The dominant grass species in the grasslands at Anathodu was *Chrysopogon hackelii*. *Raorchestes travancoricus* was mainly found on this grass species. The average height of *C. hackelii* grass was 192.55 cm (±14.002), with an average basal area of 159.25 cm (±26.34) and the average total area of the grass clump recorded was 260.51 cm (±43.97). The average leaf blade width of *C. hackelii* where the *R. travancoricus* was found was 13.82 mm (±1.34) (Fig. 7.1A and 7.1B). Apart from *C. hackelii, R. travancoricus* was found on *Ageratina adenophora*, *Hedychium coronarium* and *Melastoma malabathricum*.

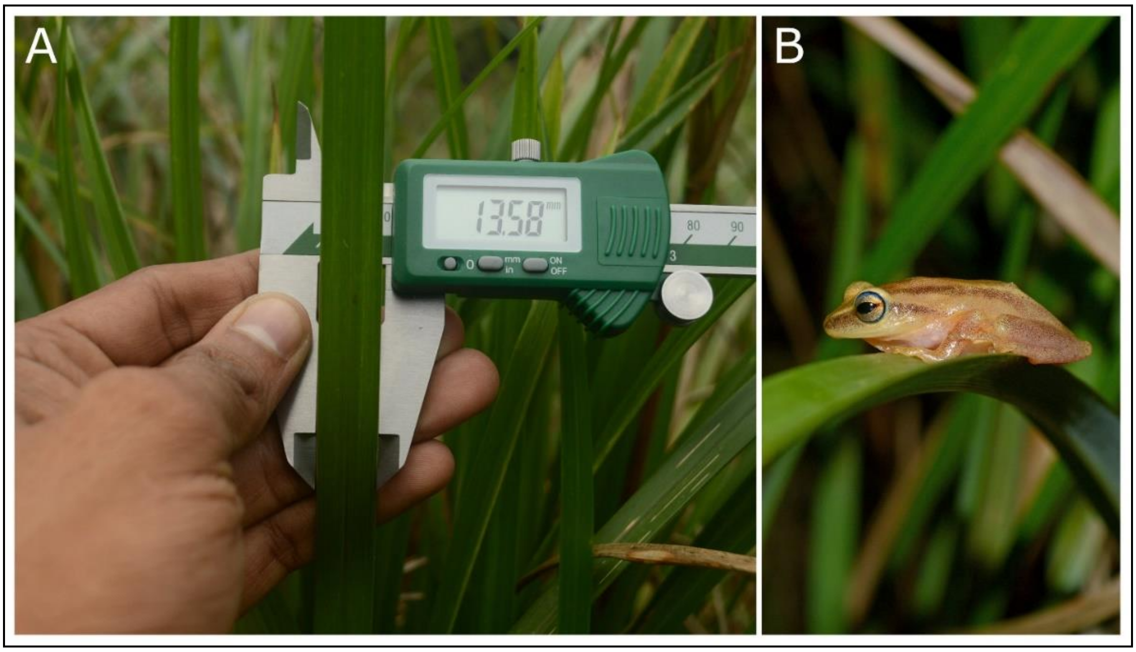

Fig. 7. 1 Measuring *Chrysopogon hackelii* leaf blade width

The average height at which *R. travancoricus* occupied a niche in the *C. hackelii* was 103.09 cm (±12.71). The niches in the top layer of the *C. hackelii* grass was dominated by *R. travancoricus* (Fig. 7.2). Lowest recorded height of *R. travancoricus* on *C. hackelii* grass was 62cm and the highest was 135cm. The niches in the bottom part of the *C. hackelii* grass clumps was occupied by *R. griet* 11.24 cm (±3.85). Lowest recorded height of *R. griet* was 3cm and the highest was 34cm. *Pseudophilautus wynaadensis* and *Raorchestes akroparallagi* were using the niches between *R. travancoricus* and *R. griet* niches. *Raorchestes akroparallagi* was found to occupy mostly the niches below *R. travancoricus* at a height of 63.80 cm (±17.38) and *P. wynaadensis* mostly used the niches below *R. akroparallagi* and above *R. griet* at 48.80 cm (±13.43). The lowest and highest recorded height of *P. wynaadensis* was 24cm and 87cm and *R. akroparallagi* was 27cm and 102cm. During the survey, some non-vocalizing individuals were found close to the base of the *C. hackelii* clump (Fig. 7.3).

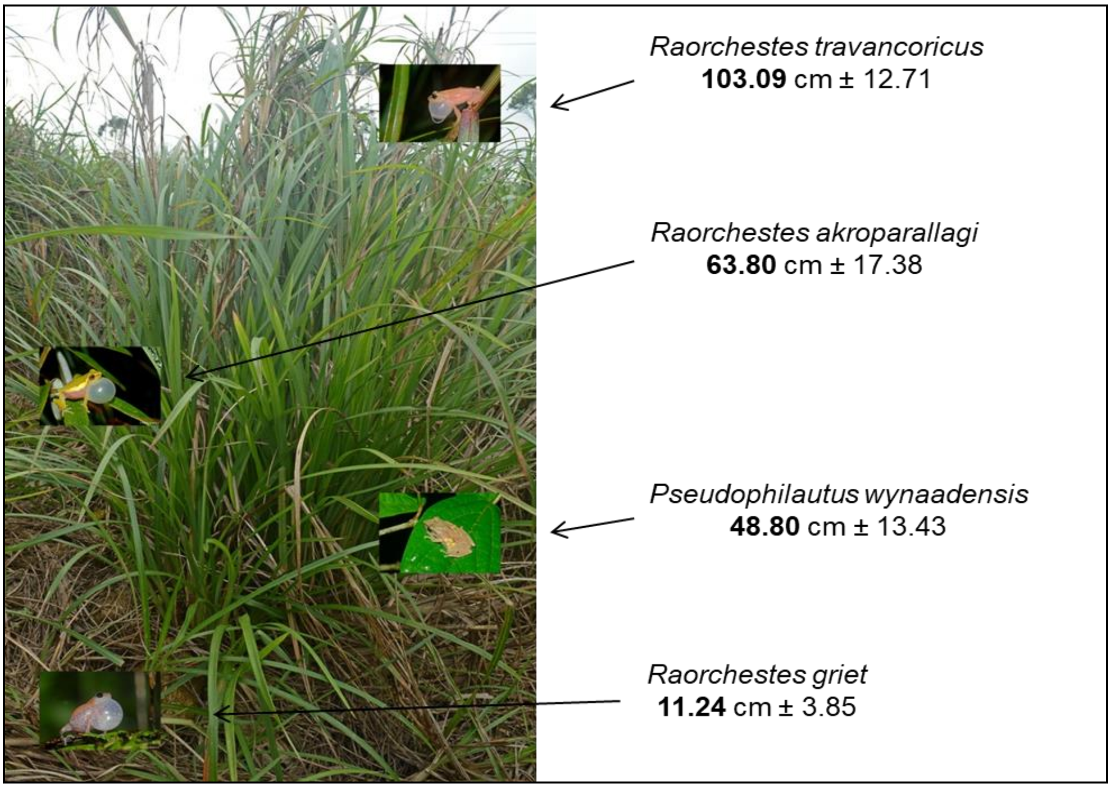

Fig. 7. 2 Pictorial representation of niche partitioning by *Raorchestes travancoricus* and its sympatric species.

Fig. 7. 3 Adult *Raorchestes travancoricus* recorded close to the base of the *Chrysopogon hackelii* clump

7.3.2. Acoustic activity partitioning/pattern

Audio strip transect surveys were done during the monsoon, starting from the end of May to June, and July. The highest activity of *R. travancoricus* was observed between 22:00 to 02:15 hours (Fig. 7.4). Peak activity of *R. travancoricus* was recorded at 00:00 to 00:15 hours with a relative abundance (RA) of actively calling males was 69.35%. The next recorded peak activity was between 23:00 to 23:15 hours with RA 67.64% followed by 22:00 to 22:15 hours, 01:00 to 01:15 hours and 02:00 to 02:15 hours with RA 61.53%, 60%, and 56.86% respectively. The least activity was recorded at 18:00 to 18:15 hrs and the RA was 7.89%.

The highest activity of *P. wynaadensis* was recorded at two time periods (Fig. 7.4). One was from 18:00 to 21:15 hours and the second was from 03:00 to 06:15 hours. The highest activity was recorded between 18:00 to 18:15 hours with a RA of 31.57% followed by 06:00 to 06:15 hours and 20:00 to 20:15 hours with 25% and 20% RA respectively. *P. wynaadensis* was least active during 22:00 to 22:15 hours with 3.84 RA and no actively calling individuals were found from 23:00 to 02:15 hours from the transect.

