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Vascular epiphyte diversity and host tree architecture in two forest management types in the Himalaya

Yagya P. Adhikari[a,d,*], Samuel Hoffmann[a], Ripu M. Kunwar[b], Maria Bobrowski[c], Anke Jentsch[d], Carl Beierkuhnlein[a]

[a] *Chair of Biogeography, BayCEER, University of Bayreuth, Universitätsstr. 30, 95447 Bayreuth, Germany*
[b] *Ethnobotanical Society of Nepal, 44600 Kathmandu, Nepal*
[c] *Center for Earth System Research and Sustainability, Institute of Geography, University of Hamburg, Bundesstraße 55, 20146 Hamburg, Germany*
[d] *Department of Disturbance Ecology, BayCEER, University of Bayreuth, Universitätsstr. 30, 95447 Bayreuth, Germany*

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ABSTRACT

Epiphytes are one of the most diversified plant life forms, whose species richness peaks in the tropics and subtropics. Here we examined vertical distribution metrics (i.e., number of epiphyte individuals and epiphyte species richness) of vascular epiphytes (i.e., orchids and ferns) on two dominant host trees (i.e., *Schima wallichii* (DC.) Korth. and *Quercus lanata* Sm.) in sub-tropical forests of Nepal. We sampled a total number of 72 host trees of *Q. lanata* and *S. wallichii* from two forest sites: a government protected national park forest and community managed forest. We applied generalized linear mixed models and Kruskal-Wallis rank sum tests to explain epiphyte diversity by tree architecture (i.e., diameter at breast height, tree height, crown size, number of forks, bark rugosity, bark pH and tree layer), host species and forest management types. After variable selection via multi-model inference technique, we found diameter at breast height to be the most powerful and significant explanatory variable for the number of epiphyte individuals and epiphyte species richness across host tree species, tree layers, and forest management types. Interestingly, epiphyte diversity was on average higher in the community managed forest than in the national park forest, on *S. wallichii* than on *Q. lanata* and particularly on the trunk below forks. We conclude that effective conservation of epiphyte diversity in the Nepal Himalaya requires conservation of old-growth host trees through community approaches. If large and old tree stands are maintained, community managed forests can host high diversity of vascular epiphytes and provide ecosystem goods to local people alike.

1. Introduction

In contrast to their outstanding richness in species (Benzing, 1990; Zotz, 2016), epiphytes are largely under-investigated. Approximately ten percent of all vascular plant species world-wide are epiphytes (Nieder et al., 2001). In addition to lichens, mosses, liverworts and ferns, orchids (Orchidaceae) and bromeliads (Bromeliaceae) are representing the most diverse groups of

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* Corresponding author at: Chair of Biogeography, BayCEER, University of Bayreuth, Universitätsstr. 30, 95447 Bayreuth, Germany.
E-mail address: yagya.adhikari@uni-bayreuth.de (Y.P. Adhikari).

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epiphytic higher plants at the global scale, the latter being restricted to the neotropics (Agudelo et al., 2019). Even more than terrestrial plants, epiphytic species richness is accelerating towards the tropics (Krömer et al., 2005), with highest diversity in relatively undisturbed and primary forests (Gentry and Dodson, 1987; Werner and Gradstein, 2009). However, tropical and subtropical forests are increasingly degraded resulting in the loss of habitat for epiphytes (Wolf, 2005). Due to its steep terrain and the high amounts of precipitation, Nepal is naturally favored in terms of forest ecosystems. Nevertheless, Nepal lost 59,050 ha of forest between 1990 and 2010 (DFRS, 2015). Deforestation and habitat degradation are considered as the greatest threats to Nepal's biodiversity (Adhikari et al., 2015; Devkota, 2019). One reason is the lack of governance and control. Local people see, for instance, government-managed forests as an open-access and freely available commodity (Kunwar et al., 2019). Uncontrolled urbanization and deforestation are prime factors for the decline of forest ecosystems and epiphyte diversity, respectively (Wolf et al., 2009). Without the preservation of mature host trees, epiphytes cannot be protected (Barthlott et al., 2001). Additional pressures are effective such as illegal collection and trade of Himalayan epiphytes, especially orchids, resulting in local extinction (Adhikari et al., 2016). In the future, climate change is likely to add to such negative drivers of species loss (Zotz and Bader, 2009; Acebey et al., 2017).

The vertical distribution of epiphytes on trees is determined by microclimatic gradients of air temperature, humidity, wind speed and solar radiation as well as by substrate conditions and tree architecture (Benzing, 1990). The forest understory with small trees and shrubs also offers habitat to epiphytes. In montane forests of the Bolivian Andes, Krömer et al. (2007) found more than 20% of 500 species only occurring in the understory. Epiphytes can be categorized as habitat generalists, habitat specialists, canopy epiphytes, trunk epiphytes or hemiepiphytes, according to the vertical zones at which they are occurring during their life cycle. A vertical stratification scheme was first introduced by Johansson (1974). A more recent scheme defines seven zones derived from compositional differences of the epiphytic vegetation induced by structural characteristics and microenvironmental gradients of the phorophytes (Krömer et al., 2007): the understory phorophytes; the tree trunk base; the lower part of the trunk; the upper part of the trunk; the lower canopy; the middle canopy; and the outer canopy. The epiphyte communities and microenvironmental conditions significantly differ between the canopy and the zones below the canopy (Engwald, 1999). The forest management, tree age and architecture determine the size and microenvironmental conditions of each zone.

