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Endemism-based butterfly conservation: insights from a study in Southern Western Ghats, India

M. Anto[1*], C. F. Binoy[1] and Ignatious Anto[2]

Abstract

Background: The Western Ghats, a biodiversity hotspot in India harbours a high percentage of endemic species due to its unique and diverse habitats. These species which cannot survive elsewhere due to their specialised habitat requirements are at high risk from climatic and anthropogenic disturbances. The butterfly fauna of the region although well documented has not been investigated intensively at local scales. In this study, we present information on species presence within 10 km × 10 km grid cells (n= 30; area=3000 km^2) of 94 butterfly species in the Western Ghats region. The data on the species distribution within these grids which included three wildlife sanctuaries and four forest divisions was mapped. Indicator analysis was performed in R using multipatt function in indispecies package to determine species associated with sites/site combinations. The corrected weighted endemism indices of the study grids were estimated.

Results: The data collected over a 4-year period comprised of 393 records of 60 endemic species belonging to five families observed along 102 transects. *Troides minos* was the most widespread species occuring in 19 grids. Seventeen species indicative of sites and site combinations were obtained, of which *Cirrochroa thais*, *Papilio paris tamilana*, *Papilio helenus daksha*, *Parthenos sylvia virens and Mycalesis patnia* were significant. The highest corrected weighted endemism index was observed in grid 25 (14.44) followed by grids 24 (12.06) and 19 (11.86). Areas harbouring unique and range restricted species were Parambikulam WLS/TR: Kuthirakolpathy, Pupara, Kalyanathi, Top slip and Muthalakuzhy; Peechi-Vazhani WLS: Ayyapankadu; Thrissur FD: Chakkapara and Vellakarithadam; Nenmara FD: Karikutty, Pothumala and Nelliampathy estate; Vazhachal FD: Poringalkuthu dam, Meenchal and Vazhachal.

Conclusions: The study area which covers 2.14% of the Western Ghats hotspot harbours almost 63.82% of the region's endemic butterfly species making this particular region crucial for butterfly conservation and management. Studying the phylogenetic endemism of the butterflies, identification of microrefugia and testing the mountain geobiodiversity hypothesis with respect to butterflies are the suggested approaches to be adopted for fine-tuning research and conservation of butterflies in this fragile hotspot.

Keywords: Distribution mapping, Indicator species, Endemism index, Biodiversity hotspot

* Correspondence: drmaryanto@gmail.com
[1]Research and Post Graduate Department of Zoology, St. Thomas College, Thrissur, Kerala 680001, India
Full list of author information is available at the end of the article

Background

The forests in the Kerala region of the Western Ghats, a biodiversity hotbed, have recently been the target of unpredictable monsoons (Mishra et al., 2018). Studies show an increasing trend of extreme rainfall (Roxy et al., 2017) as well as increases in minimum temperature in the Western Ghats and peninsular India (Dash, Nair, Kulkarni, & Mohanty, 2011; Mondal, Khare, & Kundu, 2015). Butterfly migrations of several species of Papilionidae, Nymphalidae and Pieridae have been reported to coincide with the monsoonal system in peninsular India (Bhaumik & Kunte, 2018; Kunte, 2005). Apart from decades of anthropogenic disturbances leading to forest fragmentation (Jha, Dutt, & Bawa, 2000; Menon & Bawa, 1998; Nair, 1991), recent studies have highlighted other detrimental activities like mining, road construction and irrigation projects (Bharucha, 2006).

In the backdrop of increasing habitat degradation, formulation of priorities for conservation in the Western Ghats is challenging. Many approaches may be adopted