Raorchestes akroparallagi was also highly active during almost the same period of that of *P. wynaadensis* (Fig. 7.4). Peak activity was recorded from 18:00 to 21:15 hours and 04:00 to 06:15 hours. This species was found to be highly active during 05:00 to 05:15 hours with a RA of 67.64% followed by 18:00 t0 18:15 hours and 19:00 to 19:15 hours with 57.89% and 56.41% of RA respectively. The least activity of *R. akroparallagi* was recorded between 01:00 to 01:15 hours with 2.5% RA.

The highest activity of *R. griet* was recorded from 22:00 to 03:15 hours (Fig. 7.4). Peak activity was recorded between 02:00 to 02:15 hours (RA 39.21%) followed by 01:00 to

01:15 hours and 03:00 to 03:15 hours with 37.5% and 29.41% RA. The species was least active from 18:00 to 18:15 hours with 2.63% RA.

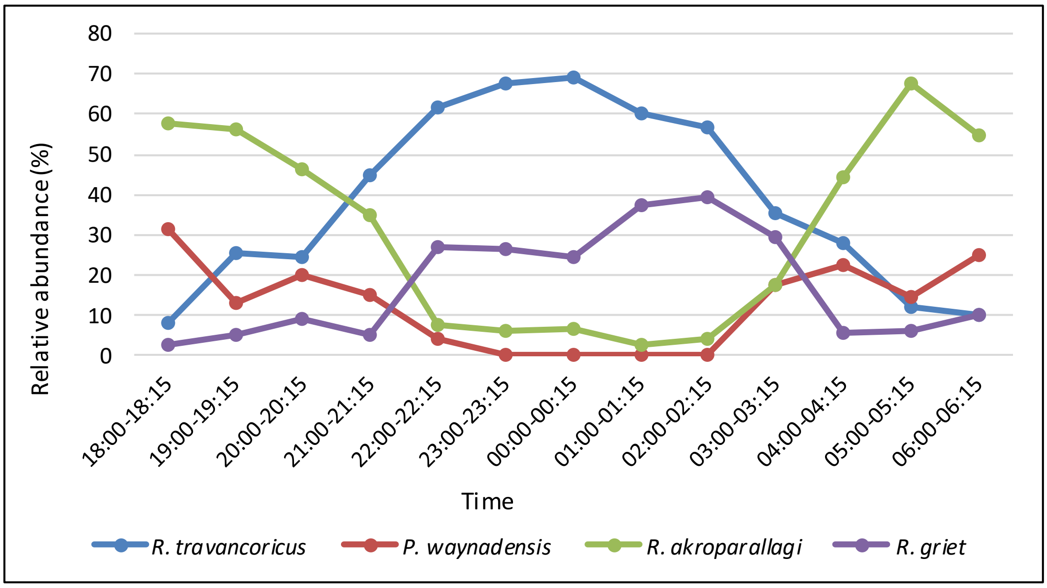

Fig. 7. 4 Graph showing temporal acoustic activity partitioning of *Raorchestes travancoricus* and three sympatric frogs.

7.3.3. Niche modelling

Niche-based prediction model of *R. travancoricus* was prepared using published sighting records from Bodinayakanur, Vagamon and Vandiperiyar and the eight new locations from our reconnaissance survey *viz.* Uppupara, Gavi, Upper Manalar, Ervangalar, Mangaladevi, Moolavaiga, Kumarikulam and Chokkampatti (Fig. 7.5). The niche-based prediction model suggests that *R. travancoricus* is restricted to the Western Ghats. The extent of occurrence calculated by overlying hexagonal grids over the niche-based prediction map was approximately 10,176 km^2 (Fig. 7.5). Based on the prediction map, ground-truthing surveys were conducted at locations inside Periyar Tiger Reserve. Surveys were conducted in three monsoon seasons (2016 to 2018). The frog was recorded from similar kind of grassland habitats in Navikkayam, Swamikkayam, Manakkavala, Sathram, Undenmedu, Ottakkallu, Anathodu, Ponnambalamedu, Vavala Halla, Varayadinkoka, Manamutti Mala, and Aruviyoda (Table 7.1). The recorded calls were also used to identify the presence of *R. travancoricus* during the survey. Altogether there are 23 locations (Fig. 7.6) out of which 20 were from Periyar Tiger Reserve (Fig. 7.7). The Extent of Occurrence (EOO) and Area of Occupancy (AOO) based on the 23 locations are 2,054.10 km^2 and 92.00 km^2 respectively (AOO calculated based on IUCN default cell width 2 km).

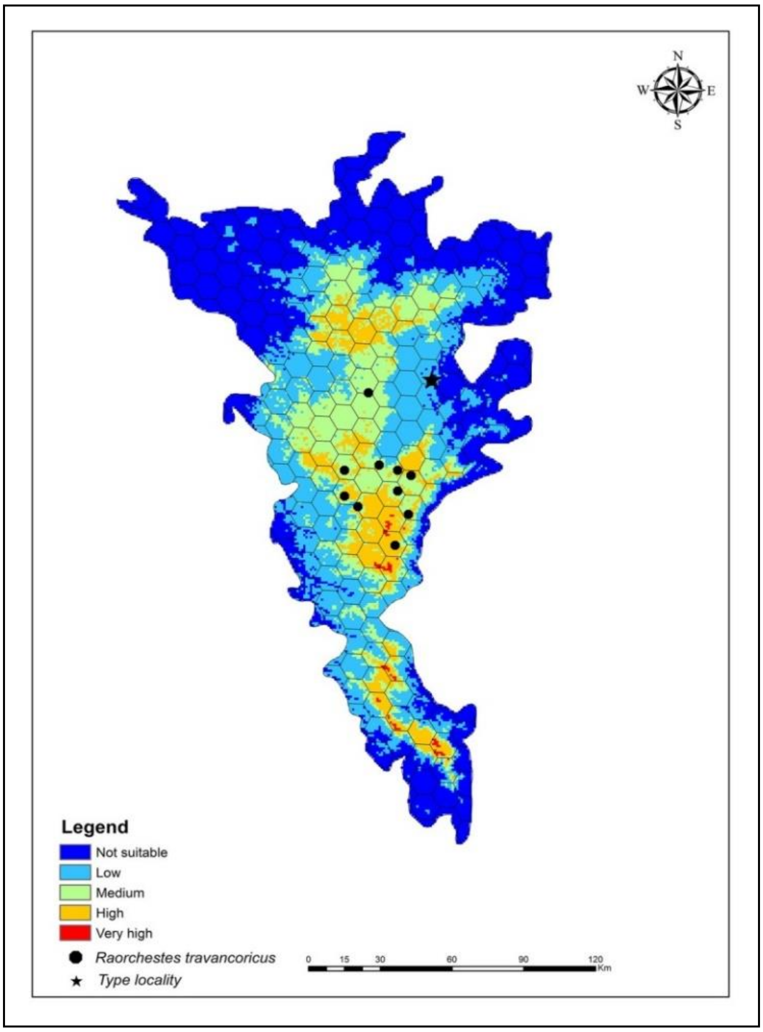

Fig. 7. 5 Map showing niche based prediction of distribution of *Raorchestes travancoricus* in the southeern Western Ghats.

Table 7. 1 Sighting locations of *R. travancoricus* in the southern Western Ghats

No	Location	Elevation (msl)	Latitude	Longitude
1	Bodanayakanur	350	10.01	77.35
2	Vandiperiyar	853	9.57	77.09
3	Vagamon	991	9.69	76.91
4	Uppupaara	1188	9.47	77.09
5	Gavi	1205	9.45	77.16
6	Upper Manalar	1638	9.56	77.32
7	Eravangalar	1484	9.58	77.30
8	Mangaladevi	1250	9.60	77.22
9	Moolavaiga	1552	9.35	77.30
10	Kumarikulam	1092	9.50	77.27
11	Chokkampatti	1323	9.29	77.28
12	Navikkayam	1204	9.54	77.25
13	Swamikkayam	1226	9.52	77.24
14	Manakkavala	1204	9.47	77.29
15	Sathram	1118	9.50	77.09
16	Undenmedu	1066	9.46	77.06
17	Ottakkallu	936	9.48	77.31
18	Anathodu	1064	9.37	77.16
19	Ponnambalamedu	1095	9.42	77.12
20	Vavala Halla	1043	9.49	77.25
21	Varayadinkoka	1151	9.39	77.14
22	Manamutti Mala	1063	9.52	77.12
23	Aruviyoda	1226	9.46	77.24

