Shola habitats on sky islands: status of research on montane forests and grasslands in southern India

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The Shola habitat on the high elevation sky islands of the Western Ghats in southern India is a unique habitat. Although this habitat hosts a disproportionately high level of endemism and is threatened by anthropogenic modifications, it has received little research attention. We compiled publications of research conducted in this habitat from scientific databases and the grey literature to examine trends in publication. For a quantitative summary, all publications were classified according to the taxa of research and the broad topic of research. We identified 279 publications from 1964 and found an almost threefold increase in the number of publications and diversity of research topics studied over the last decade. Studies on flora, birds and mammals have been numerous (62% of the studies examined), but certain taxa like fish (1%) have been ignored. Most studies (65%) are descriptive, focusing on diversity, distribution trends and management suggestions, while surprisingly few have concentrated on climate change, ecological restoration and invasive species, all major threats to this landscape. We have identified some key gaps in research and conservation focus that future studies could address. We also suggest that initiatives like edited volumes and special journal sections, along with the use of creative commons licensed data-sharing portals, can be used to usher unpublished work into the public domain.

Keywords: Birds, conservation, grasslands, montane forest, sky islands.

TROPICAL montane habitats exhibit high endemism with several species restricted to narrow elevational bands[1]. One of the biggest threats in the present times is global climate change and its possible effects on natural life[2], including further restriction and reduction in the ranges of montane species[3,4]. The Western Ghats, a mountain chain in southern India, is a global biodiversity hotspot[5] and hosts one of the most isolated sky islands systems in the world[6]. The montane habitats that occur on these islands between 1,400 and 2,400 m are better known as Shola habitats and are a natural mosaic of grasslands and forest patches in an undulating terrain, with forests in the valleys (Figure 1 *a* and *b*). This habitat has received little conservation and research attention in India, and there is an urgent need to assess the threats to it and its inhabitants. We review the state of knowledge of research in this montane habitat and consolidate all known information to date about this system, in order to guide future studies and conservation managers.

Shola forests (review of the origin of the name Shola in Nair *et al.*[7]) are wet evergreen montane forests, categorized as southern montane wet temperate forests[7,8] or tropical montane forests[9]. They are typically characterized by stunted trees of 12–15 m height[10].

Important centre of biodiversity

The Shola habitat hosts disproportionately higher endemism within one of the global biodiversity hotspots, while being faced with disproportionately high deforestation (reviewed below). India has lost 30% of its forests in the last few decades[11] and continues to lose 0.28% every year[12], with over 50% of Shola forests having been lost since 1850 (ref. 13). Shola habitats also comprise a complex landscape with multiple nested levels of patchiness. Since Sholas are found only on sky island mountain-tops, they are isolated at a large geographical scale. Within each one of these islands, however, the habitat is a natural complex of grasslands and forests[14], where forests are found in the depressions or folds of the mountains and are separated by grasslands. To add to the complexity of the system, extensive plantations of wattle *Acacia* sp., pine *Pinus* sp. and *Eucalyptus* sp. were planted over a century ago and more recent invasions of exotic grasses and shrubs[15] contribute to further discontinuity (Figure 1 *c*)[16]. While such patchiness, both natural and anthropogenic, provides us a natural laboratory to examine the effects of