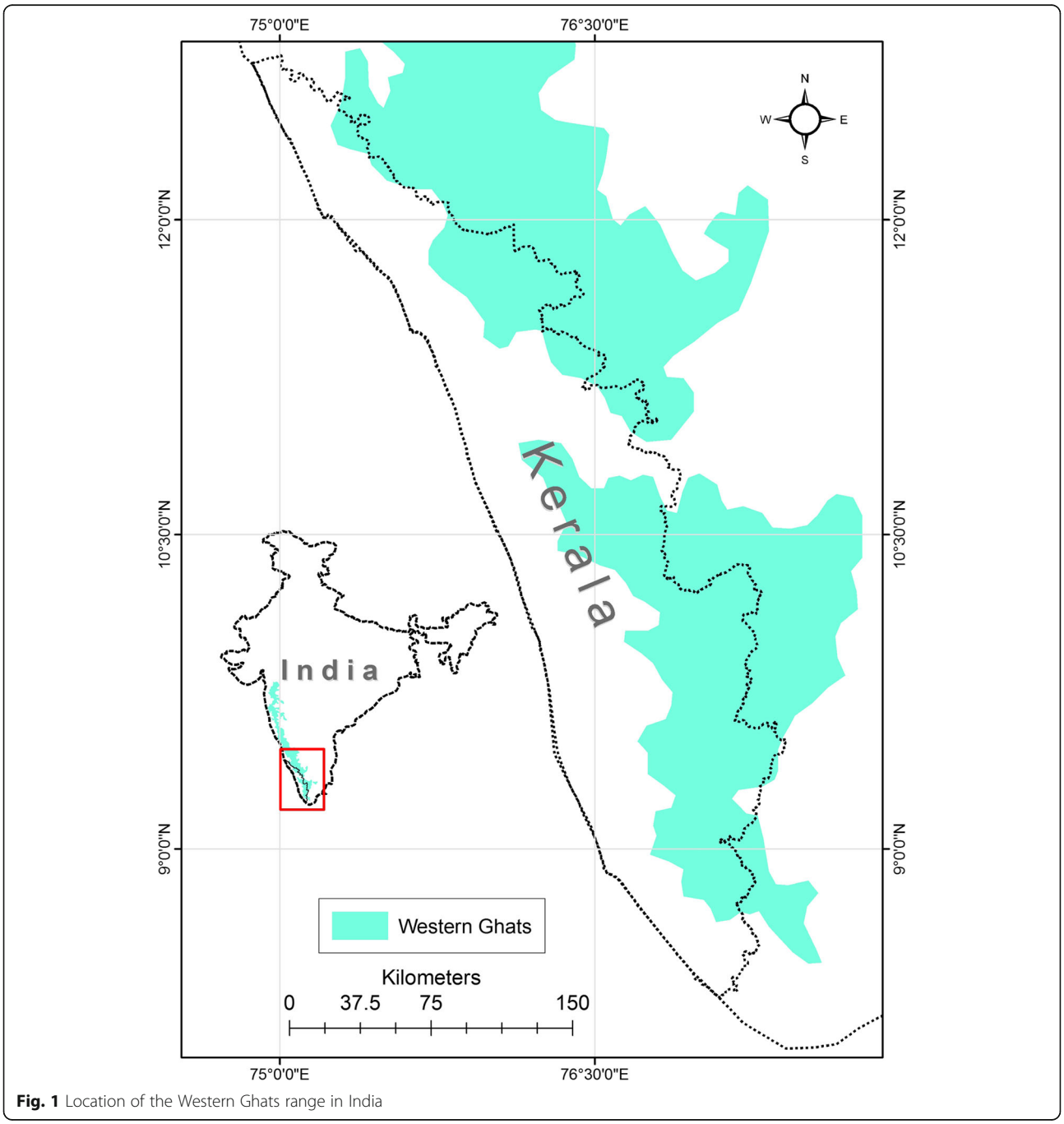


Fig. 1 Location of the Western Ghats range in India

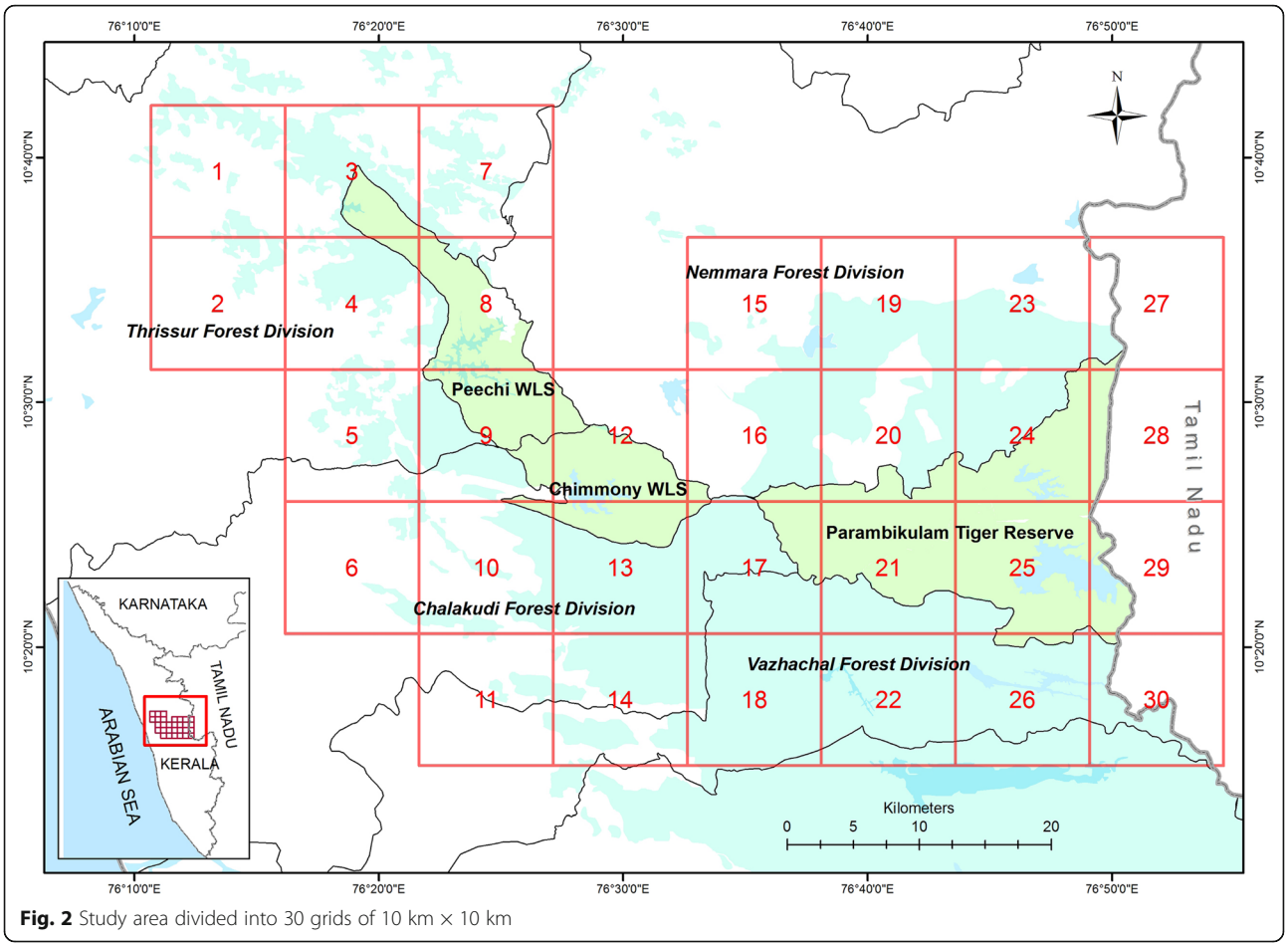


Fig. 2 Study area divided into 30 grids of 10 km × 10 km

but the simplest and most effective would be focusing our attention and action towards reducing the loss of biodiversity based on a framework of vulnerability and irreplaceability (Margules & Pressey, 2000). Subsequently, areas with exceptionally high concentrations of endemic species were prioritised for conservation and the global 'biodiversity hotspot' concept was developed to address this crucial issue (Mittermeier, Myers, Robles-Gil, & Mittermeier, 1999; Myers, 1988, 1990, 2003; Myers, Mittermeier, Mittermeier, da Fonseca, & Kent, 2000). Although hotspots are designated as areas for priority conservation action, the fauna and flora of many hotspots are poorly studied and relevant data are insufficient for effective conservation planning (Mittermeier et al., 2004; Mittermeier, Turner, Larsen, Brooks, & Gascon, 2011). Moreover, it is also likely that true hotspots may go unrecognised due to lack of organised data, biogeographical biases and regional misconceptions (Noss et al., 2015).

In the hotspot analysis whereby 25 areas were identified, the Western Ghats was among the top eight critical regions in terms of endemism and extent of original primary vegetation (Myers et al., 2000) and later designated as 'hyperhot' for conservation prioritisation (Brooks et al., 2002). The number of global hotspots was later expanded to 35 (Mittermeier et al., 2011). The Western Ghats is a 1600 km mountain chain running almost parallel to India's western coast and spread over six states—Gujarat, Maharastra, Goa, Karnataka, Tamil Nadu and Kerala. It includes two biosphere reserves, the Nilgiris Biosphere Reserve (11,040 km^2) and the Agasthyamalai Biosphere Reserve (3500 km^2). Kerala lies between 8° 18′ and 12° 48′ N latitude and 74° 54′ and 77° 12′ E longitude in the south-west region of the Indian peninsula between the Arabian sea and the Western Ghats (Fig. 1).

Topographic heterogeneity (from sea level to 2695 m at its highest point) and a strong precipitation gradient (annual rainfall of < 50 cm in eastern valleys to > 700 cm along western slopes) has given rise to remarkable diversity in flora and fauna. The forests in the state are classified into wet evergreen, semi-evergreen, moist deciduous, dry deciduous and thorn forest types (Champion & Seth, 1968). Studies by Reddy, Jha, & Dadhwal (2016) on the extent, distribution and changes in forests of the Western Ghats reveal a net loss of 35.3% of forest

Table 1 Geographic coordinates of transects sampled in 30 grids of study area

No.	Grid	Location	Transect	Longitude	Latitude
1	1	Thrissur Division	Kuranchery	76.23205	10.62663
2	1	Thrissur Division	Mangad	76.18482	10.68173
3	1	Thrissur Division	Mudathikode	76.19416	10.64304
4	1	Thrissur Division	Tiruttiparamba	76.21115	10.62360
5	1	Thrissur Division	Velur	76.15370	10.64022
6	1	Thrissur Division	Kiralur	76.16385	10.61472
7	1	Thrissur Division	Ottupara	76.25026	10.66278
8	1	Thrissur Division	Attatra	76.19828	10.67283
9	2	Thrissur Division	Poomala dam	76.24048	10.60182
10	2	Thrissur Division	Kottekad	76.19345	10.57240
11	2	Thrissur Division	Pambur	76.20394	10.56038
12	2	Thrissur Division	Mukkattukara	76.25250	10.53585
13	2	Thrissur Division	Peringavu	76.21604	10.54587
14	2	Thrissur Division	Kolazhi	76.22042	10.57027
15	3	Thrissur Division	Chelakkara	76.35251	10.68421
16	3	Thrissur Division	Karumathara	76.28095	10.64745
17	3	Peechi-Vazhani WLS	Vazhani dam	76.30601	10.63308
18	3	Peechi-Vazhani WLS	Kunnamkadu	76.31664	10.63913
19	3	Peechi-Vazhani WLS	Kadamkandachal	76.32311	10.63853
20	3	Peechi-Vazhani WLS	Valiyathodu	76.30891	10.64841
21	3	Peechi-Vazhani WLS	Ettachola	76.30917	10.64121
22	3	Peechi-Vazhani WLS	Ayyapankadu	76.31289	10.64147
23	3	Peechi-Vazhani WLS	Vellapara	76.32895	10.62220
24	4	Peechi-Vazhani WLS	Vellanipacha mala	76.33732	10.58139
25	4	Thrissur Division	Mudikode	76.30584	10.55354
26	4	Thrissur Division	Pattikad	76.33561	10.54970
27	4	Thrissur Division	Kanara	76.33492	10.52959
28	4	Thrissur Division	KFRI	76.34466	10.53252
29	4	Thrissur Division	Canal	76.35319	10.53498
30	5	Thrissur Division	Marotichal	76.35786	10.47914
31	5	Thrissur Division	Moorkinikkara	76.27925	10.51414
32	5	Thrissur Division	Kainoor	76.30233	10.49713
33	5	Thrissur Division	Puthur	76.27932	10.48710
34	5	Thrissur Division	Mannamangalam	76.34639	10.50081
35	6	Chalakudy Division	Velupadam	76.35910	10.43505
36	6	Chalakudy Division	Mupliyam	76.35094	10.39540
37	6	Chalakudy Division	Kundukadavu	76.30326	10.38947
38	6	Chalakudy Division	Kodakara	76.31415	10.37230
39	7	Thrissur Division	Pazhayannur	76.42017	10.67873
40	7	Thrissur Division	Elanad	76.39383	10.61718
41	8	Peechi-Vazhani WLS	Peechi dam	76.37174	10.53201
42	8	Peechi-Vazhani WLS	Vellamkandapara	76.49185	10.48322
43	8	Peechi-Vazhani WLS	Kallichempara	76.38353	10.50249
44	9	Peechi-Vazhani WLS	Vengapara	76.40705	10.48101

Table 1 Geographic coordinates of transects sampled in 30 grids of study area *(Continued)*

No.	Grid	Location	Transect	Longitude	Latitude
45	9	Thrissur Division	Vellakarithadam	76.36928	10.49332
46	9	Thrissur Division	Chakkapara	76.38664	10.49008
47	10	Chalakudy Division	Vellikulangara	76.37124	10.38481
48	10	Chalakudy Division	Kanakamala	76.36602	10.35835
49	11	Chalakudy Division	Pariyaram	76.37166	10.31984
50	11	Chalakudy Division	Ezhattumugham	76.43271	10.28292
51	11	Chalakudy Division	Melur	76.85444	10.29543
52	11	Chalakudy Division	Nalukettu	76.39679	10.27311
53	12	Chinmoni WLS	Virakkuthodu	76.45117	10.44045
54	12	Chinmoni WLS	Kavala	76.00000	10.45117
55	13	Chinmoni WLS	Ollakarakavu	76.46475	10.46725
56	13	Chalakudy Division	Check dam	76.25777	10.48728
57	13	Chalakudy Division	Anapathan	76.44871	10.35522
58	14	Chalakudy Division	Thumburmuzhi	76.45114	10.30532

area from 1920 to 2013. Endemism in butterflies is closely linked to the endemism of their host plants. The Western Ghats harbours 330 species out of Indian butterfly fauna of 1501 species. Of these, 37 species are narrow endemics found only in the Western Ghats and 23 species are endemic to Sri Lanka as well (Gaonkar, 1996). Endemism and species richness are widely used indicators of conservation value and an index combining both has been calculated and mapped at regional, continental and global scales (Crisp, Laffan, Linder, & Monro, 2001; Kier & Barthlott, 2001; Kier et al., 2009; Venevsky & Venevskaia, 2005). However, such studies at local scales (less than 5000 km^2) are still scarcely seen. As a result of detailed analyses of Australian flora, Crisp et al. (2001) concluded that the corrected endemism index is a useful method to detect centres of endemism using species-in-grid-cell data.

