Epiphytic orchid diversity in farmer-managed *Soppinabetta* forests of Western Ghats: implications for conservation

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Conservation of biodiversity in managed landscapes is of critical importance due to the rapid degradation and loss of primary habitat in the tropics. *Soppinabetta* forests are farmer-managed, fragmented evergreen forests of the Western Ghats biodiversity hotspot in India. We hypothesized that these forests have immense importance in conservation of epiphytic orchid flora, although management intensity may differentially affect the diversity. Orchid diversity of the *Soppinabetta* forests of two degrees of management (sustained *Soppinabetta*, *N* = 11; degraded *Soppinabetta*, *N* = 4) has been compared with protected reserve forest fragments (*N* = 6). A total of 3537 orchid individuals of 41 species were recorded from 1.05 ha area; 39 species were found in the *Soppinabetta* forests. Orchid species richness was highest in sustained *Soppinabetta* forests (26.2) compared to degraded *Soppinabetta* (23) and reserve forest fragments (20.5). Non-metric multidimensional scaling ordination revealed that the orchid community of the degraded *Soppinabetta* was distinct. It was found that even when the total alpha diversity was preserved, a shift in the orchid species can take place with anthropogenic disturbance. About 21% of the overall surveyed trees were phorophytes. Mean phorophytes ranged between 15% and 46.5% among three forest types. Compositional variation of phorophyte trees had little effect on orchid diversity of the fragments. The present study shows that the deficiency of properly protected reserve forests can be compensated by the farmer-managed local *Soppinabetta* forests for epiphytic orchid conservation in the region. Comparison with other studies revealed that the *Soppinabetta* forests harbour high local orchid diversity in the entire Western Ghats.

Keywords: Conservation, epiphytic orchids, fragmentation, managed forests, *Soppinabetta* forest.

HISTORICALLY, humans have managed natural landscapes and resources in the tropics[1–4]. The importance of managed forest fragments and production landscapes in conserving biodiversity, ecosystem structure and services has been magnified by the accelerating and drastic decline of primary and continuous forests[5,6]. In many regions, managed forest reserves are the last refuge for the conservation of biological diversity[7–10]. However, habitat management indirectly affects ecological communities. To mitigate these indirect effects, it is imperative that we improve our understanding of the consequences of the implemented management practices[11]. To understand the effect of human intervention on native biodiversity, recent studies have focused on landscape matrixes composed of managed tropical landscapes and agricultural landscapes, which include pastures[12] and plantation crops[8]. Formed as a result of tropical primary forest destruction, these landscapes sustain considerable diversity of the original vegetation and associated ecosystem services and functions[13]. More studies are needed from a diversity of managed landscapes, ranging across geographical regions, to improve our understanding of the contribution of managed landscapes in sustaining global biodiversity.

The 160,000 sq. km mountain range of the Western Ghats, India, is one of the 22 global biodiversity hotspots[14]. This region contains the largest stretch of pristine evergreen forests and comprises several managed landscapes, including agricultural lands. The *Soppinabetta* forests (*Soppu* means foliage and *Betta* means hills in the local language) are a kind of usufruct forests legally provided to the betel nut (*Areca catechu*) farmers for the purpose of compost production. These forests are comparable to the sacred groves of the central Western Ghats[15].

Orchids are generally considered to respond to variations in the ecosystem processes and changes. Studies that have examined the effects of ecosystem processes and changes and conservation significance of managed and production landscapes in maintaining epiphytic orchid diversity, report contradictory results[7,8,16–19]. Nevertheless, most of these studies are from neotropical climates and the pattern in old-world tropics is not clear, and a lot of opportunity exists to study these effects (but, see refs 10, 20 and 21). In this article we examine

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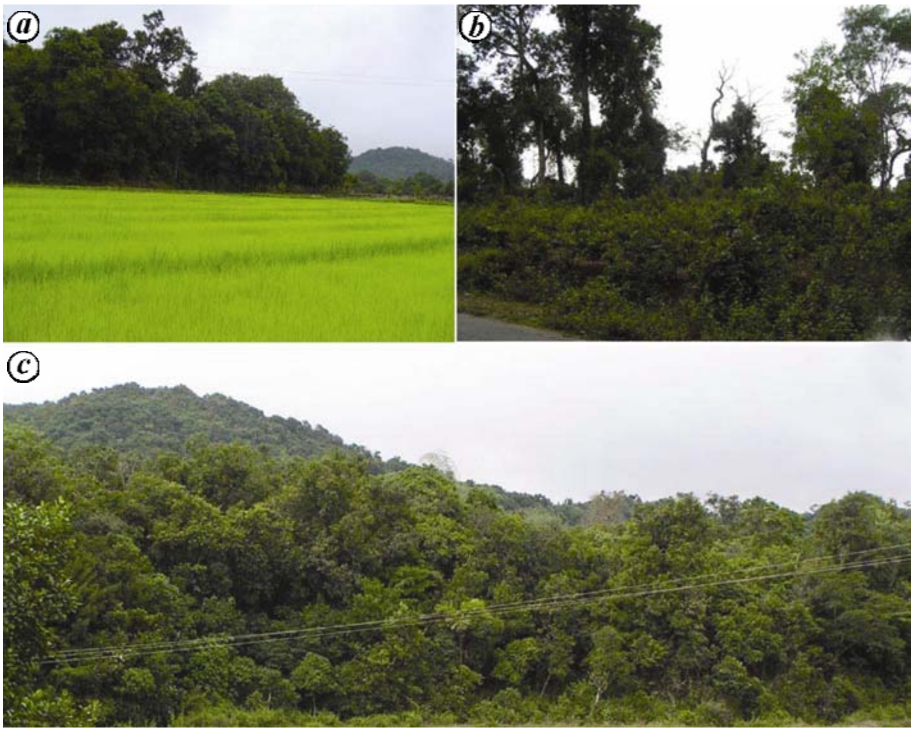

Figure 1. Photographs of a sustained *Soppinabetta* forest (***a***), a degraded *Soppinabetta* forest (***b***) and a reserve forest (***c***) of Sringeri area in the central Western Ghats, India.

the epiphytic orchid floristic diversity in fragmented, human-influenced forests of the Western Ghats. This study is part of an ongoing research programme analysing the efficiency of farmer-managed *Soppinabetta* forests in conserving biodiversity and biotic interactions in fragmented landscapes. To understand how the orchid community responds to different levels of disturbance in the *Soppinabetta* forest landscape, we compared the orchid diversity undergoing two management regimes. This study reports on the contribution of the *Soppinabetta* forests in preserving the regional orchid flora and provides critical information that will aid in the development of more appropriate management practices to conserve the local orchid biodiversity.

