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Effect of host tree site conditions of *Schima wallichii* on vertical structure of epiphytic orchid community

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Abstract. *Fardhani I, Kitagami Y, Torimaru T, Kisanuki H. 2025. Effect of host tree site conditions of* Schima wallichii *on vertical structure of epiphytic orchid community. Biodiversitas 26: 715-722.* It is crucial to recognize the conservation challenges and potential intertwined with the delicate balance of epiphytic orchid communities. Therefore, it is imperative to deepen our understanding regarding the factors influencing the ecology of the epiphytic orchid community, including how orchid diversity is distributed on a host tree. To clarify the variation in vertical community structure of epiphytic orchids on a host tree species, *Schima wallichii*, species richness and abundance of these orchids were investigated. Epiphytic orchids occurring on each host tree were allocated to one of five vertical zones. To understand their effects on community structures, host tree site factors such as density of trees surrounding the host, and angle and direction of slope on which the host tree stood, were measured. The crown zones of *S. wallichii* trees accumulated more species of epiphytic orchids than the trunk zone because the crown contains many branches, to which epiphytes can attach more easily than on the trunk. Zone 3, at the bottom of the crown zone, offered the most potential for many kinds of epiphytic orchids to colonize, according to the accumulation curves of species richness against both the number of host trees and orchid abundance; this is probably because it had larger branches than the other crown zones. The vertical community structures of epiphytic orchid on *S. wallichii* were not clearly segregated, even between trunk and the three crown zones. The host tree angle of slope significantly drove the vertical structure of the epiphytic orchid community.

Keywords: Epiphytic orchid, host tree conditions, slope, vertical community structure, vertical zonation

INTRODUCTION

The orchid family (Orchidaceae) is among the largest groups in the plant kingdom, having about 750 different genera with at least 28,000 native species (Christenhusz and Byng 2016). Java Island, Indonesia has at least 731 species of orchids of which 231 are endemic. In Java, most orchid species have been recorded in mountainous areas ranging in elevation from 1,000 to 2,400 m asl (Comber 1990). West Java is the province on the island with the highest diversity of epiphytic orchids with 642 species compared to 295 species in Central Java and 390 species in East Java (Comber 1990). Despite the high number of species, studies about the epiphytic orchid community in West Java are limited (Comber 1990; Fardhani et al. 2021; Prapitasari and Kurniawan 2022; Prapitasari et al. 2024).

In addition, epiphytic orchids in Java face numerous threats to their existence including illegal collection and trade (Hinsley et al. 2018) and habitat loss due to deforestation and land conversion (Sadili and Sundari 2017; Setiaji et al. 2018). It is crucial to recognize the conservation challenges and potential intertwined relationships with the delicate balance of epiphytic orchid communities. Therefore, it is imperative to deepen our understanding of the factors influencing the epiphytic orchid community, including how orchid diversity is distributed on a host tree.

Turnover of species such as composition, abundance and diversity across the vertical gradient is one of the most commonly studied aspects of epiphytic plant ecology (Sanger and Kirkpatrick 2017; Parra-Sanchez and Banks-Leite 2020; Rahayu and Yusri 2022). Host tree conditions for epiphytes such as humidity, light radiation, substrate longevity, plant part for attachment (stem, branch, twig), bark rugosity, and water holding capacity are all likely to change with tree height (Sarmento et al. 2015; Zotz 2016). Such varying conditions result in vertical stratification patterns, with specific epiphytes associated with the different zones of the host tree (Zotz 2007). The most popular system of classifying host tree zonation was originally developed by Johansson (1974) for emergent trees in West African rainforests (Figure 2). This zonation scheme is based on the overall structure of the host tree, not on the absolute height (Zotz 2016).

Variations in the vertical community structure of epiphytic orchids may be influenced by the biophysical environment where the host tree is growing (Zotz 2016). The conditions of a host tree are also believed to influence the epiphytic orchid community. When a focal tree hosts epiphytic plants, the density of surrounding trees may also influence the community of epiphytic plants on that tree. According to a recent report, the density of trees surrounding the host tree negatively impacts epiphytic orchid abundance (Fardhani et al. 2021). However, the effect of the density of surrounding trees on the vertical structure of an epiphytic orchid community on a host tree remains unclear.