Studies in the last decade indicate that microrefugia may be formed due to topographic variations at scales of metres (Dobrowski, 2011) as well as local influences (De Frenne, Rodríguez-Sánchez, Coomes, et al., 2013) and that these effects are not reflected in GIS models of climate change (De Frenne et al., 2013; Keppel et al., 2017). However, most of these studies are based on flora (Bátori et al., 2017; Keppel et al., 2017; Noss, 2013) and mammals (Camacho-Sanchez et al., 2018). In a study of bush frogs in the Western Ghats, Vijayakumar, Menezes, Jayarajan, & Shanker (2016) highlighted the evolutionary significance of massifs which harbour unique refugia due to steep topographical and environmental shifts. Thus, protection of refugia resulting from mountain topography and climatic stability which buffers lineages against extinction is the current trend as it assures future protection (Klein et al., 2009; Mosblech, Bush, & van Woesik, 2011; Stewart, Lister, Barnes, & Dalén, 2010). Gaonkar (1996) details the state-wise distribution of the butterflies of the Western Ghats and Kunte (2008) delineated their distribution within the four zones whilst assigning conservation values to species.

In this context of impending challenges both biotic and abiotic to the forest ecosystems in the Western Ghats, we venture to ask the key question—Can endemic butterflies be used as indicators for conservation management at local scales in the Western Ghats hotspot? In this study, we have mapped the distribution of endemic butterfly species in an area of 3000 km^2 in the central region of the Kerala part of the Western Ghats and calculated the endemic richness index of various grids of the study area. We expect that the sampling of endemic butterfly species at this microscale level will help detect microrefugia and unique habitats in this fragile hotspot. The indicator species occurring in the study area were identified using the R software.

Methods

The study was carried out in the central region of the Kerala part of the Southern Western Ghats which included three wildlife sanctuaries: Peechi-Vazhani wildlife sanctuary (Peechi-Vazhani WLS), Chinmony wildlife sanctuary (Chinmony WLS), Parambikulam wildlife sanctuary/tiger reserve (Parambikulam WLS/TR) and four forest divisions: Nenmara forest division (Nenmara FD), Vazhachal forest division (Vazhachal FD), Thrissur forest division (Thrissur FD) and Chalakudy forest division (Chalakudy FD). The study area was divided into 10 km × 10 km grids and a total of 30 grids were obtained (Fig. 2). In each grid cell, ten transects were covered over the study period and the length of transects in the different grids ranged between 800 m and 1000 m.

Table 1 Geographic coordinates of transects sampled in 30 grids of study area *(Continued)*

No.	Grid	Location	Transect	Longitude	Latitude
59	14	Chalakudy Division	Kanampuzha	76.33498	10.29722
60	15	Nenmara Division	Pothundi dam	76.62190	10.53865
61	15	Nenmara Division	Seetharkundu	76.69860	10.54274
62	16	Nenmara Division	Pothumala	76.66952	10.46523
63	16	Nenmara Division	St. George church	76.67397	10.50333
64	16	Nenmara Division	Pulaya para	76.67878	10.53075
65	16	Nenmara Division	Karikatty	76.67407	10.53764
66	16	Nenmara Division	Greenland farm	76.72923	10.55685
67	17	Chalakudy Division	Muduvarachal	76.62040	10.38440
68	17	Vazhachal Division	Irumpupalam	76.38678	10.57347
69	18	Vazhachal Division	Charpa	76.57567	10.30352
70	18	Vazhachal Division	Konnakuzhi	76.42740	10.30210
71	18	Vazhachal Division	Vazhachal	76.58499	10.31719
72	18	Vazhachal Division	Athirampilly	76.55946	10.29151
73	19	Nenmara Division	Kollengode	76.69916	10.60972
74	19	Nenmara Division	Elavenchery	76.63347	10.59170
75	20	Nenmara Division	Nelliampathy estate	76.69558	10.53104
76	21	Parambikulam WLS	Muthalakuzhy	76.66888	10.39424
77	21	Parambikulam WLS	Orukomban	76.71386	10.40721
78	21	Parambikulam WLS	Medamchal	76.67452	10.39607
79	21	Parambikulam WLS	Ezhuvathampalam	76.62680	10.38281
80	22	Vazhachal Division	Poringalkuthu dam	76.63881	10.32114
81	22	Parambikulam WLS	Kurankuzhipalam	76.65754	10.38551
82	22	Vazhachal Division	Erumapara	76.83393	10.45923
83	22	Vazhachal Division	Thavalakuzhipara	76.69077	10.27635
84	23	Nenmara Division	Chuliyar dam	76.76469	10.59161
85	23	Nenmara Division	Muthalamada	76.76690	10.59786
86	24	Parambikulam WLS	Anappadi	76.82922	10.45397
87	24	Parambikulam WLS	Kuthirakolpathy	76.80731	10.45627
88	24	Parambikulam WLS	Sunkam colony	76.75723	10.44809
89	25	Parambikulam WLS	Earth dam	76.76570	10.37714
90	25	Parambikulam WLS	Rest para	76.75837	10.36382
91	25	Parambikulam WLS	Water hole	76.75369	10.36216
92	25	Parambikulam WLS	Karimala	76.74693	10.36687
93	25	Parambikulam WLS	Kalyanathi	76.74333	10.36720
94	25	Parambikulam WLS	Pupara	76.75859	10.36401
95	25	Parambikulam WLS	Bamboos	76.76049	10.36689
96	26	Vazhachal Division	Sholayar dam	76.73917	10.31139
97	26	Vazhachal Division	Meenchal	76.75833	10.32333
98	27	Nenmara Division	Chemmanampathy	76.83667	10.58284
99	28	Parambikulam WLS	Shekailmudi	78.85671	10.31404
100	28	Parambikulam WLS	Top slip	76.84181	10.47327
101	30	Vazhachal Division	Malakkapara	76.85541	10.27813
102	30	Vazhachal Division	Upper Sholayar	76.89703	10.32432

Table 2 Species recorded as endemic to the Western Ghats, Sri Lanka and peninsular India

Scientific name	Common name
Troides minos[a]	Southern birdwing
Pachliopta pandiyana[a]	Malabar rose
Pachliopta hector[b]	Crimson rose
Papilio liomedon[a]	Malabar banded swallowtail
Papilio dravidarum[a]	Malabar raven
Papilio polymnestor[b]	Blue Mormon
Papilio buddha[a]	Malabar banded peacock
Papilio crino[b]	Common banded peacock
Eurema nilgiriensis[a]	Nilgiri grass yellow
Colias nilagiriensis[a]	Nilgiri clouded yellow
Delias eucharis[b]	Common jezebel
Prioneris sita[b]	Painted sawtooth
Appias wardii[a]	Lesser albatross
Pareronia ceylanica[b]	Dark wanderer
Discophora lepida[b]	Southern duffer
Parantirrhoea marshalli[a]	Travancore eveningbrown
Lethe drypetis[b]	Tamil treebrown
Mycalesis subdita[b]	Tamil bushbrown
Mycalesis igilia[a]	Small long brand bushbrown
Mycalesis orcha[a]	Pale brand bushbrown
Mycalesis patnia[b]	Glad eye bushbrown
Mycalesis oculus[a]	Red disc bushbrown
Mycalesis adolphei[a]	Red eye busbrown
Mycalesis davisoni[a]	Palni bushbrown/Lepcha bushbrown
Zipoetis saitis[a]	Tamil cats'eye
Ypthima ceylonica[b]	White fourring
Ypthima chenui[a]	Nilgiri fourring
Ypthima ypthimoides[a]	Palni fourring
Cethosia nietneri[b]	Tamil lacewing
Cirrochroa thais[b]	Tamil yeoman
Euthalia nais[c]	Baronet
Kallima horsfieldi[a]	Blue oakleaf
Parantica nilgiriensis[a]	Nilgiri tiger
Idea malabarica[a]	Malabar tree nymph
Tarucus indica[a]	Transparent pierrot
Udara akasa[b]	White hedgeblue
Udara singalensis[b]	Singalese hedgeblue
Celatoxia albidisca[a]	White disc hedgeblue
Arhopala alea[a]	Rosy oakblue/Kanara oakblue
Arhopala bazaloides[b]	Dusted oakblue
Spindasis schistacea[b]	Plumbeous silverline
Spindasis ictis[b]	Common shot silverline
Spindasis abnormis[a]	Abnormal silverline
Zesius chrysomallus[b]	Redspot

Table 2 Species recorded as endemic to the Western Ghats, Sri Lanka and peninsular India *(Continued)*

Scientific name	Common name
Tajuria jehana[b]	Plains blue royal
Hypolycaena nilgirica[b]	Nilgiri tit
Rapala lankana[b]	Malabar flash
Curetis thetis[b]	Indian sunbeam
Curetis siva[a]	Shiva sunbeam
Sarangesa purendra[a]	Spotted small flat
Aeromachus pygmaeus[a]	Pygmy scrub hopper
Sovia hyrtacus[a]	Bicolour ace/White branded ace
Thoressa honorei[a]	Madras ace/Sahyadri orange ace
Thoressa astigmata[a]	Unbranded ace/Southern spotted ace
Thoressa sitala[a]	Tamil ace/Sitala ace/Nigiri plain ace
Thoressa evershedi[a]	Evershed's ace/Travancore tawny ace
Arnetta mercara[a]	Coorg/Kodagu forest hopper
Arnetta vindhiana[a]	Vindhyan bob
Quedara basiflava[a]	Golden/Yellow-base tree flitter
Oriens concinna[a]	Tamil/Sahyadri dartlet
Caltoris canaraica[a]	Kanara/Karwar swift

[a]Species endemic to the Western Ghats
[b]Species endemic to the Western Ghats and Sri Lanka
[c]Species endemic to the Western Ghats and peninsular India

Butterflies in the study grids were sampled along the transects using the Pollard line transect method (Pollard & Yates, 1993) with slight modifications. Butterflies sighted within 5 m on either side and in front of the observer walking at a constant pace of 1 km/h were recorded. The individuals that could not be identified by sight were either caught with an insect net for close examination or photographed and released. The butterflies were identified using suitable keys (Evans, 1932; Kehimkar, 2008; Wynter-Blyth, 1957). The sanction obtained from the Kerala Forest and Wildlife Department (No. WL 10-36790/15) for sampling in protected areas in the Western Ghats prohibited collection of endemic species. Hence, identification of smaller species belonging to families Lycaenidae and Hesperidae by sight was difficult.