Previous studies on epiphytes in Nepal Himalaya are mostly focused on taxonomy (Rokaya et al., 2013), conservation management (Adhikari et al., 2015; Timsina et al., 2016), medicinal use (Pant and Raskoti, 2013; Subedi et al., 2013), propagation (Pant et al., 2008), and ecological niche assessment (Adhikari et al., 2016, 2017; Timsina et al., 2016). However, there is still limited knowledge about the interplay between epiphyte diversity, its vertical stratification, host tree architecture and forest management in the Nepal Himalaya (Larrea and Werner, 2010). In this study, we contribute to a better understanding of this interplay by investigating the relationships between epiphyte diversity, its vertical distribution, host tree architecture in two forests with different management types in Nepal Himalaya. We particularly compare vascular epiphyte diversity between two host tree species, *Quercus lanata* and *Schima wallichii*, and between a government protected national park forest and a community managed forest. We also performed regression models to identify important traits of host tree architecture for the abundance and richness of vascular epiphytes.

We hypothesize that increasing tree surface area associated with the diameter at breast height, tree height, crown size, number of branches, twigs and forks, and bark rugosity enhance epiphyte diversity due to increased habitat availability (hypothesis 1). The larger the bark surface, the more likely it is that epiphytes establish on a tree. We also conducted tests on differences in the abundance and species richness of epiphytes between the two host tree species, forest sites and three vertical tree layers (trunk layer, lower canopy layer, and upper canopy layer). Because of reduced pressures and exploitation, we expect that epiphyte diversity is higher in the government protected national park forest compared to the community managed forest. Forest use by humans is more restricted in the government protected forest than in the community managed forest (hypothesis 2). Furthermore, we propose a higher diversity of epiphytes in the lower canopy layer in comparison to the upper canopy or the trunk layer. From our observations, the trunk layer and upper canopy layer contain less potential habitat area with a lower probability of epiphytic establishment (hypothesis 3).

2. Materials and methods

2.1. Study sites

We selected two sites for this study (i) the community managed forest (CF hereafter), managed through Community Forest User Groups (CFUGs) and (ii) the government protected national park forest (NF hereafter), managed through the government. The former is Naudhara CF located at the Godawari, Lalitpur district whereas the latter is Shivapuri-Nagarjun National Park located at Shivapuri, Kathmandu district. Both are characterized with the same elevation range (1600–1900) and lying at the outskirt of Kathmandu valley. Community managed forests and national park forests are two main regimes to conserve forests in Nepal (Pandey et al., 2014). They are widely recognized by local people, policy-makers and other stakeholders such as non-governmental organizations. However, their effects on biodiversity conservation is not yet entirely understood. By focusing on epiphyte diversity in relation to tree architecture in both forest management types, we aim at contributing to this understanding.

The study area has three seasons round the year: cold and dry winter (October to February), pre monsoon dry summer (March to May) and monsoon (June to September). The temperature range of study area is 15.8–28.2 °C in summer and

2.6–18.7 °C in winter. The annual average rainfall is 1882 mm with the absolute maximum (around 80%) during monsoon period (Kattel et al., 2015). Relative humidity is ca. 90% in July, with a minimum of 63% in April (Poudyal, 2013).

The Naudhara CF is a secondary forest managed by people with some relict tree stands of *S. wallichii*, lies between 27° 57′~ 58′ N latitude and 85° 38′~ 39′ E longitude and ranges between 1600 m a.s.l. and 1900 m a.s.l. elevation. The forest was handed over to the community in 1990, and is co-dominated by *Q. lanata*, *Castanopsis tribuloides, Myrsine semiserrata, Rhododendron arboreum, Lyonia ovalifolia* and *Michelia spp* (Devkota and Kunwar, 2006). The canopy cover of Naudhara CF is dense, i.e., about 80%. The average tree height of *S. wallichii* in this forest is 21 m with a maximum 28 m and a minimum 15 m, whereas the *Q. lanata* is found as high as 14 m with canopy cover of about 50%.

The national park forest (NF) is a young subtropical forest. In 2002, it was declared as a National Park that ranges between 27° 77′~ 78′ N latitude and 85° 41′~ 42′ E longitude and 1600 m a.s.l. and 1800 m a.s.l. elevation. It is dominated by the *Schima-Castanopsis* forest at lower elevations and by *Q. glauca, S. wallichii* and *Rhododendron arboreum* at higher elevations. The other associated tree species are *C. tribuloides, C. indica, Myrica esculenta, L. ovalifolia, Pinus roxburghii* and *Symplocus* sp. at southern slopes and higher elevations. The canopy cover is moderate (60%) and the average tree heights of both sample host tree species are 14 m. Despite the forest being protected, some illegal harvestings such as logging, and collection of medicinal plants were observed while doing fieldwork. (Fig. 1).

2.2. *Field sampling*

Since the study area was dominated by *Q. lanata* and *S. wallichii*, trees of these two species were selected for sampling. The species are native to the Himalayas and suitable hosts for epiphytic orchids (Adhikari et al., 2012). We sampled a total number of 72 host trees, i.e., 18 individuals per species and per forest management type. The rope climbing technique was used to access the canopy (Mitchell et al., 2002). Fieldwork was conducted between April and June 2015 following the procedure proposed by Wolf et al. (2009). The abbreviations used in this study were ‘Ql_NF’ and ‘Ql_CF’ for *Q. lanata* in national park forest and community managed forest, respectively; and ‘Sw_NF’ and ‘Sw_CF’ for *S. wallichii* in national park forest and community managed forest, respectively. Species were identified following published literature (Shrestha, 1998; Bose et al., 1999; White and Sharma, 2000; Rajbhandari and Bhattarai, 2001).

We assigned each epiphyte individual to one of three predefined tree layers, following a modification of the Johansson’s scheme (Zotz, 2007; Adhikari, 2013): layer 1 (the trunk up to the first branch), layer 2 (lower canopy layer) and layer 3 (upper canopy layer, if the tree height is 15 m then the upper 1/3 of the tree canopy, and if the tree height is less than 15 m then it is divided into three equal tree layers). We aggregated Johansson’s scheme into these three layers because a more detailed tree layer separation was simply not applicable due to the complex tree architecture encountered in the field. On both host tree species and in all three layers, we found a total of 35 epiphyte species in the CF, and 22 species in the NF. CF and NF shared 16 species. 6 species were uniquely found in NP, and 19 species were uniquely sampled in CF.

