EDGE TRANSITION IMPACTS ON SWAMP PLANT COMMUNITIES IN THE NILGIRI MOUNTAINS, SOUTHERN INDIA

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Abstract. Swamps represent a relatively understudied ecosystem in many regions, which contrasts markedly with the research attention which other wetlands and Mangrove ecosystems have received. In the upper Nilgiris of southern India, montane swamps are restricted to geographic areas with flat surfaces and bounded by different edge transition vegetation types including grasslands and shola forests. Our study examined whether species richness, endemism, edge and the composition of swamp interior communities have a significant relationship with swamp area. Using species-area curves we continued sampling for species in each swamp until species richness reached the asympote within that swamp. Our results suggest that species richness (log n), log endemism, and edge and swamp interior species composition do not increase significantly with increasing area due to edge effect. Moreover, swamp area and vegetation parameters showed no significant relationships. However our results did indicate that swamps species richness and endemism were affected by abiotic and biotic edge effects, particularly physical topographic environment and the structure of adjoining matrix vegetation. Therefore swamp protection and restoration, in addition to the preservation and management of buffer regions may be important conservation criteria to preserve these fragile ecosystems.
Keywords: *endemism, ecotone, grasslands, Nilgiris, species richness, swamp area, sholas*

Introduction

Habitat loss represents one of the major drivers of regional species loss, and even total species extinction across much of the globe. Therefore developing methods to manage and mitigate the impact of habitat destruction on species diversity are major components of conservation strategy (He and Hubbell, 2011). Research is urgently required to develop the best methods to mitigate species loss, through targeted conservation and managing remaining intact habitat regions.

One of the oldest tenets within ecology is that of the species-area relationship (Arrhenius 1921; Gleason 1922; Rosenzweig 1997), whereby the number of species any habitat patch can retain is directly related to the size of that patch. Species-area relationships are also useful predictors to estimate the species richness a patch should be capable of retaining, and thereby a means of calculating the number lost through either habitat loss or other human actions (Rybicki and Hanski, 2013). A further debate is how the shape of the habitat, and the relative proportion of habitat edge (often characterised by denser vegetation and a higher incidence of invasion by alien species) to core habitat effects the ability of that patch to sustain species and how much it impacts (relative to overall area) on the retention of species within habitat fragments (Gonzalez et al., 2010).

Edge effects are also major drivers of change in many fragmented landscapes, but are often highly variable (in terms of structure, and effects) across space and time (Laurance et al. 2007; Murcia 1995; Ries et al. 2004; Laurance et al. 2007). However edge effects can have serious impacts on species diversity and composition, dynamics and ecosystem functioning (Saunders et al. 1991; Chen et al. 1992; Laurance et al. 2007), yet have only been properly considered in a small number of ecosystems.

The total area of a habitat patch/fragment has been found to relate directly to species richness in studies of many ecosystems across the globe (Rosenweig, 1997; Whittaker et al., 2001; William, 1943; Wilcox, 1980; Schoener and Schoener, 1981; Rydin and Borgegard, 1988; Holt et al., 1999; Moody, 2000; Gonzalez et al., 2010). This area to richness relationship exists across extended scales, with mid-domain effects also contributing at larger extents of intact habitat; such as the Amazon basin (Laurance et al. 2007). Interestingly, the number of endemic species is also significantly related with area (Moody, 2000), though this relationship is much more complicated as many endemic species occur in small areas, which are either isolated or have high turnover due to high topographic heterogeniety-and therefore endemism is a much more complex measure than simple species richness. Thus an understanding of floristic patterns and, the species-area relationship of any habitat type (especially rarer habitat types) potentially provides useful insights into the planning of conservation strategies for plant communities within such habitats.

Swamps (wetlands) represent biologically diverse assembelages of species, yet are amongst the most vulnerable ecosystems (Nirmal Kumar and CiniOommen, 2011; Puyravaud et al., 2012; Pitman et al., 2014). In addition to pressures on swamps through drainage and conversion to agriculture, swamps are made more vulnerable by their sparse distribution, as they represent isolated islands, patchy in nature and are dominated by endemic and endangered herbaceous species. This high endemism has been recorded and analysed in a number of regions including in the upper Nilgiris of southern India (Mohandass, 2008; Puyravaud et al., 2012; Mohandass, 2013). Within the Nilgiris region human usage, agricultural conversion and grazing pressures threaten many of the swamps within a formerly highly diverse region and thus these pressures may drive local, or even total extinction of species within the Nilgiris region (Puyravaud et al., 2012). As a consequence of these pressures swamps are becoming increasingly rare and fragile ecosystems throughout the Nilgiri Mountains.

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However, knowledge of swamp plant communities succession and dynamism and community function has received little attention, and therefore determining the impacts of human mediated pressures on biodiversity are difficult to quantify, making prioritisation for conservation difficult or impossible. Because of the lack of baseline information for many regions the use of the relationship between swamp diversity and endemism relative to the area could provide a means of gauging the impacts on habitat loss or alteration on species diversity.

Tropical montane evergreen forest in the upper Nilgiri Mountains (locally termed *sholas),* are normally stunted and occur in discrete patches, and are confined to sheltered valleys, hollows and depressions, and frequently surrounded by grasslands and swamps. Our former studies investigated that the relationship between species richness and area among 18 shola patches and found a positive relationship between species richness and patch area (Mohandass and Davidar 2010). Many of the swamps within the study area have been affected by various anthropogenic factors including exotic tree plantation, burning, grazing and conversion into agricultural fields. Long-term grazing of swamps within our study area is linked with a higher susceptibility to drought stress in resident plant species (Dong et al., 2011). We build on this knowledge in the present study by exploring natural succession in vegetation surrounding swamp plant communities. This study sets to examine the relationship between swamp species richness and endemism with swamp area, to understand process of succession surrounding the swamp, and ecological response in terms of diversity and endemism to swamp area.

Swamps of the Nilgiri region may be affected in a similar way to those in previous studies which reported that the structure of the adjoining matrix vegetation had a major effect on swamp communities and diversity (Mesquita et al. 1999; Cronin 2003; Pohlman et al. 2007). Thus, this study focused on testing the relationship between total species richness, endemism, edge and swamp interior species richness an assessing the interactions between the swamp edge region with core swamp plant communities.

Therefore, the study examines how swamp species richness and endemism varies at edge transition zones around swamp margins, and estimates relative capacity of swamps to maintain diversity using species-area relationships to understand swamp community dynamics. We explore if there is a relationship between species richness and endemism in both edge and interior regions compared to swamp area, to explore if the swamp buffer region has a significant effect on the capacity of the swamp to maintain species diversity.

Materials and Methods

Study area

The study was conducted in the tropical montane swamps of the Korakundah and Upper Bhavani Reserve Forest of the upper Nilgiri Mountains. Reserve Forests represent a category of forest which has lower levels of protection than National Parks (Mohandass and Davidar, 2010). The study sites lie between 11° 13’ latitude N and 76° 35’ longitudes E and the elevation ranges between 2100–2400 m above mean sea level (*Fig. 1*). The mean annual rainfall recorded at Upper Bhavani Electricity department and Korakundah tea estate, during the periods for ten years (1993–2006) was 2637mm and 1887mm respectively. The distance between these two sites was approximately 8-

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13 kms. The climate and geological information for the region has been published in previous studies (Mohandass, 2008; Puyravaud et al., 2012).