The sampling was done over a 4-year period from May 2015 to April 2019 and the transect data collected along 102 transects (Table 1) was used to map the distribution of endemic species/subspecies onto the grids of the study area. The species occurrence matrix was prepared by scoring the presence/absence (1/0) of endemic species within the sampling grids. The geographic coordinates of transects were marked using Global Positioning System (GPS; GPSMAP 76Cx) which has good receptivity in forest areas. The GPS readings are plotted over geo-referenced Survey of India (SOI) by using open source Geographic Information System (GIS) software. The base layers such as water bodies, forest and boundaries were digitised from SOI topo sheets and updating of layers from latest satellite imageries done using GIS and remote sensing software. The final distribution map of endemic species whereby each point represents the occurrence of a single individual within the study area was prepared using the GIS software (Environmental Systems Research Institute (ESRI), 2011).

Using the sampling data for 4 years, the relationship between the observed species occurrence in the surveyed sites and site groups was analysed and the indicator species determined (De Cáceres & Legendre, 2009; De Cáceres, Legendre, Wiser, & Brotons, 2012; Dufrene & Legendre, 1997). Analyses were implemented in RStudio ver. 3.6.2 (RStudio Team, 2015) and indicative species were identified using multipatt function in package indispecies ver.1.7.9. The total count of species within each grid cell was measured as the species richness. Weighted endemism (WE) is a function of species richness and range size rarity (Crisp et al., 2001; Kier & Barthlott, 2001):

$$\mathbf{WE}=\mathbf{\Sigma}\ \mathbf{1}/\mathbf{C}$$

where C is the number of grids in which each species occurs.

The total WE index of each grid was obtained by summing the WE indices of all species recorded in that particular grid. Finally, the corrected weighted endemism index (CWEI) was calculated for each cell by dividing

Table 3 Subspecies recorded as endemic to the Western Ghats

Scientific name	Common name
Graphium antiphates naira	Sahyadri five bar swordtail
Graphium sarpedon teredon	Sahyadri narrow banded bluebottle
Papilio helenus daksha	Sahyadri red helen
Papilio paris tamilana	Sahyadri paris peacock
Eurema andersonii shimai	Sahyadri one spot grass yellow
Appias indra shiva	Sahyadri plain puffin
Appias lyncida latifasciata	Sahyadri chocolate albatross
Cepora nadina remba	Sahyadri lesser gull
Pieris canidia canis	Sahyadri cabbage white
Hebomoia glaucippe australis	Sahyadri great orange tip
Rohana parisatis atacinus	Sahyadri black prince
Charaxes schreiber wardii	Sahyadri blue nawab
Vindula erota saloma	Sahyadri cruiser
Dolpha evelina laudabilis	Sahyadri redspot duke
Athyma ranga karwara	Sahyadri blackvein sergeant
Athyma selenophora kanara	Sahyadri staff sergeant
Lassipe viraja kanara	Sahyadri yellow jacksailer
Neptis clinia kallaura	Sahyadri sullied sailer
Neptis nata hampsoni	Sahyadri clear sailer
Neptis soma palnica	Palni/Creamy sailer
Parthenos sylvia virens	Sahyadri clipper
Doleschallia bisaltide malabarica	Malabar autumn leaf
Vanessa indica pholoe	Sahyadri red admiral
Melanitis phedima varaha	Sahyadri dark eveningbrown
Melanitis zitenius gokala	Sahyadri great eveningbrown
Mycalesis anaxias anaxias	Sahyadri white bar bushbrown
Actolepis lilacea lilacea	Sahyadri lilac hedgeblue
Celastrina lavendularis lavenduris	Sri Lankan plain hedgeblue
Thaduka multicaudata kanara	Sahyadri many tailed oakblue
Catapaecilma major callone	Sahyadri common tinsel
Zinaspa todara todara	Sahyadri silver streaked acacia blue
Aeromachus dubius dubius	Sahyadri dingy scrub hopper
Pseudocoladenia dan dan	Sahyadri fulvous pied flat

the weighted endemism index by the total count of species in that particular cell (Linder, 2000). Since the proportion of endemics in a grid cell is measured, this index corrects the species richness effect.

$$\mathbf{CWEI = WE/K}$$

where C is the number of grid cell in which each endemic species occurs, and K is the total number of species in a grid cell.

Results

The data set for sampling comprised of 94 endemic species (Tables 2 and 3) which include 60 species recorded as endemic to Western Ghats and Sri Lanka (Gaonkar, 1996), 1 species endemic to peninsular India and 33 subspecies reported as endemic to the area (Kunte, Nitin, & Basu, 2018).

The number of species occurrence varied from one to thirty-eight and consisted of only presence points. Overall, 393 sightings of endemic species and subspecies were recorded within the 30 grids over the 4 years. The distribution of 60 endemic species/subspecies recorded during the study was mapped onto grids of the study (Figs. 3, 4, 5, 6 and 7).

When considering the family-wise distribution of endemics recorded, Papilionidae had the highest number of sightings (194) followed by Nymphalidae (116), Pieridae (54), Hesperidae (17), and Lycenidae (12). *Troides minos* was the most sighted (38 sightings) and widespread species being recorded in 19 grids (63.3%). Species which were restricted to the montane and upper montane areas of the Karimala peak in Parambikulam WLS/TR and Nelliampathy in the Nenmara FD include *Celatoxia albidisca*, *Udara akasa*, *U. singalensis*, *Curetis thetis*, *Eurema nilgiriensis*, *E. andersonii shimai*, *Colias nilagiriensis*, *Melanitis phedima varaha*, *Ypthima ceylonica*, *Y. chenui*, *Y. ypthimoides*, *Athyma selenophora kanara*, *Lassipe viraja kanara* and *Parantica nilgiriensis. Sovia hyrtacus* was recorded only from the Vazhachal FD whilst *Kallima horsfieldi* was recorded from Vazhzachal FD and Peechi-Vazhani WLS. Widespread endemic species like *Troides minos*, *Pachliopta hector* and *Delias eucharis* were observed along transects which were located near settlements and roads. *Rohana parisatis atacinus*, *Parthenos sylvia virens* and *Graphium sarpedon teredon* were forest edge species whilst *Cirrocroa thais* and *Papilio polymnestor* were common at low elevations. Twenty-one out of the 37 Western Ghats endemics (56%); 18 out of the 24 Western Ghats, Sri Lanka and peninsular India endemics (75%) and 21 out of the 33 endemic subspecies (63%) were observed during the 4-year period. Seven endemic species was recorded in family Nymphalidae followed by Papilionidae (5), Hesperidae (4), Lycaenidae (3), and Pieridae (2).

Indicator analysis identified seventeen indicator species of which five, namely *Cirrochroa thais*, *Papilio paris tamilana*, *Papilio helenus daksha*, *Parthenos sylvia virens* and *Mycalesis patnia* were significant at $p \leq 0.001$ and the remaining twelve species were significant at $p \leq 0.05$ (Table 4). In the former group, two were endemic to Western Ghats and Sri Lanka whilst three were endemic to the Western Ghats at subspecies level. An interesting and unexpected trend noticed is that out of the seventeen indicator species, five species were endemic to the Western Ghats, four were endemic to the

