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# Influence of aspect on vegetation dynamics: insights into the understory vegetation diversity of the dry temperate forests of South Waziristan Agency, Pakistan

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The dry temperate forests of Pakistan exhibit rich diversity of understory floral species. These important and endemic plant species play a pivotal role in ecosystem functioning and providing livelihoods to the forest communities. South Waziristan, located in the southwest of Pakistan, is known for its rare pure stands of *Pinus gerardiana* Wallich ex. D. Don forests. The rapidly expanding population and current state of affairs are leading to deforestation and causing disturbance to the understory vegetation of this valuable forest. The current study aims to fill the currently scanty information present in the literature regarding the diversity status of understory vegetation in *P. gerardiana* forests. Data of understory vegetation diversity were gathered for the northern and southern aspects of the forest. A 50 m<sup>2</sup> sampling plot along with the placement of fifty 1x1m<sup>2</sup> quadrats on both sites were laid out to determine species dominance, diversity, and evenness using Simpson, Shannon, Marglef, and Buzas–Gibson indices. The study depicted 612 individuals of about 29 species representing 23 families from the study site. The most abundant species in all of the sites was *Salvia Glutinosa* cccIV = 0.52. The southern aspect depicted the lowest diversity, but had high species dominance. *Allium carolinianum* DC. in this site was the most important species (IV = 0.74). The most abundant species were medicinal plants (75%), followed by edible plants (25%). Aspect had a significant effect on the understory vegetation and different categories of plants with respect to their diversity, dominance, and evenness as predicted by the various diversity indices. This study provides essential insight into the floristic diversity and community structure of the fragile pine nut understory vegetation in South Waziristan, which was hitherto not available. It was concluded that the southern aspect of understory dry temperate forests depicted lower diversity and density as compared with the northern aspect. But it was observed that the southern aspect more specifically had more density and diversity of medicinal plants. It is therefore the need of the hour that conservation of these species from grazing and unsustainable harvesting must be ensured to sustain the livelihood of the inhabitants.

## KEYWORDS

understory vegetation, diversity indices, medicinal plants, aspect vegetation diversity, *Pinus gerardiana*

## 1. Introduction

Majestic conifers around the world mostly occupy temperate, boreal, and subtropical climates (1). Global populations of these long-lived species are facing serious threats to their existence mostly due to anthropogenic activities and climate change (2). Among these conifers, *Pinus gerardiana* Wallich ex. D. Don forests are extremely important. They are native to the Western Himalayas and are distributed in eastern Afghanistan, southern Xizang (Tibet) in China, Jammu and Kashmir in India, and northern Pakistan (Shalizi et al., 2018; Urooj, 2019). These forests are extremely valuable, having key socioeconomic importance. However, rapid exploitation of these forests is gradually leading them toward extinction from their original habitat (Urooj and Jabeen, 2015; Aziz et al., 2018; Shalizi et al., 2018). Globally, *P. gerardiana* forests are native to South East Asia, West Asia, and in the states of Central Asia (Shalizi and Khurram, 2016; Urooj, 2019). Pakistan is home to one of the largest *P. gerardiana* forest stands in the world (Print et al., 2015; Urooj and Jabeen, 2015; Urooj et al., 2020). These forests are extensively located in the Sulieman and Hindu Kush mountain ranges in the west (Khyber Pakhtun Khwa and Baluchistan) and north (Kashmir and Gilgit Baltistan) of the country (Print et al., 2015; Urooj and Jabeen, 2015; Urooj, 2019). *P. gerardiana* forests are major economic players in the region, generating a hefty revenue of 13 million USD annually (Haq et al., 2013; Print et al., 2015; Urooj, 2019). These forests are responsible for sustaining rural livelihoods in the form of employment and businesses (Shalizi et al., 2018; Alami and Mousavi, 2020; Rahimzadeh, 2020; Urooj et al., 2020; Alami and Mousavi, 2021). Forest understory vegetation is regarded as an ecological indicator due to its quick response to changing environmental conditions (Von Oheimb and Härdtle, 2009). As such, understory vegetation can serve as an important indicator of species composition in a forest. The understory layer is known to affect the establishment, survival rate, and adaptability of plant species, including soil physicochemical properties such as nutrient content, pH, and moisture (Dzwonko and Gawroński, 2002; Tinya et al., 2009). Understory medicinal plant species are an important component of forest communities' livelihood, playing a vital role in providing subsistence and cash income to a large part of the world's population, particularly in developing countries (Sher et al., 2014; Muhammad et al., 2019).

Studies have depicted the importance of understory species among the people living in the forest vicinity in the north of Pakistan (Kayani et al., 2014; Sher et al., 2014, 2016). Muhammad et al. (2019) displayed the inventory of medicinal plants in the dry and moist temperate forests of Kashmir. The authors depicted a large dependence of local communities upon these medicinal plants. Moreover, majority of people in these communities were dependent upon medicinal plant collection, processing, and marketing for sustaining their livelihood (Zubair et al., 2019). Understory species are affected by structural changes in the forests resulting from anthropogenic disturbances and overexploitation (Vellend et al., 2006; Liira et al., 2007; Wyatt and

Silman, 2010). Such changes in forest structure may even lead to the local extinction of certain species (Vellend et al., 2006).