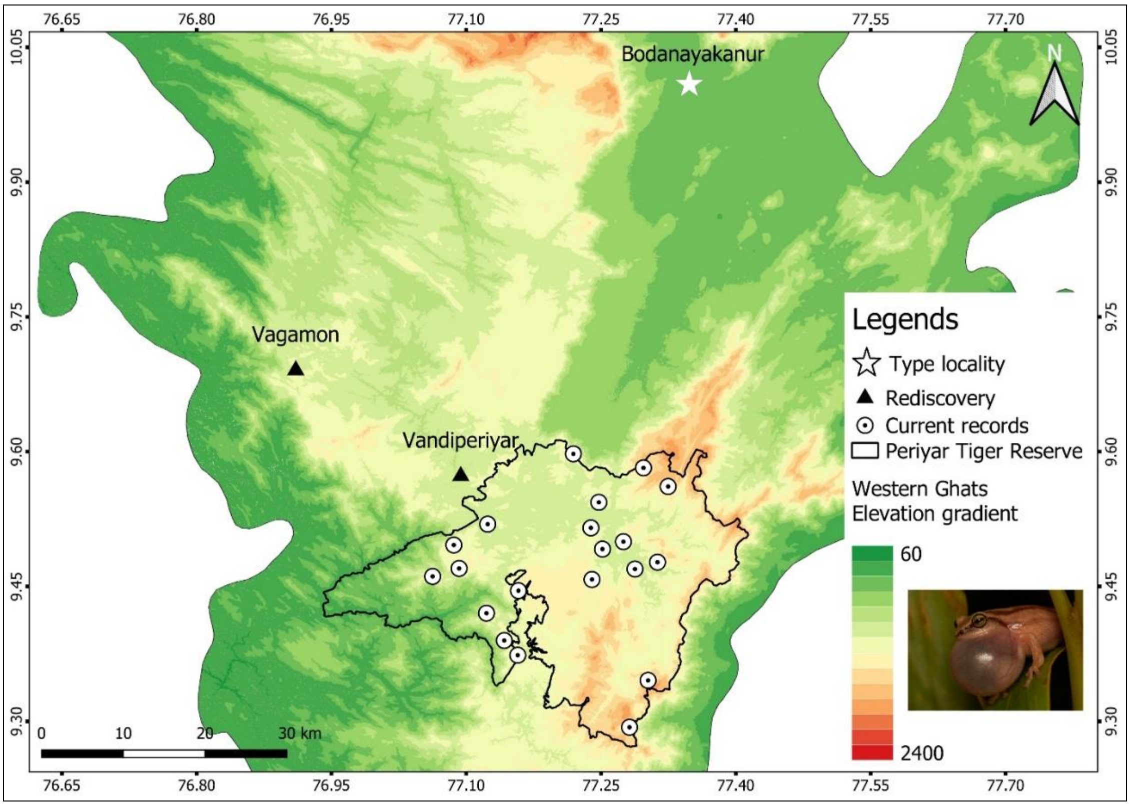

Fig. 7. 6 Map showing the distribution range of *Raorchestes travancoricus* in the Southern Western Ghats

7.3.4. Call description

Raorchestes travancoricus has two types of calls, pulsatile and non-pulsatile (Fig. 7.8). It starts with a pulsatile call with 15.93 (±1.94) pulses followed by non-pulsatile call with 7.21 (±1.75) notes. The average call duration of the pulsatile call was 600ms (±80ms) and the non-pulsatile call was 2770ms (±730ms) (total duration is 3.37s). The average note duration of the non-pulsatile call was 64ms (±10ms) and the average note repetition rate was 2.18 (±0.12). The recorded inter-call duration was 5630ms (±2590) and the dominant frequency of both pulsatile and non-pulsatile calls was 2842.38 (Hz) (Fig. 7.9). Call rise time is 364.13ms (±91.20ms) and the call fall time was 238.80ms (±63.54ms). Compared to non-pulsatile calls, the pulsatile call has a relatively lower amplitude (Fig. 7.8).

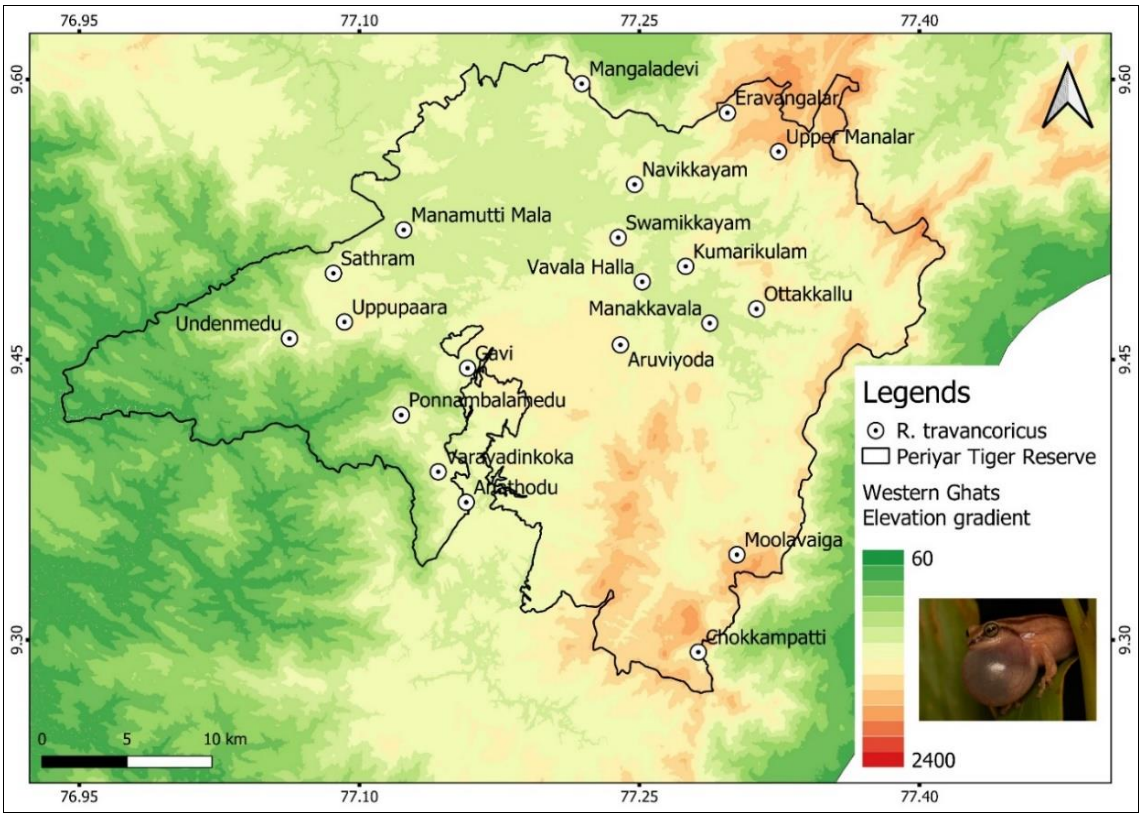

Fig. 7. 7 Map showing final distribution of *Raorchestes travancoricus* inside Periyar Tiger Reserve

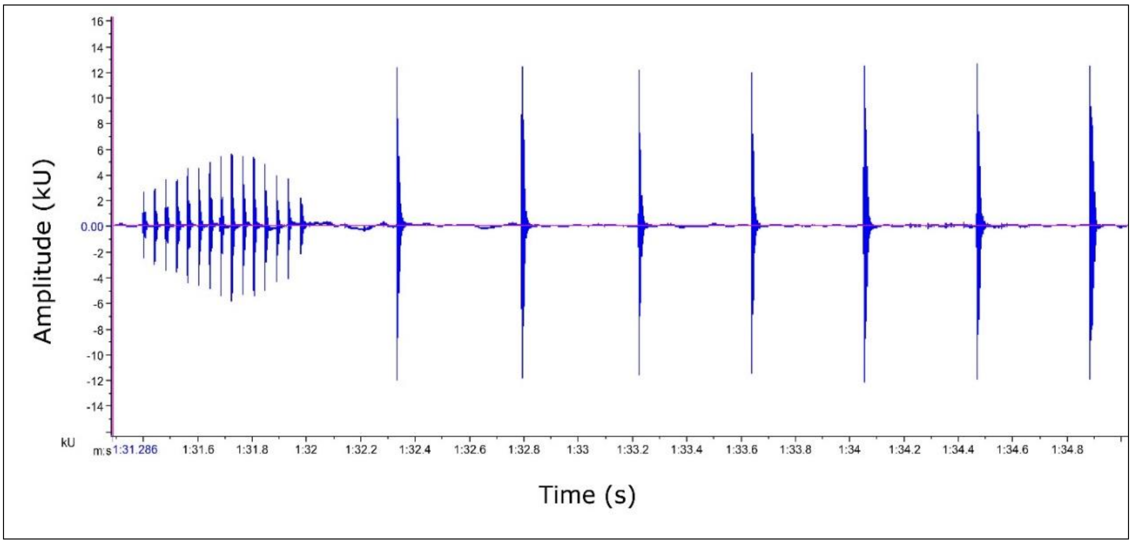

Fig. 7. 8 Waveforms of *Raorchestes travancoricus* male advertisement call (3.3s)

