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Diversity of Ferns and Fern Allies Across Elevation and Aspect in Rukum, Nepal

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Abstract

Fern and fern allies are the group of non-flowering vascular plants that are playing an important role in ecosystem structure and functioning. In this research we aimed to compare the diversity of ferns and their allies between northern and southern aspects along the elevational gradient of eastern Rukum, Nepal. Total 160 quadrats, each measuring 5 m × 5 m were laid using purposive sampling at each elevational band to cover all possible vegetation habitats. A total of 50 species of ferns and fern allies under 32 genera and 14 families were recorded. Species richness was recorded highest around 2000 m above sea level, indicating a mid-elevation diversity peak. The southern aspect of hill supported higher diversity with 41 species, compared to the northern aspect, which had 33 species. This diversity difference suggests that microclimatic variations between two aspects of hill. Similarly, species evenness was peaked at around 2200 m asl., while both species richness and evenness declined above 2300 m likely indicates the effects of extreme climatic conditions and reduced habitat suitability. These results therefore show the importance of this less explored mountain region for future botanical exploration.

Keywords: *Aspect and vegetation, Central Himalaya, Plant diversity, Pteris wallichiana, Vegetation sampling*

Introduction

Pteridophytes are the most primitive seedless vascular plants, appeared around 400 million years ago during the silurian period of the palaeozoic era. They are subsequently diversified and become a dominant component of earth vegetation between the devonian and permian periods (Pires & Dolan, 2012; Fraser Jenkins et al., 2015). This group of plants represent an important evolutionary linkage between non-vascular bryophytes and seed-bearing vascular plants. Globally, there are approximately 12,000 species of pteridophytes, of which about 97% are true ferns and the remaining 3% are fern allies or lycophytes (WCMC, 1992; PPG I, 2016). In Nepal, around 550 species and 30 subspecies making a total of 580 taxa of pteridophytes are recorded which highlights the rich floristic diversity of Nepal (Fraser Jenkins et al., 2015; Rajbhandary, 2016; Kandel, 2020).

Various factors including climatic and environmental variables strongly influence the species richness along elevation gradients, a pattern well-documented across a wide range of taxa (Körner, 1999; Whittaker et al., 2001; Chataut et al., 2025). Pteridophytes, which are highly sensitive to microclimatic variations show particularly strong responses to such environmental factors. Among these, moisture is considered the most critical determinant of their distribution and diversity (Young & León, 1991; Kessler, 2001; Bhattarai et al., 2004). Adequate moisture availability is essential for most of the pteridophytes for physiological activities, spore germination and gametophyte development.

In local level moisture availability of vegetation habitat is significantly affected by the aspect or orientation of hills. In general, southern slopes in the Himalayas receive more solar radiation leading to increased temperatures and higher rates of evapotranspiration. While, this may favor certain drought-tolerant species, it can also lead to moisture stress for many pteridophytes. In contrast, northern aspects are relatively cooler and retain moisture for longer periods which creates a more stable and favorable microhabitat for a wider range of fern species. This interaction between moisture, temperature and aspect results in distinct community compositions and species richness across slopes (Körner, 1999; Bhattarai et al., 2004; Fraser Jenkins et al., 2015).

Therefore, both elevation and aspect of hills together play a significant role in determining pteridophyte diversity and distribution patterns. Understanding these environmental variables is essential for the interpretation of distribution patterns and predicting the potential impacts of climate change on mountain plant communities, particularly in sensitive ecosystems like the central Himalayas (Panthi et al., 2007; Mendez- Toribio et al., 2016; Thapa et al., 2023). In addition to their ecological significance, many pteridophyte species have been valued for their medicinal properties. Species such as *Pteridium aquilinum*, *Dryopteris sp., Adiantum capillus-veneris, Adiantum philippense*, and *Selaginella moellendorffii* are traditionally used in herbal remedies for treating a variety of human and animal ailments (Parihar & Parihar, 2006; Sen & Ghosh, 2011; Sathiyaraj et al., 2015; Rajbhandary, 2016). This study aimed to collect herbarium, document and compare the diversity of ferns and fern allies along the elevational gradient and hill aspects of eastern Rukum, Nepal.