Slope aspect remains pivotal in affecting plant communities in terms of their characteristics, functional groups, and aspect orientation (Zhang et al., 2022). Slope aspect is instrumental in changing solar radiation distribution patterns, thereby altering soil temperature and moisture levels (Burnett et al., 2008). Thus, slope aspect affects almost all vegetation properties, importantly, species composition, photosynthetic efficiency, species diversity, cover, nutritional dynamics, and, in turn, productivity (Kakembo et al., 2007; Ortiz-Pulido and Pavon, 2010; Sharm et al., 2010; Aimme and Normaniza, 2015).

In Pakistan, the dependence of people on pine forest resources has continued to rise in the last few decades. This is mostly due to the increasing population inhabiting previously untouched forest ecosystems (Ali et al., 2005). Pakistan, with 260 km<sup>2</sup> of *P. gerardiana* forest, experiences unsustainable overexploitation of resources. This not only leads to decreased production but aids deforestation. In these mountain ranges, most of the *P. gerardiana* forests are exploited by local people for pine nut collection and medicinal plant collection (Alami and Mousavi, 2020). Non-timber forest products (NTFPs) collected from the understory of these forests play a significant role in the socioeconomics of the forest community. But unsustainable and continuous resource exploitation coupled with deforestation mostly leading to settlements for new communities are having adverse effects on the understory vegetation that has been poorly explored by the scientific community of this region (Vellend et al., 2006; Urooj and Jabeen, 2015; Aziz et al., 2018). Hence, there is need of a study to measure the resources in the understory layer of these forests and to observe their relationship with changing land-use patterns (Hayat et al., 2021). The current study will provide crucial knowledge regarding the suitability of the ecosystem, especially in terms of habitat management.

There are already extensive studies reporting the benefits and importance of pine nut forests regarding its top story. But there are very few studies exploring the ecological, ethnological, and economic importance of the understory of *Pinus* spp. forests (López-Marcos et al., 2019, 2020). It is extremely crucial that the understory vegetation of pine forests are studied, and in particular *P. gerardiana*. This would help in effective forest management and resource sustainability, thus ensuring the stable livelihood of the inhabitants dependent upon them (Mölder et al., 2008; Muhammad Azam Khan et al., 2010; Haq et al., 2011). Researching the understory vegetation of these forests can help in determining the vital role that it plays in nutrient cycling and carbon sequestration, thus influencing the overall ecosystem's health and resilience (Ou et al., 2020; Ali and Khan, 2022). More importantly studying the diversity and distribution of understory vegetation can help in identifying invasive species, promoting biodiversity conservation, and mitigating the risk of pest and disease outbreaks (Ullah et al., 2013; Zilliox and Gosselin, 2014).

In this study, we aim to explore the understory vegetation of *P. gerardiana* forests in South Waziristan Agency under different aspects (northern and southern). There are limited cross-sectional studies and systematic documentation highlighting the understory vegetation density concerning various aspects and the use of different plant species in Pakistan (Liira et al., 2007; Wyatt and Silman, 2010; Ali and Khan, 2022). The present study introduces an avenue of knowledge about the role of different aspects influencing the distribution, abundance of understory vegetation, and its diversity for this precious forest resource. Since aspects were the focus of study across which different vegetation parameters were assessed, therefore, the core objectives of the study was to assess species diversity across different aspects (northern and southern) of the understory vegetation in *P. gerardiana* stands in the dry temperate forest of South Waziristan, Khyber Pakhtunkhwa (KPK), Pakistan.

## 2. Materials and methods

### 2.1. Description of the study area

South Waziristan extends over an area of 6,500 km<sup>2</sup>, located about 580 km northeast of Islamabad, Pakistan, and shares a 300 km border with Afghanistan. The *P. gerardiana* forest is located near the Pakistan–Afghanistan border (Ullah et al., 2013). The study area is situated at 32031.5810' N 69023.6470' E with an altitude of 1,250–2,134 m above sea level (Figure 1). The Suleiman Mountain range consists of dry temperate forest with an area of 260 km<sup>2</sup>. The vegetation diversity is composed of dry temperate forest, dominated by *P. gerardiana*, *Cedrus deodara* (Lamb.) G. Don., *Abies pindrow* (Royle ex D. Don.), and *Quercus incana* Roxb. Some of the lower areas have the *Juglans regia* L. species. Among the shrub species are *Alhagi maurorum* Medik. Medik., *Berberis lycium* Royle, and *Viburnum grandiflorum* f. foetens, while *Salvia glutinosa* L., *Salvia mocroftiana* Wall. ex Benth., *Senecio flaevus* (Herb), *Artemisia scoparia* Maxim., *Convolvulus arvensis* L., *Urtica dioica* L., *Peganum harmala* L., *Portulaca oleracea* L., and *Amaranthus viridis* L. are common herb species in the study area (Richardson and Rundel, 1998; Arnold and Perez, 2001).

The area receives an average annual precipitation of about 152.4 mm. Winters are usually characterized by heavy snow, whereas summers are hot with scanty rainfall (Ullah et al., 2013; Aziz et al., 2018). Summers are short, of about four months, whereas winters are long, starting from October up to the end of May. The short interval of summers provides a short time for the growth and regeneration of trees and understory plants, herbs, and shrubs. The average altitude of the *P. gerardiana* forest is 2,473.47 m according to the data collected through GPS from the study site. We conducted the data collection in the summer season to get easy access to the high altitudes of the forests and document the vegetation in the study site. In a similar study, the authors indicated that most of the population in the nearby settlements of the forest were dependent upon the *P. gerardiana* forest for nutritional and economic needs (Ullah et al., 2013). People living near or near pine nut forests are extremely dependent upon pine nut collection (Richardson and Rundel, 1998).

