

Distribution pattern, zoogeographic similarities and affinities of montane herpetofauna of Southern Eastern Ghats, peninsular India

SUMAITHANGI RAJAGOPALAN GANESH*¹ and MUNUSAMY ARUMUGAM¹

¹Department of Zoology, University of Madras, Guindy Campus, Chennai 600 025, India

* Corresponding author: snakeranglerr@gmail.com

Abstract

We examined the distribution pattern, across-site similarities and zoogeographic affinities of amphibians and reptiles in the montane zones (> 900 m a.s.l.) of the Southern Eastern Ghats mountains in peninsular India. We deployed long-term field surveys in four select massifs namely Jawadi, Shevaroy, Kolli and Sirumalai and generated herpetofaunal species lists. Based solely on our species occurrence data, we identified taxa that characterise sites, site-pairs and site-clusters. We quantified the number of the various target taxa characterising each such Operational Geographic Unit. To infer faunal similarities, we performed cluster analysis using Jaccard's similarity index. Our cluster diagram tree topologies differed between the various target taxa. The pooled data (amphibians, lizards and snakes) tree topology was similar to that of the lizard trees but the amphibian- and snake-similarity trees were similar in their topologies. Our observations and analyses indicate that physical separation distance and intervening rivers between massifs decreased herpetofaunal similarity. To identify the zoogeographic affinities of range-restricted taxa, we segregated the species into classes, based on decreasing extent of their geographic ranges. Our analyses reveal that widespread species were predominant in this community even at high elevations, followed by Western Ghats dispersers, Eastern Ghats endemics (both presumed and confirmed), and lastly peninsular Indian and Sri Lankan elements.

Key words: amphibians, reptiles, endemism, cluster analysis, hill range, similarity tree, southern India.

INTRODUCTION

Mountain-tops are considered as 'sky islands' and harbour an endemic radiation of biota which is often absent in the adjacent plains (McCORMACK ET AL. 2009). This phenomenon is much more pronounced in the tropics, where mountain-passes and their abiotic and biotic characterizations exhibit a much sharper contrast (MITTELBECH ET AL. 2007). Landscape reconfigurations by orogenies generate super diverse montane biota creating a vastly differing biodiversity gradient between

the plains and the peak (GRAHAM ET AL. 2014). Broad general patterns that apparently govern and shape the distribution of biota in patchy areas have been reviewed (Walting & Donnelly 2006). These indicate that physical and ecological isolations drive faunal differences (PYRON & BURBINK 2010). Among terrestrial vertebrates, amphibians and reptiles, being ectotherms, are relatively poor dispersers that are acutely susceptible to ambient abiotic fluctuations (Vitt & Caldwell 2014).

Hence, herpetofauna are potential model organisms for zoogeographic studies (PYRON & BURBINK 2010).

The Indian peninsula supports a major endemic radiation of herpetofauna, owing to the Western Ghats hill range, a recognised biodiversity hotspot (MYERS ET AL. 2000, DINESH ET AL. 2009, AENGALS ET AL. 2011). The Eastern Ghats are a series of discontinuous hill ranges that extend from Sirumalai hills, running nearly 1500 km northeast to up to Kondmal hills (MANI 1974, JAYAKUMAR ET AL. 2008). Eastern Ghats due to its further inland location and lower height than Western Ghats, is much drier and supports an impoverished biota (MANI 1974). These hills are considered as ancient refugia that provided a stable habitat patch resisting the past climatic oscillations during the historical aridification that impacted the biotic evolution in the surrounding plains (PONTON ET AL. 2012). Previous studies reveal that peninsular Indian herpetofaunal assemblages exhibit significant beta diversity with differing hill ranges (ROUX 1928), drainages (VASUDEVAN ET AL. 2006), elevations (NANIWADEKAR & VASUDEVAN 2007) and habitat types (INGER ET AL. 1987, VIJAYAKUMAR ET AL. 2006). In peninsular India, the Eastern Ghats is reported to be rather faunally poor and depauperate (DINESH ET AL. 2009, AENGALS ET AL. 2011).

