Diversity and Distribution Patterns of Orchidaceae in Wumeng Mountain National Natural Reserve

2026-06-26

ChinaRxiv

Abstract

Orchidaceae, which includes numerous rare and endangered species, has long been a focus of biodiversity conservation research in terms of its distribution characteristics and survival status. To comprehensively determine the species diversity, distribution patterns, and current survival status of Orchidaceae in Wumengshan National Nature Reserve in northeastern Yunnan, this study systematically investigated Orchidaceae in the reserve using the quadrat method, and further revealed the diversity characteristics of Orchidaceae in the region through species diversity index analysis and phylogenetic tree construction. The results showed that: (1) Orchidaceae in the reserve was mainly represented by the genera Habenaria, Calanthe, and Platanthera, with oligotypic genera accounting for as much as 73%; Calanthe puberula, Liparis campylostalix, Neottia nanchuanica, Odontochilus elwesii, and Goodyera henryi were the dominant species. The Margalef richness index (DMG) of Orchidaceae was 4.0356, the Shannon-Wiener diversity index (H′) was 2.6228, and the Simpson dominance index (λ) was 0.1136. (2) In terms of elevational distribution, Orchidaceae in the reserve was mainly distributed in the mid- to high-elevation zone of 1700~2100 m, and closely related species tended to aggregate at similar elevations and in similar habitats. (3) In the reserve, 30% of Orchidaceae species were threatened, especially species with important medicinal and ornamental value, such as Anoectochilus emeiensis, Cremastra appendiculata, Pleione yunnanensis, and Cymbidium goeringii, whose survival status was particularly concerning. In summary, the overall diversity of Orchidaceae in the reserve is not high, its elevational distribution is uneven, and some species face relatively high survival risks. This study provides important baseline data for research on Orchidaceae diversity in Wumengshan National Nature Reserve, and its results can provide scientific support for the subsequent systematic conservation and management of Orchidaceae.

Full Text

DOI:10.11931/guihaia.gxzw202504028

Diversity and Distribution Patterns of Orchidaceae in Wumeng Mountain National Natural Reserve

HE Yanli1,2, HU Haixia3,4, YANG Wenke2, LI Dan1, LIU Qiang2, SONG Liang3*

(1. College of Forestry, Southwest Forestry University, Kunming 650224; 2. Yunnan Forestry Technological College, Kunming 650224; 3. Key Laboratory of Tropical Forest Ecology, Xishuangbanna Tropical Botanical Garden, Chinese Academy of Sciences, Mengla 666303, Yunnan; 4. University of Chinese

Academy of Sciences, Beijing 101408)

Abstract: Orchidaceae includes many rare and endangered species, and its distribution characteristics and survival status have long been a focus of biodiversity conservation research. To comprehensively understand the species diversity, distribution patterns, and current survival status of Orchidaceae in Wumeng Mountain National Natural Reserve in northeastern Yunnan, this study systematically surveyed orchids in the reserve using sampling methods, and further revealed the diversity characteristics of orchids in the region through analyses of species diversity indices and construction of a systematic phylogenetic tree. The results showed that: (1) The orchids in the reserve were mainly distributed in the genera *Habenaria*, *Calanthe*, and *Platanthera*; genera with few species accounted for as much as 73%. *Calanthe puberula*, *Liparis campylostalix*, *Neottia nanchuanica*, *Odontochilus elwesii*, and *Goodyera henryi* were the dominant species. The Margalef richness index (D_{MG}) of Orchidaceae was 4.0356, the Shannon-Wiener diversity index (H') was 2.6228, and the Simpson dominance index (λ) was 0.1136. (2) In terms of elevational distribution, orchids in the reserve were mainly distributed in the mid- to high-elevation zone of 1 700–2 100 m; species with close affinities tended to cluster at similar elevations and in similar habitats. (3) In the reserve, 30% of orchid species were threatened, especially species with important medicinal and ornamental value, such as *Anoectochilus emeiensis*, *Cremastra appendiculata*, *Pleione yunnanensis*, and *Cymbidium goeringii*, whose survival status was particularly worrying. Overall, the orchid diversity in the reserve is not high, the elevational distribution is uneven, and some species face relatively high survival risks. This study provides important baseline data for research on orchid diversity in Wumeng Mountain National Natural Reserve, and its results can provide scientific support for subsequent systematic conservation and management of Orchidaceae.