Swamps in the study area are generally flat-tables in depressions between slopes and grasslands and are normally small and isolated from one another, although large extensive swamps do occasionally occur. Swamps are a reflection of local topography coupled with drainage and local climate, and therefore can only occur in specific, limited regions. Slope gradient and topographic structure determines swamp location, through influencing soil nutrients and enhancing water holding capacity, and therefore swamp plant communities are non-randomly distributed. As a consequence, swamp ecotones may be more sensitive to disturbance and colonization especially of grassland species, as any changes which alter the retention of moisture or cause the drainage properties to change (Kent et al., 1997), are likely to facilitate the transition of the swamp to other types of habitat.

Flowering of most swamp species occurs during the monsoon period (June to November). Swamp communities are largely dominated by grasses and forbs, however some woody species also occur and generally flower from January to May (Mohandass pers. obs.). Most of the swamps in the study region were dominated by exotic tree plantations, of Australian black wattle and various Eucalyptus species (introduced in the 1950s) and pine trees which were planted from the 1960s onwards. Many swamps have already been converted into grasslands, grazing land and agricultural areas and belong to private owners or local government bodies. Local government agencies generally consider swamps as wastelands and there is generally a lack of awareness of both the floristic diversity of swamps and their ecological value.

Methods of data collection

A floristic survey was carried out from September 2001 to February 2002, and August 2002 to October 2002 in thirteen swamps throughout the Korakundah and Upper Bhavani regions *(Fig. 1*) (surrounding vegetation types including exotic tree species such as *Acacia dealbata* Link. *Eucalyptus globules* Labill, and *Pinus patula* Schiede ex Schltdl. & Cham., within plantations, in addition to native sholas and grasslands. All the studied swamps were marked by GPS points and topographical maps were made (*Fig.1; Table 1*).

Various anthropogenic activities including grazing, exotic tree plantation and fire have occurred in all swamp regions included within the study (Puyravaud et al., 2012). For all thirteen swamps, sampling effort success and effectiveness was quantified through construction of cumulative species-area curve for each individual swamp starting from the first sample unit (0.5 m^2) to the largest swamp present within the study region (1024 m^2) (*Fig. 2*). For five swamps included within this analysis, abundance and ground cover of plant species had previously been recorded and published (Mohandass, 2008; Puyravaud et al., 2012). In all thirteen swamps sampling effort was terminated once the species-area curve reached its asymptote. All plants were identified to species using various regional published floras (Bor, 1960; Fyson, 1932; Gamble, 1967; Matthew, 1999). The botanical revised names were followed according to APG III plant classification (Bremer et al. 2009). Species identification was confirmed by consulting herbaria collections at the Botanical Survey of India, Coimbatore, and Survey of Medicinal Plants and Collection Unit, Ootacamund. Rare, Endangered and Threatened (RET) and Endemic species were categorized according to the Flora of endemic plants (Nair and Henry, 1983; Ahemdullah and Nayar, 1986). A voucher

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specimen of each species was deposited at the Department of Ecology and Environmental Sciences, Pondicherry University, India.

***Table 1**. showed site code, swamp names, geographical location, , altitude (m), swamp size (ha), sampling unit of each site, number of species, number of edge species, number of swamp interior species, number of endemics, and surrounding vegetation types status of the 13 surveyed swamps in the upper Nilgiris Mountains, India.*

Site code	Geographical coordinates	Altitude (m)	Shapes	Size (ha)	Sampled area (m^2)	Species richness	Number of edge species	Number of swamp interior species	Number of endemic species	Surrounding vegetation types
GD	11° 14. 367′ N 76° 35. 657′ E	2236	Rectangle /triangle	0.8	64	50	18	32	10	Grassland
KT	11° 12. 387′ N 76° 34.158′ E	2224	Rectangle /triangle	4,2	128	51	19	32	7	Grassland & shola forest
KG	11° 12. 879′ N 76° 33. 352′ E	2270	oval/round	4	256	47	17	29	9	Grassland & Plantation
KK	11° 12. 992′ N 76° 33. 638′ E	2251	oval/round	2	512	53	16	36	9	Grassland & Plantation
KV	11° 14. 978′ N 76° 35. 200′ E	2279	oval/round	6	256	52	18	31	8	Grassland & shola forest
NT	11° 12. 069′ N 76° 33. 628′ E	2254	Rectangle /triangle	0.7	256	50	14	33	8	Grassland & Plantation
NU	11° 13. 082′ N 76° 32. 989′ E	2289	oval/round	1.2	128	53	15	36	10	Grassland
OT	11° 13. 889′ N 76° 36. 173′ E	2218	Rectangle /triangle	2.8	512	63	12	51	12	Grassland & Shola forest
PT1	11° 12. 580′ N 76° 34. 523′ E	2209	oval /round	1.5	128	57	10	43	8	Grassland & Shola forest
PT2	11° 12. 542′ N 76° 34. 527′ E	2206	Rectangle /triangle	1	256	56	19	34	9	Grassland & Shola forest
PC	11° 14.632′ N 76° 35. 488′ E	2258	Rectangle /triangle	0.9	128	51	17	31	10	Grassland
QT	11° 12. 898′ N 76° 34. 482′ E	2215	Oval /round	3.3	128	66	19	45	10	Grassland & Plantation
TE	11° 13. 186′ N 76° 32. 581′ E	2259	Rectangle /triangle	1.8	256	46	16	29	7	Grassland & Plantation

All swamps species were pooled for estimation of species richness. The area of each swamp was determined using data provided by the Tamilnadu Forest Department. RET/species were categorized as per the Flora of endemic plants (Ahmedullah and Nayar, 1986; Nair and Henry, 1983). Edge zone species were considered as the species found within 5-10 metres (m) of swamp edges. Species found at a distance of ≥ 10 m from the edges were considered as swamp interior species (*Fig. 2*). Life form was recorded through morphological and vegetative characters with field observation made during 2001 to 2002. Plant group was categorized according to plant classification of angiosperms viz., dicots and monocots. Life form was classified as: annual forbs, perennial forbs, perennial grass, annual grass and perennial woody stems (Rogers and Hartnett, 2001).

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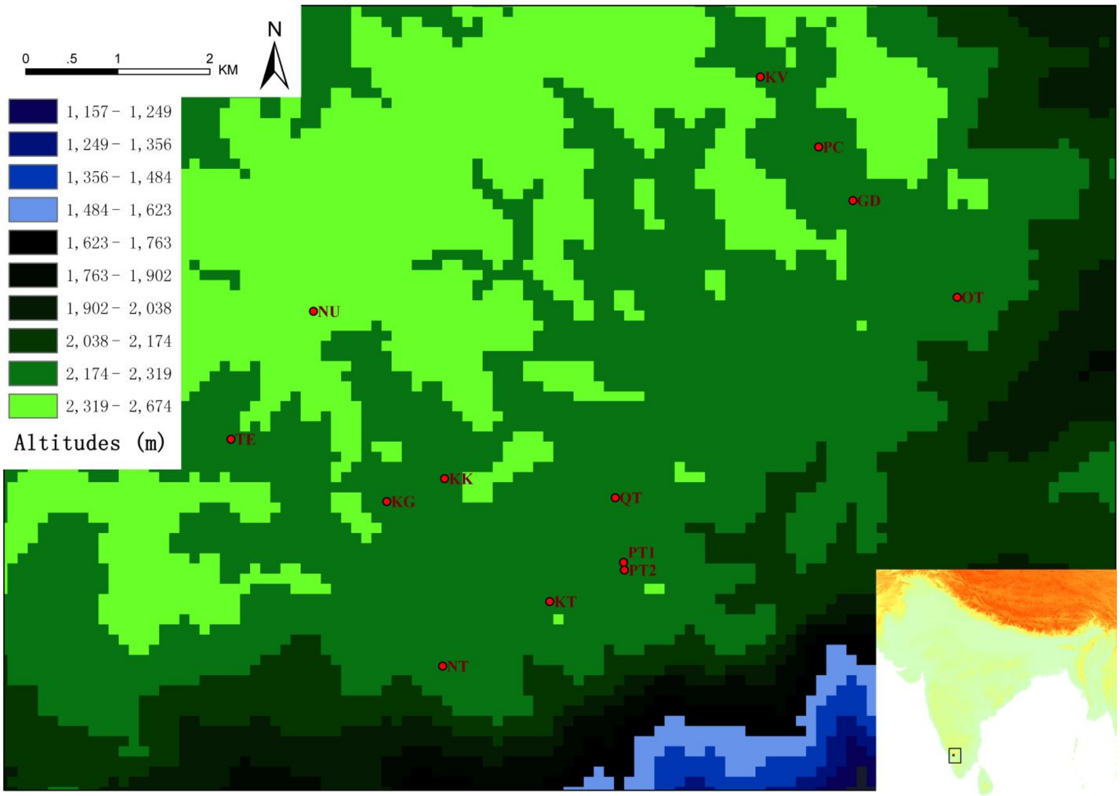