Materials and Methods

Study Area

The study area is located in Bhume Rural Municipality-09, Chunwang, Rukum East, which lies between latitudes/longitudes 28°37′99″ N/82°37′60″ E and 28°36′59.99″ N/82°36′59″ E, covering an area of 1161.13 sq. km. This study area covers the part of four community forests, namely: Sijakhola CF, Mulpani Sukadhara CF, Mulko Thuma CF, and Ghobisada CF. The elevation of the study area ranges from 1600 m asl to 3100 m asl **(Figure 1)**. The study area, based on 30 years (1989–2018) climatic data obtained from Musikot station (2100 m asl), exhibits a temperate climate with distinct seasonal variations. Mean maximum temperatures ranged from 20°C to 35°C, peaking in May and June, while mean minimum temperatures varied between 5°C and 20°C, with the lowest values in January and December. Rainfall predominantly occurred from June to August, with July and August receiving the highest precipitation. The average annual rainfall was approximately 1800 mm (DHM, 2019).

Vegetation distribution followed an altitudinal gradient. Lower elevations (1500–1800 m) supported *Pinus roxburghii* forests, with understory species like *Berberis aristata*, *Rubus ellipticus*, and *Thysanolaena latifolia*. Mid-elevations (1800–2500 m) featured mixed *Quercus* forests with species such as *Q. semecarpifolia*, *Rhododendron arboreum*, *Lyonia ovalifolia*, and *Juglans regia*. Upper regions (>2500 m) hosted *Quercus–Juniperus* forests. Diverse angiosperm shrubs and herbs were found throughout the area. Notably, the invasive species *Ageratina adenophora* was widespread. Ground vegetation included dominant herbs like *Bidens pilosa*, *Artemisia* sp., and *Cynodon dactylon*. Common medicinal plants included *Swertia chirayita*, *Dactylorhiza hatagirea*, and *Zanthoxylum armatum*, reflecting rich floristic and ethnobotanical value across the elevational zones.

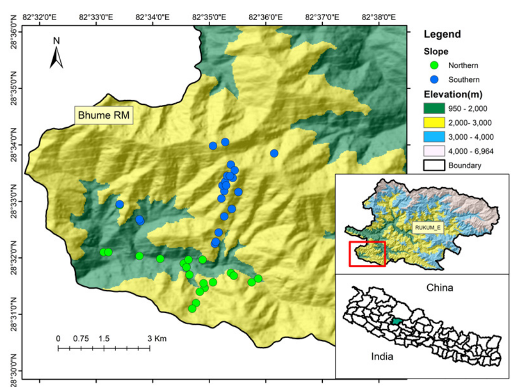

Figure 1. *Map of the study area; Rukum east district of Nepal showing sample plots (green and blue dots) in Bhume rural municipality.*

Vegetation Sampling

Field visit was conducted in October-November 2018 for data collection. Sample plots measuring 5 m × 5 m were laid to collect vegetation data. In the northern aspect, sampling started from the lowest available elevation (1600 m asl) up to the highest peak (2400 m asl), and in the southern aspect, from 1700 m asl to 2900 m asl. At least five quadrats were laid at 100 m elevation intervals.

Altogether, 160 quadrats were laid, 64 in the northern aspect and 96 in the southern aspect. All vegetation and plot characteristics were recorded. Unequal sample size in two aspects was due to the difficult terrain of the hill. Herbarium specimen collection and photographs were taken for further confirmation.

Plant Identification

Most of the plant species were identified in the field using field guidebooks such as Fern and Fern Allies of Nepal (Fraser-Jenkins et al., 2015) and Fern and Fern Allies of Nepal (Fraser-Jenkins & Kandel, 2019). The unidentified specimens were verified in the National Herbarium, Godawari (KATH).

Vegetation Analysis

Species richness was determined by the count of species present in the sample plots, Importance Value Index (IVI) was determined following Zobel et al. (1987). For the comparison of species diversity Simpson and Shannon index were measured (Shannon & Weaver, 1949; Simpson, 1949; Kumar et al., 2022). Simpson index measures the probability that two individuals randomly selected from a sample belong to the same species, its value ranges from 0 to 1 which means value closer to 1 indicates low diversity (high dominance), while a value closer to 0 indicates high diversity. Similarly, Shannon index (H) measures the uncertainty of predicting the species identity of an individual chosen at random. High Shannon diversity means many species, evenly distributed. Sorensen similarity index (Sorensen, 1948) was also determined to compare the fern richness in two aspects. Its value ranges from 0 to 1 or 0-100%. Higher the value higher the similarity in species richness between sites.