We additionally sampled the tree architecture by tree diameter at breast height (DBH), tree height, crown size, number of forks, bark rugosity and bark pH. Bark pH was measured by using a flat head electrode. A stable equilibrium value represents the actual bark pH of the host plant. We took the mean measurements of two sides of each tree trunk at the height of 1.3 m (Farmer et al., 1990). Bark rugosity was measured based on the visual estimation of roughness of bark, and categorized into three classes following Adhikari et al. (2012): smooth, medium, and rough. The field data is available at https://figshare.com/articles/Adhikari_et_al._2020_xlsx/11861130.

2.3. *Species diversity metrics*

Species abundance (i.e., number of individuals) and species richness (i.e., number of epiphyte species) are fundamental measures of biodiversity, which are often applied in biodiversity conservation as they can be easily understood by stakeholders and reveal a high degree of diversity information (Hoffmann et al., 2019).

2.4. *Statistical analyses*

We performed all analyses in R Version 3.5.2 (R Core Team, 2019). We applied linear models (LM), linear mixed models (LMM), generalized linear models (GLM) and generalized linear mixed models (GLMM) to explain epiphyte diversity metrics (i.e., number of individuals and species richness) by tree architecture (i.e., tree diameter at breast height [DBH], tree height, crown size, number of forks, bark rugosity and bark pH), tree species (i.e., Ql=*Quercus lanata* and Sw=*Schima wallichii*) and forest management types (i.e., CF=Community managed forest and NF=National park forest). Since the number of individuals and species richness represent count data, we applied GLMs and GLMMs considering Poisson data distribution and a log-link function. The explanatory variables were normalized before being put into the models to enable fair comparison of variable importance. If over-dispersion occurred in the Poisson-models, we used negative binomial data distribution (Kleiber and Zeileis, 2008). To reveal the importance of explanatory variables, we calculated variable importance from multi-model inference based on Akaike weights following Bartoń (2015) built on Burnham and Anderson (2002). For the mixed effect models, we provided marginal (i.e., excluding random effects) and conditional (i.e., including random effects) pseudo-R^2 values according to Bartoń (2015) based on Nakagawa and Schielzeth (2013). Model performances can be compared by the second-order Akaike

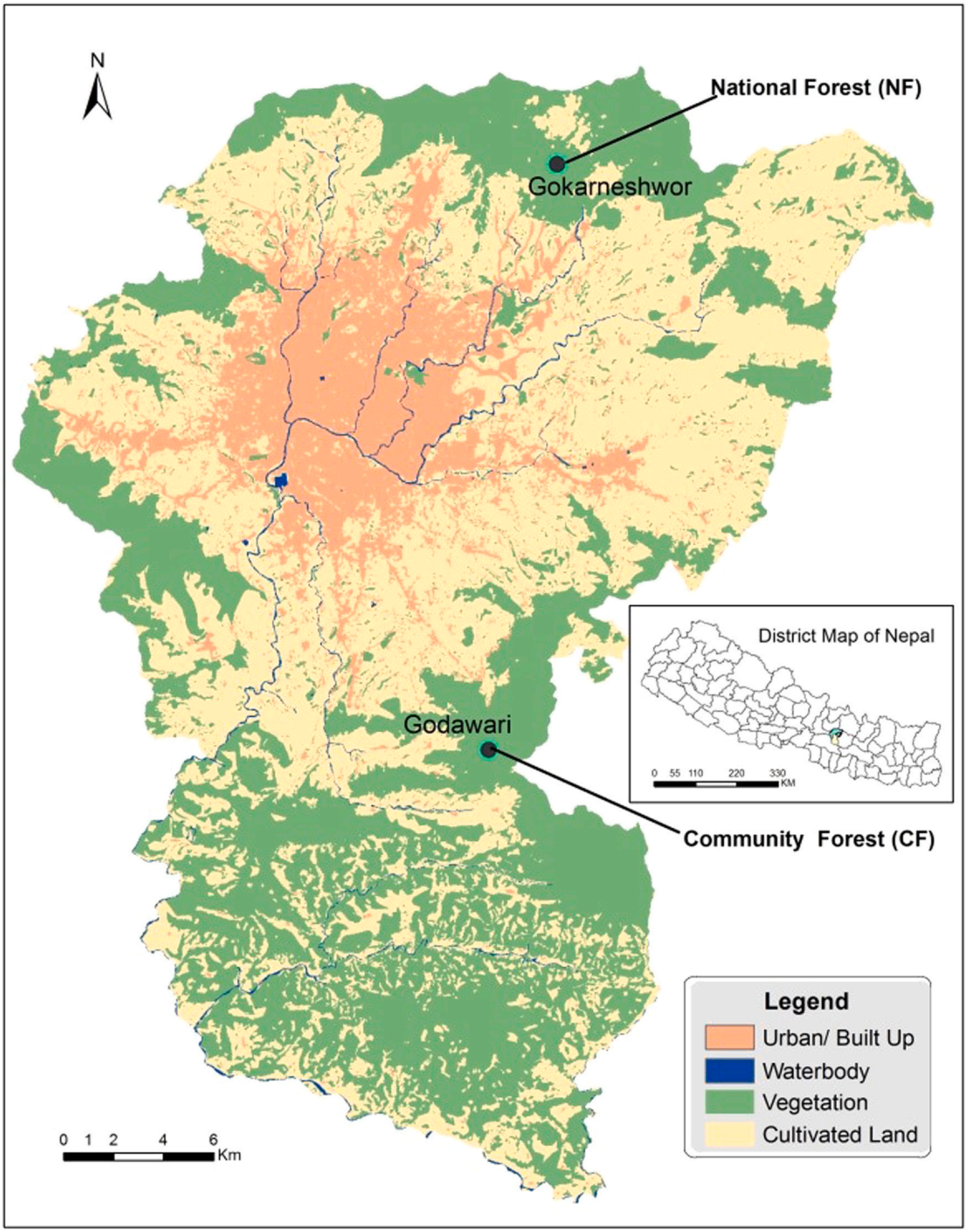

Fig. 1. Map of the study area on the mountain slope in the vicinity of Kathmandu (orange): upper; Gokarneshwor national park forest (NF) and lower; Godawari community managed forest (CF) in the Kathmandu Valley, Nepal.