Figure. 1. *Location of the surveyed thirteen swamps with site code of the upper montane rainforest of the Nilgiris, Western Ghats, India.*

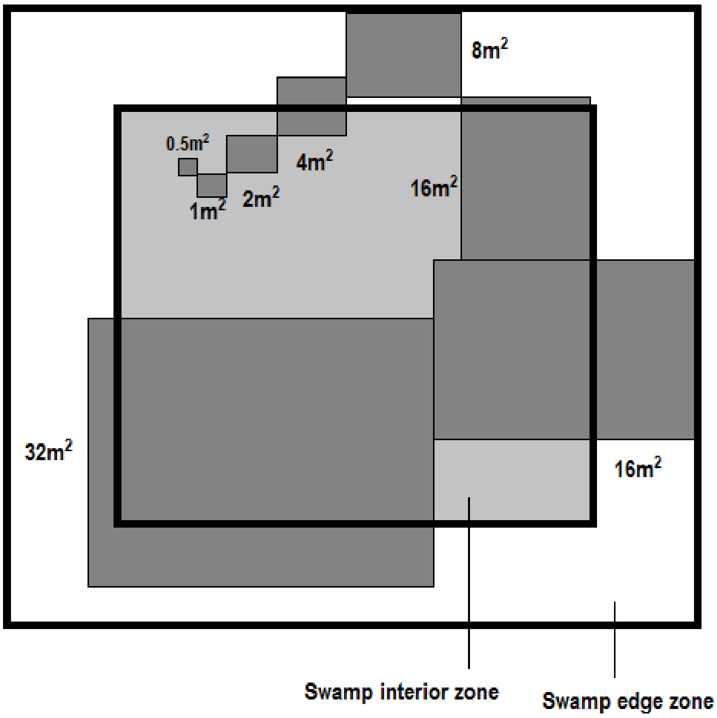

Figure 2. *Sampling quadrat pattern in each swamp that have made sampling effort to cover edge zone and swamp interior zones of the Nilgiri mountains.*

Floristic analyses

A Chi-square test was used to determine the variation of species richness among different vegetation variables. The species richness, endemism and area size was log transformed for analysis. The relationship between swamp area and vegetation parameters were analyzed using linear regression and ANOVA. Pearson correlation coefficient was used for analysis between swamp size (ha) and vegetation parameters. Differences between life forms were tested using one way ANOVA. Significant association was tested between life and plant group by likelihood ratio chi-square (G-test) of two-way contingency tables. All statistical tests were conducted using SPSS Inc (2000) and Past version 2.12 (Hammer et al., 2001).

Species area curves

In all the sampled swamps, the cumulative number of species was terminated when it reached a plateau or asymptote. In twelve of the swamps, the cumulative number of species was terminated at the area unit of 512 m2 however a large swamp reached a plateau at 1024 m2 (*Fig. 3*).

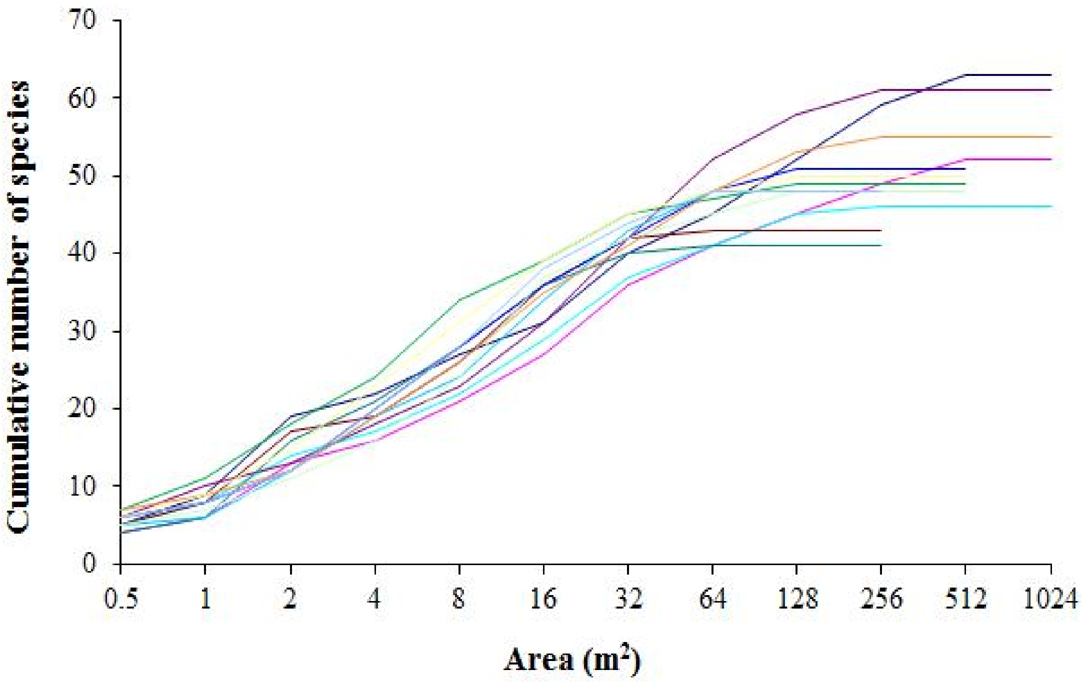

Figure 3*. It exhibits sampling effort made showing cumulative number of species increases and reaches a plateau at 512 m2 in twelve swamps and a large swamp reached a plateau at 1024 m2 in thirteen swamps of the upper Nilgiri Mountains, India.*

Results

A total of 84 species belonging to 67 genera and 33 families were recorded in the thirteen swamps (Appendix 1). The average species richness of each swamp was 53.4 (*Std. Deviation SD* = 5.8, range 46–66) (*Table 1*). Overall annual forbs represented 39%

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of species found, followed by perennial grass (31%), perennial forbs (23%), perennial woody stems (5%) and annual grasses (2%) (*Fig. 4*). The frequency of life-form was not significantly different among different swamps (F = 0.07, df = 44, ns). However, there is a significant association between life form (such as grasses, forbs, and woody plants) and plant group (i.e dicot and monocot) (G-test = 60.81, df = 4, P = 0.0001) (Appendix 1).