Data Management and Analysis

Microsoft Excel was used to manage and analyze the data. Various descriptive statistical tools were applied to compare the species diversity between aspects and elevations. Bar graphs and tables were presented to compare the species richness, diversity and importance value index (IVI). Scatter diagram was used to compare the distribution pattern of species richness with elevation. Species diversity along the elevation was compared in two ways: first, the number of species present within each 100 m interval was recorded, creating 8 intervals in the northern aspect and 12 intervals in the southern aspect; these were then regressed against elevation.

Results

Species Diversity

A total of 50 species of pteridophytes belonging to 14 families and 32 genera were recorded, among which 41 species were present in the southern aspect and 33 species in the northern aspect.

Table 1: *List of recorded fern and fern allies in the study area*

SN	Name of species	Family
1.	*Asplenium dalhousieae* Hook.	Asplenaceae
2.	*Asplenium ensiforme* Wall. *ex* Hook. and Grev	Asplenaceae
3.	*Asplenium yoshinagae* Makino subsp. *indicum* (Sledge) Fraser-Jenk.	Asplenaceae
4.	*Woodwordia unigemmata* (Makino) Nakai	Bleachaceae
5.	*Katoella pulchra* (D.Don) Fraser-Jenk, Kandel & Pariyar	Davilllaceae
6.	*Pteridium revolutum* (Blume) Nakai	Dennstadtiaceae
7.	*Dryopteris corolihopei* L.	Dryopteridaceae
8.	*Dryopteris chrysocoma* (Christ) C.Chr.	Dryopteridaceae
9.	*Tectaris coadunanta* Fraser-Jenk	Dryopteridaceae
10.	*Polystichum squarrosum* (D.Don) Fée	Dryopteridaceae
11.	*Polystichum discretum* (D.Don) J.Sm.	Dryopteridaceae
12.	*Peranema cyatheoides* D.Don	Dryopteridaceae
13.	*Polystichum obliquum* (D.Don) T.Moore	Dryopteridaceae
14.	*Crytomium anomophyllum* (Zenker) Fraser-Jenk.	Dryopteridaceae
15.	*Dryopteris* sp.	Dryopteridaceae
16.	*Equisetum arvense* L. subsp. *diffusum* (D.Don) Fraser-Jenk.	Equisetaceae
17.	*Lindsaea odorata* Roxb.	Lindsaeceae
18.	*Huperzia hamiltonii* (Spreng.) Trevis.,	Lycopodiaceae
19.	*Huperzia pulcherrima* (Wall. *ex* Hook. & Grev.) Pic.Serm.	Lycopodiaceae
20.	*Lycopodium japonicum* L.	Lycopodiaceae
21.	*Oleandra wallichii* (Hook.) C.Presl	Oleandraceae
22.	*Botrychium lanuginosum* Wall. *ex* Hook. & Grev.	Ophiglossaceae
23.	*Arthromeris moulmeinensis* (Bedd.) Fraser-Jenk	Polypodiaceae
24.	*Arthromeris* sp.	Polypodiaceae
25.	*Drynaria mollis* Bedd.	Polypodiaceae
26.	*Goniophlebium argutum* (Wall. *ex* Hook) Bedd.	Polypodiaceae
27.	*Loxogramme involuta* (D.Don) C.Presl	Polypodiaceae
28.	*Pichisermollodes quasidivaricata* (Hayata) Fraser-Jenk.	Polypodiaceae
29.	*Polypodiodes henderronii* (Epiphyte)	Polypodiaceae
30.	*Pyrrosia costata* (C.Presl) Tagawa & K.Iwats	Polypodiaceae
31.	*Adiantum capillus*-veneris L.	Pteridiaceae
32.	*Adiantum philippense* L. subsp. *Philippense*	Pteridiaceae
33.	*Adiantum venustum* D.Don	Pteridiaceae
34.	*Aleuritopteris bicolor* (Roxb.) Fraser-Jenk.	Pteridiaceae
35.	*Aleuritopteris albomarginata* (C.B.Clarke) Ching	Pteridiaceae
36.	*Nothalaena himalaica* Fraser-Jenk	Pteridiaceae
37.	*Hemionitis sp.* (Hook.) Fraser-Jenk.	Pteridiaceae
38.	*Onychium lucidum* (D.Don) Spreng	Pteridiaceae
39.	*Pteris aspericaulis* Wall. *ex* J. Agardth	Pteridiaceae
34.	*Pteris cretica* subsp. *cretica*. L	Pteridiaceae
41.	*Pteris terminalis* (Wall *ex* J.Agardha)	Pteridiaceae
42.	*Pteris vittata* L.	Pteridiaceae
43.	*Pteris wallichiana* J.Agardh	Pteridiaceae
44.	*Selaginella chrysocaulos* (Hook. & Grev.) Spring.	Sellaginceae
45.	*Selaaginella subdiaphana* (Wall. *ex* Hook. & Grev.)	Sellaginaceae
46.	*Telypteris dentata* (Forssk.) E.P.St.John	Thelypteridaceae
47.	*Thelypteris sp.* (Wall. *ex* Hook.) Ching	Thelypteridaceae
48.	*Deparia boryana* (Willd.) M.Kato subsp. *Boryana*	Woodsiaceae
49.	*Diplazium longifolium* T.Moore	Woodsiaceae
50.	*Diplazium maximum* (D.Don) CS.Chr.	Woodsiaceae

