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INVITED ARTICLE

Geographical Restrictedness of Species and Climate Resilience: Insights from the Endemic Cold-blooded Vertebrates of the Western Ghats, India

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Western Ghats, Endemic, Vertebrates, Cold-blooded, Bioclimate, Resilience

Abstract

This paper focuses on the geographical distribution of endemic cold-blooded vertebrates in the Western Ghats, one of the world's biodiversity hotspots. Western Ghats are among the earth's oldest tropical hill ranges. More than 1,500 vertebrate species are currently known in the ecoregion. 42% of the species are endemic. Majority of the endemic vertebrates are cold-blooded, including fish, amphibians and reptiles. When the latitudinal distribution of 454 species of vertebrates, endemic to the Western Ghats, was analysed, it became evident that 49% of the species are local endemics and 80% of the local endemics are not known north of 13 ° N latitude. Higher levels of endemism in the south are attributed to the shorter dry season. While the role of massifs and the Palghat Gap in limiting the geographical distribution of local endemics needs to be investigated in greater detail, it is emerged that hill streams and the associated species of fish and amphibians, when studied in the context of the local bioclimate, can offer clues to understanding climate resilience in the Western Ghats.

Introduction

The geographical distribution of any species is primarily determined by environmental conditions, such as temperature, light, and moisture, and by available food resources (Cox and Moore 1980). Limits imposed by physical and biological factors can restrict some species to smaller areas. Species with restricted geographical distribution are called endemic.

Endemism, apparent at different geographical scales, influenced the thoughts and theories of nineteenth-century naturalists such as Charles Darwin and Alfred Russel Wallace. Robert H MacArthur and Edward O Wilson chose endemic species as the most appropriate candidates to explain the origin and diversification of biological communities in islands (MacArthur and Wilson 1967).

Can the distribution and diversity of endemics in a region be useful in understanding climate resilience? The discussion that follows examines the distribution patterns of endemic cold-blooded vertebrates in the Western Ghats and attempts to explain how climate influenced local patterns of endemism and whether the apparent patterns have something to say about the resilience of the biodiversity hotspot.

Western Ghats

Western Ghats are among the earth's oldest tropical hill ranges with high levels of endemism (Daniels and Vencatesan 2008). The average annual rainfall is 2500mm. However, rainfall ex-

tremes of less than 800mm and more than 10,000mm are also known locally (Daniels and Vencatesan 2008 and Daniels 2023).

Spread south-north, between 8°N and 21°N latitudes, the approximately 1600km long hill range is climatically heterogeneous. The southern parts experience equatorial climate with shorter dry seasons (2-5 months), while the northern parts are more seasonal, with longer dry seasons (5-9 months) (Pascal 1988 and Daniels 1992).

Altitude does not normally exceed 1000 or 1200m ASL. But massifs of 1800m or more exist locally, attaining their best development in the Nilgiri, Anamalai and Palani plateaus where peaks in excess of 2000m are frequent (Daniels and Vencatesan, 2008). Temperature is generally warm and humid but extreme cold and frost-like conditions are experienced above 2000m (Daniels 1992 and Daniels and Vencatesan 2008).

Western Ghats are characterised by a diversity of vegetation types. A comprehensive study of wet evergreen forests by J. P. Pascal showed, for the first time, that altitudinal variations in ambient temperature and the south-north gradient in the length of the dry season mainly determined the distribution, structure, and composition of the primary evergreen forests (Pascal 1988).

The factors that determine the distribution and diversity of animals are still poorly understood. With close to 600 species, birds are the most diverse and well-studied class of vertebrates in the Western Ghats. However, low levels of endemism (<5%), majority of the species being habitat generalists, and being highly mobile, have rendered birds, unsuitable candidates for understanding how local geography and climate affects the patterns of distribution and diversity in the Western Ghats (Daniels 1997).

Similarly, mammals are also not appropriate candidates. Diversity of mammals is the lowest among vertebrates, with endemism only marginally higher than birds. Endemism is, however, the highest among cold-blooded vertebrates, namely fish, amphibians and reptiles (Daniels and Vencatesan 2008).