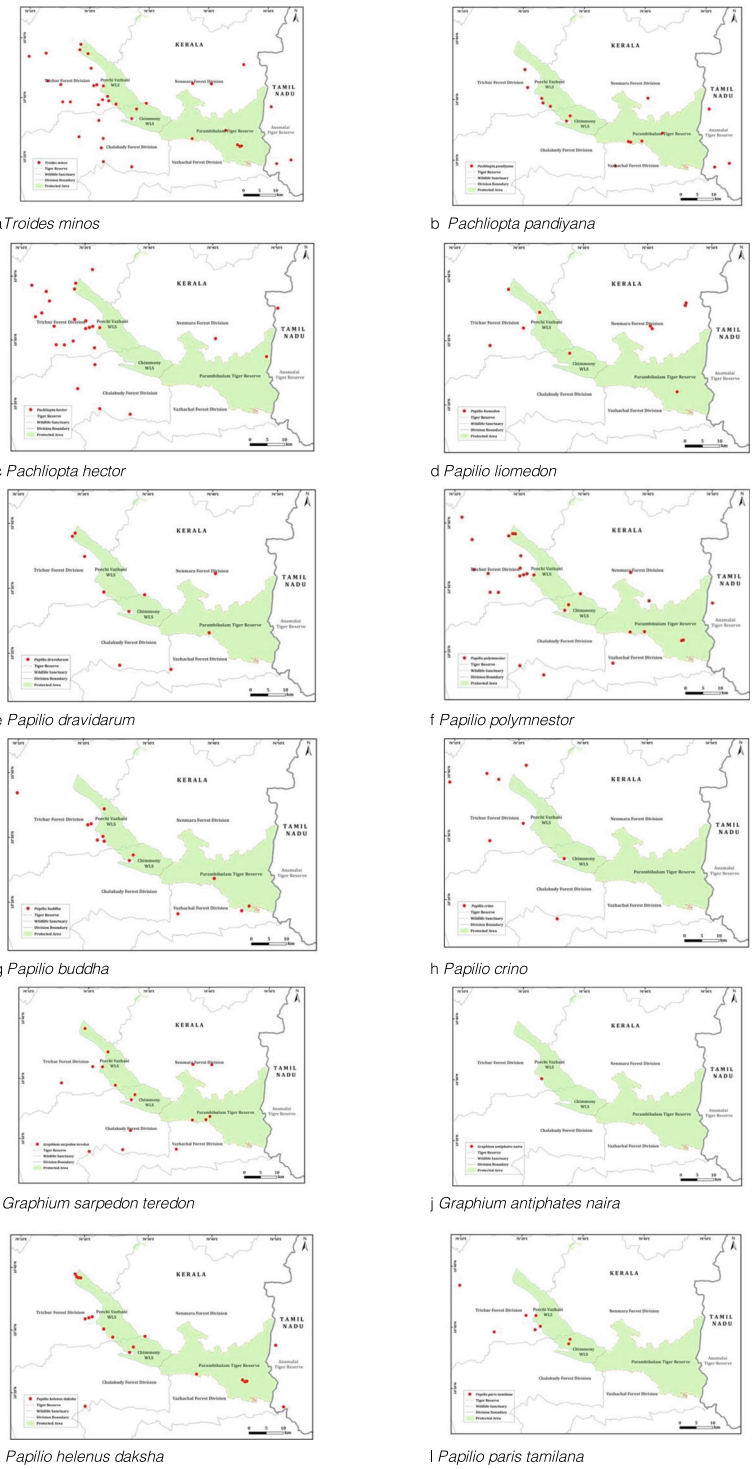
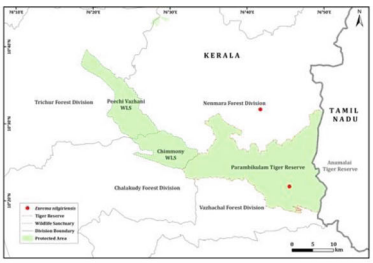
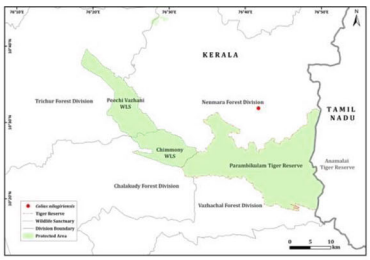


Fig. 3 a-**l** Distribution maps of endemic butterflies of family Papilionidae within study area. **a** *Troides minos*. **b** *Pachliopta pandiyana*. **c** *Pachliopta hector*. **d** *Papilio liomedon*. **e** *Papilio dravidarum*. **f** *Papilio polymnestor*. **g** *Papilio buddha*. **h** *Papilio crino*. **i** *Graphium sarpedon teredon*. **j** *Graphium antiphates naira*. **k** *Papilio helenus daksha*. **l** *Papilio paris tamilana*

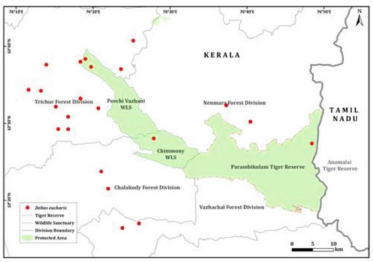
Western Ghats and Sri Lanka region and eight species were endemic at the subspecies level. Does a greater number of subspecies level endemic indicators hint at subtle speciation events in progress? The five most significant species were indicative of habitats in Chinmony WLS, Peechi-Vazhani WLS, Parambikulam WLS/TR,



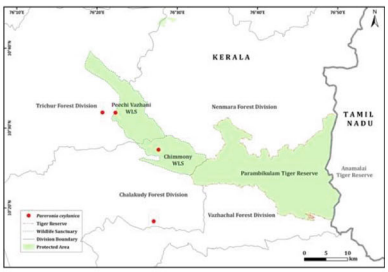
a *Eurema nilgiriensis*



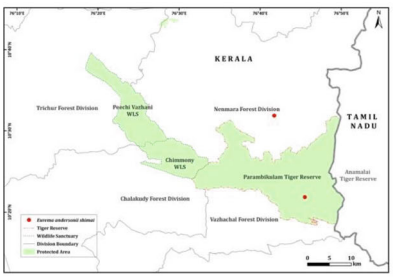
b *Colias nilagiriensis*



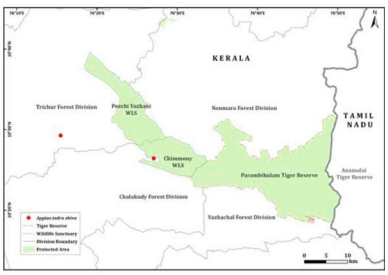
c *Delias eucharis*



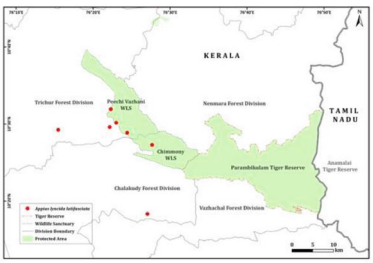
d *Pareronia ceylanica*



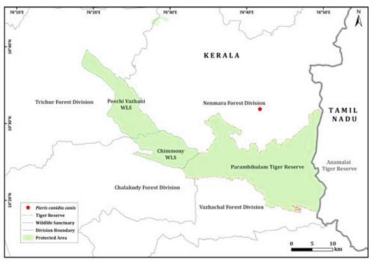
e *Eurema andersonii shimai*



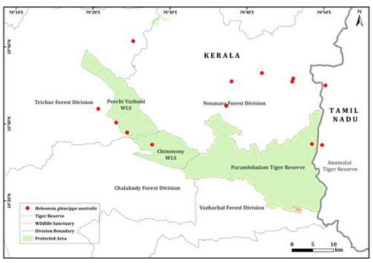
f *Appias indra shiva*



g *Appias lyncida latifasciata*



h *Pieris canidia canis*



i *Hebomoia glaucippe australis*

Fig. 4 a-**i** Distribution maps of endemic butterflies of family Pieridae within study area. **a** *Eurema nilgiriensis*. **b** *Colias nilagiriensis*. **c** *Delias eucharis*. **d** *Pareronia ceylanica*. **e** *Eurema andersonii shimai*. **f** *Appias indra shiva*. **g** *Appias lyncida latifasciata*. **h** *Pieris canidia canis*. **i** *Hebomoia glaucippe australis*

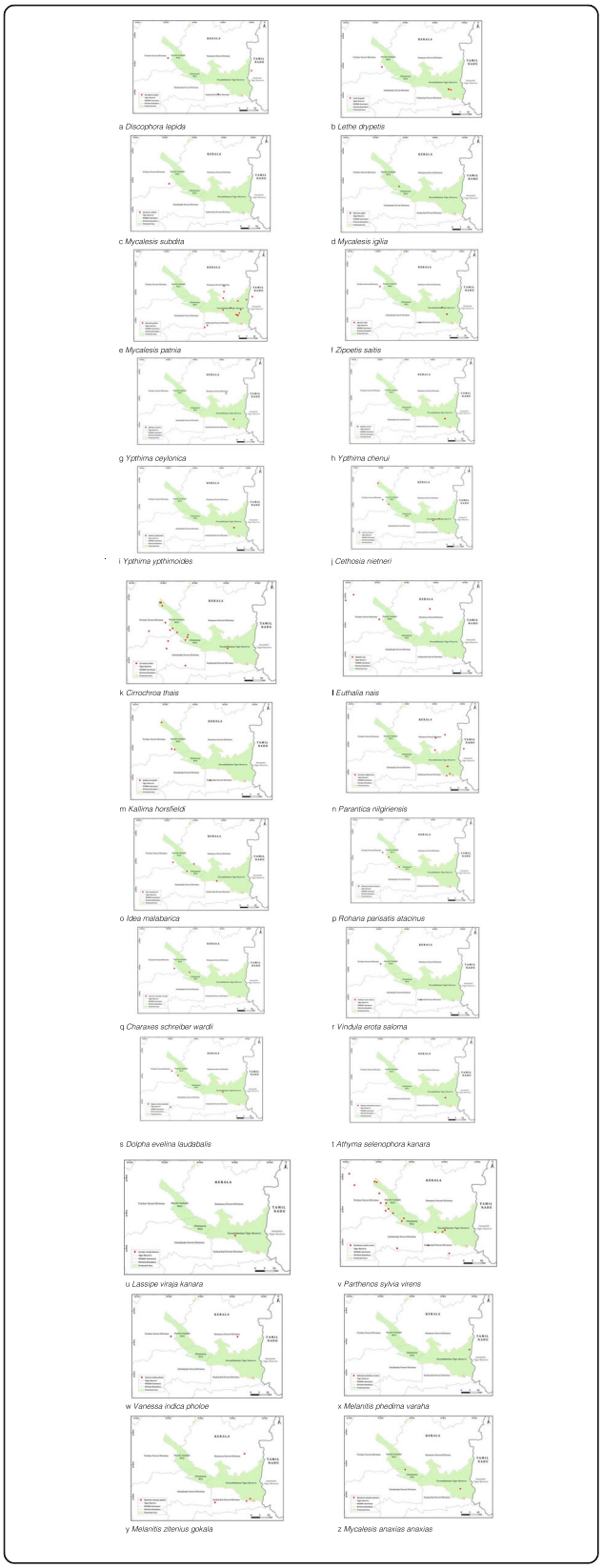


Fig. 5 **a**-**z** Distribution maps of endemic butterflies of family Nymphalidae within study area. **a** *Discophora lepida*. **b** *Lethe drypetis*. **c** *Mycalesis subdita*. **d** *Mycalesis igilia*. **e** *Mycalesis patnia*. **f** *Zipoetis saitis*. **g** *Ypthima ceylonica*. **h** *Ypthima chenui*. **i** *Ypthima ypthimoides*. **j** *Cethosia nietneri*. **k** *Cirrochroa thais*. **l** *Euthalia nais*. **m** *Kallima horsfieldi*. **n** *Parantica nilgiriensis*. **o** *Idea malabarica*. **p** *Rohana parisatis atacinus*. **q** *Charaxes schreiber wardii*. **r** *Vindula erota saloma*. **s** *Dolpha evelina laudabalis*. **t** *Athyma selenophora kanara*. **u** *Lassipe viraja kanara*. **v** *Parthenos sylvia virens*. **w** *Vanessa indica pholoe*. **x** *Melanitis phedima varaha*. **y** *Melanitis zitenius gokala*. **z** *Mycalesis anaxias anaxias*