Methods

Study area

The study was carried out in Sringeri Taluk (= sub district; 12°55′–13°54′N and 75°01′–75°22′E), Chikmagalur District, Karnataka, India. The study was conducted between August 2006 and November 2007. Sringeri is a sparsely populated (< 100 people per sq. km) Taluk, with forest covering 75% of the area. The forests are located on the eastern slope of the Western Ghats and border the pristine wet evergreen forests of Kudremukh National Park and the wet evergreen forests of Agumbe in the western slope of the Western Ghats. The mean altitude of Sringeri is 725 m asl. The majority of precipitation occurs during the southwest monsoon (June–September). Total rainfall during the study years, 2006 and 2007, was 4250 and 4825 mm respectively (unpublished data). Mean daily maximum temperature varies between 22.8°C (July) and 35.1°C (April) (courtesy: Sringeri municipality).

The *Soppinabetta* forests of Sringeri are a component of a mosaic of agricultural lands, such as betel nut and coffee orchards, rice paddies and protected reserve forest (RF) fragments (Figure 1 *a*). They are the parts of RFs that were leased to areca growers for sustainable use of organic resources for the production of compost more than a century ago[22]. Nearly 55% of the total geographical area of Sringeri is composed of *Soppinabetta* forests of various sizes (0.1–1.5 ha; courtesy: Sringeri Taluk Office). The alpha diversity of tree species of these forests is comparable to that of Kudremukh National Park at similar altitude, but considerable differences exist in species composition[23]. For local farmers, *Soppinabetta* forests are a vital resourceful land as they supply leaf litter and green leaves. Management plans incorporate forest sustainability with direct farmer involvement in forest resources use and protection, specifically by providing the farmers with rotational collection (once in three years) of organic material (leaf litter and green foliage) from a given forest area (sustained *Soppinabetta* (SSB) forests); this practice has continued since its implementation (pers. commun.). Few farmers have violated the practice of rotational use of forest products some decades ago and the dependency has increased. In order to collect more compost raw material and fuel wood, primary branches of trees were being felled frequently, resulting in the trees growing short and stunted, and distributing them sparsely (degraded *Soppinabetta* (DSB) forests). DSB forests have a corresponding thinning in canopy structure of trees (Figure 1 *b*). Forest fragments of SSB maintain good habitat quality in terms of canopy structure and species composition and are comparable to RFs of the region (Figure 1 *c*). The earlier management of *Soppinabetta* forests included selective growing of certain high leaf-producing tree species such as coppicing dipterocarpaceans[23]. This has resulted in many *Soppinabetta* forest fragments growing with monodominant species. Although RFs are under the control of the Forest Department, poor conservation practices make them accessible to landless poor (below poverty line) people who unsustainably collect firewood and construction materials. Felling and logging are also frequent in RFs.

Recently, government has resurveyed all the *Soppinabetta* forests and relabelled them as RFs in order to declare them as a buffer zone of the Kudremukh National Park. Recent household surveys have shown that the management of *Soppinabetta* forests by the farmers is a fine example of reconciliation ecology (Sinu *et al.*, unpublished).

Sampling design and data analyses

We established 21 study plots in three management types of varying tree species composition and structural heterogeneity: 11 in SSB fragments, 4 in DSB forest fragments and 6 in RF fragments (Figure 2). Maximum attention was given to selecting study plots of all the three management types in the same study location, but this could be achieved only in two locations. In other study locations comparable SSB and RF fragments were obtained adjacent to each other. The DSB fragments were restrictted to certain areas of Sringeri and we could include only four fragments in the study. Table 1 provides a general description of the study plots. However, all the study sites are located in about 20 km radius from Sringeri town and are comparable in topography, vegetation, soil, etc.

Belt transects were used to sample the orchid community. A single belt transect of 100 × 5 m^2 was laid within 100 m from the forest edge. Trees, liana and their saplings (hereafter, trees) were identified and counts were recorded in each of the study plots. Plants associated with orchids (phorophytes) were separately recorded and percentage of phorophytes in each study plot was calculated. A binocular was primarily used to identify canopy orchids, but we occasionally had to climb the trees to identify small orchids. The number of individuals was counted for species in which these were clearly demarcated, whereas the species that showed clumped branching pattern such as *Bulbophyllum* spp., *Trias stocksii* and *Pholidota imbricata* were counted based on the total discontinuity of the clump. This means, if the clump is separated contiguously, each such separated contiguous patches, even within a clump, was considered as separate individuals. A continuous clump was counted as one individual with several branches. Girth at breast height of the phorophytes was recorded that is used to calculate diameter of the tree (DBH). For each transect, we estimated canopy height and ranked canopy cover (%) using visual estimation at 10 random points; the mean values of each transect were used in the analysis. As lopping of primary branches was practised in DSB fragments, the canopy cover was often zero. Most of the trees were sparsely distributed in DSB. The data on area of each studied forest fragment was collected from the records of Sringeri forest and the Revenue Department.

Observed and rarefied species richness and abundance, and Simpson's diversity[24] of the orchids were considered as the alpha diversity measures of each management type. Non-parametric species estimators, Jack-knife 1 and Chao 2, were used to predict orchid species richness at each site[25]. These give a better estimate of species richness in an assemblage having rare species[26]. Individual-based rarefaction curves were used to compare the patterns of orchid species richness between management types, as the number of sampling plots selected for each of the habitat type was unequal. Rarefied species richness per plot per management type was used in diversity statistics. Kruskal–Wallis rank ANOVA test was used to find out if management has an effect on orchid species richness, orchid abundance and phorophyte abundance of the forest fragments.