Therefore, the focus of the discussion will be more on the cold-blooded vertebrates. It will start with amphibians and then deal with fishes and reptiles. The possible influence of temperature and length of the dry season on the diversity and distribution of endemic fishes, amphibians and reptiles will be examined.

Insights from amphibians

Amphibians are relatively more sedentary than other vertebrates. They have complex life histories that are closely linked to water which limits their geographical distribution (Duellman and Trueb 1985). For reasons that are not yet fully understood, the highest level of endemism among animals is that in amphibians. From what was known during the early nineties, it was inferred that 76% of the species in the Western Ghats were endemic. Patterns of geographical distribution and diversity of amphibians were therefore investigated, for the first time, during 1990-1992 (Daniels, 1992).

Following J P Pascal (Pascal 1988), the entire Western Ghats were divided into thirteen one-degree latitudinal segments from south to north and thirteen 200m altitudinal segments spanning the elevation gradient from sea level to 2600m ASL. Exhaustive field research conducted between 1990 and 1992 (including bight surveys) provided firsthand data on the distribution of more than 25% of the known species. And, with supplementary data from published literature, it was possible to analyse the patterns of distribution and diversity of amphibians in the Western Ghats (Daniels 1992).

A few general patterns of distribution characterized the amphibian fauna of the Western Ghats: 1) Western Ghats south of 13°N had greater diversity and endemism than the more extensive north, 2) length of the dry season apparently played an important role in determining local species richness and endemism, 3) 46% of the species appeared to be local endemics with geographical ranges limited to just one latitudinal segment, and 4) 83% of the local endemics were not known above 1200m (Daniels 1992).

Other than the four general patterns, it also became evident that amphibians shared patterns of diversity and endemism with angiosperms. But they differed vastly from birds (Daniels 1992&1997). Also, the hypothesis of Robert Inger and colleagues (Inger et al. 1987) that massifs are important for endemism in amphibians was not substantiated (Daniels 1992). Inger et al (1987) had only surveyed the Ponmudi Hills in the southern Western Ghats. A critical review of Inger et al (1987) and Daniels (1992) is available in Huggett (1995).

K A Subramanian and colleagues at the Zoological Survey of India, discussed the characteristics of 158 endemic species of amphibians (Subramanian et al. 2013). The 2013 publication reiterated the observations made by Daniels (1992), that diversity of amphibians and endemism are both higher south of 13°N. According to the 2013 study, around 53% of the endemic species are arboreal, and those which depended on streams to complete their life histories. Majority of the arboreal species are direct-developing bush frogs belonging to the genus *Raorchestes*. It also stated that lower diversity of amphibians in the massifs is a pattern that can be directly linked to the cooler temperature (Subramanian et al. 2013). That cold-blooded vertebrates such as amphibians are more sensitive to ambient temperature is a well-known fact (Duellman and Trueb 1985).

A more recent study (Vijayakumar et al. 2016) has however argued that geology, ecology and climate have played varying roles at different periods since glacial times in the diversification of bush frogs (*Raorchestes*) in the Western Ghats. The study also highlighted the roles played by massifs above 1800m in the diversification of *Raorchestes*. According to the authors, the diversification was facilitated by the massifs and the lower elevations have only served as ‘museum’. Other than massifs, possible role that the Palghat Gap played in influencing the distribution and diversity of local endemics has also been highlighted by amphibian ecologists (Bossyut et al. 2004).

Endemic vertebrates and their distribution in the Western Ghats

During the twenty years since the results of the 1990-92 study on amphibians were published, the number of species of vertebrates known in the Western Ghats increased considerably taking the total to 1282 species. And, of the 454 species of endemic vertebrates, 35% were fish, 32% amphibians, 22% reptiles and the rest (11%) were birds and mammals (Daniels, unpublished). Interestingly, 67% of the endemic species belonged to fish and amphibians, two classes of vertebrates, the distribution of which is limited by water (Figure 1).