Information Criterion (AICc), which is robust against small sample sizes. We included the quadratic term of bark pH as we assume a humped shaped relationship between epiphyte diversity and bark pH.

In a stepwise approach, we first analyzed full models including all explanatory variables. Then we applied a multi-model inference technique to reveal the best model with lowest AICc and to identify the most important explanatory variables. We applied these two steps for mixed models including ‘tree species’ as a random effect and for mixed models including the combination of tree species and forest management types (i.e., ‘forest type: tree species’) as a random effect. We could thus correct relationships between epiphyte diversity and tree architecture for the effects of tree species and forest management types. We eventually compared the epiphyte diversity metrics by tree species, forest management type and tree layer using the Kruskal-Wallis rank sum test, which is robust against non-normally distributed data.

3. Results

In total, we recorded 39 species of epiphytes (33 orchids and 6 ferns) within four families. Epiphyte individuals on a single tree vertically distributed along three tree layers ranged between 1 and 189. Considering the full model including all variables explaining the number of epiphyte individuals as fixed effects, 'tree species', 'DBH', 'bark rugosity' and 'forest type' were the most important predictors, although only 'tree species' and 'bark rugosity' were significant in the full model (Table 1). This order of important variables was confirmed by all subsequent models. When 'tree species' was considered a random effect, 'forest type' was not significant, while 'DBH' and 'bark rugosity' were significant. When 'forest type: tree species' was considered a random effect, 'DBH' was the only significant variable. In the full model explaining species richness, 'tree species', 'DBH', 'forest type' and 'crown size' were the most important predictors, but only 'tree species' and 'DBH' were significant in the full model (Table 1). All subsequent models confirmed this order of important variables, but in those models only 'DBH' remained a significant variable.

The relationships between the most important explanatory variables and epiphyte diversity are shown in Fig. 2. These relationships represent the model selections including 'forest type: tree species' as a random effect (Table 1). DBH was significantly and positively associated with the number of individuals across tree species and forest management types, but not significantly related to any combination of tree species and forest management type (Fig. 2a). Bark rugosity was not significantly related to the number of individuals across combinations of tree species and forest management types but was significantly and negatively related to the number of individuals within *S. wallichii* of any forest management type (i.e., 'Sw_CF' and 'Sw_NF') (Fig. 2b). DBH was significantly and positively related to the number of individuals across combinations of tree species and forest management types, and within *Q. lanata* of any forest management type (i.e., 'Ql_CF' and 'Ql_NF') as well as within 'Sw_CF', but not 'Sw_NF' (Fig. 2c).

The number of epiphyte individuals per tree differed between all tree species and forest management types except for the pairwise comparison between 'Ql_CF' and 'Sw_NF' (Fig. 3a). Epiphyte species richness also differed between all tree species and forest management types except for the pairwise comparison between 'Ql_CF' and 'Sw_NF' (Fig. 3b).

When pooling all tree species and forest management types, the number of individuals was highest in tree layer 1 (trunk layer) followed by layer 2 (lower canopy layer), while layer 3 (upper canopy layer) was not significantly different from layers 1 and 2 (not shown). When pooling, species richness was also highest in tree layer 1 followed by layer 2, while layer 3 was not significantly different from layer 2 (not shown). These relationships differed, however, between combinations of tree species and forest management types (Fig. 4).

4. Discussion

The associations of orchids and ferns with host tree architecture may depend on different variables (traits) of the host species (e.g., DBH, bark rugosity, etc.) (Adhikari et al., 2016; Timsina et al., 2016). We found significant associations between epiphytes and some variables of host tree architecture (Table 1). The DBH is the most important parameter explaining the abundance and species richness of epiphytes. This is in line with our first hypothesis that epiphyte richness and abundance is higher in old stands of primary forests compared to secondary forests where tree size is also low due to the young age of trees (Barthlott et al., 2001). Older trunks exhibit larger branches and, in most cases, also a rougher bark texture even if this is strongly species-specific. In Nepal, epiphytic orchids tend to prefer large and tall host trees (Adhikari et al., 2012). At the slopes of the Himalayas, for example, a large number of epiphytic orchid species are associated with the tall trees of *Shorea robusta* (Timsina et al., 2016). The larger the DBH, the larger is the tree trunk and branch surface for epiphytic seeds and spores to establish (Callaway et al., 2002; Migenis and Ackerman, 1993; Tewari et al., 1985; Zotz, 2007). Surprisingly, we found bark rugosity negatively associated with epiphyte abundance on *S. wallichii*. In contrast, other studies show that rough bark texture of host trees supports the establishment of epiphytes especially in the early stage (Song et al., 2010; Adhikari et al., 2012, 2016). Accordingly, tree age is likely an important indicator for epiphyte diversity. Increasing tree age enhances the tree attributes such as DBH, bark rugosity and canopy cover.