Non-metric multidimensional scaling (NMDS) was performed with complement of the Sorensen's quantitative dissimilarity index to study orchid floristic similarity. This was computed with the Vegan library[27] in R[28]. To determine the interrelation with the ordination axes,

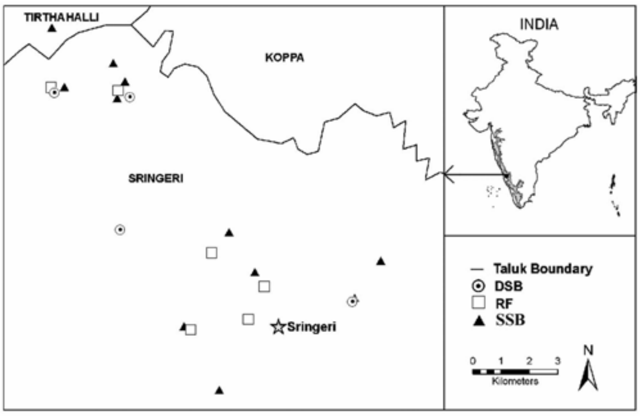

Figure 2. Map showing the study sites of reserve forest (RF), sustained *Soppinabetta* (SSB) forest and degraded *Soppinabetta* (DSB) forests in Sringeri.

Table 1. General description of forest fragments of 21 study locations in Sringeri area of the central Western Ghats, India

Location	Elevation (m)	Canopy height (m)	Canopy cover (%)	Area of fragment (ha)	Tree abundance (% of phorophytes)	Tree species richness	Rarefied orchid species count per plot per management type	Rarefied tree species count per plot per management type	Mean DBH (cm) of phorophytes (range)	Species richness of orchids (abundance)
Harkodu*	726.9	31	90	41.2	101 (1)	26	4	23.4	16.91 (1–79.6)	4 (21)
Kotte*	649.2	22	80	64	85 (16.5)	27	5.2	26.4	15.68 (1–37.6)	9 (154)
Kumbarakodu*	659.9	20	80	73	82 (35.4)	25	1.4	25.0	16.81 (1.6–29.3)	2 (47)
Makkimane*	691.6	22	60	44.5	126 (16)	24	4.5	20.1	29.33 (1–114.6)	8 (415)
Meega*	705.3	35	70	121.4	109 (7.3)	21	3.5	17.8	56.95 (2.2–110.8)	7 (81)
Vishwanath Mane*	683.3	21	80	20.4	118 (14.4)	27	4.5	22.4	22.39 (2.22–73.25)	10 (320)
Begar**	633.6	13	85	1.3	342 (3.7)	24	1.7	7.7	15.12 (1.0–78.0)	3 (83)
Bidrugodu**	642.2	16	75	2.4	86 (33.7)	33	1.8	21.1	11.06 (1.27–57.32)	6 (257)
Halanthur**	664.4	8	30	2.5	100 (15)	9	3.1	5.9	20.25 (5.09–51.91)	10 (289)
Harkodu**	716.5	19	80	4.4	98 (24.5)	27	5.1	14.7	18.62 (1.0–101.9)	11 (106)
Honnavalli**	700.4	29	76	2	150 (2.7)	39	3	16.7	13.61 (7.3–18.47)	3 (12)
Kaimana**	637.9	10	80	1.4	171 (23.4)	17	4.1	10.1	11.07 (1.0–28.7)	11 (128)
Kumbarakodu 1**	687.6	10	70	4	116 (31)	29	2.4	17.1	13.22 (2.5–44.6)	16 (404)
Kumbarakodu 2**	640.4	16	80	2.4	81 (23.5)	23	2.5	16.0	16.06 (1.6–57.3)	9 (58)
Mense**	665.3	17	65	2.4	141 (15.6)	16	4.5	9.9	28.9 (6.7–81.2)	12 (117)
Nemmar**	680.0	15	65	2	62 (34)	18	1.1	14.7	9.14 (0.5–43)	2 (133)
Tyavana**	720.2	11	70	2.4	39 (51.3)	15	3.1	15.0	10.56 (1.91–31.8)	7 (115)
Halanthur 1***	643.4	12	0	2.3	11 (27.3)	3	6.0	3.0	14.23 (10.19–19.10)	6 (57)
Halanthur 2***	670.5	8	30	2.2	67 (52.2)	7	7.0	3.7	17.50 (7–46.5)	12 (412)
Kumbarakodu 3***	649.5	9	5	2.3	46 (54.3)	23	7.3	8.5	14.63 (1.91–108.2)	9 (124)
Meega1***	690.9	2.5	0	3.8	58 (82.8)	16	11.7	6.6	10.10 (1.91–63.7)	17 (204)

*Reserve forest; **Sustained *Soppinabetta* forest; ***Degraded *Soppinabetta* forest.

management and fragment vegetation attributes were correlated (Spearman). Relationships between pairwise plot phorophyte floristic and orchid similarities (Sorensen's index) were studied within management types to examine whether tree species composition had an effect on orchid species composition.

Spearman's rank correlation was used to find the relationship of orchid diversity with vegetation and fragment attributes. We used multiple linear regression analysis to examine the significance of phorophyte and fragment variables in determining orchid diversity; pooled data were used in the regression analysis. Variables with no

Table 2. Orchid individuals and frequency of 41 epiphytic orchid species and associated phorophyte species diversity in fragments of reserve forest (RF), sustained *Soppinabetta* (SSB) and degraded *Soppinabetta* (DSB) forests of Sringeri