When the proportions of endemic species in the five classes were compared, amphibians stood at the top with 86% and fish came next with 54% (Figure 2). Forty per cent endemism in fish was earlier reported by Neelesh Dahanukar (Dahanukar 2003) and 87% endemism among amphibians was reported by K A Subramanian and colleagues of the Zoological Survey of India (Subramanian et al. 2013).

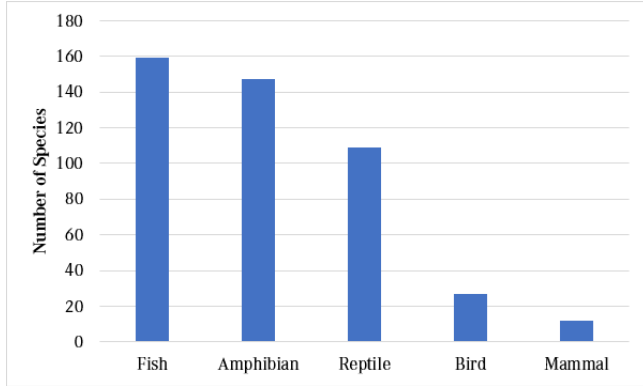

Figure 1: Distribution of the 454 endemic species of vertebrates across five classes in the Western Ghats

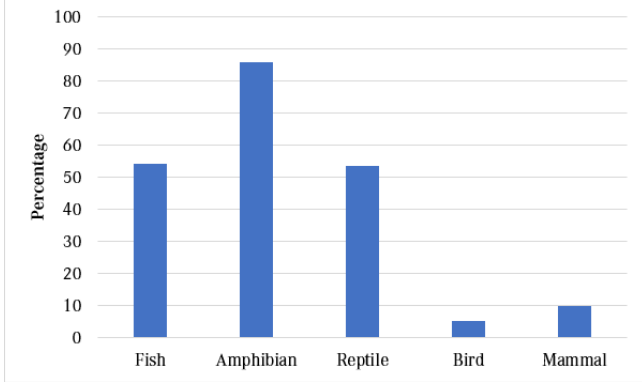

Figure 2: Percentage of endemic species in the five classes of vertebrates in the Western Ghats

In 2012, a project jointly executed by Care Earth Trust and the French Institute of Pondicherry, offered renewed opportunities to analyse the patterns of diversity and distribution of endemic vertebrates including all five classes. The project supported by the Critical Ecosystems Partnership Fund came with the specific mandate of mapping the distribution of endemic vertebrates. The 454 endemic vertebrate species were therefore mapped across the 13 one-degree latitudinal segments as was done with amphibians thirty years ago (Daniels 1992).

Two patterns that emerged from the analysis, reiterated what was observed in amphibians twenty years ago (Daniels 1992). First, endemism in vertebrates was higher southwards of 13°N (Figure 3). Second, 49% of the endemic vertebrate species (cf. 46% in Daniels 1992) were local, restricted to one latitudinal segment (Figure 4). The third pattern that emerged from the 2012 analysis, and for the first time is that, 80% of the local endemic species were not known north of the 13°N latitude (Figure 5).

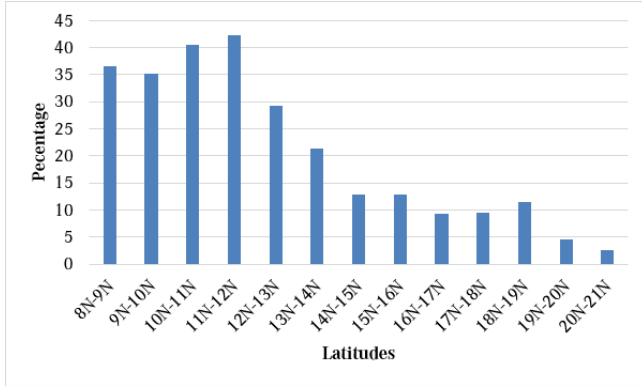

Figure 3: Latitudinal distribution of the 454 species of endemic vertebrates in the Western Ghats