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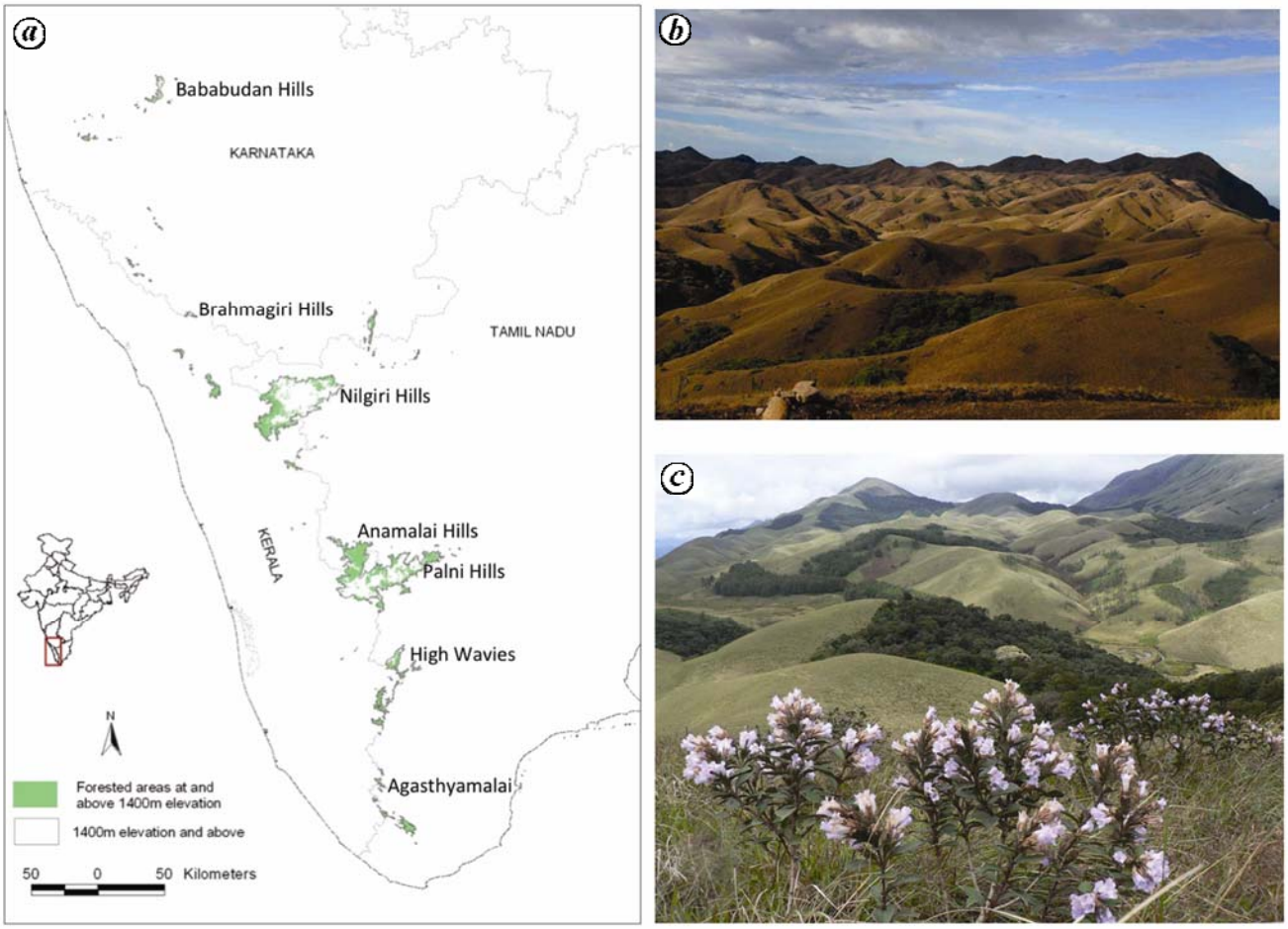

Figure 1. ***a***, Map of sky islands with Shola habitat in the Western Ghats, southern India. ***b***, Natural Shola forest–grassland mosaic in Mukurthi National Park, Nilgiri Hills, Western Ghats, India. (Picture credit: Kalyan Varma.) ***c***, Shola patches in Grass Hills National Park along with plantations of exotic species of wattle *Acacia* (Picture credit: Divya Mudappa).

various levels of patchiness, all information that arises from this unique habitat will help focus conservation efforts such that informed adaptive management measures could possibly be implemented.

This restricted but unique habitat, by being on the highest reaches of the Western Ghats is likely to be most affected by global warming. This makes it imperative to focus conservation efforts in this region with more contribution from scientific research. There are, however, very few reviews of research done in the Sholas and almost no large-scale overviews. Although Thomas and Palmer[17] provided a good review of some work in the grasslands part of the Sholas, they did not touch upon forests or the varied taxa that inhabit them. Here we attempt the first broad overview of information from this habitat. Although this review is not intended to be exhaustive, it is meant to provide an overview of work in this unique habitat, drawing attention to focused research required in this landscape.

Here we provide (i) a broad quantitative review of trends in the publication of research in Shola habitats, and (ii) a brief qualitative overview of the research so far, highlighting some gaps and suggesting possible ways to increase information available from this region.