Orchid species	Individuals per plot			Percentage of plots with orchids			Phorophyte species count
	RF	SSB	DSB	RF	SSB	DSB	
Aerides crispum Lindl.	–	0.18	–	–	18.2	–	2
A. ringens (Lindl.) C. E. C. Fisch.	0.50	0.18	–	16.7	9.1	–	3
Bulbophyllum fimbriatum (Lindl.) Reichb.f.	10.00	–	–	16.7	–	–	1
B. mysorensis (Rolfe) J. J. Sm.	7.83	0.73	1.75	33.3	9.1	50.0	5
B. neilgherrense Wight.	–	0.64	–	–	9.1	–	2
Coelogyne breviscapa Lindl.	0.17	0.27	0.25	16.7	18.2	25.0	4
Cottonia peduncularis (Lindl.) Reichb.f.	2.67	2.09	–	50.0	63.6	–	16
Cymbidium aloifolium (L.) Sw.	0.17	0.27	0.50	16.7	27.3	50.0	6
Dendrobium crepidatum Lindl. & Paxton.	–	3.73	8.25	–	27.3	50.0	6
D. herbaceum Lindl.	28.33	0.09	2.50	16.7	9.1	25.0	6
D. aphyllum (Roxb.) C. E. C. Fisch.	4.67	5.09	17.75	33.3	72.7	100.0	23
D. jerdonianum Wight.	–	–	0.50	–	–	25.0	2
D. ovatum (L.) Kraenzl.	–	0.27	14.50	–	18.2	100.0	12
D. peguanum Lindl.	–	–	1.00	–	–	25.0	3
Dendrobium sp.	–	0.36	10.00	–	9.1	50.0	7
Eria dalzellii Lindl.	–	0.18	10.50	–	18.2	50.0	3
E. exilis Hook. f.	6.33	2.45	0.25	33.3	27.3	25.0	7
E. mysorensis Lindl.	–	–	0.25	–	–	25.0	1
Flickingeria nodosa (Dalz.) Seidenf.	0.17	–	–	16.7	–	–	1
Gastrochilus fabelliformis (Blatt. & McCann)	2.33	3.55	–	66.7	54.5	–	17
Gastrochilus sp. 2	–	0.36	–	–	9.1	–	2
Gastrochilus sp. 3	–	0.09	–	–	9.1	–	1
Kingidium mysorensis (Saldhana) Kumar	3.83	1.18	–	16.7	18.2	–	8
Luisia macrantha Blatt. & McCann.	1.17	1.36	–	50.0	54.5	–	10
L. zeylanica Lindl.	–	0.27	1.00	–	9.1	25.0	2
Oberonia brunoniana Wight.	0.17	–	0.25	16.7	–	25.0	2
O. iridiflora Lindl.	–	0.09	–	–	9.1	–	1
O. platycaulon Wt.	–	0.27	–	–	9.1	–	1
O. chandrasekharanii Nair, Ramachandran & Ansari	0.67	0.45	–	50.0	18.2	–	5
Oberonia sp. 1	0.33	0.27	–	16.7	18.2	–	5
Oberonia. sp. 2	0.67	0.36	–	16.7	9.1	–	2
O. tenuis Lindl.	–	–	2.00	–	–	25.0	2
Pholidota imbricata Lindl. in W. J. Hook	0.17	6.09	14.25	16.7	72.7	100.0	29
Porpax jerdoniana (Wight.) Rolfe.	–	–	1.75	–	–	50.0	2
P. reticulata Lindl.	–	–	0.50	–	–	25.0	1
Rhyncostylis retusa (L.) Bl.	0.17	0.36	1.00	16.7	27.3	25.0	6
Robiquetia josephiana Manilal & Sathish	11.50	0.09	–	16.7	9.1	–	2
Cleisostoma tenuifolium (L.) Gareay	73.50	120.82	19.25	100.0	90.9	100.0	66
Trias stocksii Benth. ex Hook.f.	17.67	2.45	91.00	33.3	54.5	100.0	15
Unidentified sp. 1	–	0.09	–	–	9.1	–	1
Vanda sp.	–	–	0.25	–	–	25	1

significant effects were removed step-wise to get the best explained linear model. The coefficients of determination are given throughout as adjusted r^2 to account for differences in the sample size and the number of independent variables[29]. Tree abundance, tree species richness, DBH of phorophytes, abundance of large trees (DBH ≥ 10 cm), canopy cover and canopy height of fragment were included in the model.

The importance value index (IVI) of the orchid species was compared between forest fragments of the three management types. IVI of an orchid species is the sum value of relative frequency and relative abundance of the orchid species in a given study plot[21,30]. Estimated diversity and similarity indices were calculated using Estimates 8.0 (ref. 25). Diversity analysis was performed using STATISTICA software (1999 edition). Biodiversity PRO (version 2) was used to calculate rarefied species richness. Regression and correlation analyses and ordination were performed using R (ref. 28).

Results

Species richness, abundance and composition of epiphytic orchids

A total of 3537 individuals of 41 epiphytic orchid species (Table 2; Figure 3) were recorded from the sampled 1.05 ha area of SSB, DSB and RF fragments. There were 31 observed orchid species in SSB ($S_{\text{rarefied}} = 26.16$), 23 in DSB ($S_{\text{rarefied}} = 22.96$) and 22 in RF ($S_{\text{rarefied}} = 20.5$).

Table 3. Comparison of epiphytic orchid diversity of forest fragments of RF, SSB and DSB in Sringeri

Diversity statistics	RF	SSB	DSB
Observed species richness	22	31	23
Rarefied species richness	20.5	26.16	22.96
Abundance	1038	1702	797
Simpson's diversity ($1/D$)	0.23	0.62	0.24
Jack-knife 1 species estimator	32.8	42.8	32
Chao 2 species estimator	35	39.86	30.07
Chao 1 species estimator	29.5	33.5	25.5
Percentage of captured species (Chao 2)	63	78	76
Average number of observed species per plot	6.7 ± 3.07	8.18 ± 4.4	11 ± 4.7
Average number of rarefied species per plot*	0.65 ± 0.21	0.27 ± 0.11	2 ± 0.64
Average number of individuals per plot	173 ± 160	154.7 ± 115	199.2 ± 154
Average number of phorophytes per plot	15.1 ± 11.6	26.6 ± 16.6	46.5 ± 27.4

*$P < 0.005$ KW: H(2, 21) = 14.15.

Mean orchid abundance per plot was 173 (± 160; $N = 6$), 154.7 (± 115; $N = 11$) and 199.2 (± 154; $N = 4$) in RF, SSB and DSB fragments respectively. The Simpson's diversity was high in SSB (0.62) compared to RF (0.23) and DSB (0.24; Table 3). Considering the study plots of all three management types together, an average of 168.4 individuals (± 130; range = 12–415; $N = 21$) and 8.3 species (± 4.3; range = 2–17; $N = 21$) was found per study plot. The rarefied species richness showed high variability in the study plots, ranging from 1.08 to 11.73 species (Table 1). Mean rarefied orchid species richness was significantly different in SSB, DSB and RF fragments (Kruskal–Wallis test, $H = 14.15$, $P = 0.004$; Table 3).