Nenmara FD and Vazhachal FD. The number of transects in the above locations which had sightings of these species were as follows: *Cirrochroa thais* (15), *Papilio paris tamilana* (8), *Papilio helenus daksha* (19), *Parthenos sylvia virens* (17) and *Mycalesis patnia* (15). The endemic species indicative of Chalakudy FD and Thrissur FD were *Troides minos* and *Pachliopta hector* which were common and widespread species.

Calculating the endemism index of the species helped identify locations having higher conservation implications (Fig. 8). When examining the corrected endemism index (CWEI) values, the highest index was observed in grid 25 (CWEI—14.44) followed by grids 24 (CWEI—12.06) and 19 (CWEI—11.86). Sixteen grids (3, 4, 5, 8, 9, 11, 12, 15, 17, 18, 20, 21, 22, 23, 26, 28) have CWEI values ranging from 4.07 to 7.75 and seven grids (1, 2, 6, 7, 10, 27, 30) have CWEI values between 2.07 and 3.89. In four grids (13, 14, 16, 29), no endemic species were recorded. Grids with the lowest values were those located in areas within towns with high human activities.

Discussion

Out of the 94 endemic species and subspecies reported from the Western Ghats, 60 species were recorded and mapped in this study. The study area which covers 2.14% of the Western Ghats hotspot harbours almost 63.82% of the region's endemic butterfly species making this particular region as important and crucial for conservation and management. Assessment of selected sites with respect to butterflies indicate that locations like Vazhachal Reserve Forest, Nelliampathy Reserve Forest, Parambikulam Wildlife Sanctuary/Tiger Reserve, and Peechi-Vazhani Wildlife Sanctuary harbour endemic species and should be prioritised in biodiversity conservation plans. A simple monitoring protocol using endemic butterflies was developed and the GIS mapping provided information on the distribution of endemic species within the study area. These monitoring studies clearly emphasise the well documented fact that reliable field data along with robust analytic tools will help guide conservation of these fragile endemics in this biodiversity hotspot.

Kessler and Kluge (2008) postulated that distribution patterns of endemic species along tropical elevational

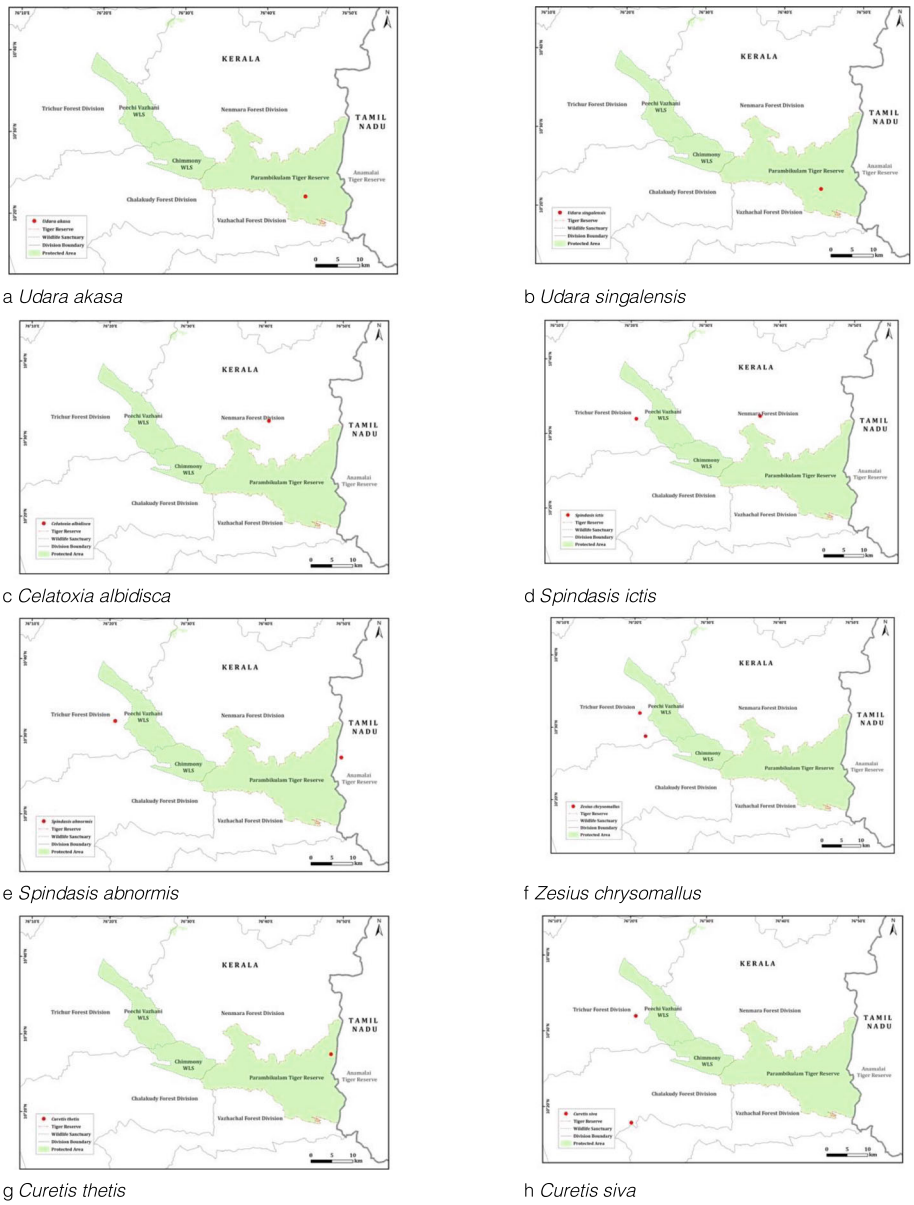
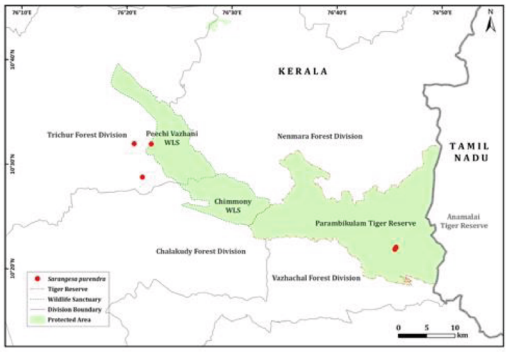


Fig. 6 a-**h** Distribution maps of endemic butterflies of family Lycaenidae within study area. **a** *Udara akasa*. **b** *Udara singalensis*. **c** *Celatoxia albidisca*. **d** *Spindasis ictis*. **e** *Spindasis abnormis*. **f** *Zesius chrysomallus*. **g** *Curetis thetis*. **h** *Curetis siva*

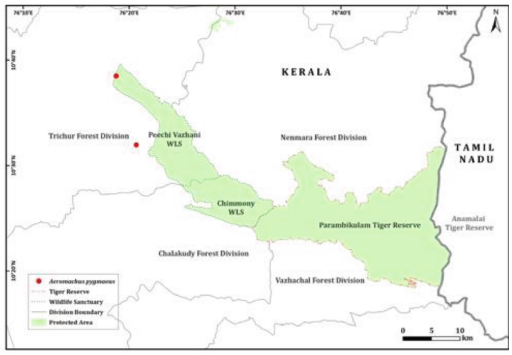
gradients usually reach a maximum richness between 500 and 2000 m. In this study, the grids with the highest peaks, Padagiri (1585 m; grid 19) and Karimala (1438 m; grid 25) also showed high endemism indices of 11.89 and 14.14 respectively. Mangattu Kumban (grid 9) at mid elevation of 635 m had an endemism index of 7.78 (Fig. 9). These findings thus support the elevational gradient-species richness relationship proposed above.

The main advantage of the CWEI is its non-correlation to species richness and ability to distinguish range-restricted species at a very subtle level. We could identify unique pockets where such species occur within the study area: *Parambikulam WLS/TR*: Kuthirakolpathy, Pupara, Kalyanathi, Top slip and Muthalakuzhy; *Peechi-Vazhani WLS*: Ayyapankadu; *Thrissur FD*: Chakkapara and Vellakarithadam; *Nenmara FD*: Karikatty, Pothumala and Nelliampathy estate; *Vazhachal FD*: Poringalkuthu dam, Meenchal and Vazhachal (Fig. 10). The biotic and abiotic factors in these areas should be rigorously studied to determine if they are microrefugial habitats of these rare species.