### 2.2. Sampling design and instruments

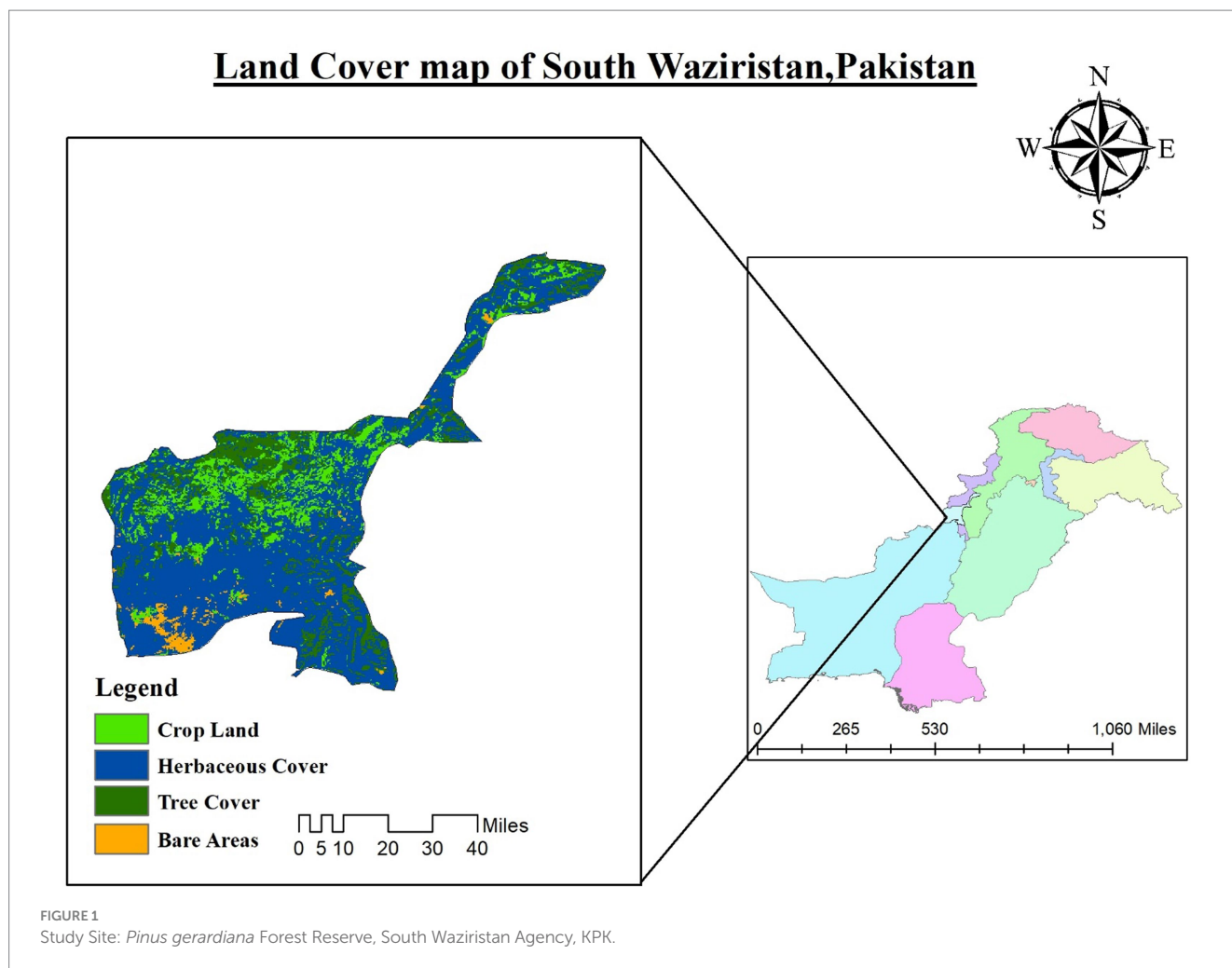
We employed the plot sampling method in the current study for the vegetation inventory. This technique considers an efficient and normalized way to deal with already gathered information on plant species, density diversity, and other vegetation qualities in a particular region or territory (Greig-Smith, 1961). Plots of a certain size were formulated throughout the sites and quadrats were placed randomly for collecting the vegetation data. A total of 12 sampling plots were established for biodiversity assessment of the research study site. Six random plots were formed at each site on both the aspects. These study sites were divided based on the two different aspects: the southern aspect at an altitude of 2,437 m and the northern aspect at 2,435 m. The instruments used for the field data collection were a 1 × 1 m quadrat, measuring tape, GPS, clippers, weight balance, pegs along with field range vegetation forms and a map of the study area, paper bags, pencil, sharpeners, and erasers.

### 2.3. Data collection

For each plot, 10 quadrats of 1 m<sup>2</sup> were randomly placed for vegetation assessment during August and September 2021 (northern and southern aspects). The quadrats were placed randomly across the six plots selected per site. A total of 120 quadrats were inventoried. Species within the quadrats were quantified for diversity data. The nomenclature of the species as proposed by Peruzzi et al. was followed (Peruzzi, 2020). Vegetation was analyzed quantitatively for density (D) and frequency (F). Moreover, the Global Biodiversity Information Facility (gbif.org) and the Angiosperm Phylogeny Group III classifications were used for the identification of plant species nomenclature and family names (The Angiosperm Phylogeny Group, 2009).