Thirty species were common to both aspects showing Sorensen similarity index 0.82. Among the families Pteridaceae was the largest with twelve genera and thirteen species, followed by Dryopteridaceae with five genera and nine species. Blechnaceae, Davalliaceae, Equisetaceae, Dennstaedtiaceae, Ophioglossaceae, and Oleandraceae were other families represented by a single species each. Regarding genera, *Pteris* was the largest with five species, while *Dryopteris* and *Polystichum* had three species each **(Table 1)**.

Out of 50 species recorded, ten species were present only in the southern aspect viz., *Thelypteris dentata*, *Pteris aspericaulis*, *Arthromeris* sp., *Hemionitis* sp., *Pteris cretica, Polystichum obliquum, Huperzia pulcherrima, Katoella pulchra, Tectaria coadunata*, and *Lindsaea odorata*, while three species namely *Cyrtomium anomophyllum*, *Pteridium revolutum*, and *Dryopteris chrysocoma* were present only in the northern aspect. The Importance Value Index (IVI) was used to determine dominant fern and fern ally species where *Selaginella chrysocaulos* ranked highest overall with an IVI of 46.94 and was the most dominant in both the southern (43.46) and northern (41.73) aspects. *Equisetum arvense* (34.40) and *Hemionitis* sp. (25.26) also showed high ecological significance. Southern slopes favored species like *Oleandra wallichii* (30.70) and *Drynaria mollis* (14.90), while northern slopes had higher IVI for *Asplenium ensiforme* (11.72) and *Adiantum capillus-veneris* (7.65), reflecting aspect-driven species dominance patterns **(Table 2)**.

Table 2: *Important Value Index (IVI) of top 10 fern and fern allies species in the study area*

SN	Overall study area	Southern aspect	Northern aspect
1.	*Selaginella chrysocaulos* (46.94)	*Selaginella chrysocaulos* (43.46)	*Selaginella chrysocaulos* (41.73)
2.	*Equisetum arvense* (34.40)	*Oleandra wallichii* (30.70)	*Equisetum arvense* (33.59)
3.	*Hemionitis* sp. (25.26)	*Hemionitis* sp. (29.62)	*Hemionitis* sp. (14.98)
4.	*Oleandra wallichii* (24.14)	*Equisetum arvense* (29.35)	*Oleandra wallichii* (11.44)
5.	*Adiantum philippense* (14.49)	*Drynaria mollis* (14.90)	*Asplenium ensiforme* (11.72)
6.	*Drynaria mollis* (14.05)	*Adiantum philippense* (13.55)	*Drynaria mollis* (10.21)
7.	*Polypiodes hendersonii* (13.01)	*Polypiodes hendersonii* (13.38)	*Polypiodes hendersonii* (9.97)
8.	*Polystichum discretum* (10.87)	*Dryopteris carolihopei* (11.87)	*Adiantum capillus-veneris* (7.65)
9.	*Asplenium ensiforme* (8.86)	*Polystichum discretum* (8.72)	*Lycopodium japonicum* (7.56)
10.	*Aleuritopteris albomarginata* (8.82)	*Asplenium ensiforme* (5.00)	*Pteris vittata* (8.58)