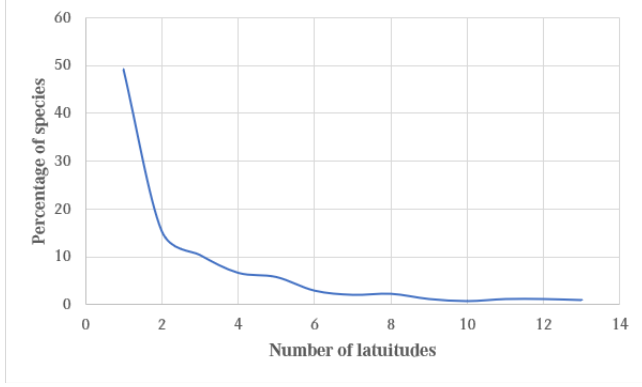

Figure 4: Distribution of the 454 species of endemic vertebrates in the 13 one-degree latitudinal segments

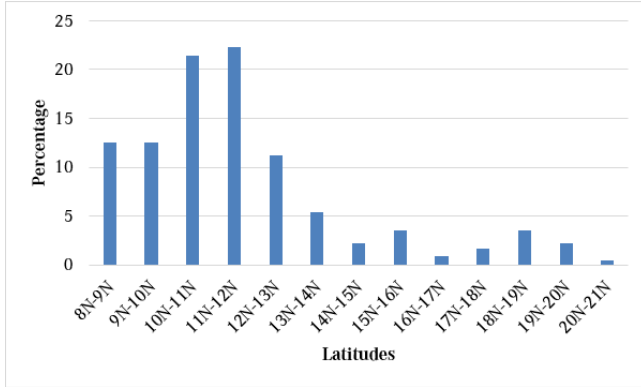

Figure 5: Latitudinal distribution of the 223 species of local endemic vertebrates in the Western Ghats

Role of massifs in limiting the distribution of endemic vertebrates

Forty-four per cent of the local endemic species were restricted to 10°N-12°N latitudes (Figure 5). Further, the chance of any these species being a fish or amphibian was 66%. The segment 10°N-12°N is where the massifs above 2000m are located. It is also here that the Palghat Gap the only pass in the Western Ghats is located. This is an interesting pattern that may correspond with the observations reported by Vijayakumar et al (2016). Nevertheless, without complete data on the altitudinal distribution of the 223 species of local endemics, it will be difficult to explain the apparent pattern.

A study by Easa and Shaji (1997) in the western slopes of the Western Ghats that lie north of the Palghat Gap and limited by the 11°N and 12°N latitudes reported the presence of 92 species of fish. Of these 40% were species endemic to the Western Ghats. Species that they had mentioned as 'strictly' endemic to Kerala amounted to 10%. However, except for the two new species that the study added, all others were those already known in Kerala. Although the study coincided with the segments in which massifs are located, the streams and rivers were not montane.

Cold-blooded vertebrates can be model organisms

Table 1 summarizes the attributes of the 223 species of local endemic vertebrates. Seventy-seven per cent of the local endemic fish belong to the order cypriniformes (danios, loaches, garras, masheers, barbs, etc.). Small-sized cypriniform stream fish tend to be local endemics because of their narrower habitat niche. Of these thirty-two species (loaches, garras, etc.) are bottom-dwellers (44%) and 19 species are small barbs (26%).