### 2.4. Data analysis

The data were subjected to biodiversity analysis. Some of the basic quantitative analysis including vegetation frequency, density, and richness was estimated using Curtis and McIntosh (1950); the relative values for species frequency (RF), density (RD), cover percent (CP), and important value index (IVI) were also estimated and presented. Species distribution and abundance was calculated following Wiegert (1989), and the important value (IV) index was used for the determination of species dominance (Wang and Shangquan, 2010). The species richness, dominance, evenness, and heterogeneity were determined through various indices including Simpson (1949), Margalef (1958), Buzas and Gibson (2010), and Shannon (1949) index calculations at plot level. The Sorensen–Dice index (Sorensen, 1948) was used for the calculation of similarities in various plant species composition among the different sampling sites. Furthermore, the species richness and evenness were visualized through plotting the rank abundance curve. Rank abundance was plotted to determine the accumulation of the species in the study area (Baker et al., 2006; Society and Press, 2016). Sample efficacy, species richness in a specific habitat in comparison with species richness in numerous habitats, was determined by plotting an equal basis rarefaction curve (Hall and Bawa, 2012; Hurlbert, 2012).



## 3. Results

### 3.1. Global vegetation description

The research site was composed of pure stands of *P. gerardiana*. A total of 612 plant specimens representing 29 species from 23 families were identified in the *P. gerardiana* forest understory (Tables 1, 2). Regarding the composition of species, about 70% of the plants were identified as herbs. The shrubs found on the study site accounted for 20%, whereas fern species accounted for about 10%. The survey was conducted on two different aspects, the southern (southwest and southeast) and northern (northwest and northeast) aspects. The southern aspect exhibited slightly higher species richness, with 15 observed species, compared with the northern aspect, which had 14 observed species (Table 1). On the northern aspect, the most abundant plant species identified was *Allium carolinianum* DC., while on the southern aspect, *Salvia nubicola* (Darshel) emerged as the dominant species.

When assessing the importance value (IV) index of species, variations between the northern and southern aspects were observed. The highest IV value of 0.74 was recorded for *A. carolinianum* DC. on the northern aspect, while *S. glutinosa* L, Jupiters Distaff (Rashal), had the highest IV value of 0.5 on the southern aspect. The majority of the species fell within the range of 0.02–0.06 IV. Notably, three species,

namely, *A. carolinianum*, *T. mongolicus*, *S. glutinosa*, and *S. nubicola* showed high IV values at both sites (Tables 1, 2). Overall, the data indicate differences in species abundance and IV values between the northern and southern aspects, highlighting the specific characteristics and composition of each site. The study showed a higher presence of medicinal plants on the southern aspect (80%) as compared with the northern aspect (70%).

### 3.2. Vegetation composition on the northern aspect

The values of frequency (F) and density (D) calculated among the various aspects showed different results. During the sampling in the northern and southern aspects, the most dominant species found was *A. carolinianum* (RF = 39%; RD = 135) followed by *T. mongolicus* (F = 25%; D = 103) present on the northern aspect, wherein 70% of plant species were classified as highly important medicinal plant species. The second most important plant present on the northern aspect was *T. mongolicus* (RF = 25%; RD = 103). The northern aspect also contained significant numbers of *A. grahamianus* (RF = 9%; RD = 38). However, *P. harmala* L (RF = 0.26%; RD = 1) was also found in the area, being an endangered and endemic medicinal plant. The most important and widely used species was *T. mongolicus* (F = 27%;

TABLE 1 Species importance value index for the understorey vegetation of *Pinus gerardiana* forest on the northern aspect.

Species	Family	Frequency	C.P	R.F	R.D	IVI
<i>Allium carolinianum</i> DC	Liliaceae	54	135	0.39	0.35	0.74
<i>Thymus mongolicus</i> (Ronniger)	Labiatae	34	103	0.24	0.26	0.51
<i>Senecio flaevus</i> (Decne) Sch.	Compositae	1	4	0.007	0.01	0.01
<i>Astragalus grahamianus</i> Royle ex Benth	Fabaceae	13	38	0.09	0.09	0.19
<i>Oxalis corniculata</i> L.	Oxalidaceae	3	10	0.021	0.02	0.04
<i>Salvia nubicola</i> Wall. Ex	Lamiacea	3	5	0.02	0.01	0.03
<i>Lactuca serriola</i> L.	Asteraceae	4	8	0.02	0.02	0.04
<i>Helvella compressa</i> (Snyder) N.S.Weber	Helvellaceae	6	21	0.04	0.05	0.09
<i>Cymbopogon jwarancusa</i> (Jones) Schult.	Poaceae	1	5	0.007	0.01	0.02
<i>Caralluma tuberculata</i> N.E.Br.	Pamanai	2	13	0.01	0.03	0.04
<i>Cynodon dactylon</i> (L) Pers.	Poaceae	10	27	0.07	0.07	0.14
<i>Xanthium strumarium</i> L.	Asteraceae	4	11	0.02	0.02	0.05
<i>Peganum harmala</i> L.	Nitrariaceae	1	1	0.007	0.002	0.009
<i>Astracantha cretica</i> (Lam.)	Leguminosae	2	1	0.01	0.002	0.01

CP, cover percent; RF, relative frequency; RD, relative density; IVI, important value index.

TABLE 2 Species importance value index for understorey vegetation of *P. gerardiana* forest on the southern aspect.