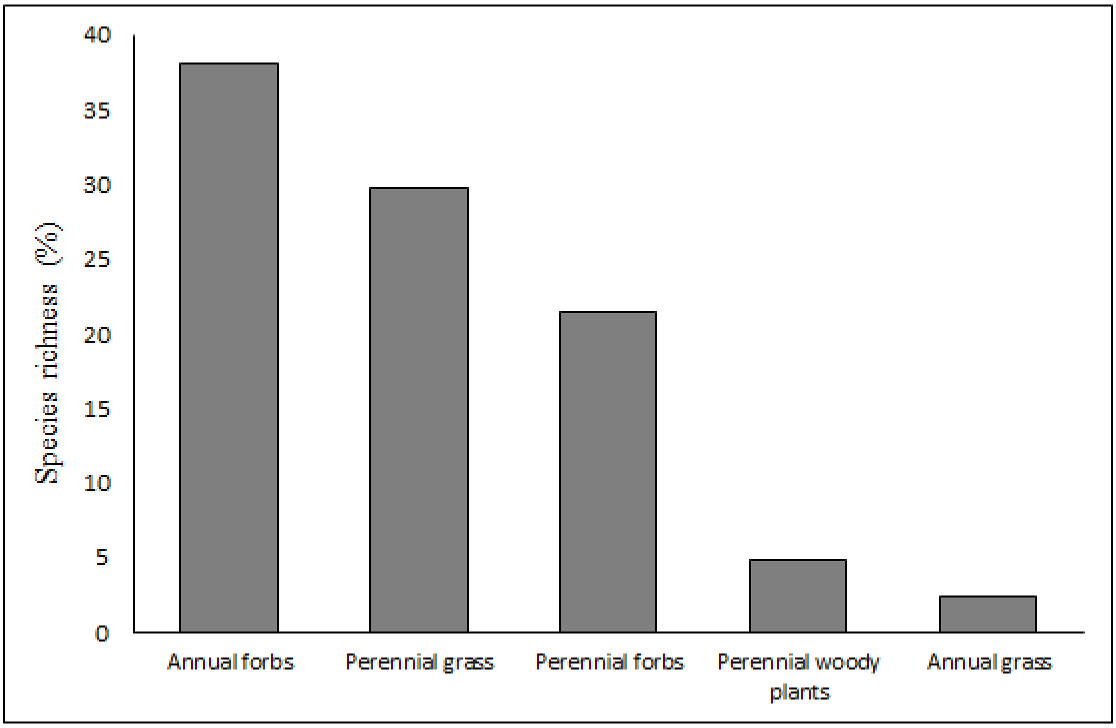

Figure 4*. Percentage frequency of swamp life-form species among thirteen swamps in the upper Nilgiri Mountains*

Of these, 17% of species recorded were RET/endemic to Nilgiri/Palni hills and Western Ghats, with a mean value of 8.84 *(SD = 1.1)* and shared species ranging from 7–10 (approximately 15% of total species encountered). Additionally, the average edge species richness was 16.2 *(SD = 2.8)* and the average swamp interior species was 35.5 *(SD = 6.7)* for each swamp studied.

The frequency of endemism was not significantly varied from total species richness (χ^2 = 1.57, df = 12, ns), thus showed endemism was relatively higher among all swamps. Besides, the frequency of edge species richness was not significantly varied from total species richness (χ^2 = 7.12, df = 12, P = 0.85), thus indicates edge species richness was relatively high.

The log species (log*n* species richness) did not significantly increase with swamp area (R^2 = 0.052, n =13; P = 0.45; *Fig.5a* ANOVA $F_{12, 13}$= 0.60, ns). When analyzed separately edge and swamp interior species were found not to increase significantly with swamp area (R^2 = 0.00, ns, and R^2 = 0.04, ns), respectively. Similarly log endemism did not increase with swamp area (R^2 = 0.072, n = 13; P = 0.38, *Fig. 5b*; ANOVA $F_{13, 12}$ =

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2.73, ns). This shows that regionally, swamps plant communities are impacts on edge effect caused by the structure of the adjoining matrix vegetation such as grasslands and sholas with the influence of topographic structure.

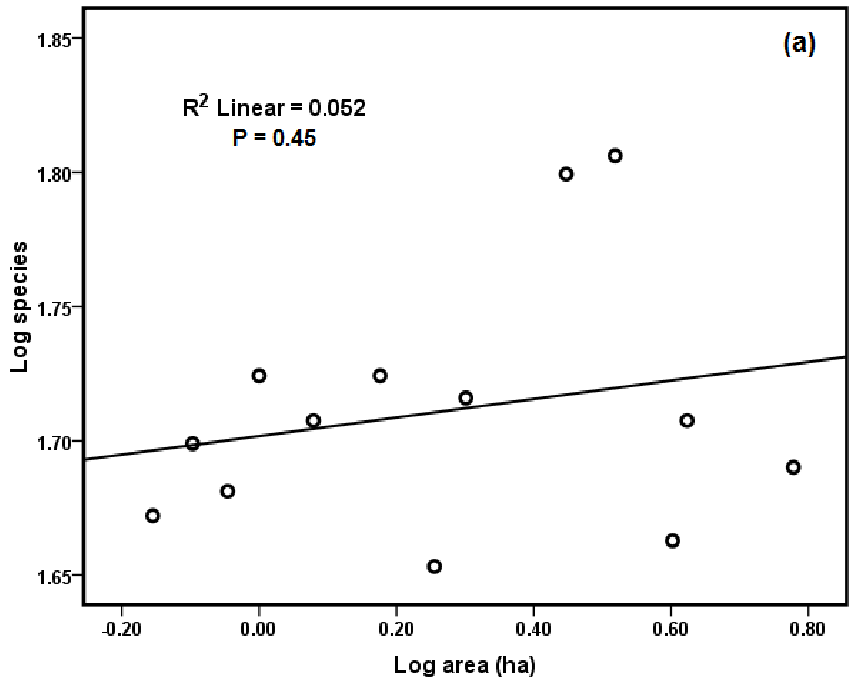

Figure 5a. *The log species and (log) and swamp log area (ha) (R2 = 0.05 N =13, n.s) with each point representing an individual swamp*

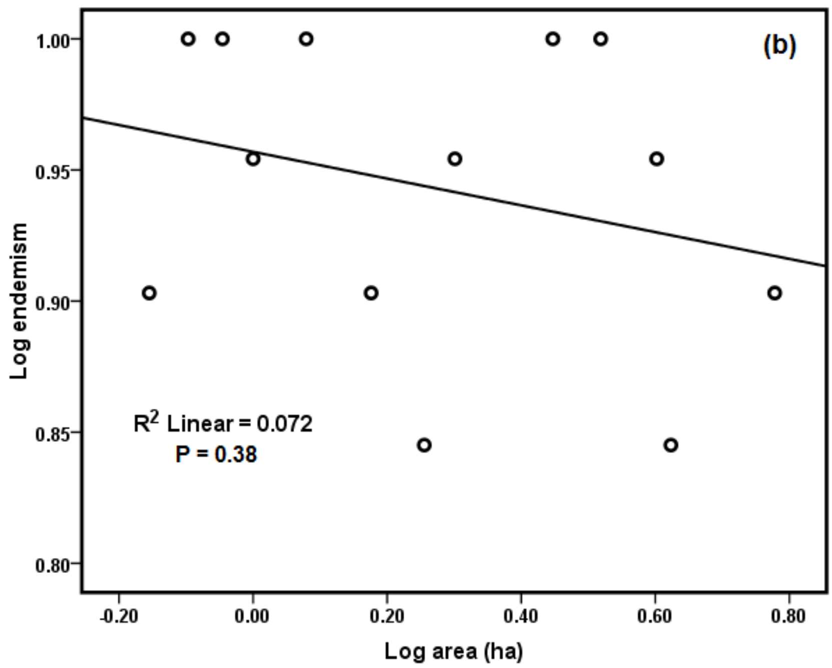

Figure 5b*. The log endemism to (log) and swamp log area (ha) (R2 = 0.072, N= 13, n.s.) of the thirteen surveyed swamps (shown as dot points) from thirteen swamps of the Upper Nilgiris, India.*

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Swampy areas and vegetation community were not significantly correlated with swamp area among the thirteen swamps (*Table 2*). In particularly, there is no significant positive correlation between swamp-area (log) and total species richness (r = 0.12; n = 13; P = 0.70) or area size relative to endemism (r = −0.29; n = 13; P = 0.33) respectively. There was a marginal significant negative correlation found between swamp edge and interior species (r = −0.51; n = 13; P = 0.07). However, no significant relationship was found between edge or interior species richness with swamp area (edge: r = 0.30; n = 13; P = 0.32; interior: r = − 0.02; n = 13, P = 0.94).