Jack-knife 1 predicted the occurrence of 54.3 species (Chao 2 = 51.8 species, Chao 1 = 44 species) in 21 study plots. But in the present study 76% (Jack-knife 1) and 80% (Chao 2) of the total estimated species were recorded. In the fragments of the three management types, 63% (RF), 78% (SSB) and 76% (DSB) of the total predicted species (Chao 2) were observed (Table 3).

We counted 2189 individuals of 161 tree and liana species from the sampled area; however, only 93 species (about 58%) and 463 individuals (21.2%) were phorophytes. The proportion of phorophytes varied among study plots, ranging from 1% to 82.8% (Table 1). Mean phorophyte abundance was high in the forest fragments of SSB (26.6% ± 16.6) and DSB (46.5% ± 27.4) compared to RF (15.1% ± 11.6); but the difference was insignificant (Kruskal–Wallis test, $H = 4.91$, $P = 0.08$).

The response of orchid species richness and abundance to phorophyte girth size (DBH) differed among the management types. In RF, abundance ($r = 0.29$, $P = 0.03$) was positively related with the phorophyte girth size, but no relation was found with orchid species richness. In SSB, no considerable relationship existed between phorophyte girth size and orchid species richness ($r = –0.11$; $P > 0.05$) and abundance ($r = –0.13$; $P > 0.05$). In DSB, orchid abundance increased significantly with phorophyte girth size ($r = 0.41$, $P = 0.003$), but the negative relationship with species richness was insignificant ($r = –0.20$, $P > 0.05$).

About 36% of orchid species (± 0.18; range = 0–88%) and 24% (± 0.11; range = 0–48%) of the phorophytes were common. The degree of overlap of orchid species was 36% (RF/SSB), 25% (RF/DSB) and 38% (SSB/DSB). The compositional similarity of phorophytes was 30% (RF/SSB), 13% (RF/DSB) and 16% (SSB/DSB). Correlation studies showed that pairwise plot tree species compositional similarity related positively with the orchid compositional similarity in RF fragments, but the correlation was insignificant ($r = 0.42$, $P > 0.05$). However, in SSB and DSB, no relationship exist between pairwise tree and orchid compositional similarities ($r = 0.10$, $P > 0.05$).

NMDS ordination showed that the orchid community of DSB fragments was distinct (Figure 4). Tree species richness ($r^2 = 0.28$, $P = 0.05$), canopy cover of fragments ($r^2 = 0.56$, $P = 0.001$) and management type ($r^2 = 0.28$, $P < 0.01$) were related significantly with the ordination axes (Figure 4).

IVI calculations showed that *Cleisostoma tenuifolium* was the most common and important species in the fragments of RF (IVI = 91.20) and SSB (IVI = 138.77). In DSB, the most frequent and important species was *Trias stocksii* (IVI = 58.56). *C. tenuifolium* was only the fourth important species (IVI = 21.31) in DSB (Figure 5). Although many orchid species were common, their relative frequency and abundance varied among the three management types (Table 2).

Effect of management and vegetation on epiphytic orchid diversity

Epiphytic orchid abundance ($r = 0.74$, $P < 0.0001$) and species richness ($r = 0.82$, $P < 0.0$) increased with the abundance of large trees in the fragments (Table 4). Orchid species richness ($r = –0.49$, $P < 0.05$) decreased with canopy height of the fragments. Other phorophyte and fragment variables had no significant effect on orchid diversity of the forest fragments in Sringeri.

Considering all the three management types together, the largest proportion of variation in the orchid species

Figure 3. Some common and rare orchid species of the *Soppinabetta* forests in Sringeri. ***a***, *Aerides crispum* Lindl.; ***b***, *Aerides ringens* (Lindl.) C. E. C. Fisch; ***c***, *Trias stocksii* Benth. exHook.f.; ***d***, *Porpax reticulate* Lindl.; ***e***, *Eria exilis* Hook. f.; ***f***, *Oberonia tenuis* Lindl.; ***g***, *Cleisostoma tenuifolium* (L.) Gareay; ***h***, *Dendrobium ovatum* (L.) Kraenzl.; ***i***, *Luisia macrantha* Blatt. & McCann.; ***j***, *Cottonia peduncularis* (Lindl.) Reichb.f.l; ***k***, *Cymbidium aloifolium* (L.) Sw. and ***l***, *Robiquetia josephiana* Manilal & Sathish.

richness (r^2_{adj}. = 0.65; $F_{5,15} = 8.61$; $P = 0.0005$) was explained by the linear model that included tree species richness, tree abundance, canopy height, phorophyte DBH and density of large trees (Table 5). Variation in orchid abundance (r^2_{adj}. = 0.42; $F_{3,17} = 5.91$; $P = 0.005$) was explained by abundance of large trees, tree species richness and mean canopy cover of the fragments.

Discussion

The primary aim of the present study was to examine the conservation significance of farmer-managed *Soppinabetta* forest fragments of the Western Ghats. Orchid diversity of managed *Soppinabetta* forests of two degrees of disturbance has been compared with local small protected RF fragments. These fragments were considered in the present study, because the vegetation structure and composition, topography and environmental conditions of RFs are comparable to the *Soppinabetta* forests. It was also necessary to understand the quality of RFs of Sringeri in the conservation paradigm, as measures have been taken to reallocate the *Soppinabetta* forests as RFs. The differences between *Soppinabetta* and RFs of Sringeri are primarily due to forest use and ownership; *Soppinabetta* forests, especially SSB forests, are managed in a sustainable fashion and receive local protection from owner farmers. Unlike this, RFs of the landscape are accessed by landless poor people for firewood, fodder collection and used for grazing, where the forest use is not in a sustainable fashion. Hence the quality of RFs is not comparable to a pristine forests of the Western Ghats. One probable caveat of the study is that orchid diversity of the *Soppinabetta* forest has not been compared with a continuous pristine forest of the Western Ghats. This is because continuous forests stand away from the *Soppinabetta* forest landscape in the western slope of the Western Ghats that differs geographically and ecologically from the *Soppinabetta* forests. However, we have compared our findings with other studies that have examined epiphyte and orchid diversity in continuous forests of the region. Because the forests of the study area are small, the sampling transects had to be laid within 100 m from the forest edge in most of the fragments.