In addition to tree density, another factor that may influence the vertical community structure of epiphytic orchids is the topography of the area where the host tree stands. Topographic conditions, such as the aspect or the direction of the slope, have the possibility to affect the host tree. Several studies have revealed the effect of slope direction on tree growth (Lembrechts et al. 2018). In addition, host trees standing on slopes at different angles would grow differently because slope topography causes large-scale heterogeneity with respect to light (Getzin and Wiegand 2007). Thus, not only the direction but the slope angle of the host tree base can influence vertical variation in the diversity of epiphytic orchids.

Schima wallichii was focused on as a host tree species for epiphytic orchids in this study because several authors have mentioned this species as being favored as a host by epiphytic plants such as bryophytes, orchids, and ferns (Rai and Moktan 2023; Timsina et al. 2024). The authors chose this specific species for the study because it was dominant in the study site. *Schima wallichii* is an evergreen tree species found across subtropical and tropical zones at altitudes from 5 to 3300 m in Southeast Asia, the Himalayas, and East Asia (Koirala et al. 2021; Kumar et al. 2023). The diameter of trees of this species is up to 250 cm and the height is up to 45 m (Orwa et al. 2009).

In this study, we clarified whether the pattern of species richness of epiphytic orchids relative to a number of hosts or to increasing numbers of epiphytic orchids differ among orchid communities grouped into Johansson zones. We also determined the effects of host tree conditions on the community structures of these orchids in each Johansson zone. In doing so, we expected the results of this study might contribute to the enhancement of our knowledge about epiphytic orchid ecology for conservation efforts.

MATERIALS AND METHODS

Study period and area

The data for this study were collected from a protected forest managed by a state-owned forestry company (Perum Perhutani) in the Legok Jero area (6º48’41”S, 107º44’43”E) of Mt. Sanggara (1903 m asl), West Bandung District, West Java Province, Indonesia (Figure 1). The altitude at the study site is between 1656 m and 1724 m asl. The average annual temperature is 20.1ºC and annual rainfall is 2985 mm at Lembang, which is located about 20 km from the study site (en.climate-data.org 2023). The forest is dominated by evergreen broadleaved trees *S. wallichii* (Theaceae) along with other tree species such as *Sloanea sigun*, *Schefflera rugosa*, and *Castanopsis acuminatissima* (Fardhani et al. 2020). Much of the forest floor had been cleared for coffee plantation under the shade of large trees as a part of a community development program (Fardhani et al. 2015). However, the forest floor had become covered with shrubs by August 2018, having received no additional treatment. Data were collected from July 29th to August 7th, 2018.

Procedures

In an attempt to compare differences in the vertical distribution of epiphytic orchids, their occurrence on each host tree was allocated to one of five vertical zones, according to Johansson (1974, Figure 2). The five different levels of a tree's canopy are referred to as: Zone 1 (basal part of the trunk): the area from the ground to 1 meters above the ground; Zone 2 (trunk): the area from 1 meters above the ground to the first point of branching; Zone 3 (inner crown): the inner third of the branches in the crown; Zone 4 (mid crown): the middle third of the branches in the crown; Zone 5 (outer crown): the outer third of the branches in the crown (Sanger and Kirkpatrick 2017). However, Johansson Zone 1 was omitted from the analysis because no epiphytic orchid was found there.