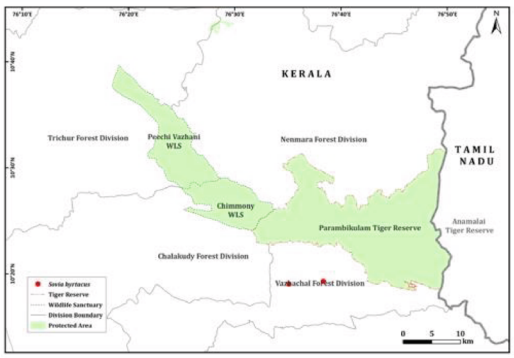
It is a well-established fact that current spatial distribution and diversity patterns are a reflection of a long evolutionary and biogeographical history. In order to



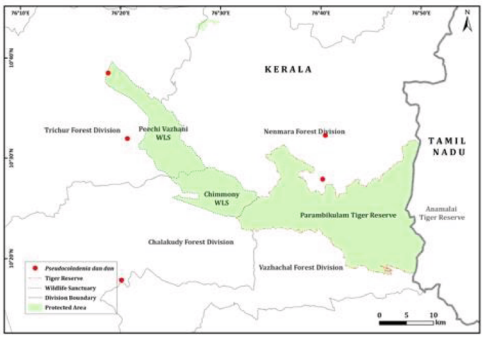
a *Sarangesa purendra*



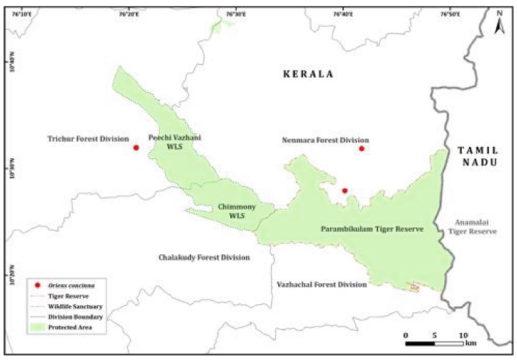
b *Aeromachus pygmaeus*



c *Sovia hyrtacus*



d *Pseudocoladenia dan dan*



e *Oriens concinna*

Fig. 7 **a**-**e** Distribution maps of endemic butterflies of family Hesperidae within study area. **a** *Sarangesa purendra*. **b** *Aeromachus pygmaeus*. **c** *Sovia hyrtacus*. **d** *Pseudocoladenia dan dan*. **e** *Oriens concinna*

elucidate these complex mechanisms we suggest further studies in this vulnerable hotspot by adopting the following three approaches: (1) studying the *phylogenetic endemism* (Rosauer, Laffan, Crisp, Donnellan, & Cook, 2009) would help uncover the events that have shaped the rich diversity of this region having Gondwanan, Sundaland and recent biogeographical elements with respect to butterflies. The butterfly fauna of this region with over 300 well documented species would an ideal template for such investigations (2) identification of *microrefugia* which Harrison and Noss (2017) caution will assume greater relevance against the backdrop of climate change would be another area for butterfly research in this hotspot and (3) finally, the Western Ghats with its steep gradients and undulating terrain would be the perfect arena to test the 'Mountain Geobiodiversity Hypothesis' (Mosbrugger, Favre, Muellner-Riehl, Päckert, & Mulch, 2018) with respect to butterflies.

Endemic species are useful indicators of habitat quality and can also act as umbrella species for conservation planning and management. Given the high diversity and endemism among the butterfly communities of the

Table 4 Indicator species analysis for all combinations of site categories

Site categories—Wildlife Sanctuaries/Forest Divisions (WLS/FD)	Species	IndVal.g	*P* value	Endemicity
Chinmony WLS	*Cirrochroa thais*	0.749	0.003**	WG and SL
	Papilio paris tamilana	0.660	0.009**	WG SS
	Mycalesis igilia	0.577	0.033*	WG
	Papilio buddha	0.563	0.030*	WG
	Mycalesis anaxias anaxias	0.537	0.032*	WG SS
	Appias indra shiva	0.527	0.024*	WG SS
	Rohana parisatis atacinus	0.502	0.035*	WG SS
	Pareronia ceylanica	0.468	0.049*	WG and SL
Chinmony WLS+Nenmara D	*Hebomoia glaucippe australis*	0.581	0.018*	WG SS
	Papilio liomedon	0.475	0.043*	WG
Chinmony WLS+Peechi Vazhani WLS	*Papilio helenus daksha*	0.601	0.008**	WG SS
	Parthenos sylvia virens	0.600	0.005**	WG SS
	Appias lyncida latifasciata	0.492	0.014*	WG SS
Chalakudy D+Chinmony WLS+Peechi Vazhani WLS	*Troides minos*	0.647	0.028*	WG
Chinmony WLS+Peechi Vazhani WLS+Vazhachal D	*Papilio dravidarum*	0.497	0.028*	WG
Nenmara D+Parambikulam WLS/TR+Vazhachal D	*Mycalesis patnia*	0.598	0.005**	WG and SL
Chalakudy D+Nenmara D+Peechi Vazhani WLS+Thrissur D	*Pachliopta hector*	0.590	0.025*	WG and SL

Endemicity: WG-endemic to Western Ghats; WG & SL-endemic to Western Ghats and Sri Lanka; WG SS-endemic to Western Ghats at sub species level
Asterisks indicate *p* value: *$p \leq 0.05$; **$p \leq 0.001$