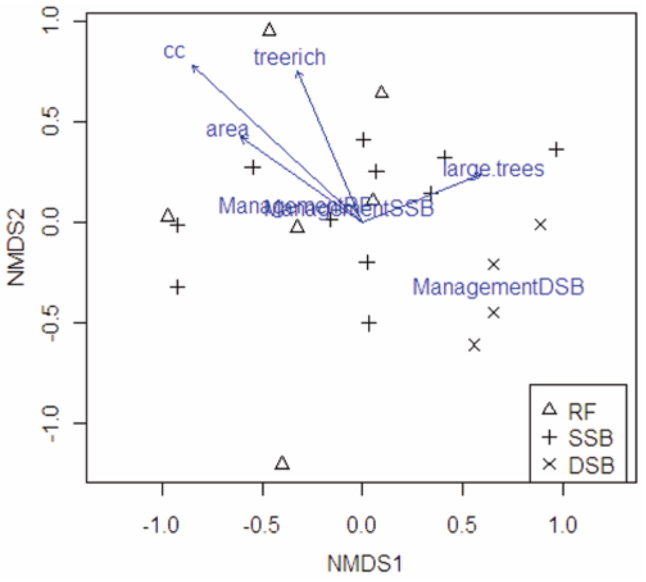

Figure 4. Epiphytic orchid similarity of 21 forest fragments of Sringeri. Two-dimensional scatter plot of non-metric multidimensional scaling (NMDS) based on Sorensen's quantitative dissimilariy values (stress = 19.29; $r^2 = 0.98$ for non-metric fit and $r^2 = 0.92$ for linear fit of ordination distances). The plot also shows the correlation between the ordination axes and environmental and fragment variables. Abbreviations used in the plot: cc, Canopy cover; treerich, tree species richness; managementRF, Reserve forest; managementSSB, Sustained *Soppinabetta* forest, and managementDSB, Degraded *Soppinabetta* forest.

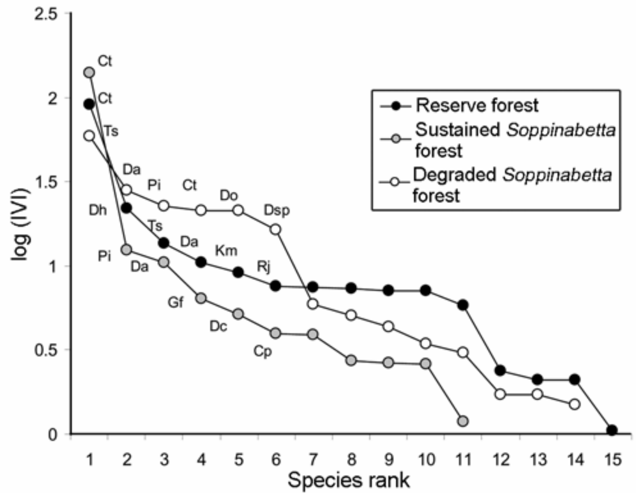

Figure 5. Plot showing the important value indices (IVI) of some of the dominant epiphytic orchid species in the fragments of RF, SSB and DSB in Sringeri. Cp, *Cottonia peduncularis*; Dc, *Dendrobium crepidatum*; Dh, *Dendrobium herbaceum*; Da, *Dendrobium aphyllum*; Do, *Dendrobium ovatum*; Dsp, *Dendrobium*; Gf, *Gastrochilus fabelliformis*; Km, *Kingidium mysorensis*; Pi, *Pholidota imbricata*; Rj, *Robiquetia josephiana*; Ct, *Cleisostoma tenuifolium*, and Ts, *Trias stocksii*.

Being a major land-use type, the *Soppinabetta* forests maintain a high diversity of angiosperms[23,31], and other functional guilds (P. A. Sinu, unpublished), that are comparable to local RFs of the study area. The 41 species of epiphytic orchids collected from 1.05 ha area of 21 forest fragments of Sringeri represent about 27% of the total orchids reported for the 160,000 sq. km area of the Western Ghats[32]. Apparently no studies have investigated the ecology of epiphytic orchids alone, or examined the effect of ecosystem processes and changes on orchid conservation in India (but, see refs 10, 20 and 21). A comparison with these studies reveals that the fragments are at par with the continuous forests in conserving epiphyte diversity in the Western Ghats. Considering epiphytic orchids alone, it is apparent that the *Soppinabetta* forests of Sringeri maintain high local diversity in the entire Western Ghats[10,20,21] (Table 6).

Human dependence on forests can either positively[8] or negatively[16] affect the orchid community. We hypothesized that DSB could be poor habitats for epiphytic orchids, because of high disturbance and poor quality of the forest stand. In contrast, the mean rarefied orchid

Table 4. Spearman rank correlation of orchid abundance and orchid species richness with environmental variables of forest fragments in Sringeri

Variable	Orchid abundance	Orchid species richness
Tree abundance	0.02	0.04
Tree species richness	–0.07	–0.22
Canopy height	–0.41	–0.47*
Canopy cover	–0.39	–0.31
DBH	0.01	0.08
Large trees (≥ 10 cm DBH)	0.74**	0.82***

$^*P < 0.05$; $^{**}P < 0.0005$; $^{***}P < 0.00005$.