Methods

We used three search engines to collect the literature on research in the Shola habitat. The *Web of Science* from *Science Citation Index* (Thomson Reuters, New York, USA) was searched from 1945 to the present (on 6 June 2011), *Biological Abstracts* (Thomson Reuters, New York, USA) from 1969 to 2011 (6 June 2011) and *Google Scholar* in 'Biology, Life Sciences and Environmental Sciences' subject area with keywords 'Shola forest' and/or 'montane forest Western Ghats' on 6 June 2011 with subscription to e-mail notifications of new publications until 12 August 2011. Although *Google Scholar* yielded a large number of results, this still may not be comprehensive due to several limitations, including biases in the journals crawled by *Google Scholar*[18]. To

this, we also added information collated from reports, books and papers that we came across over the last decade of research in this habitat. We used a snowball approach, e.g. Nandini and Mudappa[19], to find additional published and grey literature. Despite these efforts, this review is, at most, only an overview of the different fields of research since many publications in very specific journals or institutional reports may have gone unnoticed.

It must be noted that the term 'Shola' is also sometimes used as a name denoting an evergreen forest. For example, 'Karian Shola' in the Anamalai Tiger Reserve is the name of a national park that is a mid-elevation evergreen forest and is not a true Shola or montane forest. All such publications where the use of the term 'Shola' refers to the name of a specific forest were excluded. Only studies from montane forests (above 1400 m) were included in this review.

Quantified analysis

All relevant studies were categorized by the group (biotic taxa or abiotic feature) studied, subject of study and the year of publication. The groups consisted of biota like flora, exotics and plantations, mammals, birds, invertebrates, herpetofauna, fish, fungi and lichen, while abiotic aspects like fire, soil and ecosystem were also considered as groups. Although the classification of a study into subjects was often difficult, a broad classification into 18 groups was generated and studies were placed in only one of the 18 categories based on their primary focus. The groups were diversity, ecology, distribution, description, management, human impacts, spatial analysis, demography, hydrology, medicine, methodology, phylogenetics and phylogeography, climate, palynology, biogeography, fire, restoration and review. While all these groups are self-explanatory, publications that primarily focused on how to manage protected areas or Sholas were classified as 'management' and studies that examined anthropogenic impacts were classified as 'human impacts'. Studies largely describing species or habitats were classified as 'descriptions', and those on climate and climate change were classified as 'climate', while studies examining medicinal value of different plants in the Sholas were classified as 'medicinal' and other reviews were categorized as 'reviews'. All data manipulations were conducted in JMP (ver. 8.0.1, SAS Institute Inc)[20] and Microsoft Excel for Mac 2011 (version 14.1.2).

Qualitative information

Apart from the quantitative analysis, we present overviews of research on some key subjects and groups in this landscape. On subjects where good reviews exist, these have been referred to and only additional information has been presented so as not to replicate information.

Results and discussion

Quantitative description

Searches using the ISI *Web of Science* and *Biological Abstracts* resulted in 39 and 20 hits respectively, whereas the *Google Scholar* search resulted in 517 hits. After screening the results, a total of 279 relevant studies were included for analyses.

Which groups and subjects are most studied? Studies in this landscape have predominantly been on three major groups, flora (39%), mammals (13%) and birds (11%), whereas other taxonomic groups like invertebrates (8%),

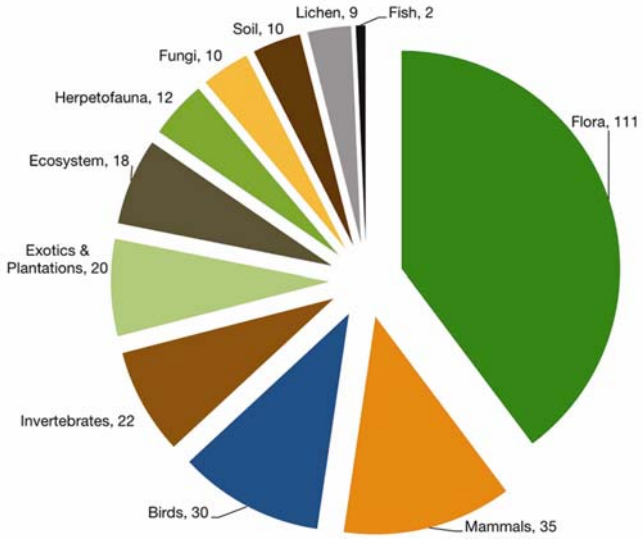

Figure 2. Proportion of studies conducted in Shola habitat on different groups. Actual numbers are listed beside group names.