The Southern Eastern Ghats, the region of interest for the present work, has been reported to harbour typical Western Ghats taxa including several species and even genera of herpetofauna (DANIELS & ISHWAR 1994, DANIELS & KUMAR 1998, KUMAR & DANIELS 1999, VANAK ET AL. 2001, DINESH ET AL. 2009, AENGALS ET AL. 2011). The plains (300-400 m a.s.l.) and lower hill ranges (< 800 m a.s.l.) present between the Western and the Eastern Ghats are barriers to population contiguity and are inhospitable for obligate wet-zone taxa. The presence of rivers and other relief features and

ecological barriers add on to this phenomenon. The Eastern and the Western Ghats are reported to have differing biogeographic histories and spatially and temporally limited wet forest contiguity (MANI 1974, ANONYMOUS [MOEF] 2004, ROY ET AL. 2006, PONTON ET AL. 2012), preventing the dispersal of several montane taxa (MANI 1974). However, the extent and precision of taxonomic representation of such range-restricted taxa in the physically isolated Eastern Ghats have remained poorly-understood. In this study, we investigated the zoogeographic patterns in the distribution of amphibians and reptiles occurring in the hill-tops of select ranges in the Southern Eastern Ghats that best represent this landscape.

STUDY AREA

Site Selection Protocol

We examined maps of the Eastern Ghats using Google Earth, Google Maps, 3-DEM ver. 20 and DIVA-GIS ver. 7.5 softwares to visualise the spatial-spread, elevation and contemporary forest cover of the constituent hill-blocks. After a careful perusal and preliminary site visits to the some of the potential areas, we selected four massifs (Fig. 1) in the Southern Eastern Ghats that represent maximum spatial extent of the landscape, include the highest peak, span across the many rivers present and harbour range-restricted herpetofauna. The four select hill ranges are: Jawadi hills (JW) 12.26-12.51°N 78.60-78.76°E; 1200 m a.s.l. in Vellore district; Shevaroy hills (SH) 11.72-11.93°N 78.12-78.36°E; 1620 m a.s.l. in Salem district; Kolli hills (KL) 11.19-11.46°N 78.28-78.47°E; 1400 m a.s.l. in Namakkal district and Sirumalai hills (SR) 10.12-10.28°N 77.92-78.11°E; 1400 m a.s.l. in Dindigul district, all politically situated in the Tamil Nadu State (RAMACHANDRAN ET AL. 2016 and references therein). The Bilgiringangan-Melagiri massif, often included in

Southern Eastern Ghats (DANIELS & ISHWAR 1994), was omitted here due to its physical contiguity with the

Western Ghats (SRINIVASAN & PRASHANTH 2006) that would impact this study's objectives.

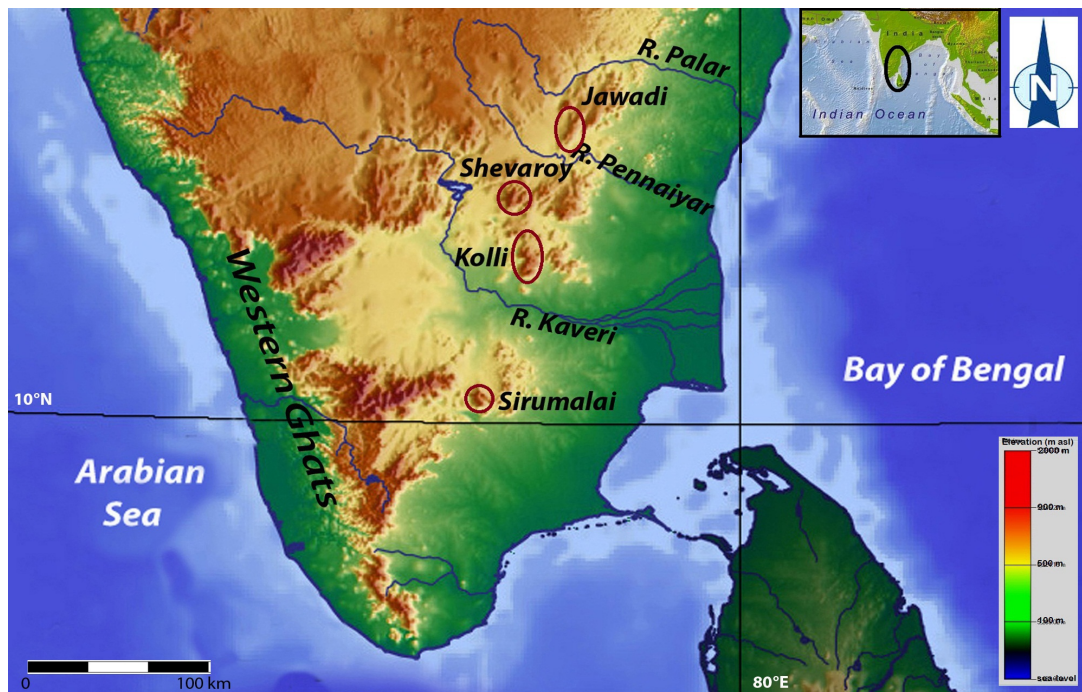


Figure 1. Elevation map of southern Indian depicting the relief features and the surveyed massifs.