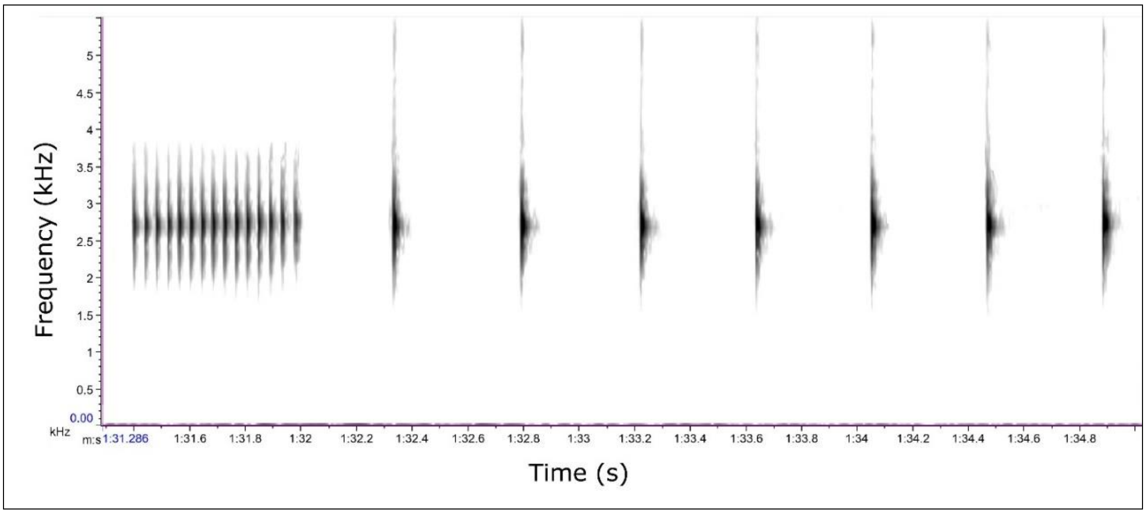

Fig. 7. 9 Spectrogram of *Raorchestes travancoricus* male advertisement call (3.3 sec)

7.3.5. Morphometric measurements

Type specimen of *R. travancoricus* from the Natural History Museum, London was examined. The following were the measurements of the type specimen (female) of *R. travancoricus* (Fig. 7.10)(BMNH 1947.2.6.35): snout-vent length (SVL) 29.65mm; head width (HW) 10.61mm; head length (HL) 10.76mm; snout length (SL) 3.68mm; eye length (EL) 3.58mm; inter upper eyelid width (IUE) 3.91mm; maximum upper eyelid width (UEW) 1.76mm; forelimb length (FLL) 6.52mm; hand length (HAL) 5.55mm; shank length (ShL) 14.23mm; thigh length (TL) 13.78mm; foot length (FOL) 8.45mm. One male specimen was collected from Periyar Tiger Reserve and the measurements were: snout-vent length (SVL) 26.49mm; head width (HW) 8.0mm; head length (HL) 7.71mm; snout length (SL) 3.8mm; eye length (EL) 3.45mm; inter upper eyelid width (IUE) 3.69mm; maximum upper eyelid width (UEW) 1.69mm; forelimb length (FLL) 5.57mm; hand length (HAL) 5.1mm; shank length (ShL) 11.9mm; thigh length (TL) 12.2mm; foot length (FOL) 9.41mm. Apart from this, the SVL of male, female and juvenile *R. travancoricus* were also measured from the field. The average

SVL of male *R. travancoricus* was 25.25mm (±0.87) and the female was 29.65mm (±0.44) (Fig. 7.11) and the juvenile was 13.65mm (±1.83) (Fig. 7.12).

The morphometric measurements of *R. travancoricus* were compared with published morphometric measurement (Biju and Bossuyt, 2009) details of its sympatric species (Table 7.2).

Table 7. 2 Average morphometric measurements of *Raorchestes travancoricus, R. akroparallagi, Pseudophilautus wynaadensis and Raorchestes griet*

#	*Raorchestes travancoricus*	*Raorchestes akroparallagi*	*Pseudophilautus wynaadensis*	*Raorchestes griet*
SVL (mm)	25.00	20.70	25.70	21.10
HW (mm)	7.80	7.80	8.70	7.00
HL (mm)	7.76	7.80	9.70	6.90
IUE (mm)	3.20	3.10	3.00	2.30
UEW (mm)	1.55	1.80	2.00	1.50
SL (mm)	3.60	3.30	3.90	2.50
EL (mm)	2.98	2.60	3.50	2.60
FLL (mm)	5.29	4.20	5.90	5.00
HAL (mm)	5.90	5.40	7.30	6.10
TL (mm)	11.15	10.50	12.60	8.90
ShL (mm)	11.00	10.30	13.40	9.10
FOL (mm)	9.36	8.00	10.80	8.60
Source	Average of Current study and Biju and Bossuyt, 2009	Biju and Bossuyt, 2009	Biju and Bossuyt, 2009	Biju and Bossuyt, 2009

Fig. 7. 10 Type specimen of *Raorchestes travancoricus* deposited at the Natural History Museum, London (BMNH 1947.2.6.35).

Fig. 7. 11 *Raorchestes travancoricus* female recorded during the study

Fig. 7. 12 *Raorchestes travancoricus* juvenile recorded during the study

7.4. Discussion

Ecological niche theory predicts segregation in the spatio-temporal habitat utilization among sympatric species (Pianka, 1981). Some areas are predicted to have multiple clades, allowing potential areas of sympatry. Such areas with several sympatric species might be satisfying partial environmental requirements for more than one species simultaneously (Hu and Jiang, 2012). Studies have indicated that closely related clades will not be equivalent in their environmental niches, but will typically be more similar than expected given the environments available to them (Hu *et al.,* 2016). Niche partitioning, the result of interaction between species, is an important mechanism for coexistence in natural assemblages (Gordon 2000). The amphibians within the same environment typically display interactions involving several niche dimensions (Bourne and York, 2001).

In the present study, *R. travancoricus* was observed to choose niches to avoid negative interaction with the sympatric species and with other neighbouring species during their most active period. *R. travancoricus* was mostly seen on *C. hackelii*. Apart from this, *R. travancoricus* was found on *Ageratina adenophora, Hedychium coronarium, and Melastoma malabathricum*. But these plants are only seen on the edges of grassland and the edge of roads. The maximum height of this grass species goes up to more than two meters but *R. travancoricus* was seen only up to 135cm. On the road edge vegetation, the species was seen up to around two meters in height. The leaf blades are not firm at the top part of the grass clump. Therefore finding a good spot on the leaf blades during windy rains will be a difficult task.

Like any other bush frogs in the Western Ghats, *R. travancoricus* and the three sympatric frog species were active during their breeding season from May to August. These four arboreal bush frogs were seen to exhibit spatial niche partitioning. This may be to avoid inter and intraspecific competitions. Studies on Neotropical anurans showed that during their peak activity, they temporally and spatially separated from other sympatric species (Luddecke *et al.,* 2000). Anurans show niche partitioning but the interactions that lead to this niche partitioning are still unclear (Hofer *et al.,* 2004). Here the niche preference may be due to a combination of factors like food preference, reproductive needs, mates' niche preference, acoustic competition, wind, humidity, and precipitation. Mostly arboreal amphibians are sit and wait predators (Wells, 2007). Therefore their preferred prey availability could also influence this pattern of niche partitioning. Arboreal amphibians are strictly active by night and stay in the hides to avoid moisture loss and avoid predators (Wells, 2007). Protazio *et al.* (2019) reported food and acoustic niche partitions facilitated coexistence of *P. albifrons and P. cicada.*