***Table 2**. Pearson (s) Correlation Coefficient was tested between vegetation parameter and swamp size (ha) among thirteen swamps in the Nilgiri Mountains.*

VEGETATION PARAMETER	SWAMP AREA	EDGE	ENDEMISM	SWAMP INTERIOR
EDGE	$0.30^{n.s}$			
P-VALUE	0.32			
ENDEMISM	$-0.29^{n.s}$	$0.03^{n.s}$		
	0.33	0.91		
SWAMP INTERIOR	$-0.02^{n.s}$	$-0.51^{n.s}$	$0.40^{n.s}$	
	0.94	0.07	0.18	
SPECIES	$0.12^{n.s}$	$-0.12^{n.s}$	$0.48^{n.s}$	0.91**
RICHNESS	0.70	0.71	0.09	0.00

***significant at < 0.0001; n.s = not significant*

Discussion

The effect of swamp area on species community and diversity

Our findings suggest that swamp plant communities are not significantly influenced by area but are primarily controlled by the two habitat transition zones on their outer margins, predominantly shola and grasslands *(Fig 6)*. This finding is contrary to our earlier study of shola forest species richness which significantly increased with increasing shola area (Mohandass and Davidar, 2010). However, among the shola forest, area significantly influences plant assemblages and vegetation features and in terms of local species richness, basal area and proportion of large trees, which all show positively relationships with area (Mohandass and Davidar, 2010). Swamp area and swamp size are determined and maintained by natural geological topography (physical environment) (Debski et al., 2000) including by various degrees of mountainous slopes which are integrated into aquatic habitat and edges (ecotonal boundaries). Furthermore,

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the relatively homogenous topographic environments within shola forests suggests that variation in eco-climatic factors has relatively little effect on species composition, due to the relative consistency within the regional conditions (Davidar et al., 2007; Mohandass and Davidar, 2009). However, species composition in swamps is influenced by annual rainfall, which couples in effects with steep mountainous slopes to create highly temporally variable conditions in terms of water influx. Former studies suggest that species richness in peat swamps is influenced by soil nutrients and rainfall (Sylvester Tan, 2004), our study indicates the same may be true within swamp environments. Swamp buffer areas also reflect physical environmental factors including topography, and drainage (soil properties), in addition to regional climatic factors (Fortin et al., 1997).

Figure 6 *(A) Swamps surrounded by pine plantation at the edges (B) Swamps bounded by grassland communities along with lower slope edges (C) One side of the swamp bounded by grassland and other side (arrow mark) bounded by sholas (native vegetation) (D)Swamps are bounded and surrounded by different vegetation types grassland, sholas, and plantation.*

The relative diversity of the buffer zone

The transition zone between swamps and surrounding vegetation types (i.e forests or grasslands) may have a higher biological diversity than either forest type which they mark the transition between, and therefore in themselves should be considered of high

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conservation importance (Leopold, 1933; Odum, 1983; Petts, 1990; Risser, 1995). In our study the composition of this transitory region includes both grassland and swamp species (Mohandass, 2008), however previous studies indicate that these transition regions may not facilitate the persistence of many species if frequently subject to intense disturbance (van der Maarel, 1990).

Species distributions and community composition in swamps

Communities and species abundance was found to change in the core (interior region) of the swamp, in addition to edge and buffer regions. In Swamp interior communities the majority of species are specialists for swamp environments. In the Nilgiris region the average species richness of 35.2 from the core regions of the swamp is significantly higher than in edge regions, with an average richness of 16.2 species. Given that species on swamp margins represent a subset of species found in interior regions of swamps, preventing further encroachment into swamps by grassland species may be a priority issue to maintain species which were only found in core regions of swamps.

A small proportion of species is shared across all swamps (15%), but communities present vary between the interior and edge regions of the swamp. There are two dominant species common to multiple swamps across the Nilgiri region (*Andropogon polyptychos* and *Eriochrysis rangacharii*). However these species are found in different zones of the swamps, *A. polyptychos* is specialized in both edge and swamp interior, whereas *E. rangacharii* is specialized only swamp interior. Within the swamps, both *Eriochrysis rangacharii* and *Coelachne perpusilla* are endemic to swamp areas and endangered, due to their specialist habitat requirements, and the decreasing availability of swamp areas.

Threats to swamp environments

Within this study we also noticed a high presence of what we would consider grassland species within the swamp itself, and not only limited to the transition, or surrounding grassland. We suggest that grassland species present in such high levels within the swamp may reflect regular disturbance or may relate to natural succession, or the drying out of swamps and slow transition to grassland. Swamp disturbances may facilitate colonization by grassland species and increase the potential for these swamp environments to be replaced by grasslands into the future. Thus swamps habitat might be highly sensitive to disturbance, in addition to climate change, especially in climate parameters which reflect changes in seasonality of precipitation.

There is also strong evidence that exotic species may invade highly disturbed ecotones and cause these regions to gradually transition to other habitat types (Fox et al., 1997; Lloyd et al., 2000; Watkins et al., 2003). Study area locations where exotic tree species were introduced by the forest department (more than five decades ago) have become increasingly dry, and no longer support the original swamp community, many have transitioned or are transitioning to grassland. Plantations further impact the swamp community through increasing the local water deficit during the dry season thereby assisting new colonizers during drier periods of the year. The diversity of tree species in tropical rainforests in the Western Ghats decreases significantly with increasing length of dry season (Davidar et al., 2005). Therefore the length of dry season may influence

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the plant community and the recruitment of grassland species into areas which are currently occupied by swamps.

Within the Upper Nilgiris, sholas have increased in species richness and overall area through various deterministic processes (Mohandass and Davidar, 2010). Shola species have progressively spread into grasslands through edge expansion, natural colonization by seed dispersal, indicating that shola species have ability and capacity to germinate in the grasslands. But in swamps, edge effects refers to the effect of a prevailing boundary between contrasting spatial environments makes swamps vulnerable to invasion by surrounding ecotones, whilst being topographically limited and therefore unable to expand (Mesquita et al. 1999; Cronin 2003; Pohlman et al. 2007). Moreover, exotic tree plantations at the boundary threatening to swamp plant communities, because high water demands of plant communities on swamp boundaries cause soils to progressively dry and therefore encroachment of other species increases the potential for further invasions and progressive conversion of swamp areas into other habitat types. The vulnerability of individual swamps therefore depends on the topography and climate of the region, in addition to the degree of disturbance and modification to the area, as disturbance can act to exacerbate soil drying (and thereby transition to other habitat types) especially if the climate is also changing seasonal water availability.