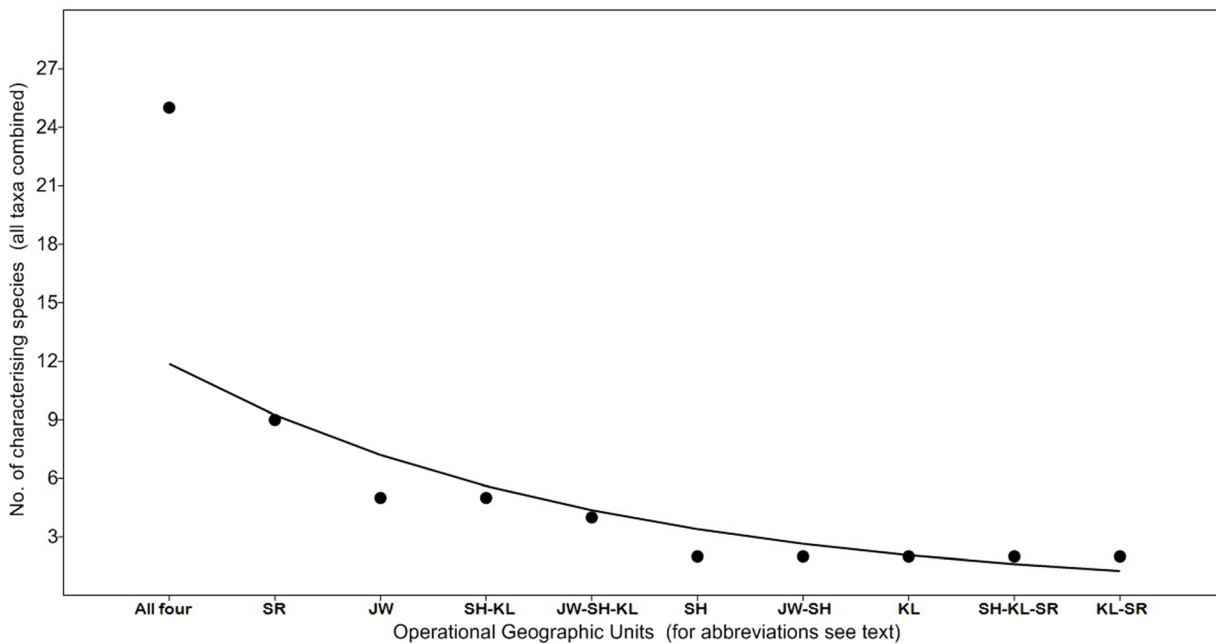


Figure 2. Rank-abundance curve, with normal trend-line, showing the relative abundance of species characterising the various sites, site-pairs and site-clusters. Abb. JW: Jawadi, SH: Shevaroys, KL: Kolli, SR: Sirumalai.

Climate and Vegetation

The hilltops of these four massifs are covered with tropical evergreen forests, mixed fruit orchards, silver oak plantations, coffee estates (except Jawadi) and some bare rocky peaks and cliffs. No protected area network covers any of these hills. January-May is dry and June-December is wet season. Average annual day-time temperature ranges between 13 and 37 °C and the rainfall ranges around 1500-1800 mm. The foothills and lower slopes (<400 m a.s.l.) are covered by scrub and thorn forests and the mid slopes (400-900 m a.s.l.) by deciduous forests, while the upper slopes (>900 m a.s.l.) are covered by evergreen forests (see JAYAKUMAR ET AL. 2008). Because of the patchy, elevation-dependant occurrence of evergreen forests, these conditions conform to tropical montane cloud forests as postulated by DOUMENGE ET AL. (1993) since these forests receive orographic rainfall and are covered by mist at the vegetation-level and are distinctly wetter than the surrounding plains (JAYAKUMAR ET AL. 2008).