Species	Family	Frequency	C.P	R.F	R.D	IVI
<i>Salvia Glutinosa</i> L.	Lamiaceae	22	69	0.22	0.3	0.52
<i>Salvia mocroftiana</i> Wall. ex Benth.	Lamiaceae	9	20	0.09	0.08	0.17
<i>Senecio flaevus</i> (Herb)	Compositae	4	8	0.04	0.03	0.07
<i>Artemisia scoparia</i> Maxim.	Compositae	3	7	0.03	0.03	0.06
<i>Convolvulus arvensis</i> L.	Convolvaceae	2	3	0.02	0.01	0.03
<i>Urtica dioica</i> L.	Urticeae	1	1	0.01	0.004	0.01
<i>Thymus mongolicus</i> (Ronniger) Ronniger	Labiatae	1	1	0.01	0.004	0.01
<i>Salvia nubicola</i> Wall. Ex	Lamiaceae	27	65	0.27	0.28	0.55
<i>Peganum harmala</i> L.	Nitrariaceae	1	3	0.01	0.01	0.02
<i>Portulaca oleracea</i> L.	Aizoaceae	1	1	0.01	0.004	0.01
<i>Amaranthus viridis</i> L.	Amaranthaceae	2	3	0.02	0.01	0.03
<i>Sporobolus indicus</i> (L.) R.Br.	Poaceae	9	25	0.09	0.10	0.20
<i>Mentha aquatica</i> L.	Labiatae	1	1	0.01	0.004	0.01
<i>Withnia coagulans</i>	Malvaceae	14	22	0.14	0.09	0.23
<i>Sophora mollis</i> (Royle) Graham ex Baker	Fabaceae	1	1	0.01	0.004	0.01

CP, cover percent; RF, relative frequency; RD, relative density; IVI, important value index.

$D=103$ ) and *P. harmala* (RF=0.72%; RD=1). Few plants were normally used by the livestock. These plants include *C. dactylon* (RF=7.2%; RD=27), *C. tuberculata*, (RF=1.44%; RD=13), and *X. strumarium* (RF=3%; RD=11). The remaining species, i.e., *S. flaevus* (Decne) Sch. (RF=0.72% RD=18) was noted in few numbers on the northern aspect.

### 3.3. Vegetation composition on the southern aspect

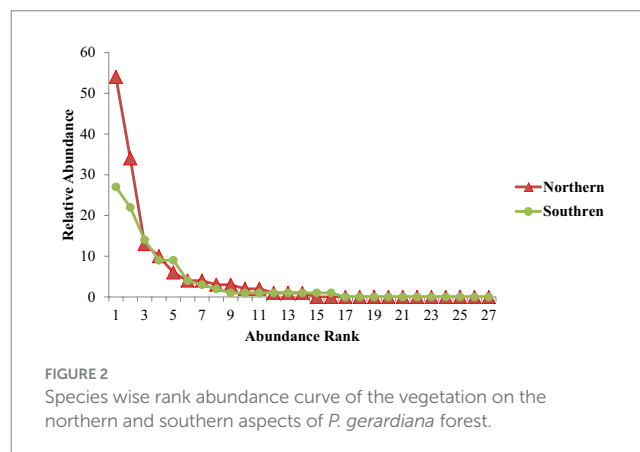
The frequency and density of vegetation on the southern aspect were higher when compared with the northern aspect. The southern aspect represented species mostly utilized by local communities for medicinal purposes and livestock grazing. The most abundant of them were *S. nubicola* Wall. Ex. (RF=27.5%; RD=65), *S. glutinosa* L (RF=22%; RD=69), and *S. moocroftiana* Wall. ex Benth. (RF=9.4%; RD=20). Plants with medicinal characteristics (64%) also existed on the southern aspect; the most important and widely used species were *S. glutinosa* L (RF=27.5%; D=65), *S. nubicola* (RF=27.5% RD=65), *W. coagulans* (RF=14.5%; RD=22), and *S. moocroftiana* Wall. ex Benth. (RF=9.4%; RD=20), while other plant species were quite rare, with minimum frequencies and densities. Among all the species on the southern aspect 13% were used as fodder for livestock whereas the remaining (86%) species including herbs and shrubs were used for medicinal purposes. The total understory vegetation on the northern and southern aspects was characterized as 70% medicinal and 25% edible plants. The southern aspect consisted of the bulk of medicinal plant species. Nonetheless, edible plants were not very dominant on the southern aspect, and hence were sparsely scattered on the sampled sites of the southern aspect (southwest and southeast). Among all these species, *S. glutinosa* L. is also used for making flavoring (RF=22% RD=69) and had considerable representation.

### 3.4. Rank abundance curve and rarefaction analyses

Figure 2 represents the abundance rank and relative abundance measured on a log scale. The northern aspect was dominated by 14 species contributing to the bulk of the biomass. The curves of the southern and northern aspects differ in their slopes, showing good evenness of the species at the southern site. The northern aspect showed more species abundance than the southern aspect. The species on the northern aspect were quite diverse as compared with the southern aspect. A rarefaction curve depicts how many samples are needed for analyzing population vegetation diversity (Figure 3). The northern aspect curve reaches asymptote after a specific point steeply going in upward direction showing prominent effect. Conversely, the southern aspect curve of the area where sampling was done was full of unique species used for medicinal purposes and it was found that the site could contain more species if further sampling had been conducted.