During the visual encounter surveys conducted in the daytime as part of the diversity study (Chapter 4), we found *R. travancoricus* inside the *C. hackelii* grass clump close to the base. Here the *R. travancoricus* uses the area close to the center of *C. hackelii* as their hide spots during daytime. When the light goes down, these animals climb up and find their spots to vocalize and find prey. Bush frog (*Pseudophilautus popularis*) from Sri Lanka is reported to move up and down among the vegetation during their most active time of a day (Dayananda and Wickramsinghe, 2014). However, such temporal variation in spatial niche partitioning in *R. travancoricus* was not observed during the present study. This may be due to limitations in the methodology used because such movement studies require methods suitable for documenting the activity budget. But if *R. travancoricus* showed any such upward and downward movement on the vegetation as part of niche partitioning, the frog should have been seen from different heights during our acoustic activity partitioning study. A few inactive individuals close to the base of the *C. hackelii* were seen at 30 to 50cm from the ground during the acoustic niche partitioning surveys around 21:00 hours. Butactive individuals were seen, at the same time, high above on the *C. hackelii* grass clump. The present observations on calling height range fall in the reported calling height of *R. travancoricus* (0.5 to 1.5m) (Garg *et al.,* 2021). The observed calling height locations of *R. akroparallagi* and *R. griet* from the grasslands were different from the observations of Garg *et al*. (2021). On the edges of grasslands with forests, *R. akroparallagi* was seen close to two-meter height. But *R. griet* was not seen above 0.5m. A juvenile *R. travancoricus* was found close to the base of the *C. hackelii* grass clump. There may be niche partitioning between adults and juveniles. A study by Williams (1980) on woodpeckers, *Dendrocopos pubescens* showed a difference in niche preference and guild preference by males and females. The home range of female *R. travancoricus* might be smaller than the male home range like in the case of dendrobatid frog (Wells, 1980). Hence there is high chance for difference in their niche preference too. Though studying three-dimensional home range (in arboreal anurans) is challenging (Hofer *et al.,* 2004; Wells, 2007), further studies on the home range and niche partitioning of *R. travancoricus* will be rewarding.

In amphibians, species like caecilians use chemical and tactile cues to identify their territory, conspecifics, and other species but arboreal anurans use acoustic signals to establish and defend territory and for sexual selection. Coexistence and resource use regulation in adult amphibians are ensured by spatial and acoustic partitions (Bernarde and Anjos, 1999; Cunha and Vieira, 2004; Cajade *et al.,* 2010). The microhabitat used for calling, the time of the call and features of the advertisement calls form the acoustic niche (Sinsch *et al.,* 2012). An acoustically complex chorus will be a problem for the breeding success of a species. In a complex chorus, males will struggle to get female's attention, and females will struggle to spot desired mates (Wells, 2007). This problem is overcome by finding an apt spot for calling, which is suitably spaced from other conspecific males and males of other species that have calls with similar frequency. This helps them reduce wastage of energy on aggressive calls and instead spend most of their energy on courtship calls (Wells, 2007). *Raorchestes travancoricus* and its three sympatric species in the grasslands showed spatial niche partitioning with some overlap in their niche preference, thereby avoiding the negative effects of a chorus. Here the results of acoustic niche partitioning study showed that *R. travancoricus* and the three sympatric frogs temporally partition their acoustic activity. This may be due to the overlap in niche preference. A combination of the spatial niche partitioning and temporal acoustic activity partitioning would also save energy spent on interspecific competition. The spacing between individuals of the same species is an important element in their energetics. Detailed studies on their home range, movement, and resource partitioning within species will shed more light on that aspect.

Studies on anuran prey-predator interactions show that chorus helps anurans to avoid predators, especially the ability to synchronize calls with neighbouring individuals (Tuttle and Ryan, 1982). Since *R. travancoricus* and the sympatric species partition niche temporally and spatially, there may be a high chance for predation. *R. travancoricus* may be able to overcome this hurdle by synchronizing its call with conspecific neighbours. Studies on ants showed that the activity of dominant species determines the activity pattern of less dominant species (Albrecht and Gotelli, 2001). When there is a negative change in the habitat, it will affect the less dominant species since they have access to very less microhabitat. A detailed study from the grasslands in Periyar Tiger Reserve and particularly on *R. travancoricus* will be helpful to understand their community ecology which will in turn contribute to their conservation.

Distribution surveys on rare and cryptic species are always difficult especially in selecting locations for the surveys and covering the maximum possible location within limited time and resources. The problem is normally overcome with the help of species distribution modelling. Siqueira *et al*. (2009) has shown the importance of species distribution modelling study on rare species. Their study on a locally extinct plant species from Sao Paulo yielded six new populations very quickly with the help of a predicted distribution map. This argument was supported by Schingen *et al*. (2014), Singh *et al*. (2015), McCune (2016), Helmstetter *et al*. (2021). There are several popular methods available for predicting the distribution of a species. MaxEnt model method was suggested for predicting distribution of rare species by producing the best results even when the sample size was as low as 5 (Pearson *et al.,* 2007).

Distribution range size is an important component of community structure and is a major factor correlated with extinction risk in organisms. Species with limited distribution range is exposed to several risks as the range could be more easily affected by several biotic and abiotic interferences. Further, the small population occupying smaller range could be affected due to inbreeding and demographic stochasticity enhancing extinction risk in the long run (O'Grady *et al.,* 2006; Cooper *et al.,* 2008; Whitton *et al.,* 2012).

Prior to the present study, *R. travancoricus* was known only from three locations and was considered a rare one. Later, eight locations of the species was reported (Rajkumar *et al.,* 2016). The MaxEnt model was used in the present study with a sample size of 11 locations. According to Pearson *et al*. (2007), the sample size was good to produce a better result, which is evident from the present subsequent report of 12 new locations of *R. travancoricus* from Periyar Tiger Reserve with the help of the predicted distribution model. Periyar thus becomes the last refuge of a viable population of *R. travancoricus* in a Protected Area since the other distribution areas. Vagamon and Vandiperiyar are outside protected areas and face severe threats like pollution, uncontrolled tourism and monoculture activities.

Recent studies used GeoCAT to calculate EOO and AOO (Meco *et al.,* 2017; Babbar *et al.,* 2020; Das *et al.,* 2020; Pinto *et al.,* 2021; Sobral *et al.,* 2021). GeoCAT was used in the present investigation to calculate EOO and AOO. All the known locations except the type locality were above 850msl and the habitat is grassland or similar open habitats like tea plantation (Vagamon and Vandiperiyar). The elevation of type locality was around 350msl and there was no evidence for the presence of open grassland or tea plantations in the type locality. It is assumed here that the type locality could be Bodimettu, which was above the type locality (Bodinayakanur). The habitat and environmental conditions at Bodimettu were similar to its other known locations. The elevation range was around 1200 msl. Currently, the species has its distribution range extending till the southernmost part of Periyar tiger reserve. So, in the future, further surveys in similar habitats towards the south of Periyar would likely provide more distribution details of the species. Based on the present findings, *R. travancoricus* was included in Endangered category of IUCN Red List as suggested in the recent IUCN's second Global Amphibian Assessment – GAA2 (August to October 2020).

Advertisement calls are well developed and capable of communicating more than one piece of information. It serves as a mechanism for establishing and defending territory, attracting a mate, and deterring males (Vitt and Caldwell, 2014). The advertisement call of *R. travancoricus* was found to consist of two types of calls - pulsatile and non-pulsatile. The calls show a close similarity with the advertisement call of *R. luteolus*. The recorded call duration and call fall time were higher than the reported values Garg *et al*. (2021). Call rise time and the number of pulses per call were similar to the reported values. The dominant frequency recorded was lower than the reported value (3.3 kHz). The number of pulses per call in *R. luteolus* was low compared to the *R. travancoricus*. The recorded advertisement calls were used for identifying the presence of *R. travancoricus* during the distribution surveys. Their peak activity was during the southwest monsoon season. Protazio *et al.* (2019), while studying niche partitioning between two *Physalaemus* specieshave also reported similar observations. According to their study, though vocalised in the same period of the year, the two species demonstrated different acoustic attributes. Fouquette (1960), Pombal (1997) and Bourne and York (2001) have also reported this phenomenon.