The epiphyte diversity was found to be higher in the community forest compared to the national park forest, which is not in line with our second hypothesis. In the community forest, users followed the CFUG operational plan and performed forest management operations in order to conserve the forest and grow timber species. The operational plan guides and regulates forest management (Kunwar and Sharma, 2004). In consequence, we recorded larger *Schima* trees in the community forest, which are remnant from the former primary forest and are still providing beneficial conditions for epiphyte growth, especially for orchids. The architecture of *S. wallichii* trees with abruptly bending trunks enhances the establishment of epiphytes. These conditions are favorable for light demanding orchid species. In contrast, shade-tolerant fern species show higher abundance in closed canopies. Additionally, abundance, species richness and diversity of epiphytes was higher in *S. wallichii* than in *Q. lanata*, the possible reasons are that *S. wallichii* trees of the study sites are older, taller and have larger DBH than the *Q. lanata* trees. The *S. wallichii* stands in the community forest are remnant trees of primary forest. The reason for this pattern could be the relatively young age of the protected site. Before it was declared as a national park in 2002, the area was subject to disturbances

Table 1
Regression model fits and variable importance.

Model fit									Variable importance								
Model type	Data distribution	Variable selection	Model formula	*p*	R^2	Marginal R^2	Condit-ional R^2	AICc	DBH	Tree height	Crown size	Number of forks	Bark rugosity	Bark pH	Bark pH^2	Forest type	Tree species
GLM	negative binomial	None	Number of individuals ~ dbh + tree height + crown size + bark rugosity + bark pH + bark pH^2 + number of forks + forest type + tree species	< 0.001	0.16	–	–	754.53	0.76	0.25	0.27	0.34	0.72**	0.40	0.31	0.63	0.93**
GLM	negative binomial	Multi-model inference	Number of individuals ~ dbh + bark rugosity + forest type + tree species	< 0.001	0.15	–	–	744.02	0.88*	–	–	–	0.79**	–	–	0.73*	0.94***
GLMM	negative binomial	None	Number of individuals ~ dbh + tree height + crown size + bark rugosity + bark pH + bark pH^2 + number of forks + forest type + (1|tree species)	0.050	–	0.19	0.33	761.14	0.77	0.25	0.26	0.31	0.58*	0.44	0.31	0.56	–
GLMM	negative binomial	Multi-model inference	Number of individuals ~ dbh + bark rugosity + forest type +(1|tree species)	0.005	–	0.17	0.34	750.89	0.87*	–	–	–	0.63*	–	–	0.61	–
GLMM	negative binomial	None	Number of individuals ~ dbh + crown size + bark rugosity + bark pH + bark pH^2 + number of forks + (1|forest type:tree species)	0.17	–	0.13	0.27	762.38	0.82*	0.25	0.27	0.29	0.45	0.40	0.30	–	–
GLMM	negative binomial	Multi-model inference	Number of individuals ~ dbh + bark rugosity + (1|forest type:tree species)	< 0.001	–	0.10	0.23	752.31	0.90**	–	–	–	0.46	–	–	–	–
GLM	Poisson	None	Species richness ~ dbh + tree height + crown size + bark rugosity + bark pH + bark pH^2 + number of forks + forest type + tree species	< 0.001	0.37	–	–	305.86	0.69*	0.26	0.38	0.31	0.33	0.25	0.25	0.51	1.00***
GLM	Poisson	Multi-model inference	Species richness ~ dbh + tree species	< 0.001	0.32	–	–	294.16	0.90	–	–	–	–	–	–	–	1.00***
GLMM	Poisson	None	Species richness ~ dbh + tree height + crown size + bark rugosity + bark pH + bark pH^2 + number of forks + forest type +(1|tree species)	0.159	–	0.10	0.36	313.55	0.73*	0.26	0.33	0.32	0.28	0.24	0.24	0.50	–
GLMM	Poisson	Multi-model inference	Species richness ~ dbh + (1|tree species)	0.007	–	0.07	0.26	300.76	0.93**	–	–	–	–	–	–	–	–
GLMM	Poisson	None	Species richness ~ dbh + crown size + bark rugosity + bark pH + bark pH^2 + number of forks + (1|forest type:tree species)	0.466	–	0.08	0.30	314.77	0.81*	0.25	0.24	0.33	0.25	0.27	0.25	–	–
GLMM	Poisson	Multi-model inference	Species richness ~ dbh + (1|forest type:tree species)	0.028	–	0.09	0.28	302.06	0.79*	–	–	–	–	–	–	–	–

Note: The column “Data distribution” shows the data distribution family for the generalized linear models (GLM) and generalized linear mixed models (GLMM). When Poisson-models were over-dispersed, we applied a negative binomial data distribution family. We used a multi-model interference technique accounting for the Akaike weights to calculate variable importance and to select variables. For mixed models we provided marginal (i.e., excluding random effects) and conditional (i.e., including random effects) pseudo-R^2. Model performances can be compared by the second-order Akaike Information Criterion (AICc). We included the quadratic term of bark pH as we assume a humped shaped relationship between epiphyte diversity and bark pH. The stars indicate the significance level (p-value) of the explanatory variables: *: $0.05 \leq p < 0.01$, **: $0.01 \leq p < 0.001$, ***: $p \leq 0.001$.