### 3.5. Biodiversity analysis

It was observed that the Shannon diversity index was at the maximum on the northern aspect of the forest (Table 3). This greater value illustrates the fact that the plant communities were more diverse,



integrating more richness and evenness, whereas the lowest value of the Shannon index was on the southern aspect of the study site. Comparatively, this site was low in diversity and the number of species as compared to northern aspect. To determine the abundance of the species and its dominance in the aspect, Simpson's index was calculated from both the aspects in the study site.

The result presented that the southern aspect was highly dominated by understory vegetation. Moreover, the site also showed dominancy of fewer plants due to the sparse vegetation. For observing the species richness and evenness, the Margalef's and Buza's and Gibson's diversity indices showed similar results when compared with the other indices used during findings. The main outcome of the findings depicted in those different indices values and aspects was the high biodiversity on the northern aspect of the sampling site. The Sorensen-Dice index presented least similarity in the northern aspect and southern aspect in the study site (Table 4). The decrease in similarity inferred that there were less species shared among the different aspects of the sampling sites. The index describes that the species prevalence in both the sites were rare.

### 3.6. Principal component analysis

Principal component analysis (PCA) was conducted to analyze the effect of aspect on the types of plant diversity and plant density. The results showed PC1 (Principal component 1) to account for 100% of the total variance. Density showed the highest loading in the first component. The experimental sites were separated along principal component 1 (PC1) where the southern aspect had higher PC1 scores, while the northern aspect displayed a lower density (Figure 4).

## 4. Discussion

The results showed the understory portion of the forest to have considerable biodiversity. Our research study depicted that the *P. gerardiana* forest of South Waziristan Agency has diverse understory vegetation. The understory is enriched with different medicinal plants that are used for various purposes including food and fodder. These plants play a key role in the livelihood of the local communities using them in herbal medicines as well as the functioning of the forest (Chidumayo and Gumbo, 2010). Most of the plants were used for

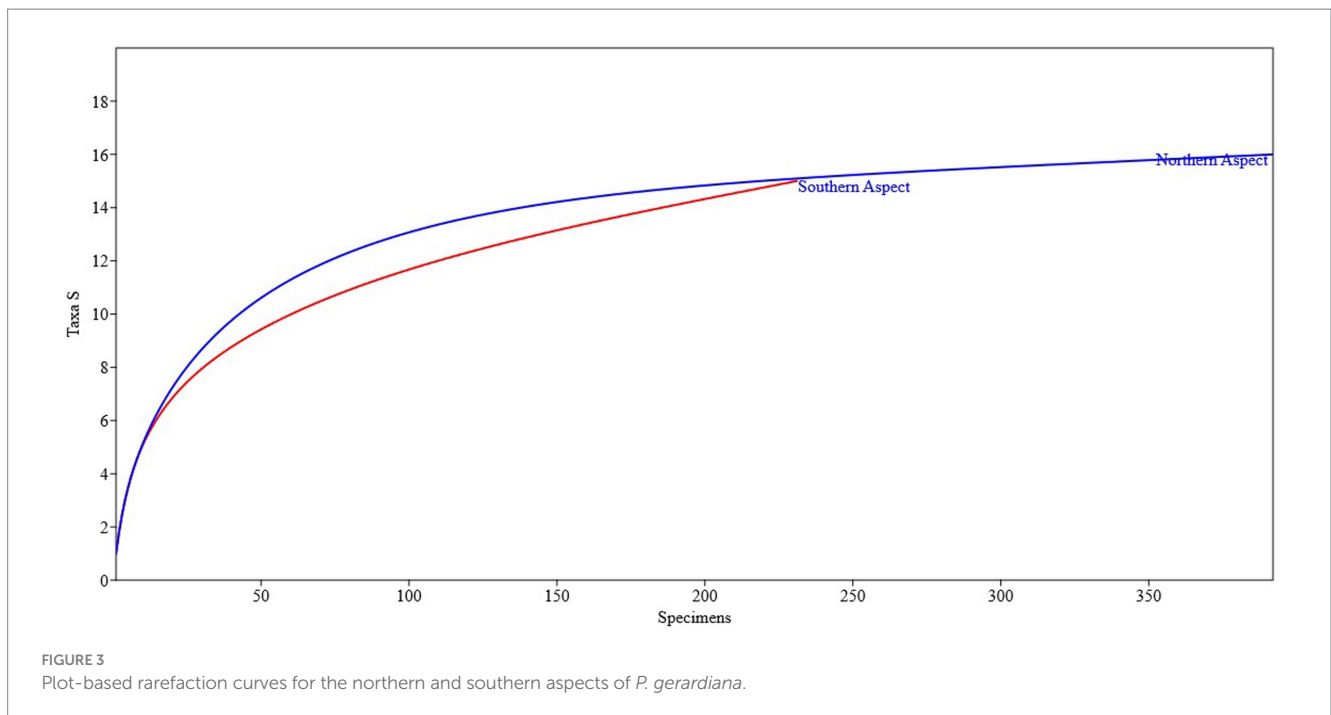


TABLE 3 Comparison of diversity indices on the northern and southern aspects of *P. gerardiana*.

Indices sites	Southern aspect	Northern aspect
Simpson_1-D	0.7422	0.7763
Shannon_H	1.712	1.837
Margalef (Spp Richness)	2.201	1.853
Buzas and Gibson's evenness	0.40	0.42

medicinal need. The current research study was similar to the research work of Qasim et al. (2013) depicting that most of the plants in the Himalayan range were being used for medicinal purposes. Vegetation density came out to be moderate in the understudied area. Qasim et al. (2013) observed similar results depicting low species diversity in *P. gerardiana* stands. Results depicted homogenous variance in understory species composition on the northern and southern aspects of the study sites. Similarly, various researchers have observed variations in understory composition and structure according to the aspects (Mishra et al., 2004; Mölder et al., 2008).