Diversity Indices

Simpson's index (D) and Shannon–Wiener index (H′) of ferns and fern allies were compared across three elevational bands. In the southern aspect, Simpson's index indicated the highest species diversity (D = 0.86) at the lower elevational band and the lowest species diversity (D = 0.68) at the higher elevational band. In contrast, in the northern aspect, the highest species diversity (D = 0.83) was recorded at the higher elevational band, while the lowest species diversity (D = 0.64) was observed at the mid-elevational band. Similarly, the Shannon–Wiener index showed the highest species diversity and evenness (H′ = 2.35) at the lower elevational band in the southern aspect, whereas in the northern aspect, the highest species diversity and evenness (H′ = 2.27) were recorded at the mid-elevational band **(Figure 2)**.

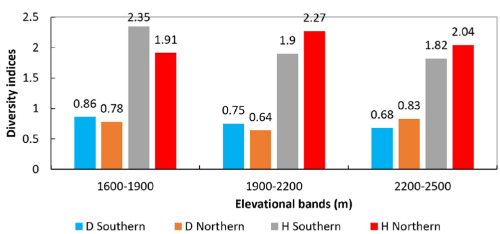

Figure 2: *Diversity indices of fern and fern allies at different elevational bands.*

Species Richness and Elevation

Diversity of ferns and fern allies was affected by both aspects and elevation in the study area. The richness was low at lower elevations in both aspects and species richness increased with elevation reaching a maximum around 2000 m showing unimodal species distribution pattern. However, the pattern is unimodal the relationship is statistically insignificant (**Figure 3** and **4**). In northern aspect peak species richness was recorded at (2100 - 2200 m). Similarly, in the southern aspect, peak species richness was recorded at (1900 - 2000 m) **(Figure 3)**. The overall diversity of fern and fern allies in the northern and southern aspects are correlated with various biotic and abiotic factors but statistically insignificant.

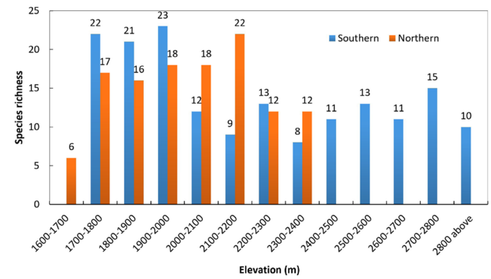

Figure 3: *Species richness of fern and fern allies at 100 m elevational interval in northern and southern aspects.*

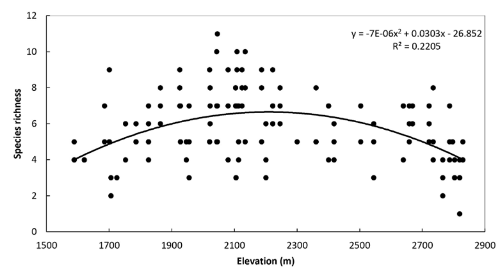

Figure 4: *Fern and fern allies species richness pattern along the elevational gradient in the study site.*

Discussion

The study area, Rukum district of Nepal was rich in fern and fern allies, with greater number of species on southern aspect than on northern aspect; however, the difference was not statistically significant. Species richness reached maximum around 2000 m asl, supported the general pattern of mid-elevation peak richness of ferns and fern allies in Nepal Himalaya. This pattern also suggests that intermediate elevations provide relatively favorable environmental conditions, including suitable moisture, temperature and canopy cover for pteridophyte establishment. The present findings are not consistent with Panthi et al. (2007) and Singh (2018), who reported higher species richness on northern aspects in the Himalayas, because northern slopes generally provide more favorable conditions for fern growth through greater moisture retention, dense canopy closure, reduced solar radiation and short durations of direct sunlight. The contrasting pattern observed in the present study may be related to the relatively narrow elevational range sampled on the northern aspect (1600–2400 m compared with 1700–2900 m on the southern aspect), together with its steep terrain and limited accessibility which may have restricted sampling coverage and habitat representation. Parker (1991) and Singh (2018) reported that landscape aspect regulates the quantity and duration of important abiotic factors such as soil moisture, temperature and rainfall which influence species diversity and distribution. Among these factors moisture availability has been reported as the most influential determinant of pteridophyte diversity (Kessler, 2001; Bhattarai et al., 2004). Mountain landscape aspect strongly influences moisture availability by affecting solar radiation, evaporation and local microclimatic conditions (Panthi et al., 2007; Thapa et al., 2023; Nettesheim et al., 2014). Likewise, Landeros-López et al. (2025) reported the fern species diversity and morphological characteristics are strongly affected by microclimatic variables particularly variations in light intensity and duration, further correlates the importance of local habitat conditions in determining fern vegetation dynamics.