Summary

Swamps of upper Nilgiris region represent fragile ecosystems and are the sole habitat for a number of endemic threatened species. The conservation of these fragile ecosystems presents a challenging task for conservationists, as enhanced restoration and rehabilitation of swamp habitat within the upper Nilgiris must occur in conjunction with sustainable management and development. In addition further experimental research is needed to understand the swamp community evolutionary processes especially through a detailed assessment on effect of ecotone and soil dynamics.

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***Appendix 1**. Complete species list surveyed from thirteen swamps includes, species names, family, life-form, habit, plant group, and total number of frequency recorded in which swamps found in the Upper Nilgiri mountains, India.*

Species names	**Family**	**Life form**	**Plant groups**	**Habit**	**Total number of frequency**
Ageratina adenophora (Spreng.) R.M.King & H.Rob.	Compositae	Forb	Dicots	Annual forbs	5
Anaphalis brevifolia DC.	Compositae	Forb	Dicots	Annual forbs	13
Andropogon lividus Thwaites	Poaceae	Grass	Monocots	Perrenial grass	10
Andropogon polyptychos Steud	Poaceae	Grass	Monocots	Perrenial grass	12
Anemone rivularis Buch.-Ham. ex DC.	Ranunculaceae	Forb	Dicots	Annual forbs	2
Athyrium hohenackerianum T. Moore	Athyriaceae	Forb	Pteridophytes	Perennial forbs	3
Bolboschoenus maritimus (L.) Palla	Cyperaceae	Forb	Dicots	Perennial forbs	4
Bupleurum distichophyllum Wight & Arn.	Apiaceae	Forb	Dicots	Annual forbs	3
Carex capillacea Boott	Cyperaceae	Forb	Monocots	Perrenial grass	5
Carex lindleyana Nees	Cyperaceae	Forb	Monocots	Perrenial grass	7
Carex nubigena D.Don ex Tilloch & Taylor	Cyperaceae	Forb	Monocots	Perrenial grass	4
Carex phacota Spreng.	Cyperaceae	Forb	Monocots	Perrenial grass	6
Centella asiatica (L.) Urb.	Apiaceae	Forb	Dicots	Perennial forbs	7
Chrysopogon nodulibarbis (Hochst. ex Steud.) Henrard	Poaceae	Grass	Monocots	Perrenial grass	9
Cirsium abukumense Kadota	Compositae	Forb	Dicots	Annual forbs	*8*
Coelachne perpusilla (Nees ex Steud.) Thwaites	Poaceae	Grass	Monocots	Perrenial grass	*11*
Commelina clavata C.B.Clarke	Commelinaceae	Forb	Monocots	Annual forbs	7
Conyza bonariensis (L.)	Compositae	Forb	Dicots	Annual forbs	2
Cyanotis obtusa (Trimen)	Commelinaceae	Forb	Monocots	Perrenial	7

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Trimen				grass	
Cyrtococcum deccanense Bor	Poaceae	Grass	Monocots	Annual grass	13
Dichrocephala chrysanthemifolia (Blume) DC.	Compositae	Forb	Dicots	Annual forbs	9
Digitaria stricta Roth	Poaceae	Grass	Monocots	Annual grass	13
Drosera burmanni Vahl	Lentibularaceae	Forb	Dicots	Annual forbs	12
Drosera peltata Thunb.	Lentibularaceae	Forb	Dicots	Annual forbs	3
Eleocharis congesta D.Don	Cyperaceae	Forb	Dicots	Perennial forbs	4
Erigeron karvinskianus DC	Compositae	Forb	Dicots	Perennial forbs	10
Eriocaulon brownianum Mart.	Eriocaulaceae	Forb	Monocots	Perrenial grass	13
Eriocaulon odoratum Dalzell	Eriocaulaceae	Forb	Monocots	Perrenial grass	11
Eriocaulon robustum Steud.	Eriocaulaceae	Forb	Monocots	Perrenial grass	11
Eriochrysis rangacharii C.E.C.Fisch.	Poaceae	Grass	Monocots	Perrenial grass	13
Eulalia phaeothrix (Hack.) Kuntze	Poaceae	Grass	Monocots	Perrenial grass	9
Fimbristylis quinquangularis (Vahl) Kunth	Cyperaceae	Forb	Monocots	Annual forbs	1
Fragaria nilgerrensis Schltdl. ex J.Gay	Rosaceae	Forb	Dicots	Annual forbs	11
Fragaria vesca L.	Rosaceae	Forb	Dicots	Annual forbs	9
Gaultheria fragrantissima Wall.	Ericaceae	Tree	Dicots	Perennial woody plants	4
Gentiana pedicellata (D.Don) Wall.	Gentianaceae	Forb	Dicots	Perennial forbs	13
Gentiana pedicellata subsp. *zeylanica* (Griseb.) Halda	Gentianaceae	Forb	Dicots	Perennial forbs	12
Gentiana quadrifaria Blume	Geraniaceae	Forb	Dicots	Annual forbs	11
Hydrocotyle sibthorpioides Lam.	Araliaceae	Forb	Dicots	Annual forbs	12
Hypochoeris argentina Cabrera	Compositae	Forb	Dicots	Annual forbs	13
Impatiens chinensis L.	Balsaminaceae	Forb	Dicots	Annual forbs	5
Impatiens rufescens Benth.	Balsaminaceae	Forb	Dicots	Annual forbs	13
Isachne kunthiana (Wight & Arn. ex Steud.) Miq.	Poaceae	Grass	Monocots	Perrenial grass	13
Ischaemum commutatum Hack.	Poaceae	Grass	Monocots	Perrenial grass	10
Juncus effusus L.	Juncaceae	Forb	Monocots	Perrenial grass	12

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Juncus inflexus L.	Juncaceae	Forb	Monocots	Perrenial grass	12
Juncus prismatocarpus R.Br.	Juncaceae	Forb	Monocots	Perrenial grass	13
Kyllinga melanosperma Nees	Cyperaceae	Forb	Monocots	Perrenial grass	7
Laurembergia coccinea Kanitz	Haloragaceae	Forb	Dicots	Perennial forbs	1
Leucas marrubioides Desf.	Lamiaceae	Forb	Dicots	Perennial forbs	12
Lipocarpha chinensis (Osbeck) J.Kern	Cyperaceae	Forb	Monocots	Perrenial grass	9
Neanotis indica (DC.) W.H.Lewis	Rubiaceae	Forb	Dicots	Perennial forbs	13
Ophelia corymbosa Griseb.	Gentianaceae	Forb	Dicots	Annual forbs	4
Osbeckia brachystemon Naudin	Melastomataceae	Forb	Dicots	Annual forbs	13
Osbeckia leschenaultiana DC.	Melastomataceae	Shrub	Dicots	Perennial woody plants	4
Oxalis corniculata L.	Oxalidaceae	Forb	Dicots	Annual forbs	12
Oxalis spiralis Ruiz & Pav. ex G.Don	Oxalidaceae	Forb	Dicots	Annual forbs	3
Parnassia mysorensis F. Heyne ex Wight & Arn.	Celastraceae	Forb	Dicots	Annual forbs	10
Pedicularis perrottetii Benth.	Orobanchaceae	Forb	Dicots	Annual forbs	1
Persicaria nepalensis (Meisn.) Miyabe	Polyagonaceae	Forb	Dicots	Perennial forbs	10
Pimpinella leschenaultii DC.	Apiaceae	Forb	Dicots	Perennial forbs	4
Pinalia polystachya (A.Rich.) Kuntze	Orchidaceae	Forb	Monocots	Annual forbs	1
Pinus patula Schiede ex Schltdl. & Cham.	Pinaceae	Tree	Gymnosperms	Perennial woody plants	2
Plantago asiatica subsp. *erosa* (Wall.) Z.Yu Li	Plantaginaceae	Forb	Dicots	Perennial forbs	11
Pleiocraterium verticillare (Wall. ex Wight & Arn.) Bremek.	Rubiaceae	Forb	Dicots	Perennial forbs	8
Polytrias indica (Houtt.) Veldkamp	Poaceae	Grass	Monocots	Perrenial grass	10
Potentilla leschenaultiana Ser.	Rosaceae	Forb	Dicots	Perennial forbs	12
Pteridium aquilinum (L.) Kuhn	Denstaedtiaceae	Forb	Pteridophytes	Annual forbs	7
Pycreus flavidus (Retz.) T.Koyama	Cyperaceae	Forb	Monocots	Perrenial grass	12
Ranunculus diffusus DC.	Ranunculaceae	Forb	Dicots	Perennial forbs	3
Ranunculus reniformis Wall. ex Wight & Arn.	Ranunculaceae	Forb	Dicots	Perennial forbs	13
Rhododendron arboreum Sm.	Ericaceae	Tree	Dicots	Perennial woody plants	6