The maximum biodiversity was found on the southern aspect of the study site. The area was open in canopy cover which provided a suitable environment for different medicinal plants (Qasim et al., 2013; Khel et al., 2022). Similar observations were found by Adnan and Hölscher (2012) at Ayubia National Park of Khyber Pakhtoon Khwa, where they perceived that the decrease in understory plants, herbs, and shrubs was due to the dense canopy cover of overstorey vegetation. Zilliox and Gosselin (2014) concluded that northern aspects showed minimum abundance of understory vegetation because of the closed canopy and less availability of sunlight, moisture, and nutrients for the understory plants and grasses. Similar observations were found by Whitmore (1978), wherein forest cover remained instrumental in affecting the vegetation underneath it.

Similar outcomes were perceived by Sagar et al. (2008), in which they exhibited that the areas with sparse canopy cover had high understory plant cover. It was observed that the evergreen forest closed canopy had less understory biodiversity. The study noted that understory vegetation is completely dependent on the overstorey of the forest trees including pure and mixed forests.

Aspect and canopy affected the diversity, density, and cover of understory vegetation of the study site, as endorsed in various similar studies (Khan et al., 2012). Overall diversity of the understory vegetation in the study area was on the lower side. This is coherent with similar studies conducted in these areas (Khan et al., 2011; Zubair et al., 2021; Ali et al., 2022). Studies in the pine nut forests of Pakistan and Afghanistan have usually depicted lower understory vegetation diversity (Khan et al., 2011; Rahman et al., 2017; Luintel et al., 2018; Ali et al., 2022; Prakash et al., 2023). However, the pine nut forests of China, India, and other regions have shown higher diversity of understory plant species compared with understory vegetation diversity of pine forests of the area under study (Huo et al., 2014; Su and Lu, 2020; Aqeel et al., 2023; Prakash et al., 2023). The study depicted a lower density and frequency of plant species in both study areas. This is mostly related to the vegetation damaging effects caused by overgrazing, unsustainable medicinal/edible plant collection, and deforestation, as reported in various studies (Shinwari and Qaiser, 2011; Shalizi et al., 2018; Hussein et al., 2021; Khan et al., 2021).

The majority of these plants are available year round and the local communities use them for their subsistence (Farooq et al., 2012; ANG et al., 2014; Aziz et al., 2016). The higher composition of species diversity and dominance on the southern aspect compared with the northern aspect was shown by the rank abundance curve highlighting the richness of *S. glutinosa* and *S. nubicola* species. Similar results were observed by Ali et al. (2007), which depicted that there was a slight decrease in the species abundance of northern aspects. Promis et al. (2012) observed similar results, stating that the areas with dense

vegetation showed less understory plants. The aspects with a decrease in grazing patterns and partially closed forest cover (southern aspects) had high understory vegetation including medicinal plants. Similar results were observed by Zubair et al. (2021), stating that the spots with medium canopy cover resulted in high understory vegetation. The research study results were obtained by appropriate samples collection as justified in the rarefaction curves. The curves were used in data to overcome difficulties and interference often experienced during counting and relating to taxon richness. (Gotelli and Colwell, 2001). The availability of plants across time is a critical factor for observing richness and abundance (Wulf and Naaf, 2009; Mestres et al., 2017). Moreover, plants grown under conditions of ample light and space are more abundant compared with plants dispersed under dense forests (Walker et al., 1999). Likewise, species tend to be more diverse and richer in their flora when the available forest condition is either termed as open canopy or undisturbed partial canopy cover (Hamilton, 2004; Promis et al., 2012).

The *P. gerardiana* forests of Pakistan are rapidly degrading due to the overexploitation of pine nuts, unsustainable collection of medicinal/edible plant species, and continuous deforestation (Urooj et al., 2020; Khan et al., 2021). These factors not only alter the structure and functioning of the forest but also increase soil erosion events and reduce nutrients availability (Mölder et al., 2008; Qasim et al., 2013; Hussein et al., 2021). Our study depicts the lower density, cover, and

diversity of important medicinal/edible plant species on the northern and southern aspects. This indicates a crucial restoration hotspot that harbors endangered species whose recovery could benefit from effective forest landscape rehabilitation and conservation practices (Höhl et al., 2020; De Matos et al., 2021).

Many previous studies have indicated direct links between diversity, composition, and the structure of understory vegetation on the functioning and provisioning of the forest (Ou et al., 2020). The quantitative inventory of the understory vegetation clearly translates as a warning of potential irreversible degradation (Xie et al., 2021). Building on the results of such vegetation surveys, it is important that we engage government departments and non-governmental organizations to take part in conservation practices utilizing wider and systematic formal monitoring activities, since forest communities have minimum input in the management and conservation of forest resources (Tabassum, 2020). This emphasized the need to understand policy and practice of forest landscape restoration (FLR) in meeting local needs and livelihoods for sustainable management of forest resources, though important, yet is important (Mansourian et al., 2020; Tabassum, 2020). Various global studies have indicated that different resource management endeavors with minimum integration of vegetation surveys in terms of monitoring usually lead to poor management and low rehabilitation success (Chazdon, 2019; Mansourian et al., 2020). Through this study, there is an opportunity for considering the incorporation of vegetation surveys with respect to aspects and canopy cover to measure the diversity of understory vegetation for better management and conservation of forest ecosystems.