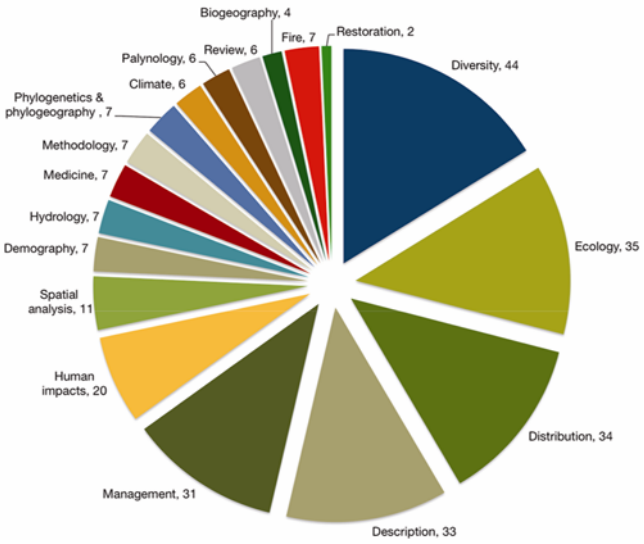

Figure 3. Proportion of studies conducted in Shola habitat on different subjects (see text for description). Actual numbers are listed beside subject names.

lichens (3%), fungi (4%) and fish (1%) have been less studied (Figure 2). Additionally, all studies on exotics and plantations (7%) were concerned with flora. Flora was, thus, the most-intensively studied group in the Sholas, and understandably so, as most of the earliest explorations and descriptions were of flora. Examining publications according to subjects, most studies clearly targeted diversity (16%), distribution (13%) and description (12%) of species. While there were studies targeting management suggestions (12%) and ecology (13%), there were very few studies on climate, restoration, biogeography, phylogenetics and phylogeography (together 7%; Figure 3).

Is there an increase or decrease in the amount of research done in this landscape? There has been a dramatic increase in the number of publications on Sholas over the last decade (Figure 4), as well as in the diversity of topics studied over the years (Figure 5). A closer inspection of the year-wise data over the last decade indicates an additional spike in the number of publications in 2001 (Figure 6). This increase is contributed by the publication of a compilation of decades of research on Shola forests by the Kerala Forest Research Institute and associated researchers[21]. This highlights the possible role of such edited volumes, and perhaps special sections/issues in peer-reviewed journals, in encouraging unpublished work into the public domain.

Qualitative description

Endemism and importance of habitat: There are hardly any reviews of the diversity and levels of endemism of Shola species. Although these habitats are in general known to have low species richness, e.g. insect diversity[22], high specialization across various taxa has resulted in a large proportion of species being endemic. Shola forests host high floral species diversity, second highest among different habitat types surveyed, with 67 species

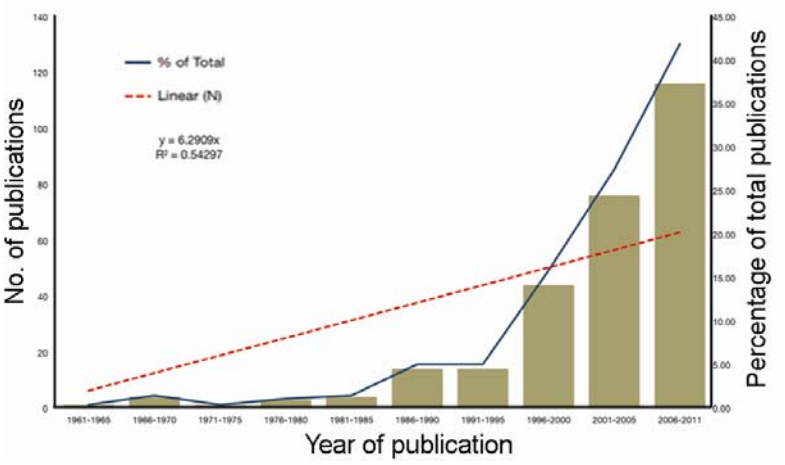

Figure 4. Number of publications on research conducted in the Shola habitat from 1961 to the present. The dotted red line is the linear trend fit to the data. The dark blue line indicates the percentage of total studies conducted.