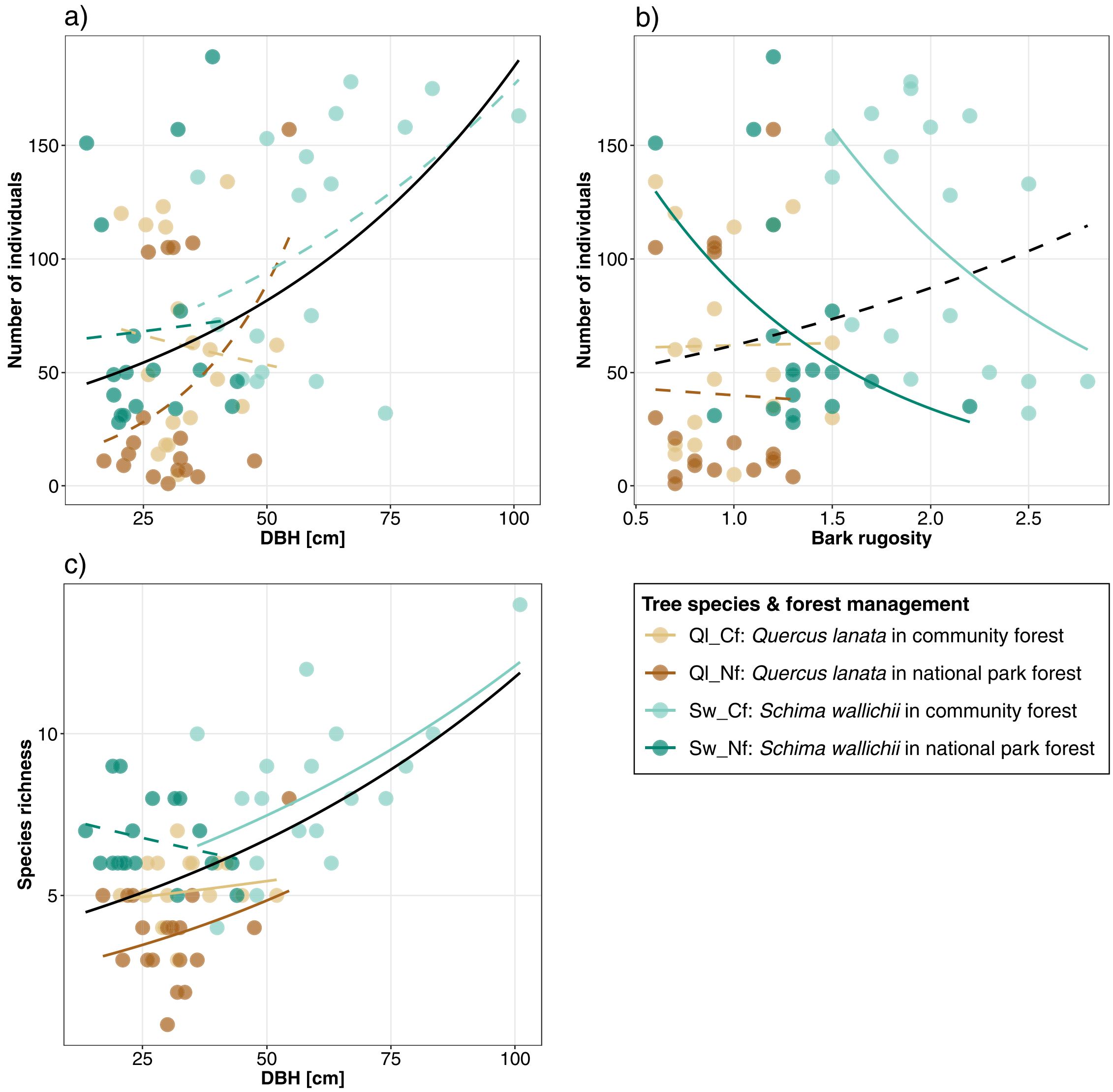

Fig. 2. Relationships between the most important explanatory variables and epiphyte diversity. The relationships were derived from generalized linear mixed effect models including the four combinations of tree species (Ql = *Quercus lanata*, Sw = *Schima wallichii*) and forest management types (CF = Community managed forest, NF = National park forest) as a random effect (see Table 1). The variable importance was calculated by a multi-model inference technique accounting for Akaike weights, following Bartoń (2015) built on Burnham and Anderson (2002). The black lines represent the full model fits, while the colored lines indicate the model fits per combination of forest management type and tree species. Stippled lines express non-significant relationships ($p > 0.05$). (a) Number of individuals versus diameter at breast height (DBH). Full model: estimate intercept $4.19 \pm 0.12^{***}$, estimate DBH $0.27 \pm 0.11^{**}$; Ql_CF model: estimate intercept $4.08 \pm 0.20^{***}$, estimate DBH -0.15 ± 0.40; Ql_NF model: estimate intercept $3.93 \pm 0.33^{***}$, estimate DBH 0.79 ± 0.51; Sw_CF model: estimate intercept $4.39 \pm 0.20^{***}$, estimate DBH 0.21 ± 0.12; Sw_NF model: estimate intercept $4.27 \pm 0.23^{***}$, estimate DBH 0.07 ± 0.27. (b) Number of individuals versus bark rugosity. Full model: estimate intercept $4.19 \pm 0.20^{***}$, estimate bark rugosity -0.08 ± 0.22; Ql_CF model: estimate intercept $4.14 \pm 0.28^{***}$, estimate bark rugosity 0.02 ± 0.34; Ql_NF model: estimate intercept $3.64 \pm 0.55^{***}$, estimate bark rugosity -0.08 ± 0.67; Sw_CF model: estimate intercept $5.20 \pm 0.24^{***}$, estimate bark rugosity $-0.40 \pm 0.12^{*}$; Sw_NF model: estimate intercept $4.18 \pm 0.13^{***}$, estimate bark rugosity $-0.51 \pm 0.21^{*}$. (c) Species richness versus DBH. Full model: estimate intercept $1.75 \pm 0.12^{***}$, estimate DBH $0.14 \pm 0.06^{*}$; Ql_CF model: estimate intercept $4.07 \pm 0.04^{***}$, estimate DBH $-0.19 \pm 0.07^{**}$; Ql_NF model: estimate intercept $3.92 \pm 0.38^{***}$, estimate DBH $0.78 \pm 0.06^{***}$; Sw_CF model: estimate intercept $4.39 \pm 0.04^{***}$, estimate DBH $0.21 \pm 0.02^{***}$; Sw_NF model: estimate intercept $4.28 \pm 0.04^{***}$, estimate DBH 0.08 ± 0.05. The stars indicate the significance level (p-value) of the explanatory variables: *: $0.05 \leq p < 0.01$, **: $0.01 \leq p < 0.001$, ***: $p \leq 0.001$.

from fetching wood and was used as a wildlife hunting recreational center for the royal family (Adhikari et al., 2017). These historic impacts are due to the close vicinity to the high population density in the valley of Kathmandu. Moreover, we only compared two sample sites, one per management category. We thus highlight the management impact of these two study sites, but cannot generalize our findings for any community managed forest or national park forest.