Table 1: Ecological attributes of 223 species of the local endemic vertebrates in the Western Ghats

Class	Subcategory	Habitat niche	Number of species
Fish	Danios & allies	Shallow stream mid-water	7
	Loaches	Shallow stream bottom-dweller	18
	Garras & other rock gleaners	Shallow stream rocky substrate	14
	Masheers	Large streams & rivers	4
	Large barbs	Large streams & rivers	11
	Small barbs	Shallow streams	19
	Swamp eels	Shallow water & soft substrate	5
	Spiny eels	Shallow streams	1
	Snakeheads	Wide	1
	Catfishes	Wide	15
			95 (60%)
Amphibians	Caecilians	Burrowing	14
	Toads	Wide	5
	Bush frogs	Arboreal, Direct development	31
	Treefrogs	Arboreal, Aquatic tadpole	6
	Cricket frogs	Litter	9
	Leaping frogs	Litter	4
	Dancing frogs	Streams	6
	Night frogs	Springs & streams	9
	Microhylids	Wide	3
	Others	Wide	3
			90 (61%)
Reptiles	Geckos	Wide	3
	Day geckos	Trees & rocks	9
	Skinks	Litter	6
	Agamids	Wide	1
	Worm snakes	Litter-burrowing	2
	Shield-tails	Burrowing	13
	Wolf snakes & allies	Wide	2
	Pit vipers	Litter	1
			37 (34%)
Mammals	Rodents	Wide	1

Note: figures in parenthesis calculated using the total number of Western Ghats endemics in the respective classes as the denominators

Among amphibians, local endemics were commoner in bush frogs (*Raorchestes*) followed by caecilians (Table 1). Caecilians are burrowing amphibians, highly secretive and poorly studied (Daniels 2005). As a result, the range and habitats of many species are incompletely known.

Bush frogs in the genus *Raorchestes* are mostly arboreal species with direct-development (Subramanian et al 2013). Sixty-one per cent of the *Raorchestes* species were restricted to the 10°N-12°N segment. S P Vijayakumar and colleagues provided an explanation for this pattern and have gone further to state that it is in the bush frog genus *Raorchestes* the 'largest vertebrate diversification has happened in peninsular India' (Vijayakumar et al. 2016). With more than 50 species in the genus (Priti et al. 2016), the Western Ghats are certainly the centre of diversity for bush frogs.

Shield-tail snakes belong to the family Uropeltidae. The family is endemic to peninsular India and Sri Lanka (Bossyut et al. 2004). At least 33 species are known from the Western Ghats (Daniels and Vencatesan 2008). Being burrowing snakes, like caecilians, the range and habitats of many species are not fully known.

Cnemaspis to which the day geckos belong, is the most diverse genus of geckos in the world (Srinivasulu et al. 2015). Around 50 species are already known in the western Ghats and many more are likely to be added (Daniels and Vencatesan 2008).

Western Ghats a hotspot of vertebrate endemism

By 2024, the number of species of vertebrates known in the Western Ghats increased to 1566 (Daniels, unpublished). Around 38% of the species are birds. With the exception of birds and mammals, almost all the species added to the Western Ghats since 2012 are new to science. This has resulted in a huge leap in the number of endemic species which currently is around 660 (Daniels, unpublished).

The proportion of vertebrates, endemic to the Western Ghats has also grown. In 2008 the percentage of endemic vertebrates was 31 (Daniels and Vencatesan 2008). By 2012, it increased to 35. Endemism among the vertebrates of the Western Ghats that we know at present (42%), and the rising trend in the discovery of new species suggest that further additions will continue for a while (Fig 6).

After analysing the trends in the discovery of new species of amphibians in the Western Ghats N A Aravind and colleagues predicted that there are many more species 'awaiting' discovery and that the new discoveries will all be endemic (Aravind et al. 2004). This prediction may be applicable not just to amphibians but to the three classes of cold-blooded vertebrates in the Western Ghats (see Figure 6).