MATERIALS AND METHODS

During 2011 - 2015 we surveyed the wet-forested, montane zones (> 900 m a.s.l.) of each of these four hill ranges for a 5 month period (total 5 x 4 = 20 months in all), both day and night for 500 man hrs (total 2000 hrs) in the wet season (June-December) of each year. We excluded surveying the drier foot-hills and lower slopes to practically enable our proper fieldwork in the wet-forested montane zones, known to be the reservoir of endemism among Indian herpetofauna (DINESH ET AL. 2009, AENGALS ET AL. 2011). Based solely on our own fieldwork, we generated species lists for the chosen massifs and prepared a data-set of presence-absence matrix with a total of 62 species. No secondary data such as literature or museum records were considered, to avoid possible influence of uncertainty associated with either the taxa or the locality,

or both. We evaluated herpetofaunal similarities across sites by performing cluster analysis. We used Jaccard's similarity index values (JACCARD 1902), constrained and run on single-linkage algorithm, based on our own species occurrence data for building the similarity trees. Jaccard's index was chosen as it was reported to be both frequently used and highly informative index for calculating similarities in many studies, including ecological ones (LEVANDOWSKY & WINTER 1971), thereby facilitating easy comparisons with many other such studies elsewhere, should it become necessary. Separate similarity trees were constructed for amphibians, lizards and snakes, plus a pooled sample with all these three target taxa. Statistical analyses were done in PAST ver.3.0 software (HAMMER ET AL. 2001). Distance (in straight line km) and difference in elevation (in m a.s.l.) between two massifs were estimated as a rounded figure, using the average value estimated by a combination of methods involving GPS readings taken by us at the field sites, the usage of Google Earth software and standard toposheet maps of the study areas available with the Tamil Nadu Forest Department.

For finding the zoogeographic affinities we quantified global distribution data for each species as: WSP – widespread (in Indian subcontinent), PI-SL – Peninsular India and Sri Lanka, PI – peninsular India, WG and EG – Western and Eastern Ghats; EG – confirmed Eastern Ghats endemics and EG? – presumed Eastern Ghats endemics. Distribution data for herpetofauna were modified from AENGALS ET AL. (2011), AGARWAL & KARANTH (2014) and SOMAWEERA ET AL. (2015) for reptiles and DINESH ET AL. (2009), BIJU ET AL. (2014), VIJAYAKUMAR ET AL. (2014) and OLIVER ET AL. (2015) for amphibians. We examined these parameters in light of the factors known to drive faunal differences in southern India's herpetofaunal communities, such as inter-site distance (ROUX 1928), elevational differences (NANIWADEKAR & VASUDEVAN 2007) and the role of

drainages / rivers (VASUDEVAN ET AL. 2006) across the various hill ranges surveyed.

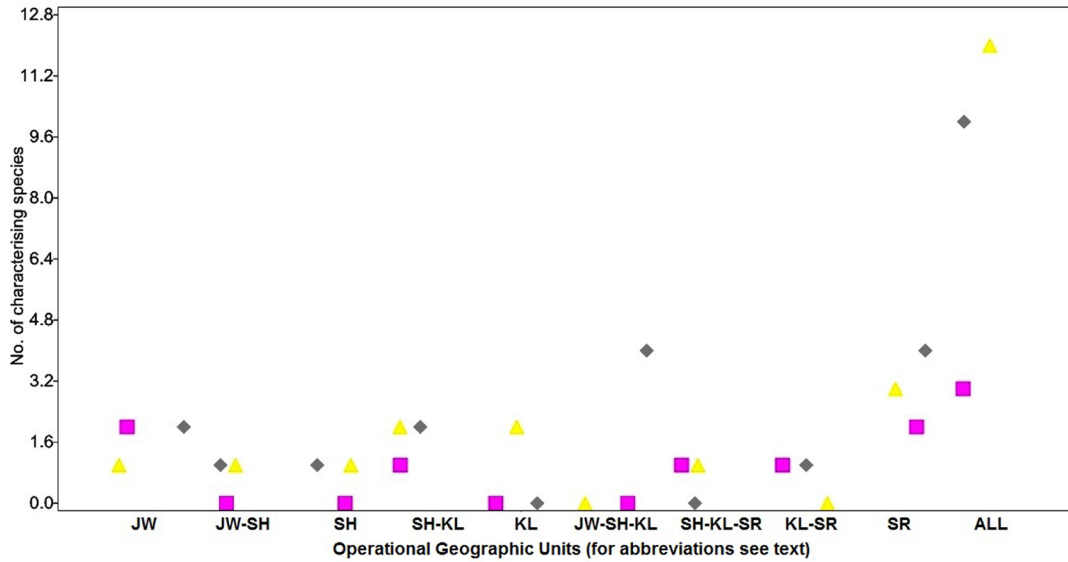


Figure 3. Scatter-plot showing the relative contribution of frogs (pink squares), lizards (yellow triangles) and snakes (grey diamonds) in characterising the various sites, site-pairs and site-clusters. Abb. JW: Jawadi, SH: Shevaroys, KL: Kolli, SR: Sirumalai.