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Rhynchospora rugosa (Vahl) Gale	Cyperaceae	Forb	Monocots	Perrenial grass	12
Rotala fysonii Blatt. & Hallb.	Lythraceae	Forb	Dicots	Annual forbs	11
Rubus racemosus Genev.	Rosaceae	Shrub	Dicots	Perennial woody plants	4
Satyrium nepalense D.Don	Orchidaceae	Forb	Monocots	Annual forbs	8
Senecio wightii (DC. ex Wight) Benth. ex C.B.Clarke	Compositae	Forb	Dicots	Annual forbs	11
Swertia minor T.Cooke	Gentianaceae	Forb	Monocots	Annual forbs	1
Themeda tremula (Nees ex Steud.) Hack.	Poaceae	Grass	Monocots	Perrenial grass	5
Utricularia graminifolia Vahl	Lentibulariaceae	Forb	Dicots	Annual forbs	11
Utricularia scandens Benj.	Lentibulariaceae	Forb	Dicots	Annual forbs	3
Viola pilosa Blume	Violaceae	Forb	Dicots	Perennial forbs	11
Wahlenbergia marginata (Thunb.) A.DC.	Campanulaceae	Forb	Dicots	Perennial forbs	5
Xyris capensis Thunb.	Xyridaceae	Forb	Monocots	Annual forbs	13

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Appendix 2. *List of frequency of each species distributed in each swamp based on presence and absence qualitative assessment among thirteen swamps in the Korakundah and Upper Bhavani Reserve Forest, Nilgiri Mountains, southern India.*

Plant species	Family	Life-form	GD	KT	KG	KK	KV	NT	NU	OT	PT1	PT2	PC	QT	TE	Grand Total
Ageratina adenophora (Spreng.) R.M.King & H.Rob.	Compositae	Forb	0	0	0	0	1	0	0	0	1	0	1	1	1	5
Anaphalis brevifolia DC.	Compositae	Forb	1	1	1	1	1	1	1	1	1	1	1	1	1	13
Andropogon lividus Thwaites	Poaceae	Grass	0	1	0	1	1	0	1	1	1	1	1	1	1	10
Andropogon polyptychos Steud	Poaceae	Grass	1	1	1	1	1	1	1	1	1	1	1	1	0	12
Anemone rivularis Buch.-Ham. ex DC.	Ranunculaceae	Forb	1	0	0	0	0	0	0	0	0	0	0	1	0	2
Athyrium hohenackerianum T. Moore	Athyriaceae	Forb	0	0	0	0	1	0	0	1	0	0	0	1	0	3
Bolboschoenus maritimus (L.) Palla	Cyperaceae	Forb	1	0	1	0	1	0	0	0	0	0	1	0	0	4
Bupleurum distichophyllum Wight & Arn.	Apiaceae	Forb	0	0	0	1	0	0	1	0	1	0	0	0	0	3
Carex capillacea Boott	Cyperaceae	Forb	0	0	0	0	1	0	0	0	1	1	1	1	0	5
Carex lindleyana Nees	Cyperaceae	Forb	1	1	1	0	0	0	0	1	0	1	1	1	0	7
Carex nubigena D.Don ex Tilloch & Taylor	Cyperaceae	Forb	1	0	0	1	0	0	0	1	0	0	0	1	0	4
Carex phacota Spreng.	Cyperaceae	Forb	0	1	1	1	0	0	0	1	0	1	0	1	0	6
Centella asiatica (L.) Urb.	Apiaceae	Forb	1	1	1	0	1	0	0	1	0	1	0	1	0	7
Chrysopogon nodulibarbis (Hochst. ex Steud.) Henrard	Poaceae	Grass	0	0	0	1	1	1	1	1	0	1	1	1	1	9
Cirsium abukumense Kadota	Compositae	Forb	1	0	0	0	1	0	1	1	0	1	1	1	1	8
Coelachne perpusilla (Nees ex Steud.) Thwaites	Poaceae	Grass	1	1	0	1	1	1	1	1	1	1	0	1	1	11
Commelina clavata C.B.Clarke	Commelinaceae	Forb	1	0	1	1	0	0	1	1	0	0	1	1	0	7
Conyza bonariensis (L.)	Compositae	Forb	1	0	0	0	0	0	0	1	0	0	0	0	0	2
Cyanotis obtusa (Trimen) Trimen	Commelinaceae	Forb	1	1	0	0	0	0	1	1	0	1	1	1	0	7
Cyrtococcum deccanense Bor	Poaceae	Grass	1	1	1	1	1	1	1	1	1	1	1	1	1	13
Dichrocephala chrysanthemifolia (Blume) DC.	Compositae	Forb	0	1	0	0	1	1	1	1	1	1	1	1	0	9
Digitaria stricta Roth	Poaceae	Grass	1	1	1	1	1	1	1	1	1	1	1	1	1	13
Drosera burmanni Vahl	Lentibularaceae	Forb	0	1	1	1	1	1	1	1	1	1	1	1	1	12
Drosera peltata Thunb.	Lentibularaceae	Forb	0	0	0	1	0	0	0	0	1	0	0	0	1	3
Eleocharis congesta D.Don	Cyperaceae	Forb	0	1	0	1	0	0	0	0	0	1	1	0	0	4
Erigeron karvinskianus DC	Compositae	Forb	1	0	1	1	1	0	1	1	1	1	1	1	0	10
Eriocaulon brownianum Mart.	Eriocaulaceae	Forb	1	1	1	1	1	1	1	1	1	1	1	1	1	13
Eriocaulon odoratum Dalzell	Eriocaulaceae	Forb	1	1	1	1	1	0	1	1	1	0	1	1	1	11
Eriocaulon robustum Steud.	Eriocaulaceae	Forb	1	0	1	0	1	1	1	1	1	1	1	1	1	11
Eriochrysis rangacharii C.E.C.Fisch.	Poaceae	Grass	1	1	1	1	1	1	1	1	1	1	1	1	1	13
Eulalia phaeothrix (Hack.) Kuntze	Poaceae	Grass	0	0	1	0	1	1	1	1	0	1	1	1	1	9
Fimbristylis quinquangularis (Vahl) Kunth	Cyperaceae	Forb	0	0	0	0	0	0	0	1	0	0	0	0	0	1
Fragaria nilgerrensis Schltdl. ex J.Gay	Rosaceae	Forb	1	1	0	1	0	1	1	1	1	1	1	1	1	11
Fragaria vesca L.	Rosaceae	Forb	0	1	0	0	1	1	1	1	1	1	0	1	1	9
Gaultheria fragrantissima Wall.	Ericaceae	Tree	0	0	1	1	1	0	0	0	0	0	0	0	1	4
Gentiana pedicellata (D.Don) Wall.	Gentianaceae	Forb	1	1	1	1	1	1	1	1	1	1	1	1	1	13
Gentiana pedicellata subsp. *zeylanica* (Griseb.) Halda	Gentianaceae	Forb	1	1	1	0	1	1	1	1	1	1	1	1	1	12
Gentiana quadrifaria Blume	Geraniaceae	Forb	0	1	1	1	0	1	1	1	1	1	1	1	1	11
Hydrocotyle sibthorpioides Lam.	Araliaceae	Forb	1	1	1	0	1	1	1	1	1	1	1	1	1	12
Hypochoeris argentina Cabrera	Compositae	Forb	1	1	1	1	1	1	1	1	1	1	1	1	1	13
Impatiens chinensis L.	*Balsaminaceae*	Forb	0	0	1	0	1	0	1	0	0	1	0	1	0	5
Impatiens rufescens Benth.	*Balsaminaceae*	Forb	1	1	1	1	1	1	1	1	1	1	1	1	1	13
Isachne kunthiana (Wight & Arn. ex Steud.) Miq.	Poaceae	Grass	1	1	1	1	1	1	1	1	1	1	1	1	1	13
Ischaemum commutatum Hack.	Poaceae	Grass	1	1	1	1	0	0	1	1	1	1	1	1	0	10
Juncus effusus L.	Juncaceae	Forb	1	1	1	1	0	1	1	1	1	1	1	1	1	12
Juncus inflexus L.	Juncaceae	Forb	1	1	1	1	0	1	1	1	1	1	1	1	1	12
Juncus prismatocarpus R.Br.	Juncaceae	Forb	1	1	1	1	1	1	1	1	1	1	1	1	1	13
Kyllinga melanosperma Nees	Cyperaceae	Forb	1	0	1	0	0	0	1	1	1	1	0	1	0	7
Laurembergia coccinea Kanitz	Haloragaceae	Forb	0	0	0	0	0	0	0	0	0	1	0	0	0	1
Leucas marrubioides Desf.	Lamiaceae	Forb	1	1	1	1	1	1	0	1	1	1	1	1	1	12
Lipocarpha chinensis (Osbeck) J.Kern	Cyperaceae	Forb	0	1	1	1	1	1	0	1	1	1	0	1	0	9
Neanotis indica (DC.) W.H.Lewis	Rubiaceae	Forb	1	1	1	1	1	1	1	1	1	1	1	1	1	13

