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

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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 x 10 km grid cells (n= 30; area=3000 km²) 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 occurring 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

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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
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, Maharasstra, 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 | Kottkekad         | 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 | Ayyappankadu      | 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  | 10.53534  |
| 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 | Manotichal        | 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 | Velupadaram       | 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  |
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 km²) 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 km² 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 micro-scale 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 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), Thirssur forest division (Thirssur 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.

| No. | Grid | Location        | Transect       | Longitude | Latitude |
|-----|------|-----------------|----------------|-----------|----------|
| 45  | 9    | Thrissur Division | Vellakanthadam | 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    | Ollarakavu     | 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 |

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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| Muduvanvarachal   | 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   | 76.62060  | 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 | Kalyanathipathy   | 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 | Shekalimudi       | 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 |
| Scientific name                        | Common name                        |
|---------------------------------------|------------------------------------|
| Troides minos                         | Southern birdwing                  |
| Pachliopta pandiyana                  | Malabar rose                       |
| Pachliopta hector                      | Crimson rose                       |
| Papilio liomedon                      | Malabar banded swallowtail         |
| Papilio dravidarum                    | Malabar raven                      |
| Papilio polymnestor                   | Blue Mormon                        |
| Papilio buddha                        | Malabar banded peacock             |
| Papilio crina                         | Common banded peacock              |
| Eurema niligiriensis                  | Nilgiri grass yellow               |
| Colias nilagiriensis                  | Nilgiri clouded yellow             |
| Delias eucharis                       | Common jezebel                     |
| Prioneris sita                        | Painted sawtooth                   |
| Appias wardii                         | Lesser albatross                   |
| Parantina ceylanica                   | Dark wanderer                      |
| Discophora lepida                     | Southern duffer                    |
| Parantinheoa marshallii               | Travancore eveningbrown            |
| Lethe drypetis                        | Tamil treebrown                    |
| Mycalesis subdita                     | Tamil bushbrown                    |
| Mycalesis igilia                      | Small long brand bushbrown         |
| Mycalesis orcha                       | Pale brand bushbrown               |
| Mycalesis patrid                      | Glad eye bushbrown                 |
| Mycalesis oculus                      | Red disc bushbrown                 |
| Mycalesis adolphet                    | Red eye bushbrown                  |
| Mycalesis dawsoni                     | Palni bushbrown/Lepcha bushbrown   |
| Zipoetis saitis                       | Tamil cats’eye                     |
| Ypthima ceylonica                     | White fourring                     |
| Ypthima chenui                        | Nilgiri fourring                   |
| Ypthima ypthimoides                   | Palni fourring                     |
| Cethosia nietmer                      | Tamil lacewing                     |
| Cirrochroa thais                       | Tamil yeoman                       |
| Euthalia nais                         | Baronet                            |
| Kallima barsfieldi                    | Blue oakleaf                       |
| Parantica niligiriensis               | Nilgiri tiger                       |
| Idea malabarica                       | Malabar tree nymph                 |
| Tarucus indica                        | Transparent pierrot                |
| Udara okasa                           | White hedgeblue                    |
| Udara singalensis                     | Singalese hedgeblue                |
| Celatoxia albidosca                   | White disc hedgeblue               |
| Arhopala alea                         | Rosy oakblue/Kanara oakblue        |
| Arhopala bazaloides                   | Dusted oakblue                     |
| Spindasis schistacea                  | Plumbeous silverline               |
| Spindasis ictis                       | Common shot silverline             |
| Spindasis abnormis                    | Abnormal silverline                |
| Zesiurn chrysamallus                  | Redspot                            |
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):

\[
WE = \sum \frac{1}{C}
\]

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

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

*Species endemic to the Western Ghats
bSpecies endemic to the Western Ghats and Sri Lanka
cSpecies endemic to the Western Ghats and peninsular India
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.

\[
\text{CWEI} = \frac{\text{WE}}{K}
\]

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 Lycaenidae (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 *Celataxia albida*, *Udana akasa*, *U. singalensis*, *Curetis thetis*, *Eurema nilgirienis*, *E. andersonii shimai*, *Colias nilagirienis*, *Melanitis phedima varaha*, *Ypthima ceylonica*, *Y. chenui*, *Y. ypthimoides*, *Athyma selenophora kanara*, *Lassipe viraja kanara* and *Paranta nilgirienis*. *Sovia hyrtaecus* was recorded only from the Vazhachal FD whilst *Kallima horsfieldii* was recorded from Vazhachal 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 *Cirrochroa 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 tamillana*, *Papilio helens daksha*, *Parthenos sylvia virens* and *Mycalaeiis 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