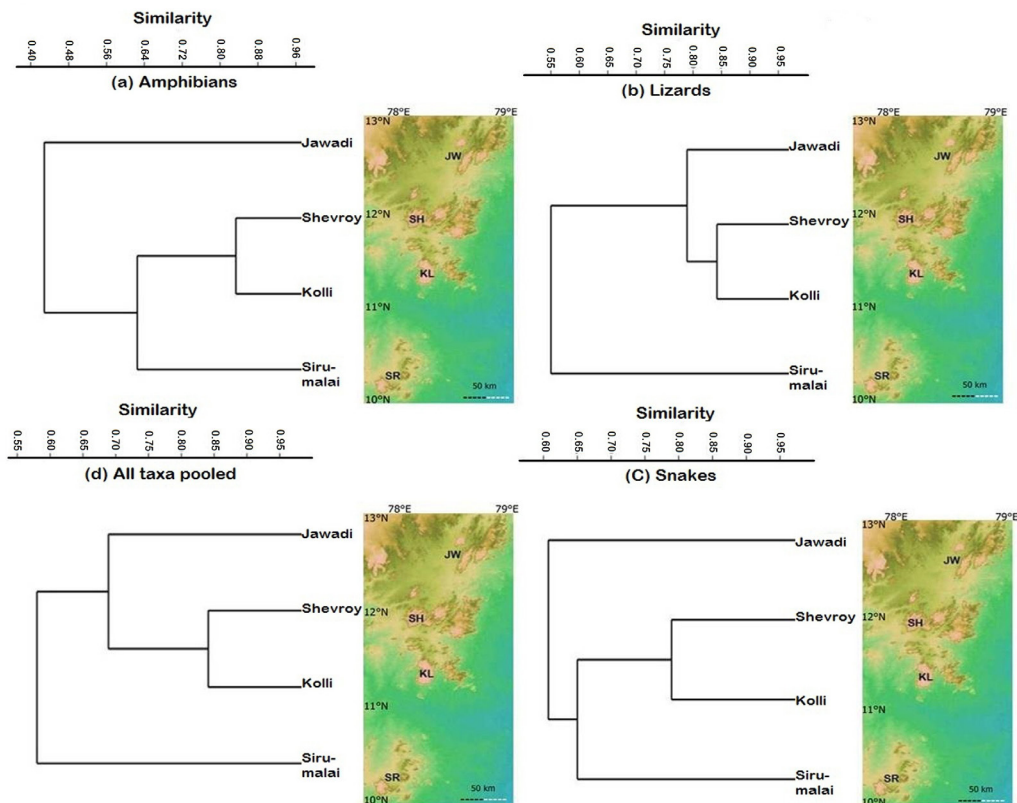


Figure 4. Jaccard's similarity trees (clockwise from top left): amphibians (n=10 spp.), lizards (n=26 spp.), snakes (n=26 spp.) and all three taxa pooled (n=62 spp.). Abb. JW: Jawadi, SH: Shevaroys, KL: Kolli, SR: Sirumalai.

RESULTS

Range-restricted taxa

Out of a total of 62 species recorded in the montane zones in the four hill ranges each hill range contained from 38 to 41 species, amounting to 66 % of the total species. Among these taxa, the genera *Raorchestes*, *Pseudophilautus*, *Indosylvirana*, *Indirana* (amphibians), *Cnemaspis*, *Hemiphyllodactylus*, *Cyrtodactylus*, *Draco*, *Kaestlea* (lizards), *Gerrhopilus*, *Uropeltis*, *Rhinophis*, *Chrysopelea* and *Trimeresurus* (snakes), totaling to 21 species (34 %), were hill forest obligates that are not represented by any congeners in the surrounding plains. Two snakes, *Uropeltis shorttii* and *U. dindigalensis* were the only confirmed endemic species of herpetofauna known from Shevaroy and Sirumalai respectively. The lizard *Cnemaspis yercaudensis* and the snake *Rhinophis goweri* ranked next to the aforesaid taxa in being known only from one other nearby hill range. Faunal differences even at genus-level were observed in this study system (Table 1). The gecko *Calodactylodes* in Jawadi, the skink *Kaestlea* in Shevaroy, the snake *Rhinophis* in Kolli and the frog *Indirana* in Sirumalai were absent in the other studied hill ranges respectively.