TABLE 4 Sørensen–Dice coefficients showing similarities between the northern and southern aspects of *P. gerardiana* forest.

Northern aspect site 1 and 2	Southern aspect site 1 and 2
0.20 (20%)	0.30 (30%)

### 5. Conclusion and policy implication

The research conducted in the *P. gerardiana* forest of South Waziristan Agency, Pakistan, has illuminated the intricate vegetation

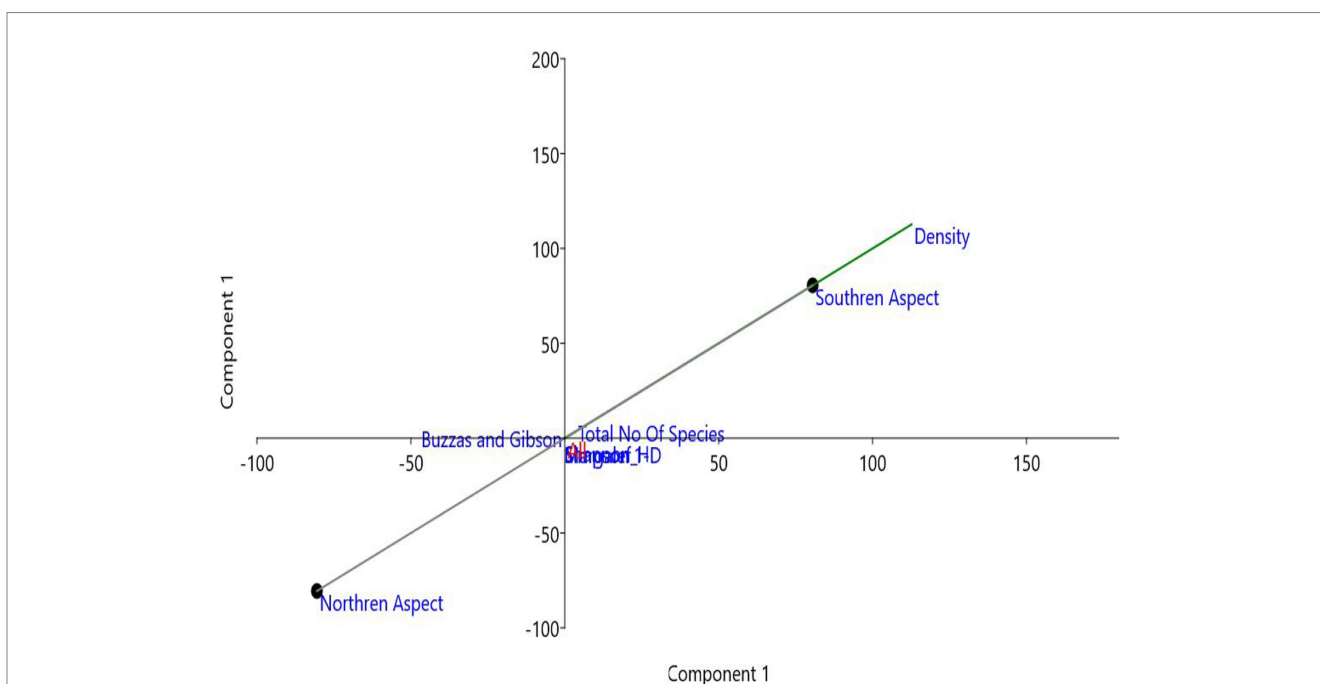


FIGURE 4 Principal component analysis (PCA) on the basis of the northern and southern aspects of *P. gerardiana* forest.



dynamics influenced by aspectual variations. Our findings underscore that the understory vegetation is rich in biodiversity, with a marked representation of both edible and medicinal plants. While both the northern and southern aspects of the study site showcased diverse species, the southern aspect stood out with a higher prevalence of medicinal plants. Notably, the vegetation diversity was found to be marginally higher on the southern aspect when compared with the northern aspect. This is particularly significant as it hints at the influence of aspect on species richness and abundance. For instance, species such as *A. carolinianum* DC. and *S. nubicola* (Darshel) emerged as dominant on the northern and southern aspects, respectively. Furthermore, the biodiversity indices, including the Shannon diversity index and Simpson's index, provided a deeper understanding of species richness and evenness across the two aspects. Such differences in vegetation dynamics between the northern and southern aspects could be attributed to various ecological factors, which may include light availability, soil properties, moisture content, and other microclimatic conditions. It is also worth noting that the region, though rich in biodiversity, is vulnerable to anthropogenic pressures, such as livestock grazing. The southern aspect, in particular, displayed signs of being more affected by these practices. Sustainable management practices and conservation efforts are paramount to ensure the protection and preservation of these ecologically valuable landscapes. In light of our findings, it becomes evident that understanding the role of aspect in vegetation dynamics can provide valuable insights for biodiversity conservation and sustainable forest management. Further studies across different forest reserves in Pakistan would amplify our knowledge about the intricate relationships between aspect and vegetation, aiding in informed conservation strategies for the country's rich biodiversity.

## Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors.

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## Author contributions

IK and DZ conceptualized and wrote the main manuscript. MZ, GY, and SM helped to perform the lab analysis. MM, MZ, GY, and SM reviewed and edited the manuscript in the present form. KAK provided resources and funds. SR and AQ supervised and provided funding and approved the manuscript. All authors contributed to the article and approved the submitted version.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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