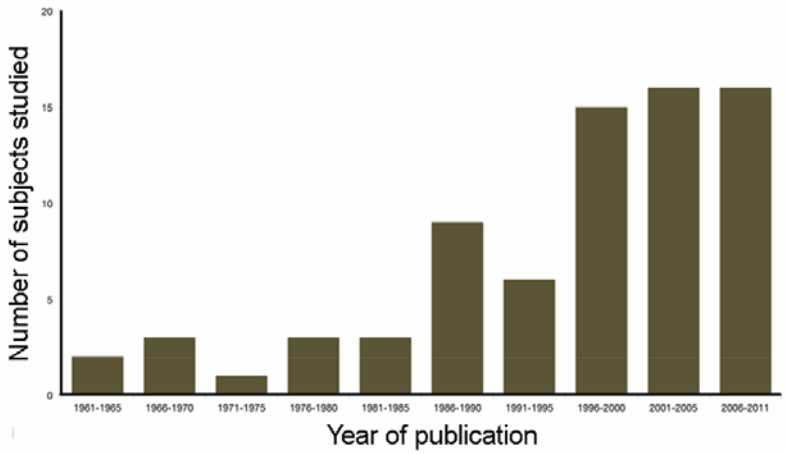

Figure 5. Number of different subjects addressed in research publications of studies conducted in the Shola habitat from 1961 to the present. (See text for classification of subject groups).

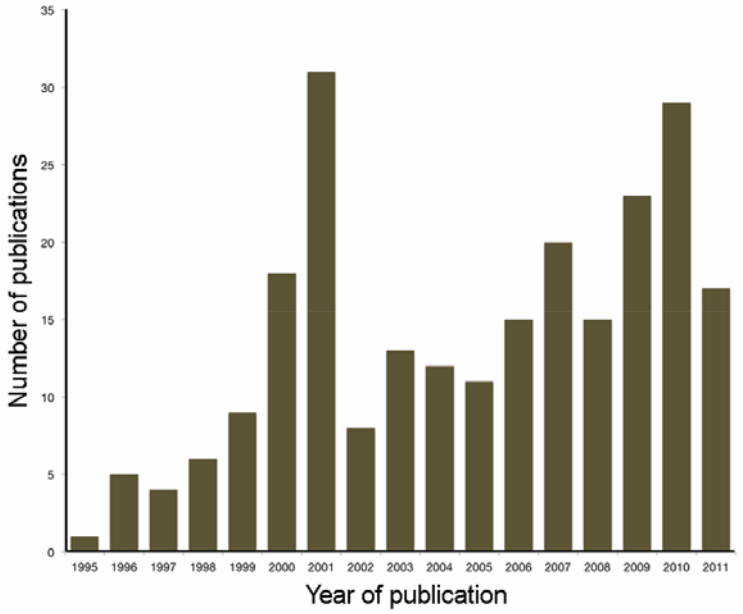

Figure 6. Detailed year-wise break up of the number of publications in the Shola habitat since the last decade. The number of publications shows an unusual peak in 2001, coinciding with the release of an edited book volume on Shola habitats. (See text for more explanation.)

recorded in a single 1 ha plot[23]. Thirty per cent of plant species in the Shola forests of the Palani Hills are endemic to the Western Ghats[24], whereas the sky islands in the Nilgiris harbour 20% of the endemic trees of the Western Ghats. Further, though the Shola forests on different sky islands share plant species[25], a high portion of the tree flora is endemic to specific islands – 83.3% in Eravikulam and 73% in the Nilgiris[26]; 20–23% of bird species in the Sholas are endemics[27], and there is high endemism in the amphibian community as well in the Shola habitat[28]. There is also high arthropod diversity in the Shola forests that has come to light in recent studies[29,30]. It is known that this habitat has high diversity of earthworms[23], centipedes and spiders[31]. Butterflies also show high endemism with about 45% of the butterflies in the Shola forests being endemic to the Western Ghats[32]. The Sholas also host many endemic fishes[33], though the exact number is not known.

The trend of high endemism is apparent in taxa with extensive studies, but in most cases such information is lacking. This crucial information can inform us about the importance of the habitat across different taxa.