Taxa and Operational Geographic Units

All the three taxonomic groups (frogs, lizards and snakes) and all the four hill ranges (Jawadi, Shevaroy, Kolli and Sirumalai) contributed to creating this faunal difference (Figs. 2 & 3). Of the 62 species observed overall, five species (two frogs, two lizards, one snake) characterise Jawadi hills; two species (one lizard, one snake) characterise Jawadi-Shevaroy pair; two species (one lizard, one snake) characterise Shevaroy; five species (one frog, two lizards, two snakes) characterise Shevaroy-Kolli pair; two species (both snakes) characterise Kolli hills; four species (all

lizards) characterise Jawadi-Shevaroy-Kolli cluster; two species (one frog, one snake) characterise Shevaroy-Kolli-Sirumalai cluster; two species (one frog, one lizard) characterise Kolli-Sirumalai pair; nine species (two frogs, four lizards, three snakes) characterise Sirumalai hills.

A total of 26 species, i.e. 41 % (3 frogs, 10 lizards, 13 snakes) were present in all the four hill ranges, even within the confined montane zone (> 900 m a.s.l.) of the respective hills. Sirumalai stood apart as a single entity, well-characterised by 14.7 % of species; followed by Jawadi that was characterized by 8 % of species. Shevaroy and Kolli hills together formed a well-bound cluster and got better characterised as a single entity by 8 % of species, but in turn were not identified as entities in isolation (only 3 % of species).

Herpetofaunal similarities

Jaccard's similarity trees with all taxa combined, revealed a faunal similarity range of 0.48 to 0.84 between the most distant (Jawadi-Sirumalai, ca. 300 km in a straight line, across two rivers) and the most proximate (Shevaroy-Kolli, ca. 60 km in a straight line, no intervening rivers) hill ranges respectively. Our similarity trees revealed differences in cluster patterns of hill range entities, when analysed on presence-absence data of amphibians, lizards, snakes separately and all three taxa pooled (Fig. 4). The amphibian similarity tree was slightly similar to that of the snakes in showing that Jawadi was placed as outlier (amphibians: 0.42; snakes: 0.60), but Shevaroy, Kolli and Sirumalai formed a cluster (amphibians: 0.60; snakes: 0.64). The lizard similarity tree differed from those of amphibians and snakes, but was similar to the pooled analysis in showing that Jawadi, Shevaroy and Kolli formed a cluster (lizards: 0.55; pooled: 0.56) but Sirumalai was placed as an outlier (lizards: 0.78; pooled: 0.69). All analysis corroborated that Shevaroy and Kolli together formed a

well-characterised unit (0.80–0.85), much more than either of these standing in isolation.

Table 1. Taxa characterising various sites and combinations of site-pairs and site-clusters.

Hill range(s)	Constituting taxa (* indicates sp. found nowhere else)
Jawadi	<i>Microhyla</i> cf. <i>sholigari</i> , <i>Sphaerotheca</i> cf. <i>dobsonii</i> , <i>Cnemaspis mysoriensis</i> , <i>Calodactylodes aureus</i> , <i>Uropeltis</i> cf. <i>hipsonii</i> , <i>Dendrelaphis</i> sp.
Jawadi and Shevaroy	<i>Calotes rouxii</i> , <i>Uropeltis ellioti</i>
Shevaroy	<i>Kaestlea</i> sp. *, <i>Uropeltis shortii</i> *
Shevaroy and Kolli hills	<i>Raorchestes</i> cf. <i>leucolatus</i> , <i>Cnemaspis</i> sp., <i>C. yercaudensis</i> , <i>Coelognathus helena monticollaris</i> var.1, <i>Calliophis beddomei</i>
Kolli hills	<i>Rhinophis goweri</i> , <i>Uropeltis</i> cf. <i>ceylanica</i>
North of Kaveri only	<i>Cyrtodactylus speciosus</i> , <i>Hemidactylus graniticolus</i> , <i>Eutropis allapallensis</i> , <i>E. beddomii</i>
Shevaroy, Kolli and Sirumalai	<i>Indosylvirana sreeni</i> , <i>Boiga nuchalis</i>
Kolli and Sirumalai	<i>Pseudophilautus</i> cf. <i>wynaadensis</i> , <i>Draco dussumierii</i>
Sirumalai	<i>Indirana</i> sp., <i>Sphaerotheca</i> sp., <i>Ophisops minor nictans</i> , <i>Cnemaspis</i> cf. <i>gracilis</i> , <i>Hemidactylus</i> cf. <i>acanthopholis</i> , <i>Cyrtodactylus</i> cf. <i>speciosus</i> , <i>Uropeltis dindigalensis</i> *, <i>Dendrelaphis girii</i> , <i>Calliophis nigrescens pentalineatus</i>

Table 2. Faunal similarity as a function of geographic traits. Values above diagonal are Jaccard's similarities between site-pairs; details below the diagonal are physical separation (in straight line km), elevational difference (in m a.s.l.) and presence of river (barrier) between each site-pair. Abbreviations: Dist – distance; Elev – difference in elevation.