Table 5. Step-wise multiple regression analysis shows the significant variables that entered in the linear model to explain the variation in epiphytic orchid species richness and abundance of the forest fragments in Sringeri

Parameter	Estimate	Standard error	*t*-value	*P*-value	R^2_{adj}.	d.f.	*F*-value	*P*-value
Orchid species richness					0.65	5,15	8.61	0.0005
Intercept	4.59	2.28	2.01	0.06				
Tree abundance	–0.02	0.01	–1.98	0.06				
Tree species richness	0.17	0.08	2.01	0.06				
Canopy height	–0.32	0.11	–2.78	0.01				
DBH	0.09	0.03	2.72	0.01				
Abundance of large trees	0.40	0.10	4.54	0.0003				
Orchid abundance					0.42	3,17	5.91	0.005
Intercept	11.36	79.90	0.14	0.89				
Tree species richness	4.13	3.43	1.20	0.24				
Canopy cover	–1.07	0.97	–1.09	0.29				
Abundance of large trees	12.73	3.15	4.04	0.0008				

Table 6. Number of epiphytic orchid species reported in comparable studies in the Western Ghats and Eastern Himalayas

Study	Study area	Status	Area sampled (ha)	Orchid species
Padmawathe *et al.*[20]	Eastern Himalayas	Wildlife Sanctuary	0.75	33
Annaselvam and Parthasarathy[21]	Southern Western Ghats	National Park	30	13
Page *et al.*[10]	Central Western Ghats	Sacred forest and continuous reserve forest	3.5	26
Sinu *et al.* (present study)	Central Western Ghats	*Soppinabetta* forest and fragmented reserve forest	1.01	41

species richness, abundance and phorophyte density were higher in DSB. These results further support the findings that remnant isolated trees[33] and fragmented forests[10,34] maintain high epiphyte (all families) and orchid (Orchidaceae alone) diversity.

Considering all the three management types together, the study shows that habitat transformation from SSB to DSB forests has an effect on the epiphytic orchid species composition. Most of the environmental variables were negatively associated with ordination axis 1, that was explained by the orchid community of DSB fragments. But, the transformation had no effect on alpha diversity of epiphytic orchids that were preserved[35,36]. The shift in orchid species in the present study was due to *C. tenuifolium* and *T. stocksii*. It is evident from Table 2 that *C. tenuifolium* had 121 individuals per study plot in SSB forests compared to 19.25 individuals in DSB. A reversal had occurred for *T. stocksii*, as at least 91 individuals per study plot occurred on phorophytes of DSB, unlike a miniscule 2.45 individuals per plot in SSB. Although the effect was not as prominent as in the case of *T. stocksii*, all species of *Dendrobium*, except *D. herbaceum*, were more likely to occur in DSB than in other two management types (Table 2).

The power of landscape and environmental factors to explain epiphyte diversity can vary with habitat type and intensity of anthropogenic disturbances[7,33,36]. Excluding a few phorophyte-related variables, our study shows that landscape and fragment variables have no or minimal effect on orchid diversity of fragments[10,33]. The study hence assumes that the *Soppinabetta* forests may be self-sustained and self-contained, where conditions for natural propagation of epiphytic orchids may be conducive.

Abundance of large trees in the fragments had a positive effect on epiphytic orchid diversity[37–39]. Some striking but unexpected results were the lack of a relation between tree abundance and orchid diversity among fragments, which is contradictory[33,36]. This, however, can be explained by the fact that some *Soppinabetta* forests are monodominant by the density of certain coppicing trees species, such as *Hopea* spp. and *Vateria indica* that are less colonized by epiphytic orchids. Therefore, the selective growing of certain trees that had been practised by farmers to get large quantity of quality leaf litter and green foliage must have had an effect on orchid diversity. High diversity of epiphytic orchids on lopped, scattered trees of DSB might have been the reason behind the inverse relation between canopy height of fragments and orchid diversity (Table 1).

With 39 species of epiphytic orchids it is apparent that the *Soppinabetta* forests, irrespective of disturbance gradient, contribute to regional orchid conservation. These findings have been supported by several recent studies that report the importance of small patch forests and production landscapes in the conservation of epiphyte diversity[7–10,33,34,40]. The *Soppinabetta* forests therefore, provide an apt example of reconciliation ecology[41].

We find that RFs of Sringeri are at par with the *Soppinabetta* forests in maintaining local epiphytic orchid diversity. We suggest that a local inclusive approach would protect the *Soppinabetta* forests in this region[42]. However, we recommend the following two management practices by the farmers: (i) cutting primary branches of the trees and (ii) selective growing of litter-producing coppicing trees may be discouraged in order to reduce the shift in orchid species and maintain orchid diversity of the fragments respectively.