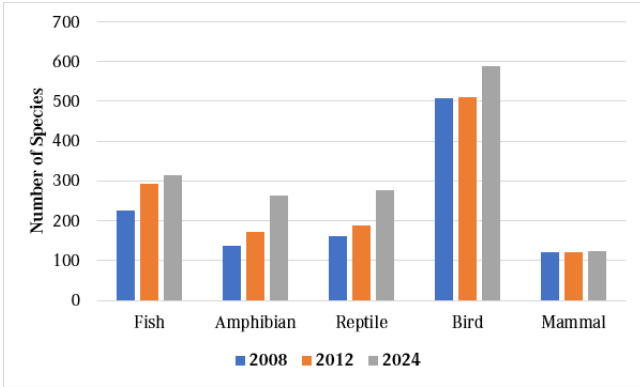

Figure 6: Total number of species in the five classes of vertebrates known in 2008, 2012 and 2024 from the Western Ghats

Number of species of vertebrates, endemic to the Western Ghats is much higher than that of its counterpart Sri Lanka. In Sri Lanka there are 26 species of birds, 21 species of mammals, 113 species of reptiles, 112 species of amphibians and 50 species of fish endemic to the island (Maleesha 2020). All classes put together it is 322 species, which is less than half of what is currently known in the Western Ghats. The only class where there are more species is mammals in which there are only 12 species in the Western Ghats.

Another widely acclaimed biodiversity-rich area is Arunachal Pradesh in northeast India. It lies within the East Himalayan biodiversity hotspot. The total number of endemic taxa (species and subspecies) of vertebrates known from the state is only 102 of which 66% are fish, 15% amphibians, 5% reptiles, 6% birds and 8% mammals (Nath and Sharma 2021).

Summary and conclusions

Studies of endemic species elsewhere in the world have reported the following: 1) endemism is an effective surrogate for conservation of vertebrates (Loyola et al. 2007), 2) endemic plants are good predictors of endemic vertebrates (Kier et al. 2009), 3) ecoregions with high numbers of endemic species need urgent conservation action (Paras et al. 2022), 4) local endemic species are more vulnerable to extinction (Wijesinghe and Brooke 2004), and 5) lowland continental species are at greater risk than island or montane species (Wijesinghe and Brooke 2004).

The above observations and recommendations are general and applicable to all endemic species. If local endemics are alone taken into consideration, then the southern Western Ghats should be seen as an ‘important endemic vertebrate area’ and the ‘epicentre’ of vertebrate endemism. When the patterns of distribution of the 660 species of endemic vertebrates are fully mapped, there may be more interesting results. Nevertheless, from what is currently known,

especially from the patterns of distribution of cold-blooded vertebrates, the following inferences can be drawn:

- Endemism is the lowest in mammals and birds
- Endemism in angiosperms is a better predictor of endemism among fish, amphibians and reptiles
- Western Ghats south of 13°N is richer in endemic vertebrates than the more extensive north
- The southern segment is also home to majority of the local endemics
- High levels of endemism in the vertebrates of the Western Ghats are primarily due to fish, amphibians and reptiles
- Fish and amphibians that have life histories directly linked to water, contribute significantly to local endemism in the Western Ghats
- Higher proportion of local endemics in fish suggests that species turnover (beta diversity) between streams can be high
- Endemism is much higher in amphibians than in the other classes of vertebrates
- Higher levels of local endemism in amphibians are largely due to bush frogs and caecilians
- Local endemics in reptiles are mainly day geckos and shield-tail snakes
- Bush frogs and day geckoes have diversified maximally among vertebrates in the Western Ghats
- The role of massifs and the Palghat Gap in adding local endemics to the vertebrate fauna of the Western Ghats needs to be investigated more carefully

Cold-blooded animals are more vulnerable to climate change than warm-blooded. Among cold-blooded vertebrates, fish and amphibians are more dependent on small streams and rainwater puddles which can easily dry up with warming climate and loss of canopy. Hill stream fishes, bush frogs and day geckos which are diverse with many local endemics can be good candidates for study of climate resilience as they represent both aquatic and arboreal guilds. Greater attention must be paid in future to understanding the latitudinal and altitudinal distribution of these vertebrates. Bioclimate studies in localities with higher levels of local endemism may answer a number of questions that concern climate resilience in the Western Ghats.

Conflict of Interest Statement:

“Author is a member of the Editorial Board of the Journal of Climate Justice and had no role in the review or publication decision for this article.”

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