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Ophelia corymbosa Griseb.	Gentianaceae	Forb	0	1	0	1	0	1	0	0	1	0	0	0	0	4
Osbeckia brachystemon Naudin	Melastomataceae	Forb	1	1	1	1	1	1	1	1	1	1	1	1	1	13
Osbeckia leschenaultiana DC.	Melastomataceae	Shrub	0	1	0	0	0	0	0	0	1	1	1	0	0	4
Oxalis corniculata L.	Oxalidaceae	Forb	1	1	1	1	1	1	1	1	1	1	1	1	0	12
Oxalis spiralis Ruiz & Pav. ex G.Don	Oxalidaceae	Forb	0	1	0	0	0	0	0	1	0	0	0	1	0	3
Parnassia mysorensis F. Heyne ex Wight & Arn.	Celastraceae	Forb	0	1	0	1	0	1	1	1	1	1	1	1	1	10
Pedicularis perrotteti i Benth.	Orobanchaceae	Forb	1	0	0	0	0	0	0	0	0	0	0	0	0	1
Persicaria nepalensis (Meisn.) Miyabe	Polyagonaceae	Forb	0	1	1	1	1	1	1	1	1	0	1	1	0	10
Pimpinella leschenaultii DC.	Apiaceae	Forb	1	1	0	0	0	1	0	0	1	0	0	0	0	4
Pinalia polystachya (A.Rich.) Kuntze	Orchidaceae	Forb	0	0	0	0	0	0	0	1	0	0	0	0	0	1
Pinus patula Schiede ex Schltdl. & Cham.	Pinaceae	Tree	0	0	0	1	0	1	0	0	0	0	0	0	0	2
Plantago asiatica subsp. *erosa* (Wall.) Z.Yu Li	Plantaginaceae	Forb	1	1	1	1	0	1	1	1	1	1	0	1	1	11
Pleiocraterium verticillare (Wall. ex Wight & Arn.) Bremek.	Rubiaceae	Forb	1	0	0	1	1	1	1	1	0	0	0	1	1	8
Polytrias indica (Houtt.) Veldkamp	Poaceae	Grass	1	1	0	1	0	1	1	1	1	1	0	1	1	10
Potentilla leschenaultiana Ser.	Rosaceae	Forb	1	1	0	1	1	1	1	1	1	1	1	1	1	12
Pteridium aquilinum (L.) Kuhn	Denstaedtiaceae	Forb	0	1	1	0	0	1	1	1	1	1	0	0	0	7
Pycreus flavidus (Retz.) T.Koyama	Cyperaceae	Forb	1	1	1	1	1	1	1	1	1	1	1	1	0	12
Ranunculus diffusus DC.	Ranunculaceae	Forb	0	0	0	1	1	0	0	1	0	0	0	0	0	3
Ranunculus reniformis Wall. ex Wight & Arn.	Ranunculaceae	Forb	1	1	1	1	1	1	1	1	1	1	1	1	1	13
Rhododendron arboreum Sm.	Ericaceae	Tree	0	0	1	1	1	1	0	0	0	0	0	1	1	6
Rhynchospora rugosa (Vahl) Gale	Cyperaceae	Forb	0	1	1	1	1	1	1	1	1	1	1	1	1	12
Rotala fysonii Blatt. & Hallb.	Lythraceae	Forb	0	0	1	1	1	1	1	1	1	1	1	1	1	11
Rubus racemosus Genev.	Rosaceae	Shrub	0	1	0	0	0	1	1	0	1	0	0	0	0	4
Satyrium nepalense D.Don	Orchidaceae	Forb	1	0	0	1	1	0	1	0	1	0	1	1	1	8
Senecio wightii (DC. ex Wight) Benth. ex C.B.Clarke	Compositae	Forb	1	0	1	0	1	1	1	1	1	1	1	1	1	11
Swertia minor T.Cooke	Gentianaceae	Forb	1	0	0	0	0	0	0	0	0	0	0	0	0	1
Themeda tremula (Nees ex Steud.) Hack.	Poaceae	Grass	0	0	0	0	1	1	0	0	1	0	1	1	0	5
Utricularia graminifolia Vahl	Lentibulariaceae	Forb	1	1	1	1	1	1	0	1	1	1	0	1	1	11
Utricularia scandens Benj.	Lentibulariaceae	Forb	1	0	0	1	1	0	0	0	0	0	0	1	0	4
Viola pilosa Blume	Violaceae	Forb	1	1	1	1	1	1	1	1	1	1	0	1	1	12
Wahlenbergia marginata (Thunb.) A.DC.	Campanulaceae	Forb	0	0	0	0	0	0	0	1	1	0	1	1	1	5
Xyris capensis Thunb.	Xyridaceae	Forb	1	1	1	1	1	1	1	1	1	1	1	1	1	13
Grand Total			50	51	47	53	52	50	53	63	57	56	51	66	46	

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