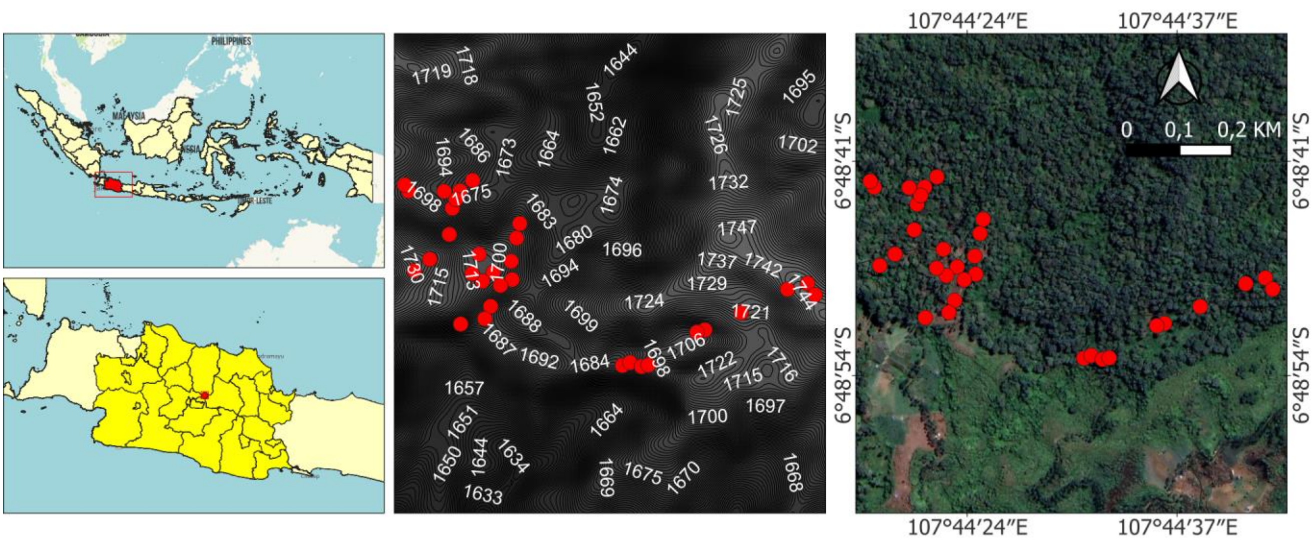

Figure 1. Map of the Legok Jero area, Mount Sanggara, West Java Province, Indonesia. The red points show the location of the sampled host trees and the contour interval is 1 m (Bakosurtanal 2001)

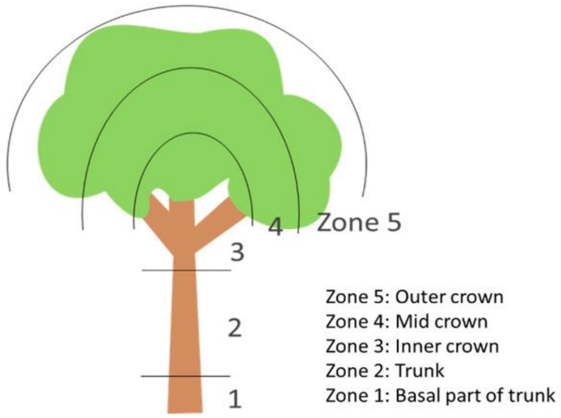

Figure 2. Zonation of epiphyte assemblage (Johansson 1974)

Numbers of species (species richness) and individuals (abundance) for epiphytic orchids attached to each host tree were recorded using both ground-based observation and the single rope technique (Taylor and Burns 2015; Bianchini et al. 2020; Mendieta-Leiva et al. 2020; Osie et al. 2022; Seto and Higa 2024). A team of 12 people participated in the field observation. We sampled 32 host trees where we climbed accessible trees using the single rope technique to estimate the presence of epiphytic orchids more accurately. However, we primarily observed epiphytic orchids from the ground with high-magnification photographs (20x magnification lens) and high-quality binoculars (12x magnification lens) as this was safer and faster. On average, it took 3-5 hours to investigate the epiphytic orchid community on each host tree. Each orchid specimen was later identified according to Comber (1990). Clumped or creeping plants were counted as one individual. To investigate the effect of the density of trees surrounding the host tree on epiphytic orchids, all trees within 20 m of each host tree with DBH greater than 20 cm were recorded by species name and DBH. The Angle of Slope (AS) and direction of slope (DS, or aspect) were measured at each host tree location using a Silva® compass and a Haglofs® Vertex III hypsometer. Each host tree was located at least 20 meters apart.

Data analysis

This study used the same dataset for epiphytic orchids with a previous study (Fardhani et al. 2021). Epiphytic orchid species diversity in each Johansson zone was calculated using the Shannon-Wiener index of diversity (H') shown below (Rohman et al. 2023; et al. 2024).

$$H' = -\sum_{i=1}^{s} (pi \ln pi)$$

Where, s is the number of species in the community, and pi is the proportion of total abundance represented by the i^{th} species. Later, ANOVA and Tukey's multiple comparison test were performed to test the difference in epiphytic orchid diversity in each Johansson zone on each host tree.

Ecologists have adopted methods collectively known as rarefaction when comparing species richness across different sites or time periods (Chao and Jost 2012; Shimadzu 2018; Kitagami et al. 2020; Kitagami and Matsuda 2022; Droissart et al. 2023). To compare the epiphytic orchid species richness among Johansson zones in *S. wallichii* trees, both sample-based and individual-based rarefaction curves were produced using the VEGAN package (Oksanen et al. 2013) in R version 3.3.0 (R Development Core Team 2016) in RStudio Version 1.0.136 (RStudio Team 2016). Generally, this curve rises relatively rapidly at first, then much more slowly for later samples ` increasingly rare taxa are added (Gotelli and Colwell 2001). If the curve becomes flatter to the right, a reasonable number of individual samples has been taken.