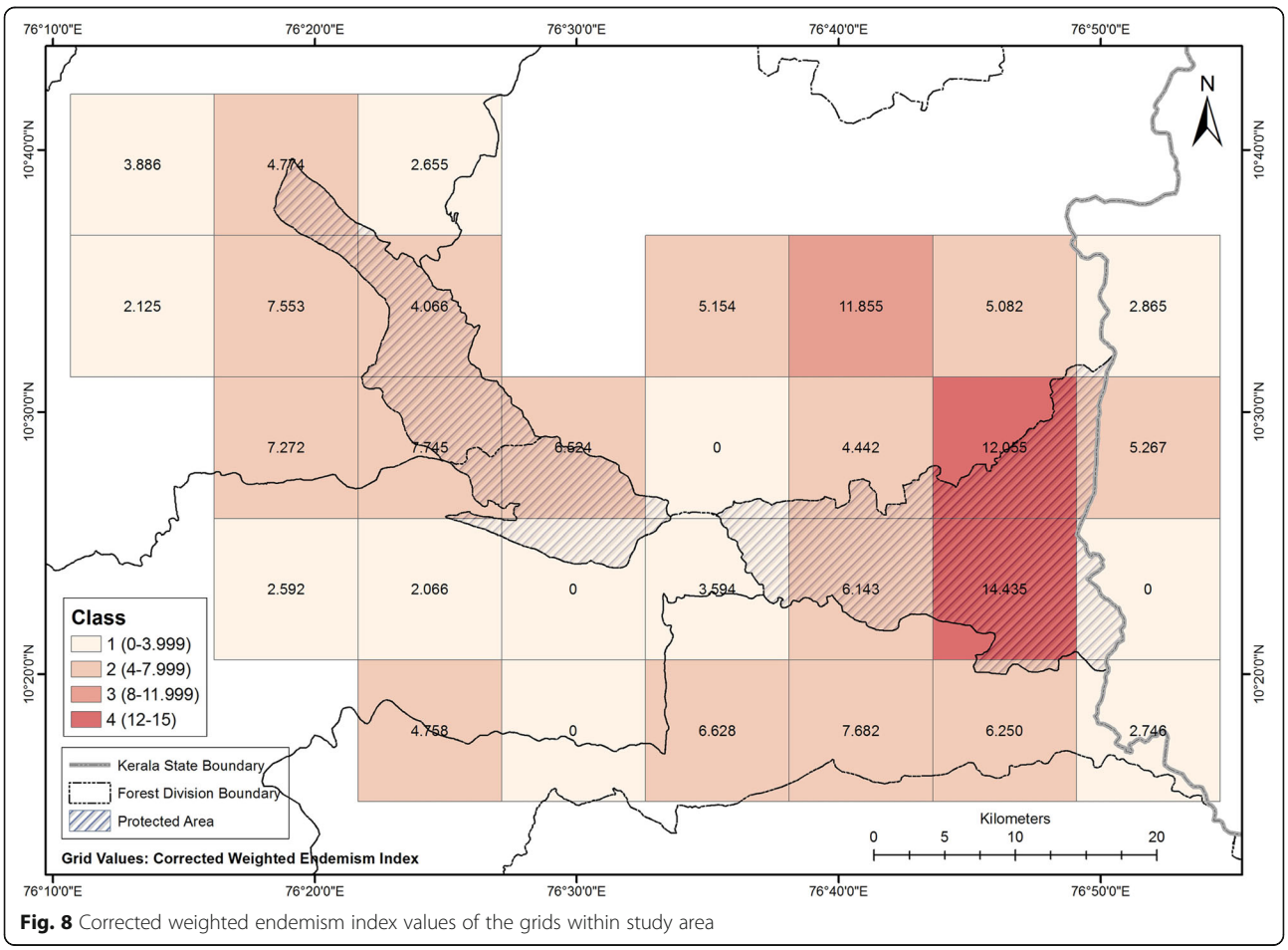


Fig. 8 Corrected weighted endemism index values of the grids within study area

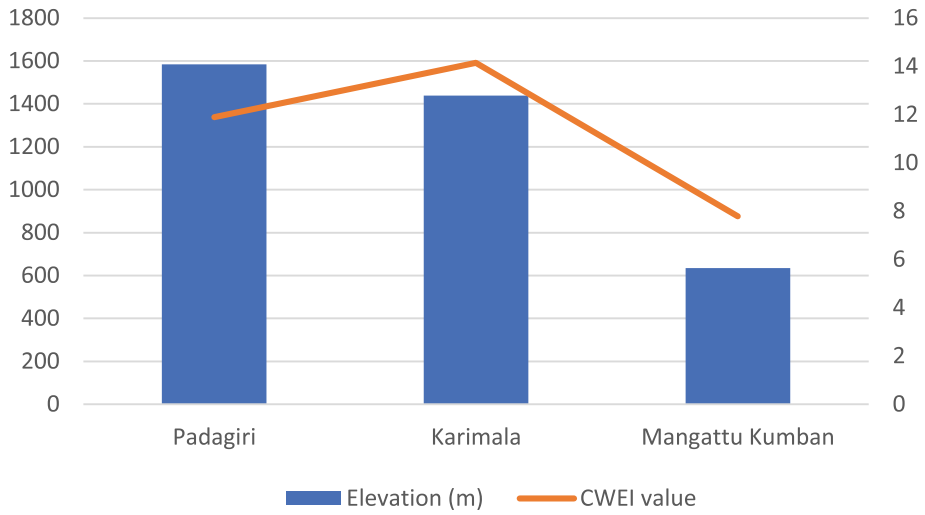


Fig. 9 Relationship between corrected weighted endemism index and elevation

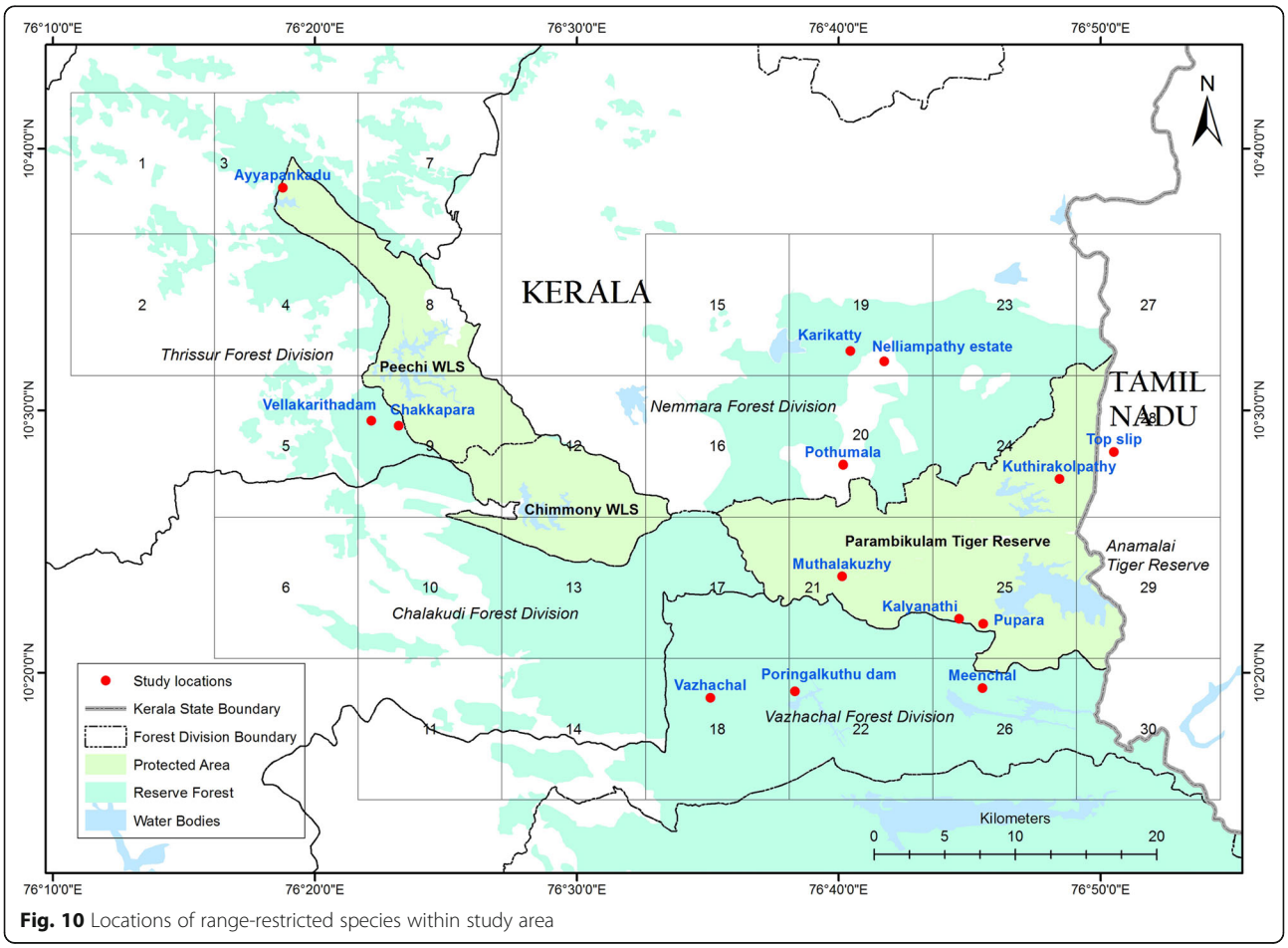


Fig. 10 Locations of range-restricted species within study area

Kerala part of the Western Ghats, implementation of effective conservation actions would require an integrated approach involving: (1) management of vulnerable and unique habitats at microscale level as landscape level management may sometimes fail to recognise truly 'hot' microhabitats (2) conservation-driven research with emphasis on phylogenetic endemism and microrefugia of species (3) continuous monitoring of habitat and populations based on community forest management through stakeholder participation (4) raising conservation awareness in local communities living in close proximity to and highly dependent on forest resources.

Conclusions

The distribution of 60 endemic species/subspecies was recorded and mapped within the 30 study grids over the 4-year study period. Overall, 393 sightings of endemic species and subspecies were recorded and the family Papilionidae had the highest number of sightings (194) followed by Nymphalidae (116), Pieridae (54), Hesperidae (17) and Lycenidae (12). Out of the total of 37 species endemic to the Western Ghats, 21 species (56%); 18 species of the total of 24 (75%) species endemic to Western Ghats, Sri Lanka and peninsular India and 21 species of a total of 33 (63%) endemic subspecies were recorded. The highest number of Western Ghats endemics was recorded in family Nymphalidae (7) followed by Papilionidae (5), Hesperidae (4), Lycaenidae (3) and Pieridae (2).

Indicator analysis identified seventeen indicator species of which five, namely *Cirrochroa thais*, *Papilio paris tamilana*, *Papilio helenus daksha*, *Parthenos sylvia virens*, and *Mycalesis patnia* were significant and were indicative of habitats in Chinmony WLS, Peechi Vazhani WLS, Parambikulam WLS/TR, Nenmara FD and Vazhachal FD. The endemic species indicative of Chalakudy FD and Thrissur FD were *Troides minos* and *Pachliopta hector*.

The highest corrected weighted endemism index was observed in grid 25 followed by grids 24 and 19. Sixteen grids showed values ranging from 4.07 to 7.75 and seven grids had values between 2.07 and 3.89. The grids with the highest peaks of the study area, Padagiri, Karimala and Mangattu Kumban also showed high endemism indices. Kuthirakolpathy, Pupara, Kalyanathi, Top slip, Muthalakuzhy, Ayyapankadu, Chakkapara Vellakarithadam, Karikatty, Pothumala, Nelliampathy estate, Poringalkuthu dam, Meenchal, and Vazhachal were areas harbouring unique and range restricted species.

This study has shown interesting geographic patterns of the spatial structure of endemism richness in a highly critical hotspot area. Conservation management in the Indian context is expected to benefit if biodiversity can be characterised to more local levels (Bossuyt et al., 2004). This study shows that even within hotspots, endemicity is not uniform and our efforts should be to focus on small areas that represent unique species associations. Even though the addition of more taxa will be useful for a more complete overview, we believe that these are primary areas in the central region of the Kerala part of the Western Ghats that harbour species of conservation value. Moreover, these are also species having a complex evolutionary history and should therefore be monitored and studied in further depth, especially when designing conservation strategies. Thus as we advance into a future wrought with climatic instabilities and increased human impacts, research should be fine-tuned and the delineation of phylogenetic endemism patterns and identification of microrefugia would definitely be a step forward in the right direction for butterfly conservation in this fragile hotspot.

Abbreviations

WLS: Wildlife sanctuary; WLS/TR: Wildlife sanctuary/tiger reserve; FD: Forest division; GPS: Global Positioning System; SOI: Survey of India; GIS: Geographic Information System; WE: Weighted endemism; CWEI: Corrected weighted endemism index

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Authors' contributions

A.M. conceived and designed the study, conducted field surveys and data collection and drafted the manuscript. B.C.F. helped coordinate the study and review the manuscript. I.A. performed the data analysis in R. The authors read and approved the final manuscript.

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Availability of data and materials

All data generated or analysed during this study are included in this published article.

Declarations

Ethics approval and consent to participate

Sampling in protected areas was conducted under permit (No. WL 10-36790/15) from the Kerala Forest and Wildlife Department, India. No animals were harmed during field sampling. No endemic butterfly or plant species were collected from protected areas during the study.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Author details

[1]Research and Post Graduate Department of Zoology, St. Thomas College, Thrissur, Kerala 680001, India. [2]Quantiphi Analytics, Trifecta Adatto, Whitefield, Bengaluru, Karnataka 560048, India.

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