Across host tree species and forest management types, the abundance and species richness of epiphytes were generally found highest in the trunk layer (L1). Often, the lower and upper canopy layer showed no significant difference in epiphyte

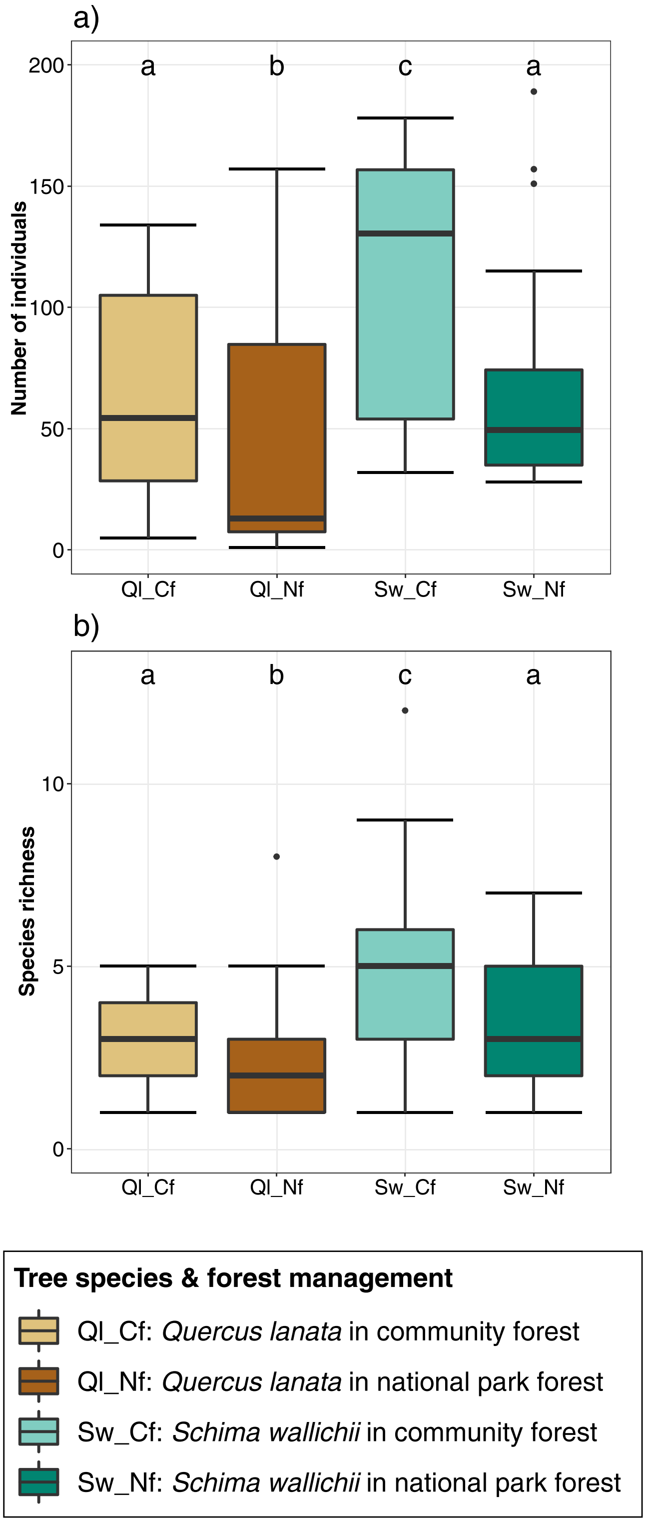

Fig. 3. (a) Number of epiphyte individuals, and (b) epiphyte species richness across tree species (Ql = *Quercus lanata*, Sw = *Schima wallichii*) and forest management types (CF = Community managed forest, NF = National park forest). In total, 72 tree individuals were sampled, i.e., 18 per combination of tree species and forest management type. The letters indicate significant ($p < 0.05$) differences between groups according to Kruskal-Wallis rank sum test. The limits of the boxes show the lower and upper quartiles, i.e., the interquartile range. The whiskers extend to the lowest and highest values within 1.5 times the interquartile range. The black dots indicate outliers beyond the whiskers.