Jaccard's similarity	Jawadi	Shevaroy	Kolli	Sirumalai
Jawadi (12°N 78-79°E; 1200 m a.s.l.) North of Pennaiyar river	1	0.68	0.60	0.48
Shevaroy (11°N 78°E; 1620 m a.s.l.) Between Pennaiyar and Kaveri rivers	Dist: 100 km Elev: 400 m Across 1 river	1	0.84	0.52
Kolli (11°N 78°E; 1400 m a.s.l.) Between Pennaiyar and Kaveri rivers	Dist: 140 km Elev: 200 m Across 1 river	Dist: 50 km Elev: 200 m Across 0 rivers	1	0.58
Sirumalai (10°N 77-78°E; 1400 m a.s.l.) South of Kaveri river	Dist: 300 km Elev: 200 m Across 2 rivers	Dist: 180 km Elev: 200 m Across 1 river	Dist: 140 km Elev: 0 m Across 1 river	1

Hill ranges separated by rivers (Table 2) had predominantly different species-composition, than those without rivers. Our data shows that the distribution

ranges of lizards such as *Hemidactylus graniticolus*, *Eutropis allapallensis* and *E. beddomei* abruptly end north of Kaveri river and that of *Calodactylodes aureus*

end north of Pennaiyar river. Similarly the ranges of the frog *Indosylvirana sreeni* and the snake *Boiga nuchalis* stopped south of Pennaiyar river. However, two species of agamid lizards showed an idiosyncratic distribution pattern – *Calotes rouxii* found in Jawadi and Shevaroyis situated on either side of the Pennaiyar river and *Draco dussumierii* found in Kolli and Sirumalai situated on

either side of the Kaveri river. The frog *Pseudophilautus* also showed a similar distribution as that of *Draco*. Our similarity trees show that the Kolli hills, although equidistant from both Jawadi and Sirumalais, was faunally more similar to Jawadi than to Sirumalai.

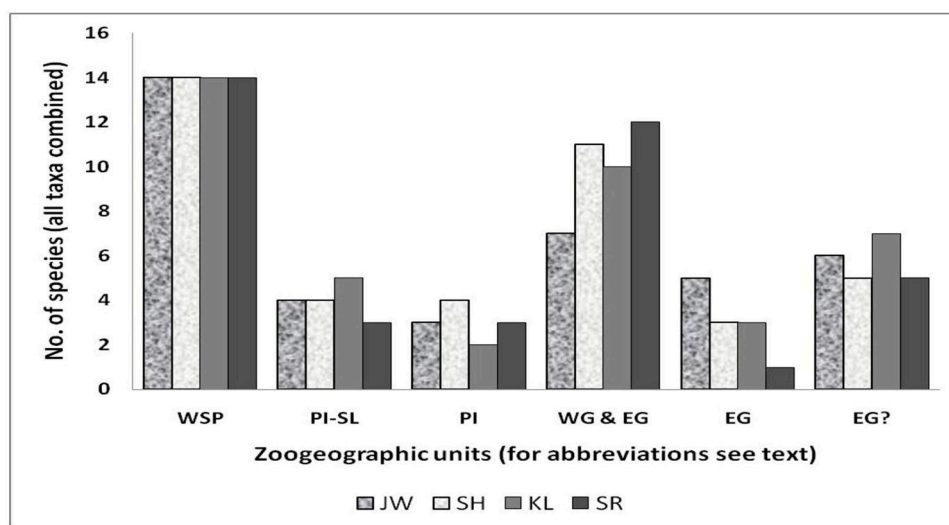


Figure 5. Zoogeographic affinities of amphibians and reptiles recorded. Abb. JW: Jawadi, SH: Shevaroyis, KL: Kolli, SR: Sirumalai, WSP – widespread (in Indian subcontinent), PI-SL – Peninsular India and Sri Lanka, PI – peninsular India, WG and EG – Western and Eastern Ghats; EG – confirmed Eastern Ghats endemics and EG? – presumed Eastern Ghats endemics.