Geography and evolution: Topographic features structure sky island systems, and have been shown to be a key determinant of isolation in other similar systems like the Madrean sky islands[34]. Very little information, however, exists from the Western Ghats on how species on these sky islands are isolated from each other[35–39]. At a large scale, the sky islands are isolated on mountain-tops of the Western Ghats along with three major geographical breaks; the youngest (65–80 Myr BP) and northernmost (16°N) is the Goa Gap[40,41], and the two older (500 Myr BP) gaps are the Palghat Gap (widest gap, 40 km at 11°N) and Shencottah Gap (narrowest gap, 7.5 km at 9°N)[42,43] (Figure 1). On each island, at a finer scale, there is further patchiness with forest patches and interspersed grasslands that are now known to be natural. Evidence suggests that the grasslands in this habitat have existed from 30–40 kya, before the advent of humans in this landscape. This has been supported by studies using different methods; C3–C4 ratios[13,44,45] and palynological records[46]. It has been found that the Shola forests are formed and maintained by a combination of factors, including aspect, temperature and rainfall[47] or by a combination of slope, wetness and terrain shape[48].

Landscape as a prospective laboratory to study natural fragmentation: Studies have shown that different regions have varying numbers and sizes of Shola forest patches. Eravikulam was found to have about 60% grasslands[49], but this could vary across different islands[50] and even within the same island; for example, Eravikulam could be divided into three categories of Shola forest cover compared to grassland cover: high (> 50%), medium (26–50%) and low (1–25%)[49]. Specialist species like the endemic threatened bird, the Nilgiri or Black-chinned Laughingthrush *Strophocincla cachinnans* were found in a matrix where about 93% of the forest patches where they could be found was less than 0.5 sq. km (ref. 51). This indicates that the species are used to certain level of natural patchiness. Even in the endemic, threatened understorey bird, the White-bellied Shortwing or White-bellied Robin, *Brachypteryx major*, survival of the species was affected more by disturbance than by habitat patchiness. The island biogeography framework can be

used to study species at different scales[52–54]. Preliminary research based on one species of plant, *Litsea floribunda* indicates that genetic heterogeneity was higher in smaller Shola patches than in larger patches[55].

Evolutionary history and climate change: The vegetation in the Shola habitat at the Last Glacial Maxima (18,000 years ago) was affected by drier climate, and the landscape was dominated by C4 grasslands with forests restricted to more humid valleys or bogs[56,57]. Since then forests have been expanding as the climate became more humid, and these fluctuations have possibly affected the population structure of the species found in these specific habitats, e.g. the White-bellied Shortwing[39]. A bibliography of the Quarternary environment in the tropics has been compiled by Smith[58].

Taxa-specific research: Most studies (excluding studies on flora) in the Sholas have been taxa-specific and focused on single species[39,51,59], with few studies on species assemblages or communities[16,60]. A broad taxa-based summary is attempted below to point out where data are available and what future research could be focused on.

Present flora: Floral studies (39% of all publications) range from documenting diversity to understanding ecology of species and habitat. These are also some of the earliest studies in this landscape and provide historic accounts from the 1950s and earlier. Some of the early efforts in the 1960s, involved mapping habitats including these high-elevation habitats that brought to light their importance[61–65]. Many present large-scale studies do not differentiate between grasslands and forests while describing the Shola habitat. For example, while describing the extent of Shola forests in the Biligiri Rangaswamy Temple (BRT) Wildlife Sanctuary, Hegde *et al.*[66] pointed out that only 0.8% of the area is under Shola habitat (including both grasslands and forests) based on the categorization of Ramesh[67].

A high proportion of the tree flora found in the Shola forests is endemic to this habitat[26]. Plants of Lauraceae and Symplocaceae dominate the Shola forest habitats today[68–71]. Some studies have found the floristic diversity to be higher in the Shola forests than in lower elevation forests[72]. A review of research on the flora of these forests can be found in the literature[10,68]. Grassland habitats in the Sholas are relatively less studied. The grasslands in Eravikulam are known to be dominated by two species, *Eulalia phaeothrix* and *Dicanthium polyptychum*[73]. On one of the sky islands in Kalakad–Mundanthurai Tiger Reserve, a comparison of grassland communities across elevations revealed that the high elevations were species-poor, but had the highest inter-site differences or heterogeneity while also supporting a distinct group of large herbivores[74]. Since a review of research on the Shola grasslands exists[17], it has not been attempted here.