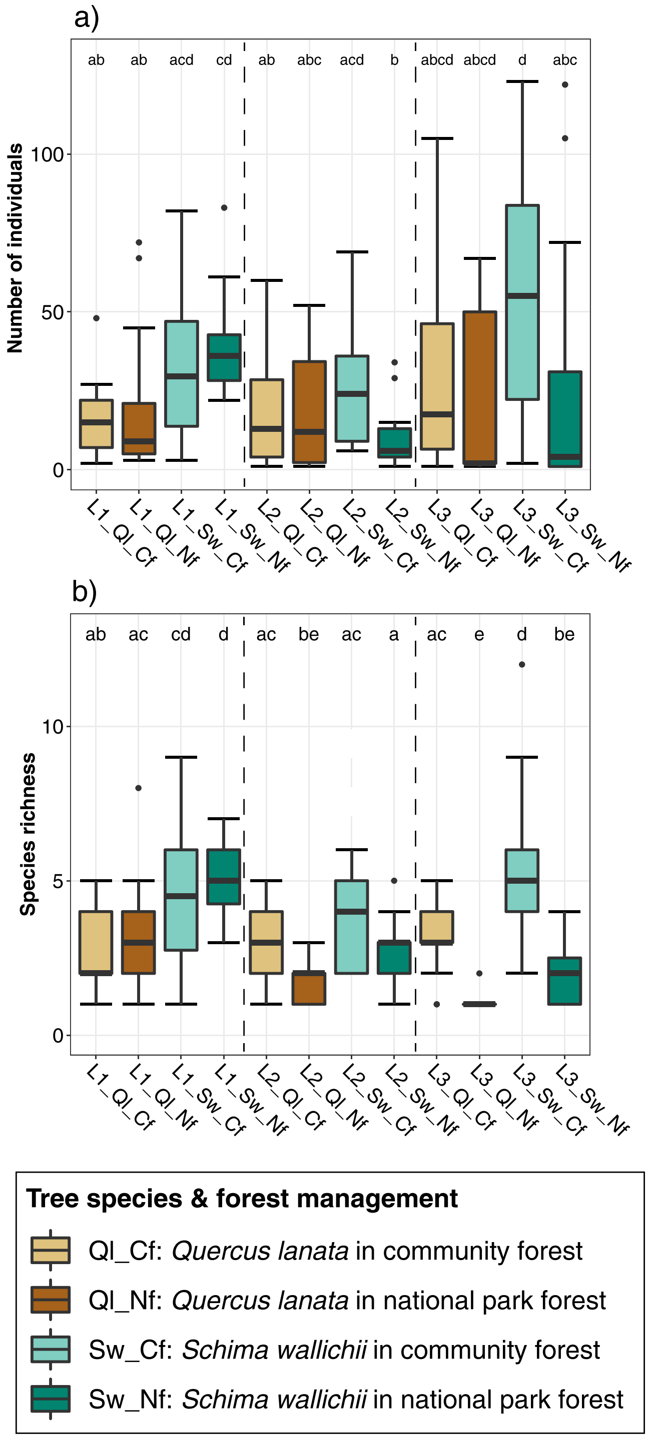

Fig. 4. (a) Number of epiphyte individuals, and (b) epiphyte species richness across tree layers (L1 = trunk layer, L2 = lower canopy layer, L3 = upper canopy layer), tree species (Ql = *Quercus lanata*, Sw = *Schima wallichii*) and forest management types (CF = Community managed forest, NF = National park forest). In total, 72 tree individuals were sampled, i.e., 18 per combination of tree species and forest management type. The letters indicate significant ($p < 0.05$) differences between groups according to Kruskal-Wallis rank sum test. The stippled lines separate the tree layers. The limits of the boxes show the lower and upper quartiles, i.e., the interquartile range. The whiskers extend to the lowest and highest values within 1.5 times the interquartile range. The black dots indicate outliers beyond the whiskers.

abundance and species richness. The two host tree species that were investigated in this study possess large, thick and partly bent trunks. This structural trait offers an appropriate habitat for epiphytes. Many epiphytic orchid species grow upon the inclined tree trunk of *S. wallichiii* where the rough and mossy bark provides additional access to water (Ghimire, 2008), particularly through trunk hollows. A few trees were with trunk hollows; however we didn't find orchids and ferns on them. Tree inclination could thus be a valuable indicator of epiphyte diversity, but as the host trees trunks were frequently curved in various directions, measuring trunk inclination is unfeasible. In our study, the trunk layer has more suitable environmental conditions for epiphytes' growth. It provides sufficient area to adhere seed of epiphytes (Trimanto and Danarto, 2020). Furthermore, it might have an optimum level of sun light. It usually contains more humus subtract and mosses which provide enough moisture for the early establishment and growth of epiphytes (Adhikari et al., 2016; Hirata et al., 2009; Wagner et al., 2015). In addition, the bark texture, its chemistry (e.g., pH) and water holding capacity directly influence the epiphytes (Ghimire, 2008; Adhikari and Fischer, 2011). Epiphytic ferns are mostly shade-tolerant and more abundant in the more shady, lower layers of the vegetation, with few exceptions such as *Drynaria propinqua.* Orchids prefer sites that offer more light such as higher layers of the vegetation (Adhikari et al., 2017).

A management associated with protection of existing large old trees and ensuring the recruitment of new cohorts of such trees is supportive to epiphyte diversity. This suggests that the forest management regime is important for epiphyte diversity. In our study, the community managed 'wise use' forest holds more diverse tree habitats than the national park forest. While the community-based forest management system is hailed for its success in providing livelihood needs, the community forest we studied is also supportive to epiphyte conservation. This does not mean that community managed forests host higher epiphyte diversity in general, because we only compared two sites. Nevertheless, our study shows that community managed forests can be important for epiphyte conservation if large trees are maintained. Landscape-level approaches protecting large and old tree stands are required for epiphyte conservation.

5. Conclusions

This study suggests potential synergies between the conservation of epiphyte diversity and forest use. Epiphyte diversity can be relatively high in community managed forests containing old and large trees, but also offering ecosystem services and goods such as fuelwood and medicinal plants. However, it remains to be proven by future investigations whether community managed forests are generally more beneficial for epiphyte preservation than government protected national park forests in Nepal.

Supplementary materials

The complete data set of this research is available online under https://figshare.com/articles/Adhikari_et_al_2020_xlsx/11861130.

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CRediT authorship contribution statement

Yagya P. Adhikari, Samuel Hoffmann, Carl Beierkuhnlein: Conceptualization. **Yagya P. Adhikari:** Data curation. **Samuel Hoffmann, Maria Bobrowski:** Formal analysis. **Yagya P. Adhikari:** Funding acquisition. **Yagya P. Adhikari, Ripu M. Kunwar:** Investigation. **Yagya P. Adhikari, Ripu M. Kunwar, Samuel Hoffmann:** Methodology. **Yagya P. Adhikari, Anke Jentsch, Carl Beierkuhnlein:** Resources. **Yagya P. Adhikari, Maria Bobrowski, Samuel Hoffmann:** Software. **Yagya P. Adhikari, Samuel Hoffmann, Carl Beierkuhnlein**: Writing - original draft. **Yagya P. Adhikari, Samuel Hoffmann, Ripu M. Kunwar, Maria Bobrowski, Anke Jentsch, Carl Beierkuhnlein:** Writing - review & editing. All authors have read and agree to the published version of the manuscript.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Nomenclature

(WCSP, 2020).

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