Zoogeographic affinities

Barring the plains species, several dispersers also occurred in these hill ranges (Fig. 5). Sreeni's stream frog (*Indosylvirana sreeni*), flying lizard (*Draco dussumierii*), Roux's forest lizard (*Calotes rouxii*), montane trinket snake (*Coelognathus helena monticollaris*), Travancore wolf snake (*Lycodon travancoricus*), collared cat snake (*Boiga nuchalis*) and striped coral snake (*Calliophis nigrescens pentalineatus*) were typical Western Ghats taxa. Eastern Ghats elements were represented by golden gecko (*Calodactylodes aureus*) and rock gecko (*Hemidactylus graniticolus*). Peninsular Indian elements were represented by rock agamas (*Psammophilus* spp.), Allapally skink (*Eutropis*

allapallensis), blinking lacertid (*Ophisops minor nictans*), Elliot's shieldtail (*Uropeltis ellioti*) and bamboo pitviper (*Trimeresurus gramineus*). Green forest lizard (*Calotes calotes*), Beddome's skink (*Eutropis beddomei*), green keelback (*Macropisthodon plumbicolor*), flying snake (*Chrysopelea taprobanica*) and Forsten's cat snake (*Boiga forsteni*) were species characteristic of peninsular India and Sri Lanka. As stated earlier, the bush frogs (*Raorchestetes* and *Pseudophilautus*), day geckoes (*Cnemaspis*) and shieldtail snakes (*Uropeltis*) dominated the Eastern Ghats endemics (either presumed or confirmed).

DISCUSSION

Most of the earlier studies on Southern Eastern Ghats herpetofauna (DANIELS & KUMAR 1998, KUMAR & DANIELS 1999, VANAK ET AL. 2001) were restricted to a single hill range. The only work (DANIELS & ISHWAR 1994) that included multiple hill ranges and brought forth presence-absence data across sites was, unlike in our case, a short-term survey, where the 'absence' is more of a non-detection than true absence. In addition, DANIELS & ISHWAR (1994) focused on conservation status and not on beta diversity. Thus, to the best of our knowledge, this study is the first to provide quantitative measures of faunal similarities and zoogeographic affinities of herpetofaunal communities in the Southern Eastern Ghats landscape as a whole. This study also revealed differences in species-composition, even at genus level—a feature that was previously believed to occur only in the Western Ghats (ROUX 1928, BIJU 2001, KUMAR ET AL. 2001, DINESH ET AL. 2009, AENGALS ET AL. 2011).

Overall, the faunal similarity closely traced back the inter-site geographic distance and the river barrier(s). Our study indicates that rivers can be potential barriers for some species of herpetofauna in this landscape. Kolli was faunally more similar to Jawadi than to Sirumalai, although equidistant from both of them. This might be due to the presence of the smaller Pennaiyar river in case of Jawadi versus the much more mighty Kaveri river in case of Sirumalai, as evidenced by the ranges of a few lizard species. Shevaroys, situated between Kolli and Jawadi hills could also facilitate dispersal, thus further increasing their similarity. While previous work (DANIELS & ISHWAR 1994) did record many of these range-restricted taxa from across many hill ranges, such biogeographic comparison were wanting. Some works focusing on the montane zone of a single hill range (DANIELS & KUMAR 1998, KUMAR &

DANIELS 1999, VANAK ET AL. 2001) did mention the potentially disjunct and biogeographically-puzzling presence of wet-zone taxa.

We present this data with a caveat that taxonomic works on some unidentified species and problematic species complexes are needed to better refine our results on distribution. Because the vast majority of amphibians, day geckoes (*Cnemaspis*) and shieldtail snakes (Uropeltids) are highly speciose in almost all southern Indian hill ranges (BIJU 2001, DINESH ET AL. 2009, AENGALS ET AL. 2011, BIJU ET AL. 2014, VIJAYAKUMAR ET AL. 2014, OLIVER ET AL. 2015), we hypothesise that any unidentified representatives of the aforesaid taxa in the surveyed hills are likely to be endemic forms that would not be found anywhere else.

As our geographic coverage and site selection protocol have a direct bearing on the resultant species records (see FREITAG & JAARVELD 1998), we stress the importance of thorough field sampling in carefully selected study sites so as to amass the greatest spatio-ecological and (hence) taxonomic diversity spectrums the region could harbor. Moreover, the elevational restriction made it practical for our inventory in the biodiverse montane zones, revealing unreported endemics. Therefore, as incomplete results belittle the true diversity and conservation importance of a region (SASTRE & LOBO 2009), fresh field surveys and complete taxonomic works are needed to reevaluate the biodiversity of understudied tropical montane hotspots, like the Eastern Ghats. To this end, our work on the zoogeography of herpetofauna would contribute to the conservation of the Southern Eastern Ghats (see GANESH & ARUMUGAM 2015).

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