| Scientific name                        | Common name                                      |
|----------------------------------------|--------------------------------------------------|
| Graphium antiphasis nairae             | Sahyadri five bar swordtail                      |
| Graphium sarpedon teredon              | Sahyadri narrow banded bluebottle                |
| Papilio helensus daksha                 | Sahyadri red helen                               |
| Papilio paris tamillana                | Sahyadri paris peacock                          |
| Eurema andersonii shima                 | Sahyadri one spot grass yellow                   |
| Appias indra shiva                      | Sahyadri plain puffin                           |
| Appias lyrca latifasciasta              | Sahyadri chocolate albatross                    |
| Cepora nadia remba                      | Sahyadri lesser gull                            |
| Pienis canidia canis                    | Sahyadri cabbage white                          |
| Hebornoa glaucippe australis            | Sahyadri great orange tip                       |
| Rohana parisatis atacinus               | Sahyadri black prince                           |
| Charaxes schreiber wardii               | Sahyadri blue nandab                          |
| Vindula erota saloma                    | Sahyadri cruiser                                |
| Dolpha elenina laudabilis               | Sahyadri redspot duke                           |
| Athyma range kanara                     | Sahyadri blackvein sergeant                     |
| Athyma selenophora kanara               | Sahyadri staff sergeant                        |
| Lassipe viraja kanara                   | Sahyadri yellow jacksailer                      |
| Neptis clina kallaura                   | Sahyadri sullied sailer                         |
| Neptis nata hampsoni                    | Sahyadri clear sailer                           |
| Neptis soma palinca                     | Palni/Creamy sailer                             |
| Parthenos sylvia virens                 | Sahyadri clipper                                |
| Dolcheslania bisaltride malabarica      | Malabar autumn leaf                             |
| Vanessa indica pholoe                   | Sahyadri red admiral                            |
| Melanitis phedima varaha                | Sahyadri dark eveningbrown                      |
| Melanitis zetanius gokala               | Sahyadri great eveningbrown                     |
| Mycalesis anaxias anaxias               | Sahyadri white bar bushbrown                    |
| Actolepis ilacea ilacea                 | Sahyadri lilac hedgeblue                        |
| Celastra insa lavendularis lavenduras   | Sri Lankan plain hedgeblue                      |
| Thaduka multicaudata kanara             | Sahyadri many tailed oakblue                    |
| Catapaeclima major callone              | Sahyadri common tinsel                          |
| Zinastra tadara tadara                  | Sahyadri silver streaked acacia blue            |
| Aeromachus dubius dubius                 | Sahyadri dingy scrub hopper                     |
| Pseudocolademia 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.
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 Chinnony WLS, Peechi-Vazhani WLS, Parambikulam WLS/TR,
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 shima. f Appias indra shiva. g Appias lycida latifasciata. h Pieris canidia canis. i Hebomoia glaucippe australis
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, Nelliyampathy 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
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
elucidate these complex mechanisms we suggest further studies in this vulnerable hotspot by adopting the following three approaches: (1) studying the phylagenetic 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  | Endemicty                      |
|--------------------------------------------------------------|--------------------------|----------|----------|-------------------------------|
| Chinmony WLS                                                | Cirrochroa thais         | 0.749    | 0.003**  | WG and SL                     |
|                                                             | Papilio paris tamlalana  | 0.660    | 0.009**  | WG SS                         |
|                                                             | Mycalesis igilia         | 0.577    | 0.033*   | WG                            |
|                                                             | Papilio buddha           | 0.563    | 0.030*   | WG                            |
|                                                             | Mycalesis anaxia anaxias | 0.537    | 0.032*   | WG SS                         |
|                                                             | Appias indra shiva       | 0.527    | 0.024*   | WG SS                         |
|                                                             | Rohana paranatis atacinus| 0.502    | 0.035*   | WG SS                         |
|                                                             | Paseronia 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 viriens | 0.600    | 0.005**  | WG SS                         |
|                                                             | Appias lyndca latifascata| 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 patria         | 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                     |

**Endemicty:** 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 ≤ 0.05; ** p ≤ 0.001
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), Hesperiidae (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 were recorded in family Nymphalidae (7) followed by Papilionidae (5), Hesperiidae (4), Lycenidae (3) and Pieridae (2).

Indicator analysis identified seventeen indicator species of which five, namely Cirrochroa thais, Papilio paris taminana, Papilio helenaus daksha, Parthenos sylvia virens, and Mycalesis patnia were significant and were indicative of habitats in Chinnmony WLS, Pechoi 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 Veilakarithadam, Karikatty, Pothumala, Nelliyampathy 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, endemism 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

Acknowledgements
A.M. acknowledges the University Grants Commission, New Delhi, India, for providing the post-doctoral fellowship. The authors thank Suganthasakthivel R. and Roby T.J. for figures and maps; Sandev V. and Vinod M.B. for assistance rendered during field surveys and the staff of the Kerala Forest Department for logistic support. The authors are also grateful to the anonymous reviewers and editor for their valuable comments/suggestions which have helped us to improve an earlier version of the manuscript.

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.

Funding
This work was supported by a postdoctoral research grant (F 15-1-2012-13/ PDFWM-2012-13-GE-KER-21937 (SA-II) to the first author from the University Grants Commission, Government of India. The funding was for research purposes, mainly travel and contingency expenses associated with the project.

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.

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