The snout-vent length of the male specimen collected and measured from the field during the study were greater than the male SVL and average SVL reported in Biju and Bossuyt (2009). Males are smaller than females. The recorded EL was also greater than the reported EL for males and the rest of the measurements like HW, HL, IUE, UEW, SL, FLL, TL, ShL and FOL were similar to the reported measurements. On comparing the SVL with the size class category of bush frogs mentioned in Biju and Bossuyt (2009), this species can be included in the medium body-sized frogs (24-34mm). A study on frog community of eight species showed the larger species in the community dominate other sympatric species and they have control over resources like microhabitats and food (Das, 1996). The data from Biju and Bossuyt (2009) and the present study were used a comparison of morphometric measurements of *R. travancoricus* with the sympatric species. The resultsshow that *R. travancoricus* and *P. wynaadensis* belong to the category of medium-sized bush frogs whereas *R. akroparallagi* and *R. griet* belong to small-sized bush frogs. A comparison of their spatial niche preference with the body size category showed some interesting patterns. The top layer niches in the *C. hackelii* grass was used by medium-sized frog (*R. travancoricus*), the niches just below to that were used by small-sized frog (*R.*

akroparallagi) and the niches below this was used by medium-sized frog (*P. wynaadensis*), and the bottom layer niches used by small-sized frog (*R. griet*) (Fig. 7.2). The medium-sized frogs and small-sized frogs keep a gap between their niches. Since the size class of all the four species do not vary much, it is difficult to find out the influence of their size on their dominance over resources similar to Das (1996). More detailed observations on this aspect may throw more light on the subject.

Not many studies have been conducted on spatial and temporal partitioning in amphibians, especially on arboreal anurans from the Western Ghats. The present study help in understanding spatial and temporal partitioning among amphibians and the factors allowing co-existence of sympatric species

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Chapter 8
Conclusions

Chapter 8. Conclusions

Information on the diversity and distribution of species are important attributes required for formulation of strategies for conservation. The information is crucial in the context of increased land use changes and global warming. Most of the studies the world over have been on the charismatic larger animals like mammals and birds. Though several studies have highlighted the role of amphibians and reptiles in the ecosystem, these groups have been almost neglected when it comes to understanding the diversity and distribution in different ecosystems. Considering the current rate of extinction among the herpetofaunal species, the present study attempted to document the diversity of amphibians and reptiles in a unique ecosystem called *vayals* (marshy wetlands) within a larger diverse forested habitat in Periyar Tiger Reserve in Kerala. The observations were also correlated with environmental and habitat variables. Further, distribution of a range restricted species was studied along with vocalization characteristics and niche partitioning with sympatrics**.**

8.1 Diversity of herpetofauna in vayals surrounded by different vegetation types

Thirty two species of amphibians and 34 species of reptiles were recorded during the study. This is about 50% of the total amphibians and reptiles recorded from Periyar. The family Rhacophoridae (17) is more species-rich than other families. In reptiles, the family of snakes Colubridae contributed more number of species (7). About 86% of amphibians and 38% of reptiles recorded in Periyar Tiger Reserve are endemic to Western Ghats. Twelve of the amphibians and six of the reptiles documented from the area under different IUCN threatened categories. *Rhacophorus pseudomalabaricus*, *Raorchestes* *munnarensis*, *Raorchestes ponmudi*, *Raorchestes griet* and *Raorchestes chlorosomma* are Critically Endangered (CR). *Raorchestes travancoricus,* a threatened species with restricted distribution was recorded only from two locations at the time of rediscovery. The present study recorded the species from 14 locations in Periyar Tiger Reserve.

The 32 amphibians and 34 reptile species recorded during the study are not confined to the microhabitats in the vayal. Four species of amphibians recorded are not using the vayal habitats. These four species belong to the bush/shrub frog family Rhacophoridae, which mostly prefer trees and reeds and their preferred microhabitat is not available in the vayals in their distribution range. Out of the 34 species of reptiles recorded, 24 species were using both vayals and its surrounding vegetation, and rest of the 10 species are not found to be preferring the vayal habitat.

Monthly amphibian richness change between vayals and their immediate surrounding vegetation in five different habitats were more or less similar. The same pattern was seen when the data from vayals in five different habitats were combined and analyzed.

High amphibian richness was recorded from May to November months during the southwest and northeast monsoon seasons. The lowest richness was recorded from winter to summer months (from November to April). Monthly abundance and diversity of amphibians also showed the same pattern. Their activity is highly associated with the rainfall, humidity and temperature. In reptiles, no such pattern was seen. The lowest richness was recorded during February (6), June (8) and November (9) and the highest was recorded during January (14) and August (14). Monthly abundance and diversity also followed a pattern similar to that of richness though there is not much difference between the lowest and the highest values.

It is evident from the diversity t-test that the amphibian diversity in vayals and its immediate surrounding vegetation is not different but the reptile diversity varies considerably. Only two vayals showed a significant difference in amphibian diversity with its surrounding vegetation and in the case of reptiles, nine vayals showed a significant difference. The confirmation test perMANOVA also showed that the amphibian diversity is similar (p=0.1145) and reptile diversity (p=0.0001) varies significantly in vayals and its immediate surrounding vegetation.

8.2 Diversity of herpetofauna in relation to environmental and habitat variables

Seven species of amphibians and five species of reptiles seemed to be broadly niched and were recorded from vayals in all five different habitats. Three species out of the seven broad-niched amphibians, *viz. Indosylvirana sreeni*, *Pseudophilautus wynaadensis,* and *Raorchestes akroparallagi* were the most abundant species recorded during the study with an average of 220 sightings. Three species among the five broad-niched reptiles, *viz. Eutropis macularia*, *E. carinata* and *Calotes versicolor* were the most abundant reptiles with an average of 45 sightings. The most abundant amphibians and reptiles were observed across the vayals that vary in size from smallest to the largest, highly degraded to natural vayals, and with a wide range of elevation limits. Apart from the broad-niched species, there are a few habitat-specific and altitude-specific amphibians; *Duttaphrynus parietalis, Raorchestes travancoricus, R. griet, Rhacophorus pseudomalabaricus*, and *R. calcadensis*. These habitat and altitude-specific species were not specific to the extent of the vayals. The distribution of both the generalist and specialist species was not associated with the extent of the vayals but the altitude, plant composition and surrounding vegetation. This was clear from the Non-metric

Multidimensional Scaling ordination result. In the case of reptiles, altitude has influence on distribution of *Grypotyphlops acutus* and *Hemidactylus leschenaultii*. Both the species were recorded from vayals situated below 1000 msl, which is within the known altitude range of *H. leschenaultii* and slightly above the known range of *G. acutus*. There were a few other reptiles *viz*. *Kaestlea laterimaculata*, *Melanophidium punctatum*, and *Ptyas mucosa* which were not recorded from the vayals above 1000 msl. But the known altitude range of these species is higher than this limit. The results of the Non-metric Multidimensional Scaling ordination also suggest that reptiles has strong association with elevation and surrounding vegetation of vayal, whereas the other factors like plant composition rank and extent of vayals have no significant association with reptiles.

The extent of vayals does not influence the species richness, abundance, and diversity of amphibians and reptiles. The highest and lowest species richness, diversity, and abundance of amphibians and reptiles were recorded from the vayals irrespective of the size of the vayal. The richness, diversity, and abundance do not increase with increasing extent or vice versa. The highest species richness, diversity, and abundance of amphibians and reptiles were recorded from the smallest vayals. Therefore protection of smaller vayals is very much important for the conservation of amphibians and reptiles. These smaller habitats provide more resources like food, protection from predators, and less interspecific competition for amphibians and reptiles. Further long-term studies will be very helpful for the future conservation of amphibians and reptiles in the Periyar Tiger Reserve.

8.3 Status, distribution and behavior of *Raorchestes travancoricus*

The present study focused on temporal and spatial distribution of *Raorchestes travancoricus,* a species with restricted distribution. A model with the information on the characteristic features of the distribution locations were used for identifying more locations of its distribution. Further, various features of the advertisement calls of *R. travancoricus* is explained and shown how it helps in niche partitioning. Morphometric studies have also been made and correlated for size class categorization of four species of frogs.

The MaxEnt model was used in the present study with a sample size of 11 known locations of *R. travancoricus*. The use of the model resulted in identifying the species from 12 new locations of from Periyar Tiger Reserve with the help of the predicted distribution model. Periyar thus becomes the last refuge of a viable population of *R. travancoricus* in a Protected Area since the other distribution areas.

Ecological niche theory predicts segregation in the spatio-temporal habitat utilization among sympatric species. During the Visual encounter surveys and audio strip transects, *Raorchestes travancoricus* was recorded from the grasslands along with the sympatric *Pseudophilautus wynaadensis, Raorchestes akroparallagi and R. griet. R. travancoricus* was observed to choose niches to avoid negative interaction with the sympatric species and with other neighbouring species during their most active period. The niche partitioning was by occupying different parts of the grass species and also at different heights. *R. travancoricus* was seen at a height of 0.5 -1.5 m while calling whereas *R. akroparallagi* was seen close to two-meter height and *R. griet* below 0.5m. *Raorchestes travancoricus* and its three sympatric species in the grasslands showed spatial niche partitioning with some overlap in their niche preference, thereby avoiding the negative effects of a chorus. The results of present acoustic niche partitioning study showed that *R. travancoricus* and the three sympatric frogs temporally partition their acoustic activity. This may be due to the overlap in niche preference. A combination of the spatial niche partitioning and temporal acoustic activity partitioning would save energy spent on interspecific competition.