Physical and chemical properties of the Shola forest patches are very different from that of the grasslands[75], and differ in soil microflora[76] with high content of *Penicillia* in the forest soils. The density of fungal propagules was higher in the grasslands[76]. Micro-climate within the Shola patches has been found to be maintained[77] between 31°C and 16°C with microenvironment and soil conditions showing striking differences at an edge–interior gradient[78]. Soil microbial diversity is rather poorly studied, but a two-year study resulted in 17 new records[79]. Bryophytes have been particularly ignored with only a couple of studies[80,81], with largely checklist-level information available so far only from a few regions[82].

There have been a few studies examining genetic relatedness of species, namely *Rhododendron arboretum*[83], *Litsea floribunda*[55], *Eurya nitida*[37] and *Gaultheria fragrantissima*[36]. The ecological correlations of genetic relatedness have been rarely examined, but see Paulsamy *et al.*[84]. The only such study compares genetic diversity between the last three species mentioned above[38]. Most of these studies use RAPD markers and no study uses more informative microsatellite or sequence data. Uses of plants, such as medicinal properties of the Shola plant species have been explored by several authors[85–88] and are not elaborated here.

Birds: These are one of the best-studied groups in the Sholas with several single-species studies. These started with a study by Khan[89] on the biology of the Black-and-Orange Flycatcher *Ficedula nigrorufa*, and subsequent studies examined the biology of species like White-bellied Shortwing *Brachypteryx* sp.[39,90–92], Nilgiri Wood Pigeon *Columba elphinstonii*[93], Nilgiri Pipit *Anthus nilghiriensis*[94] and Nilgiri Laughingthrush *Strophocincla cachinnans*[51,95], all threatened endemic birds in this habitat. Most studies, however, focus only on specific aspects of biology of the species and many gaps in knowledge still exist. Niche overlap studies of Shola birds identified six foraging guilds, where most birds fed from the vegetation[96], and the frugivorous Nilgiri wood pigeons largely utilized nine plant species, predominantly from the family Lauraceae[93]. Zarri *et al.*[51] determined that the Niligiri Laughingthrush would not occur in patches smaller than 400 sq. m in area. The study on Nilgiri Pipit by Vinod and Vijayan[94] is one of the few studies on a species in the unique grassland system and shows that these pipits specifically use marshy grassland for nesting, specifically *Andropogon* species. Distribution surveys of the White-bellied Shortwing[91,92] found the species to be restricted to the Shola forests and Robin *et al.*[39] found populations of the species to be genetically isolated by geographical gaps in the Western Ghats.

A few multi-species studies[60,97] have examined the density of many Shola endemic species through systematic sampling, while Mudappa and Raman[98] conducted an extensive survey across the Western Ghats for threatened

endemic birds (data available at www.openecology.in). Individual Shola forest patches in a sky island were seen to have higher species richness but lower species abundance than adjoining lowland forests[99]. Praveen and Kuriakose[100] reviewed the distributional range of a threatened Shola-endemic, the Black-and-Orange Flycatcher. In addition, the efforts of amateur and professional bird watchers, especially from the Kerala Birder group, have helped greatly to provide information on the status and distribution details of several species in the Shola habitats[101], and have resulted in the publication of a recent book[102]. Balakrishnan[103] described the nesting behaviour of square-tailed black bulbul, *Hypsipetes ganeesa*, while Vinod and Vijayan[94] studied the habitat requirements of the Nilgiri Pipit *Anthus nilghiriensis*. The effect of plantations on endemic bird species was examined by some researchers[89,104,105].

Mammals: Very few studies have been conducted on mammals, although the Shola forests are host to a large number of mammals. Much of the published literature is on rodents. Shanker and Sukumar[54] explored the community structure of small mammals and found that density of species other than rats was highest in the small patches. They also found synchrony in small mammal populations within and across small Shola patches[106]. In a comparison of capture rates of the Malabar spiny dormouse, *Platacanthomys lasiurus* in different elevations, Mudappa *et al.*[107] inferred lower occurrence of the species in the Shola forests due to floristic differences in the high elevation regions.

The most studied mammal in the Shola ecosystem is the Nilgiri Tahr, *Nilgiritragus hylocrius*, beginning with natural history observations[108]. Numerous studies over three decades document the distribution and population status of the Nilgiri Tahr[109–111], habitat use[112] and conservation[113]. Most exhaustive information on the species was collected by Clifford Rice whose work[59] documents predation[114], population dynamics[73], reproductive biology[115] and sexual behaviour[116] of the Tahr.