1. Gadgil, M., Biodiversity and India's degraded lands. *Ambio*, 1993, **22**, 167–172.
2. Hannah, L. *et al.*, Participatory planning, scientific priorities, and landscape conservation in Madagascar. *Environ. Conserv.*, 1998, **25**, 30–36.
3. Atran, S., Medin, D., Ross, N., Lynch, E., Coley, J., Ek, E. U. and Vapnarsky, V., Folk ecology and commons management in the Maya Lowlands. *Proc. Natl. Acad. Sci. USA*, 1999, **96**, 7598–7603.
4. Berkes, F., Rethinking community-based conservation. *Conserv. Biol.*, 2004, **18**, 621–630.
5. Turner, I. M., Tan, H. T. W., Wee, Y. C., Ibrahim, A. B., Chew, P. T. and Corlett, R. T., A study of plant species extinction in Singapore: lessons for the conservation of tropical biodiversity. *Conserv. Biol.*, 1994, **8**, 705–712.
6. Bawa, K. S. *et al.*, Tropical ecosystems in the 21st century. *Science*, 2004, **306**, 227–228.
7. Hietz, P., Conservation of vascular epiphyte diversity in Mexican coffee plantations. *Conserv. Biol.*, 2005, **19**, 391–399.
8. Solis-Montero, L., Flores-Palacios, A. and Cruz-Angón, A., Shade-coffee plantations as refuges for tropical wild orchids in central Veracruz, Mexico. *Conserv. Biol.*, 2005, **19**, 908–916.
9. Haro-Carrión, X., Lozada, T., Navarrate, H. and de Koning, G. H. J., Conservation of vascular epiphyte diversity in shade cacao plantations in the Choćo region of Ecuador. *Biotropica*, 2009, **41**, 520–529.
10. Page, N. V., Qureshi, Q., Rawat, G. S. and Kushalappa, C. G., Plant diversity in sacred forest fragments of Western Ghats: a comparative study of four life forms. *Plant Ecol.*, 2010, **206**, 237–250.
11. Peters, C. M., The ecology and management of non-timber forest resources. Technical Paper, World Bank, Washington, DC, USA, 1996.
12. Hietz-Seifert, U., Hietz, P. and Guevara, S., Epiphyte vegetation and diversity on remnant trees after forest clearance in southern Veracruz. *Biol. Conserv.*, 1996, **75**, 103–111.
13. Harvey, C. A. *et al.*, Integrating agricultural landscape with biodiversity conservation in the Mesoamerican hotspot. *Conserv. Biol.*, 2008, **22**, 8–15.
14. Myers, N., Biodiversity hotspots revisited. *BioScience*, 2003, **53**, 916–917.
15. Bhagwat, S. A., Kushalappa, C. G., Williams, P. H. and Brown, N. D., The role of informal protected areas in maintaining biodiversity in the Western Ghats of India. *Ecol. Soc.*, 2005, **10**(8).
16. Turner, I. M. and Corlett, R. T., The conservation value of small isolated fragments of lowland tropical rain forests. *Trends Ecol. Evol.*, 1996, **11**, 330–334.
17. Olmsted, I. and Juarez, M. G., Distribution and conservation of epiphytes on the Yucatan Peninsula. *Selbyana*, 1996, **17**, 58–70.
18. Hietz, P., Buchberger, G. and Winkler, M., Effect of forest disturbance on abundance and distribution of epiphytic bromeliads and orchids. *Ecotropica*, 2006, **12**, 103–112.
19. Scheffknecht, S., Winkler, M., Hülber, K., Rosas, M. M. and Hietz, P., Seedling establishment of epiphytic orchids in forests and coffee plantations in central Veracruz, Mexico. *J. Trop. Ecol.*, 2010, **26**, 93–102.
20. Padmawathe, R., Qureshi, Q. and Rawat, G. S., Effects of selective logging on vascular epiphyte diversity in a moist lowland forest of Eastern Himalaya, India. *Biol. Conserv.*, 2004, **119**, 81–92.
21. Annaselvam, J. and Parthasarathy, N., Diversity and distribution of herbaceous vascular epiphytes in a tropical evergreen forest at Varagalaiar, Western Ghats, India. *Biodiver. Conserv.*, 2001, **10**, 317–329.
22. Lele, S., Private property rights and forest preservation in Karnataka Western Ghats, India: Comment. *Am. J. Agricul. Econ.*, 1993, **75**, 492–495.
23. Nayak, S. N. V., Swamy, H. R., Nagaraj, B. C., Rao, U. and Chandrashekara, U. M., Farmers' attitude towards sustainable management of Soppina betta forests in Sringeri area of the Western Ghats, South India. *For. Ecol. Manage.*, 2000, **132**, 223–241.
24. Jost, L., Entropy and diversity. *Oikos*, 2006, **313**, 363–375.
25. Colwell, R. K., Estimates: statistical estimation of species richness and shared species from samples, version 7.5, 2005.
26. Magurran, A. E., *Measuring Biological Diversity*, Blackwell Publishing Science, Oxford, 2004.
27. Oksanen, J., Kindt, R., Legendre, P. and O'Hara, R. B., Vegan: community ecology package, version 1.8–6, University of Oulu, Oulu, Finland, 2007; Available from www.cc.oulu.fi/jarioksa/softhelp/vegan
28. R Development Core Team, R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, 2007; available from www.r-project.org
29. Sokal, R. R. and Rohlf, F. J., *Biometry: The Principles and Practice of Statistics in Biological Research*, Freeman, New York, 1981.
30. Curtis, J. T. and McIntosh, R. P., The interrelations of certain analytic and synthetic phytosociological characters. *Ecology*, 1950, **31**, 434–455.
31. Shastri, C. M., Bhat, D. M., Nagaraja, B. C., Murali, K. S. and Ravindranath, N. H., Tree species diversity in a village ecosystem in Uttara Kannada District in Western Ghats, Karnataka. *Curr. Sci.*, 2002, **82**, 101–105.
32. Kumar, S. C. and Manilal, K. S., *A Catalogue of Indian Orchids*, Bishen Singh & Mahendra Pal Singh Publication, Dehradun, 1994.
33. Köster, N., Friederich, K., Nieder, J. and Barthlott, W., Conservation of epiphyte diversity in an Andean Landscape transformed by human land use. *Conserv. Biol.*, 2009, **23**, 911–919.
34. Williams-Linera, G., Sosa, V. and Platas, T., The fate of epiphytic orchids after fragmentation of a Mexican cloud forest. *Selbyana*, 1995, **16**, 36–40.
35. Barthlott, W., Schmit-Neuerburg, V., Nieder, J. and Engwald, S., Diversity and abundance of vascular epiphytes: a comparison of secondary vegetation and primary montane rain forest in the Venezuelan Andes. *Plant Ecol.*, 2001, **152**, 145–156.
36. Wolf, J. H. D., The response of epiphytes to anthropogenic disturbance of pine–oak forests in the highlands of Chiapas, Mexico. *For. Ecol. Manage.*, 2005, **212**, 376–393.
37. Mehltreter, K., Flores-Palacios, A. and García-Franco, J. G., Host preferences of low-trunk vascular epiphytes in a cloud forest of Veracruz, Mexico. *J. Trop. Ecol.*, 2005, **21**, 651–660.
38. Zotz, G. and Vollrath, B., The epiphyte vegetation of the palm *Socratea exorrhiza*: correlations with tree size, tree age and bryophyte cover. *J. Trop. Ecol.*, 2003, **19**, 81–90.
39. Flores-Palacios, A. and García-Franco, J. G., The relationship between tree size and epiphyte richness: testing four different hypotheses. *J. Biogeogr.*, 2006, **33**, 323–330.
40. Arroyo-Rodríguez, V. E., Pineda, E., Escobar, F. and Benítez-Malvido, J., Conservation value of small patches to plant species diversity in highly fragmented landscapes. *Conserv. Biol.*, 2008, **23**, 723–739.
41. Rosenzweig, M. L., Reconciliation ecology and the future of species diversity. *Oryx*, 2003, **37**, 194–205.
42. Sinu, P. A., Kent, S. and Chandrashekara, K., Forest resource use and perception of farmers on conservation of a usufruct forest (*Soppinabetta*) of Western Ghats, India. *Land Use Policy*, 2001, in press; 10.1016/j.landusepol.2011.11.006.

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