.The microhabitat used for calling, the time of the call and features of the advertisement calls form the acoustic niche. The advertisement call of *R. travancoricus* was found to consist of two types of calls - pulsatile and non-pulsatile. The calls show a close similarity with the advertisement call of *R. luteolus*. The recorded call duration and call fall time were higher than the reported values. However, call rise time and the number of pulses per call were similar to the reported values. The dominant frequency recorded was lower than the reported value (3.3 kHz). The number of pulses per call in *R. luteolus* was low compared to the *R. travancoricus*. The recorded advertisement calls were used for identifying the presence of *R. travancoricus* during the distribution surveys. Studies on anuran prey-predator interactions have reported that chorus helps anurans to avoid predators, especially the ability to synchronize calls with neighbouring individuals. *R. travancoricus* and the sympatric species partition niche temporally and spatially thereby increasing the chance for predation. *R. travancoricus* overcome the chances of predation synchronizing its call with conspecific neighbours.

The snout-vent length when compared with the size with the size class category of bush frogs indicate that *R. travancoricus* could be included in the medium body-sized frogs (24-34mm) thereby enabling them to dominate other sympatric species in the community and also better control over the resources. The results also show that *P. wynaadensis* belong to the category of medium-sized bush frogs and *R. akroparallagi* and *R. griet* belong to small-sized bush frogs. A comparison of their spatial niche preference with the body size category showed some interesting patterns. The top layer niches in the *C. hackelii* grass was used by medium-sized frog (*R. travancoricus*), the niches just below to that were used by small-sized frog (*R. akroparallagi*) and the niches below this was used by medium-sized frog (*P. wynaadensis*), and the bottom layer niches used by small-sized frog (*R. griet*).

8.4. Recommendations

- The present study was confined to selected vayals with different types of surrounding vegetation. Studies should be conducted in more number of vayals especially in the higher reaches in Periyar Tiger Reserve.
- Holistic study on the fauna of Vayal encompassing both vertebrates and invertebrates may be taken up. Plant composition and hydrology studies in vayals may also be encouraged identifying the degradation factors, if any. These would help prepare a scientifically sound Vayal Management Plan.
- Detailed study on the distribution with microhabitat features could be initiated.
- Long term monitoring of vayals would help understand the dynamics.

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Short Communication

New locality record of the Travancore Bush Frog *Raorchestes travancoricus* Boulenger, 1891 (Amphibia: Anura: Rhacophoridae) from Periyar Tiger Reserve, Kerala, India

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Abstract: *Raorchestes travancoricus* is a rare and endemic rhacophorid from southern Western Ghats. The frog was listed in the Extinct category of the IUCN Red List until June 2015, even after its rediscovery in 2004. In June 2015, the *R. travancoricus* was reassessed to Endangered category. All published reports of the species are restricted to disturbed habitats outside protected areas and the current study report the presence of the species from eight different localities from a protected area the Periyar Tiger Reserve.

Keywords: Amphibia, Bush Frog, Periyar, Raorchestes.

Raorchestes travancoricus was listed in the Extinct category of the IUCN Red List (Biju 2004) until June 2015 even after the rediscovery of the frog from Vandiperiyar in 2004. It was reassessed as Endangered B2ab(iii) based on the area of occupancy as restricted to 30km^2 (IUCN SSC Amphibian Specialist Group 2015). The current status is based on the presence of the species in three locations, Vagamon, Vandiperiyar, and Periyar Tiger Reserve. We here report the presence of the species from eight different localities in Periyar Tiger Reserve (PTR), all through direct visual sighting. All the current reports of the species are restricted to disturbed habitats outside protected areas. Presence of this 'rare' species in several marshy grassland ecosystems, locally called 'vayals', in the Tiger Reserve indicates the need for a sound management strategy for the habitat, which holds the only known population of *Raorchestes travancoricus* within a protected area.

The Travancore Bush Frog *Raorchestes travancoricus* (Boulenger, 1891) is one of the least known rhacophorids of the Western Ghats. *R. travancoricus* was initially described as *Ixalus travancoricus* based on a single female specimen collected by H.S. Ferguson from 'Bodanaikanur' (Bodinayakkanur), presently in Tamil Nadu close to the Kerala border (Biju & Bossuyt 2009). Since there were no reports since the description *R. travancoricus* was listed Extinct in the IUCN Red List

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(Biju 2004). Later, Biju & Bossuyt (2009) reported the rediscovery of *R. travancoricus* based on the sighting of a male frog from Vandiperiyar, 70km southwest of the type locality in 2004, and two male frogs from Vagamon in 2006, both in non-protected areas. In this study, we report eight records of *R. travancoricus* from Periyar Tiger Reserve. We also present a preliminary analysis of the call of the species.

Raorchestes travancoricus was observed from Periyar Tiger Reserve on four occasions in the Uppupara region in Azhutha Forest Range in August and September 2014. A single male was first found calling 1m high on *Ageratina adenophora* (Sticky Snakeroot / Crofton weed) in a marshy grassland ecosystem (vayal) at 18.00hr in Uppupara Thannithotti Vayal on 26 September 2014 (Images 1 & 2). A total of 36 individuals were sighted and a single male specimen was collected and morphometric measurements were taken to the nearest 0.1mm with a Mitutoyo digital vernier calliper using a binocular microscope. The specimen is deposited in the wildlife museum of Kerala Forest Research Institute, Peechi. The identity was confirmed from the yellowish-pink colouration with distinct brown lines on the dorsum, dark brown streak on each side of the snout. Small snout vent length (SVL 26.49mm), snout oval in dorsal view, head wider (HW 8.0mm) than the head length (HL 7.71 mm), snout length (SL) 3.8mm. Skin of snout region, between eyes, upper eyelids, side of head and anterior and posterior parts of back shagreened. Loreal and tympanic region light brown with a prominent streak on each side of the snout from the extreme tip of the snout to the lower level of the supra-tympanic fold. The minimum distance between upper eyelids (IUE) 3.69mm and maximum width of upper eyelid is (UEW) 1.69mm. Eye length (EL) 3.45mm. Nuptial pad absent, body slender, canthus rostralis indistinct, loreal region acutely concave, tympanum indistinct, supratympanic fold indistinct. Fore limb (FLL 5.57) shorter than hand (HAL 5.1mm), fingers without lateral dermal fringe. Subarticular tubercles prominent, rounded and single. Supernumerary tubercles weekly developed. Hind limbs moderately long (Thigh length TL 12.2mm, Shank length SHL 11.9mm, Tarsus lengh Tal 6.7mm, Foot length Fol 9.41mm). Dorsal part of forelimb and hind limb shagreened, webbing reduced, subarticualr tubercles rather prominent, rounded and simple. Upper and lower parts of flank shagreened to sparsely granular. Chest, belly and posterior surface of thighs granular.

Image 1. Calling male *Raorchestes travancoricus* on *Chrysopogon nodulibarbis* grass clump

Image 2. *Raorchestes travancoricus* on *Ageratina adenophora* (Sticky Snakeroot/Crofton weed) in a marshy grassland ecosystem

Call description

The calls were recorded using ZOOM H4nSP Handy Recorder from Uppupara in Periyar Tiger Reserve and the calls were analyzed by using the software Raven v1.4 software (Cornell Laboratory of Ornithology, Ithaca, NY, USA) (Bee et al. 2013a,b; Thomas et al. 2014). The waveform and frequency of the call described is given in Fig. 1 and Fig. 2, respectively (Audio 1). Call duration was 2.2 second with two distinct notes and the first note was relatively shorter (0.6 second). The second note was long and 1.1 second in duration. The dominant frequency of both the notes was about 2.7kHz (Fig. 2) and compared to the second one the first note was relatively lower in amplitude (Fig. 1). Though the dominant frequency was within the range of its published sister taxa *R. graminirupes* (Bee et al. 2013b), the duration of both notes of *R. travancoricus* is relatively much longer than that of both notes of *R. graminirupes*.

The previous report of occurrence of the species is also close to the present area (Biju & Bossuyt 2009).