To test whether the epiphytic orchid communities in each Johansson zone were affected by host tree conditions, we performed PERMANOVA analysis. We generated a Non-Metric Multidimensional Scaling (NMDS) scatter plot based on the Bray-Curtis similarity index. All of the Direction of Slope (DS) data were transformed from azimuth to radian values (Power et al. 2018). Following Power et al. (2018), a sine-transformation was applied to the easterly direction using the formula sin (direction in radians) to produce an index for east and west or "eastness" (DS-east), and a cosine-transformation was then applied to the northerly direction with the formula cos (direction in radians) to produce a continuous index for north and south or "northness" (DS-north). The influence of factors such as host tree DBH, Density of Trees Surrounding Host Tree (DTSHT), Basal Area of Trees Surrounding Host Tree (BASHT) and host tree topographic conditions consisted of Angle of Slope (AS) and Direction of Slope (DS) was examined using the envfit function, conducting permutations 9999 times. These analyses were conducted using the VEGAN package (Oksanen et al. 2013) in RStudio. For all analyses, the significance level was set at $p<0.05$ unless otherwise stated.

RESULTS AND DISCUSSION

Accumulation of epiphytic orchids on *Schima wallichii*

The average DBH of host trees *S. wallichii* was 58.6 cm, DTSHT was 17.6 trees, and BASHT was 26.5 m^2/ha. For the host tree topographic conditions, the average AS was 19.8 degrees, DS-east was 0.25, and DS-north was -0.019 (Fardhani et al. 2021). From the survey, we found a total of 1329 epiphytic orchid individuals belonging to 35 species on 32 *S. wallichii* trees. The most abundant orchid species were *Coelogyne miniata*, *Bulbophyllum flavescens*, and *Eria multiflora* (Fardhani et al. 2021). The means of epiphytic orchid species richness and *H'* in each Johansson zone are shown in Figure 3. The average species richness and diversity of epiphytic orchids in Zone 2 was the lowest (Figure 3). Zone 3, 4 and 5 had higher means of species richness and H' than Zone 2. The growth conditions of epiphytic orchids can be visually seen in the Figure 4.

The curves of the accumulation of epiphytic orchid species in each Johansson zone against the number of host trees are shown in Figure 5. The asymptotes of curves were clearly seen to be approached as the number of host trees increased for every zone except Zone 3. Zone 3 showed the least accumulation, and its curve appeared not to converge to equilibrium, meaning that the number of species would still increase if there were more than 27 host trees (Figure 5). Although they only appeared on 11 host trees, epiphytic orchid species in Zone 2 were sampled mostly as the curve nearly reached a limit (Figure 5).

In this study, species richness of epiphytic orchids was clearly greater in the crown (Zone 3, 4 and 5) than on the trunk (Zone 2), according to the accumulation curves showing species richness against number of host trees (Figure 5) and abundance of epiphytic orchids (Figure 6). The average species richness and diversity of epiphytic orchids on trunks was low (Fardhani et al. 2020), indicating that these orchid species prefer the crown to the trunk for colonization. Only 11 of 32 host trees had epiphytic orchids on each trunk while most host trees had various species of epiphytic orchids on each crown. A study by Woods (2017) showed a clear separation of vascular epiphytic plant species between those from the tree base and those from the upper crown. However, these microhabitats are only meters apart. Richards et al. (2020) observed significant differences in accumulation of epiphytic orchid species richness between the trunk and crown of various host tree species in a tropical forest in Nicaragua. Crowns seem to accumulate more epiphytic orchid species than trunks because they have more microhabitats in which orchid species can thrive. The greater diversity of microhabitats in the host tree promotes epiphyte diversity including epiphytic orchids (Woods et al. 2015; Morales-Linares et al. 2022).