Two reviews[117,118] have summarized the occurrence of the Nilgiri Marten, *Martes gwatkinsii* in the Western Ghats, compiling several sighting records from the Shola habitats across the region. A study comparing habitat usage by carnivores within a sanctuary concluded, based on secondary signs, that wild dogs, *Cuon alpinus* and leopards, *Panthera pardus* preferred the Sholas over five other more spatially extensive habitats[119]. This study also found that the tiger, *Panthera tigris* used the Sholas as the second most preferred habitat in the same landscape. Tigers in the Sholas were found to consume a large proportion of Nilgiri Tahr[120]. Primates are not very common in the Shola landscape as revealed by a survey by Kumara[121] and the only species found is the Nilgiri langur, *Semnopithecus johnii*.

Amphibians: There have been several detailed studies on amphibians in the Western Ghats[122,123], but these have not directly addressed species on high-elevation mountain-tops. Although the Shola forests and montane ecosystems of the Western Ghats have been described to be high in amphibian endemism[28], there is very little specific information available from this region. There have been some reports of range extensions[124] or new species descriptions[125,126], but more recently there have been efforts examining the phylogenetic status of some of these species[127,128].

Reptiles: In perhaps the only study to estimate reptilian densities in Shola forests, Deepak and Vasudevan[129] examined the microhabitat association of an endemic, arboreal agamid *Salea anamallayana*. This species was thought to be restricted to high-elevation Sholas[130], but the study[129] showed that the species is also found in tea plantations adjacent to the Shola forests, a pattern found with other agamids (*Psammophilus blanfordanus*) in lower elevations as well[131].

Fish: These seem to be poorly studied with less information on diversity and endemism of native fish and more information on aquaculture and introduction of exotic fishes into the Shola forest streams[132]. Although there have been several studies on fish, with 23 papers reviewed by Ghosh[33], few studies examine biology, behaviour or distribution of the Shola habitat fish, although it is well known that these regions have high species diversity[33]. This taxa is clearly understudied and perhaps requires large amounts of effort.

Insects: There has been little work on insect fauna in the Sholas, barring a few studies describing diversity and distribution[22,29,133–135]. Mathew *et al.*[133] found a high species diversity index in the Shola forests compared to mid-elevation evergreen forests. Forest litter ant diversity was high in the Sholas and a unique group of taxa, different from evergreen and deciduous forests was found in the Sholas[30]. Vineesh *et al.*[136] found that the leaf litter ant community in the Sholas was different from moist-deciduous habitats and went on to describe the physical characteristics of the habitat that were responsible for the diversity/abundance of these ants. Robin *et al.* (under preparation) found that forest-floor arthropod communities differed significantly across wattle (*Acacia* sp.) plantations and natural forests. Small patches of natural forests differed from large patches and differing anthropogenic disturbance levels within the large forest patch also affected arthropod communities (Robin *et al.*, under preparation). Social bee diversity was not found to be as high in montane forests as in lower evergreen and deciduous forests[72].

Conclusion

This study clearly indicates a many-fold increase in the quantity and diversity of research over the last decade. A large part of this research, however, remains at the descriptive stage indicating that perhaps this rich natural history information can be used to now examine larger questions. Shola habitats are regions of high biodiversity, but also face numerous threats as seen from an examination of the literature. The apparent skew in research efforts should be addressed in order to enable comprehensive conservation efforts. We recommend a two-pronged approach. Effort should be invested in conducting new research on taxa groups and subjects that are understudied. Examples of this would include examining phenomena/subjects like climate change and understudied taxa like fish in this habitat. Meanwhile, efforts should also be made to publish information from studies already conducted but with no information in the public domain. A lot of research in India is commissioned for specific projects, and much of the results are not published in peer-reviewed journals nor do they appear in the public domain. An edited volume or a special section thus plays a big role in encouraging such information to be brought out in the public domain, as also highlighted in this study. Researchers from different fields could organize workshops, probably facilitated by the Indian Government, that result in publishable outputs. Researchers who have completed projects could be encouraged to upload their data into an open-access database with creative commons licensing (such as OpenEcology, hosted at http://openecology.in or the Western Ghats Portal www.westernghats.in), which would allow further exploration of the data as well as the compilation of better-informed management plans. All of these efforts could increase the information generated from this interesting and important landscape.

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