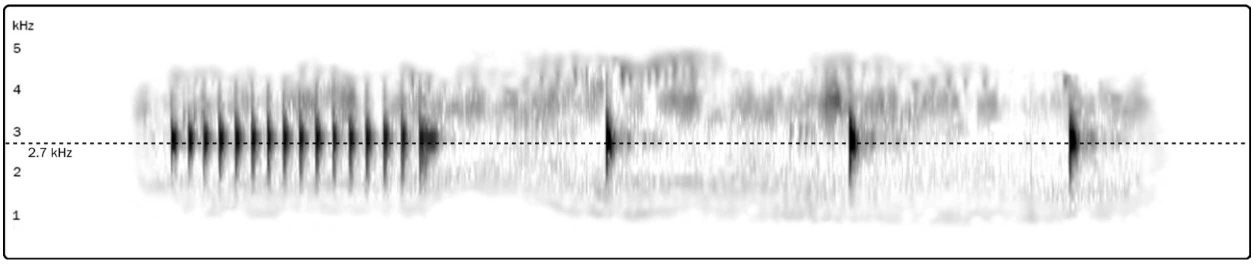

Figure 1. Waveforms of *Raorchestes travancoricus* male advertisement call (3 sec)

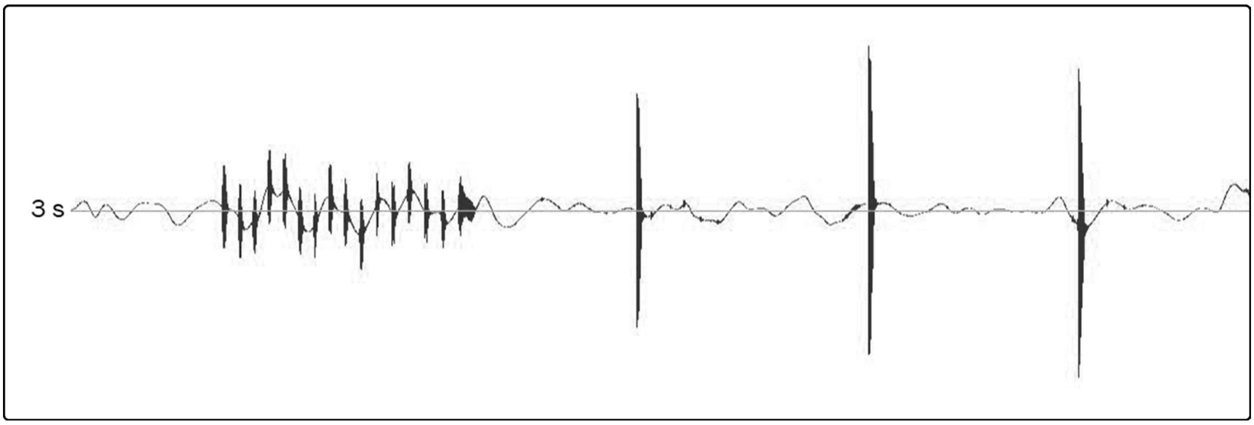

Figure 2. Spectrogram of *Raorchestes travancoricus* male advertisement call (3 sec)

Further investigation on the same day from 18.00hr to 01.00hr resulted in the sighting of 19 individuals from 20 10x10m quadrats laid randomly in the 1.21 acre vayal. Out of them 12 males (gender confirmed by presence of single subgular vocal sac) were found calling, sitting 1–2 m high from the ground on grass clumps present in the vayals. An amplected pair was found moving through grass, entered deep inside a grass clump (*Chrysopogon nodulibarbis*) and was then not followed to avoid disturbance. Random searching in the adjacent areas in different habitats resulted in 36 encounters, all of them on grasses or bushes in vayals and open grasslands. However, not a single encounter was observed in the surrounding evergreen forest patches, suggesting that this species is a vayal specialist.

R. travancoricus was also observed from seven other localities in Periyar Tiger Reserve, viz., Gavi, Upper Manalar, Eravangalar, Mangaladevi, Kumarikulam, Moolavaika and Chokkampatti during the herpetofaunal survey by the authors and the range of the species extends further south of Vandiperiyar, and increasing the altitudinal range up to 1800m. Even though the species was observed from the above seven locations in Periyar Tiger Reserve, detailed survey was carried out only at Uppupara. The details of locations of sightings of the species is summarised in Table 1 and the locations in PTR plotted in the Image 3. A detailed survey in similar habitats of Periyar Tiger Reserve is suggested to explore the possibility of more populations of the species to gauge its current distribution. Future research is required to understand the habitat preference and distribution

Table 1. Distribution range of *Raorchestes travancoricus* from southern Western Ghats

Location		Altitude (m)	Latitude	Longitude
1.	Bodanaikanur, TN	350	9.97^{0}N	77.48^{0}E
2.	Vandiperiyar, Idukki	800	9.87^{0}N	77.17^{0}E
3.	Vagamon, Idukki	900	9.57^{0}N	77.08^{0}E
4.	Uppuppara, PTR	1188	9.47^{0}N	77.08^{0}E
5.	Gavi, PTR	1179	9.43^{0}N	77.13^{0}E
6.	Upper Manalar, PTR	1495	9.55^{0}N	77.33^{0}E
7.	Eravangalar, PTR	1340	9.57^{0}N	77.28^{0}E
8.	Mangaladevi, PTR	1234	9.59^{0}N	77.21^{0}E
9.	Moolavaiga, PTR	1315	9.40^{0}N	77.32^{0}E
10.	Kumarikulam, PTR	1209	9.49^{0}N	77.28^{0}E
11.	Chokkampatti, PTR	1802	9.28^{0}N	77.27^{0}E

TN - Tamil Nadu; PTR - Periyar Tiger Reserve

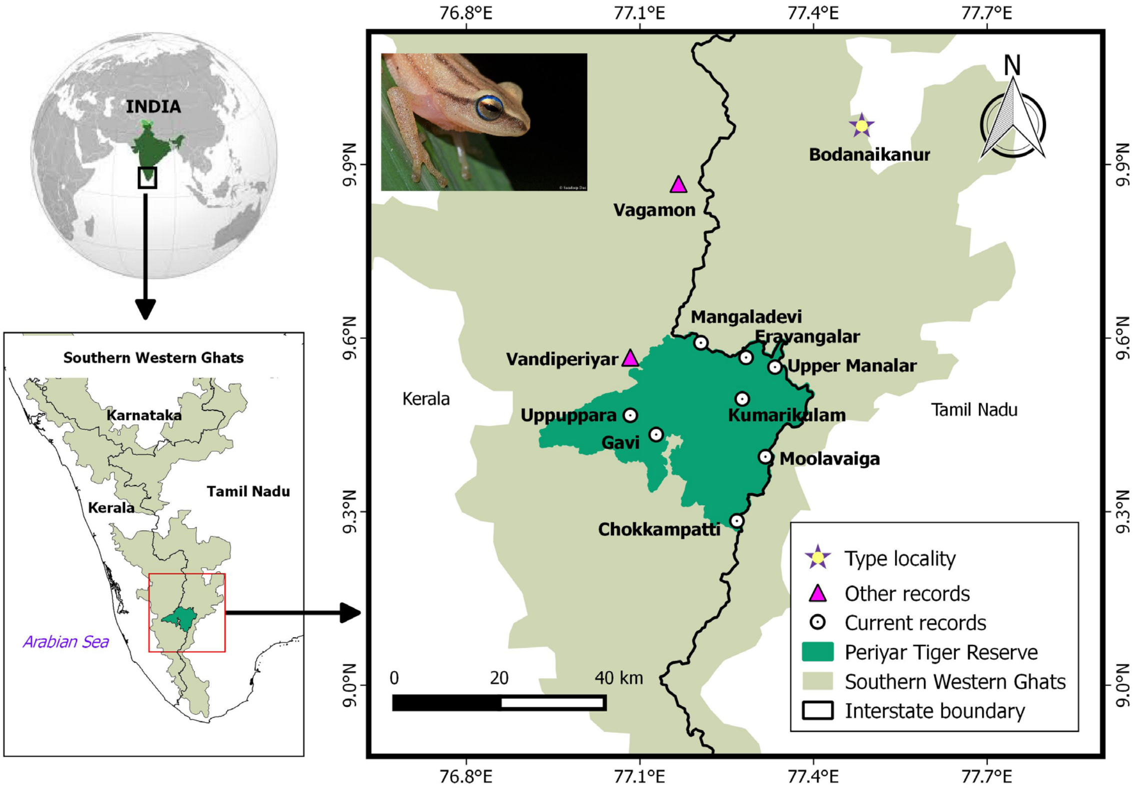

Image 3. Distribution map of *Raorchestes travancoricus* including the type locality

of this species. By reporting marshy grasslands in PTR as new localities for *R. travancoricus*, the current study also highlights the importance of conservation and management of the vayal ecosystem in Periyar Tiger Reserve.

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