Diversity indices of pteridophytes in the study area including the Simpson Diversity Index (D) and Shannon–Wiener Index (H′), provide valuable measures of both richness and evenness within the habitat. In northern aspect, the highest species diversity (D = 0.83, H = 2.04) was recorded at upper elevational band (2200–2400 m), whereas relatively lower diversity in the mid-elevational band was likely due to its proximity to residential areas and greater anthropogenic disturbance. Such disturbances can alter natural habitat, reduce heterogeneity of habitat landscapes and decrease species evenness, as discussed by Kumar and Ram (2005). In contrast the southern aspect exhibited highest species diversity (D = 0.86, H = 2.35) in the lower elevational band, which can be related to the presence of shaded habitats, greater water availability and relatively lower levels of disturbance which is consistent with the observations of Körner (1999) and Salazar et al. (2015). Lower diversity in the middle and upper elevational bands of the southern aspect may reflect reduced moisture availability, increased exposure and greater levels of disturbance, all of which can limit the establishment and distribution of moisture-dependent fern species. These findings indicated that, in addition to elevation local habitat characteristics and disturbance regimes play an important role in determining fern diversity across mountain landscapes.

The Sørensen similarity index shows that approximately 82% similarity between the northern and southern aspects which suggests a large proportion of fern and fern allies were shared between the two slopes of the mountain. This high similarity indicates that despite differences in aspect and elevation both slopes provide broadly comparable ecological conditions for many species. Similar levels of moisture, shade, temperature and other microclimatic conditions across both aspects may have contributed to this high degree of species overlap (Körner, 1999; Chaudhary et al., 2016). In addition, the presence of the same underlying bedrock across the mountain likely resulted in similar soil development, nutrient availability and substrate characteristics, thereby supporting comparable vegetation composition and creates suitable habitats for many of the same pteridophyte species. The high species similarity also suggests that local environmental conditions may be sufficiently homogeneous to support a common fern flora across the study area.

The distribution pattern of fern and fern allies in the study area generally followed a unimodal pattern with maximum species richness occurring around 2000 m asl. Although this trend was not statistically significant, it is consistent and suppports the widely reported mid-elevation richness pattern of vascular plants in the Nepal Himalaya (Bhattarai, 2004; Chaudhary et al., 2016). Similar elevational patterns have been documented in other mountain regions, where plant species richness increases with elevation up to an intermediate peak before declining at higher elevations. Hortal et al. (2013) reported that plant species richness often decreases beyond an elevational optimum, whereas Bhattarai and Vetaas (2004) found that no significant relationship between species richness and elevation in certain Himalayan landscapes. Likewise, Dorji et al. (2018) reported that species richness generally increases up to a particular elevation but is strongly influenced by multiple biotic and abiotic factors. Therefore, they suggest that elevation only is insufficient to explain patterns of fern diversity; species richness is further shaped by the combined influence of environmental gradients, habitat heterogeneity, microclimatic conditions, local disturbances and other inter-related biotic and abiotic factors that determines the complex Himalayan environment.

Conclusion

In this study we explored the diversity and distribution patterns of pteridophytes along the elevational and aspects of central Nepal

Himalaya. Total 50 pteridophyte species under 14 families and 32 genera were recorded. Southern aspect supported 16% more species than on the northern aspect. *Selaginella chrysocaulos*, *Polystichum discretum*, and *Adiantum capillus-veneris* were the dominant pteridophyte species in the study area. The species richness of fern and fern allies peaked at around 2000 m asl., which supports the widely reported mid-elevation peak vascular plant diversity in Nepal Himalaya. These findings therefore highlight the role of hill aspect and elevation on pteridophyte diversity and distribution. However to generalize these findings, future studies with additional study sites, broader elevational ranges and larger sample plots across different aspects are recommended.

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Author's Contribution

CB: Data collection and management, Formal analysis, Visualization, Writing – review & editing. **KP:** Writing – review and editing, Supervision**. KPS**: Conceptualization, Methodology, Writing – review & editing, Supervision.

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.

Data Availability

Data will be made available on request.

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