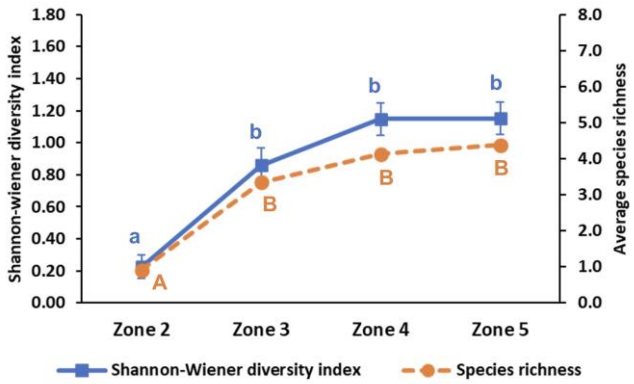

Figure 3. Mean of species richness per host tree and Shannon-Wiener diversity index per host tree for epiphytic orchids in four zones on *S. wallichii* trees at Mt. Sanggara, West Bandung District, West Java Province, Indonesia. Error bars represent SE (n: 32). Different letters indicate significant differences in the average value between the Johansson zones (one-way ANOVA with Tukey's multiple comparisons, $p<0.05$). Uppercase means species richness, lowercase means Shannon-Wiener diversity index

Figure 4. Epiphytic orchid clumps in Johansson Zones 2 (A), 3 (B), 4 (C), and 5 (D). The crown (Zones 3-5) has a denser clustering of orchids and other epiphytes (such as mosses, ferns, and lichens) compared to the trunk

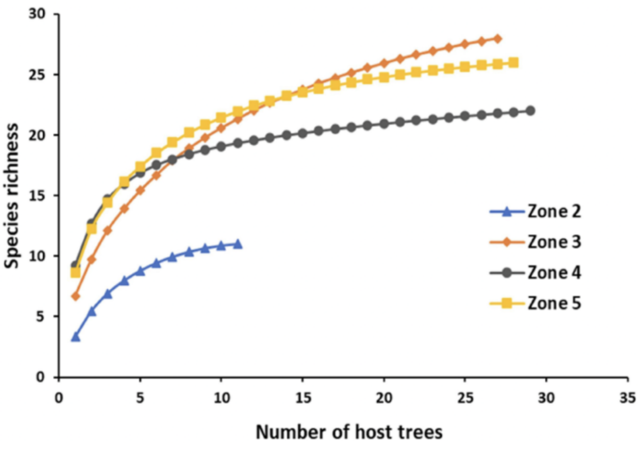

Figure 5. Accumulation curves showing the species richness of epiphytic orchids against the number of host trees *Schima wallichii*, classified by four different zones, in Mt. Sanggara, West Bandung District, West Java Province, Indonesia

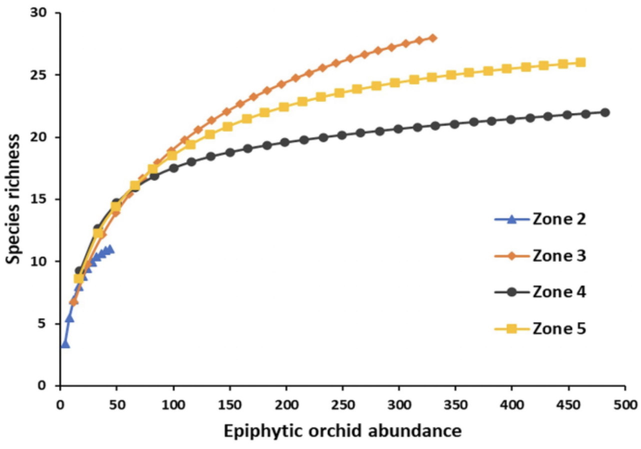

Figure 6. Accumulation curves showing species richness against the abundance of epiphytic orchids on *Schima wallichii* trees, classified by four different zones, in Mt. Sanggara, West Bandung District, West Java Province, Indonesia

The accumulation curves of species richness against the abundance of epiphytic orchids in each Johansson zone are shown in Figure 6. Unlike other zones, the number of epiphytic orchids sampled in Zone 2 was small, with only 44 individuals (Figure 6). Other zones had a considerably greater abundance of epiphytic orchids: 330 in Zone 3, 482 in Zone 4, and 461 in Zone 5 (Figure 6). It is difficult to judge whether the curve would have converged towards equilibrium for Zone 2 because it showed lower epiphytic orchid abundance compared with other zones. The three curves for Zones 3, 4 and 5 showed almost the same epiphytic orchid abundance, around 80. Over an abundance of 80, the increase in the rate of species richness greatly declined, in the order Zone 4, Zone 5 and Zone 3. The curve for Zone 4 most nearly plateaued of all crown zones (Figure 6). In contrast, the curve for Zone 3 did not converge to equilibrium with an epiphytic orchid abundance of 330.

Judging from the accumulation curve which showed low abundance and failure to reach an asymptote in Zone 2 (Figure 6), trunks cannot accommodate large numbers of epiphytic orchids. Thus only a few species with a few individuals of each were able to occupy the trunk (Figure 4). Furthermore, low light availability in a forest with dense and closed crown can promote the formation of straight trunks, which form poor-quality substrates for epiphytes (Werner et al. 2012; Hoeber and Zotz 2022). Straight trunks of host trees would therefore have lower species richness and abundance of epiphytic orchids than crowns. Crowns consist of many branches, whose number has a positive effect on epiphytic orchid species richness (Fardhani et al. 2020). Branches support epiphyte communities because they allow the accumulation of crown soil as a critical source of stored water (Taylor and Burns 2015; Ishii et al. 2018). Larger branches will accumulate more crown soil (Murray et al. 2023). Besides crown soil, other substrates, such as mosses and ferns growing on the branches, are also important for the growth of epiphytes (Komada et al. 2024). These results support previous studies. An epiphytic plant needs a certain range of conditions to grow. Based on several studies, the suitable conditions for epiphytic orchids may vary, although several characteristics of the host tree are generally suitable for epiphytic orchid growth. Several intrinsic factors including variation in tree size, tree architecture, bark characteristics, crown soil chemistry, bark texture and physicochemistry affect the variation of epiphytic plant communities on a host tree (Taylor and Burns 2015; Fardhani and Kisanuki 2019; Hidasi-Neto et al. 2019). Extrinsic factors including local light and microclimatic conditions at the host tree (Baker et al. 2014) and surrounding tree density (Fardhani et al. 2021) also affect the epiphytic plants abundance including epiphytic orchid. Generally, host tree with larger size and more branches will likely host more species and greater number of epiphytic orchids (Fardhani et al. 2021).

The effect of Angle of Slope (AS) on epiphytic orchid composition

Based on analysis using PERMANOVA, there was a significant difference in epiphytic orchid communities between zones (R^2: 0.0526, Pr(>r): 0.0085). The results of NMDS analysis showed an overlap in species composition among all Johansson zones (Figure 7). In particular, the epiphytic orchid community structures in the three crown zones were very similar, as shown by the overlapping ranges of points. Among the six variables measured for the host tree conditions, only AS showed a significant correlation (p<0.05) with epiphytic orchid community structures although clear relations were not detected (Table 1).

No clear difference in species richness of epiphytic orchids between crown layers was detected (Figures 5 and 6) in this study, though the mid-crown (Zone 4) has been reported to support the highest species richness of vascular epiphytes in previous studies (Steege and Cornelissen 1989; Nieder et al. 2001). The community structures of epiphytic orchids in the crown layer (Zone 3, 4, and 5) were not distinct from one another (Figure 7). In addition, the species richness accumulation curves almost overlapped among the three crown zones (Figure 5) although more host trees were needed for the curve to flatten in the case of Zone 3. In contrast, the epiphytic orchids in Zone 4 required smaller numbers of host trees to reach the upper limit. Branches connected to the trunk in Zone 3 will be thicker than those in Zone 4 and 5, meaning that Zone 3 will have the potential to supply more habitats for epiphytic orchids than Zone 4 and 5.

In the previous report for epiphytic orchid communities per host tree, the Density of Trees Surrounding Host Tree (DTSHT), and the Direction of Slope (DS) north affect the abundance of the epiphytic orchid on *S. wallichii* at the study site as it may prevent sunlight from reaching epiphytic orchids and thus adversely affect photosynthesis (Fardhani et al. 2021). However, in this study, the environmental factors measured, such as DTSHT and the direction of slope (both DS-east and DS-north), did not drive the vertical structure of the community significantly at the study site. Only the host tree Angle of Slope (AS) significantly drove the vertical structure of the epiphytic orchid community (Figure 7). The incident radiation levels are likely to be higher in the upper compared to the lower part of the host tree (Murakami et al. 2022). Furthermore, the steeper slope might even further shelter the lower part of the host tree and drive the difference in the vertical structure of epiphytic orchid community. Thus, the community structures of epiphytic orchids were characterized by topographical condition of host tree stands.

The average AS for 24 *S. wallichii* trees which stand on flatter sites was 12.7°, categorized as gentle to moderate slopes (Anbalagan et al. 2008; Kainthola et al. 2021), while the remaining eight trees were located on moderate to very steep slopes with an average AS of more than 26°. Besides local neighbourhood interactions (i.e. biotic factors), light conditions are affected by abiotic factors such as topography, including slope steepness, which can influence the intensity of sunlight (Lang et al. 2010). This may be the case at the study site, part of which is steeply sloping. This result is in line with other studies on epiphytic orchid community in Himalaya (Hussain et al. 2024) and epiphytic lichen community in Türkiye (Sevgi et al. 2019) that are affected by aspect and slope where the host tree stands. Furthermore, the difference in light intensity will affect the microclimate within the Johansson zones (Elias et al. 2024). Further study is needed in order to clarify the relationship between slope angle and light intensity received by each host tree in order to gain an understanding of how this site factor may regulate the community structure of epiphytic orchids. By determining the effects of host tree conditions on orchid community structures, the study sheds light on the intricate relationships between orchids and their environment. This knowledge is essential for identifying priority areas for conservation and implementing targeted interventions to mitigate the impacts of habitat degradation, deforestation, and climate change on epiphytic orchids.

Table 1. The environmental fitting against the epiphytic orchid community

Variable	R^2	**Pr(>r)**
DTSHT	0.0203	0.39
BASHT	0.0205	0.39
AS	0.0748	0.03*
DBH	0.0139	0.53
DS East	0.0089	0.67
DS North	0.0325	0.22

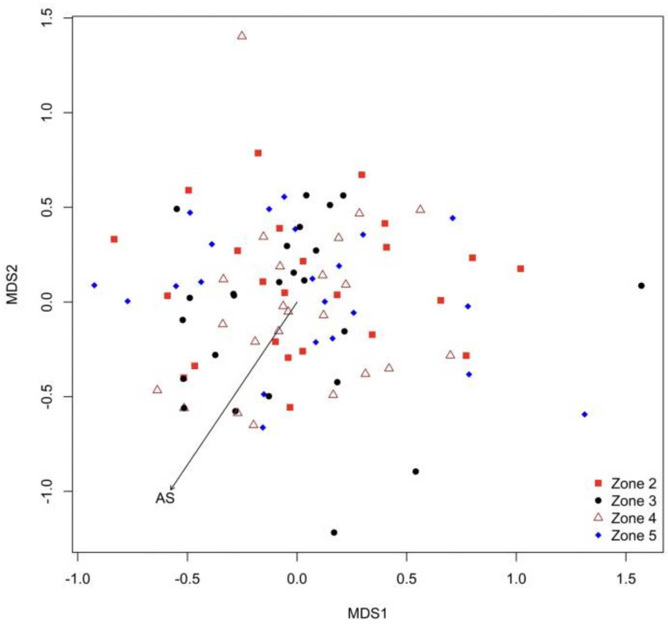

Figure 7. Non-metric multidimensional scaling (NMDS) analysis of Bray-Curtis similarity index of epiphytic orchid community structures (stress value: 0.17). Closer points indicate more similar community structures. There were significant differences of epiphytic orchid communities between zones (PERMANOVA, R^2: 0.0526, Pr(>r): 0.0085). One environmental factor (arrowed; AS, host tree angle of slope) represented a significant driver of community structures (envfit, permutation: 9999, p<0.05)

Our results have implications in terms of conservation. The number of total of 1329 epiphytic orchid individuals belonging to 35 species on only 32 *S. wallichii* trees shown the importance of this phorophyte conservation for maintaining the abundance of epiphytic orchids. Furthermore, our study makes a genuine contribution to how epiphytic orchids colonize host trees. This study provides additional information about the accumulation of epiphytic orchid species on a host tree species. Crowns of *S. wallichii* accumulated more species of epiphytic orchids than did trunks because crowns contain many branches making it easier for these orchids to attach compared with straight trunks. On the basis of the accumulation curve, Zone 3 had the most potential for many kinds of epiphytic orchids to colonize, probably because it had larger branches than the other crown zones. This study also reported that the vertical community structures of epiphytic orchids on *S. wallichii* trees were not clearly segregated among zones. Understanding how orchid diversity is distributed across different zones within host trees can inform conservation strategies aimed at preserving key habitats and protecting critical ecological niches.

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