Keywords: Orchidaceae; biodiversity; species composition; elevational gradient; threatened status

Chinese Library Classification No.: Q948.13
Document identification code: A
Article No.:

Diversity and distribution patterns of Orchidaceae in

Wumeng Mountain National Natural Reserve

HE Yanli1,2, HU Haixia3,4, YANG Wenke2, LI Dan1, LIU Qiang2, SONG Liang3*

(1. *College of Forestry, Southwest Forestry University*, Kunming 650224, China; 2. *Yunnan Forestry Technological College*, Kunming 650224, China; 3. *Key Lab-*

oratory of Tropical Forest Ecology, Xishuangbanna Tropical Botanical Garden, Chinese Academy of Sciences, Mengla 666303, Yunnan, China; 4. *University of Chinese Academy of Sciences*, Beijing 101408, China)

Abstract: Orchidaceae, encompassing numerous rare and endangered species, remains a focal group for biodiversity conservation research due to its distribution characteristics and survival status. To characterize the species diversity, distribution patterns, and conservation status of Orchidaceae in

Funding projects: Yunnan Provincial Young and Middle-aged Academic and Technical Leaders Reserve Talent Project (202305AC160024); National Natural Science Foundation of China General Program (32171529); Yunnan Provincial Key R&D Program (202403AC100028); Yunnan Province "Xingdian Talent Support Program" Young Talent Project (YNWR-QNBJ-2020-066).

First author: He Yanli (1986-), master' s student, experimenter, engaged in research on plant breeding and cultivation, (E-mail) 282734436@qq.com.

***Corresponding author:** Song Liang, Ph.D., researcher, mainly engaged in research on tropical rainforest restoration, biodiversity, and global change, (E-mail) songliang@xtbg.ac.cn.

northeastern Yunnan' s Wumeng Mountain National Nature Reserve, we systematically surveyed orchids using quadrat sampling and analyzed their diversity through diversity indices and phylogenetic reconstruction. The results were as follows: (1) The orchid flora was dominated by *Habenaria*, *Calanthe*, and *Platanthera*, with characteristic species including *Calanthe puberula*, *Liparis campylostalix*, *Neottia nanchuanica*, *Odontochilus elwesii*, and *Goodyera henryi*. Monotypic genera comprised 73% of the total. Diversity indices [Margalef' s richness index (D_{MG}) = 4.035 6, Shannon-Wiener diversity index (H') = 2.622 8, Simpson' s dominance index (λ) = 0.113 6)] indicated moderate diversity and low dominance. (2) Species richness peaked at mid-high elevations (1 700–2 100 m). Phylogenetically related species clustered at similar altitudes and habitats, suggesting strong habitat filtering. (3) Notably, 30% of species were threatened, particularly medicinal and ornamental taxa such as *Anoectochilus emeiensis*, *Cremastra appendiculata*, *Pleione yunnanensis*, and *Cymbidium goeringii*. In summary, the Orchidaceae flora in this reserve exhibits moderate diversity with pronounced mid-high elevation peaks, while significant conservation concerns exist for threatened taxa. These findings establish critical baseline data for regional orchid diversity research and provide direct scientific support for targeted conservation strategies.

Key words: Orchidaceae, biodiversity, species composition, altitudinal gradient, conservation status

The orchid family (Orchidaceae) is the second largest family of angiosperms, with more than 20,000 species worldwide. It is widely distributed in almost all regions except the polar regions and extreme deserts, with the greatest richness and abundance occurring in tropical and subtropical areas (Gustavo, 1996;

Cribb et al., 2003). However, owing to their distinctive life-history traits and strong dependence on specialized habitats, orchids often exhibit narrow-range distributions (Zhang et al., 2015; Liu et al., 2023), making them more vulnerable than many other plant groups to habitat degradation and loss (Nigel & Kingsley, 2009). At the same time, orchids not only have extremely high ornamental value but are also valuable plant resources for plant breeding, natural-medicine development, and related fields (Zhou et al., 2021; Zhang Jinkui et al., 2024). These characteristics subject orchids to greater pressure from illegal harvesting, thereby further exacerbating the continued decline of their wild populations (Liu et al., 2023). On the International Union for Conservation of Nature (IUCN) Red List, 1,085 orchid species have been assessed as Vulnerable or above (Li Dacheng et al., 2022). Statistics show that China has recorded 187 genera and 1,447 species of wild orchids, with rich resources and diverse life forms, but these are concentrated mainly in Southwest China and Taiwan (Zhang Dianbo et al., 2015); they likewise face habitat destruction and excessive human collection. At present, protection of orchids in China is also being continuously strengthened. The *List of National Key Protected Wild Plants* issued in 2021 lists all orchids as national second-class protected wild plants, while the entire genus *Paphiopedilum* and some species of *Cymbidium* are listed as national first-class protected plants. Against this background, research on the distribution and survival status of orchids in different regions is of great significance for the scientific formulation of targeted conservation strategies.

Yunnan is one of the provinces with the richest orchid diversity in China, with 145 genera and 825 species recorded (Zhang et al., 2015; Wang Ziyuan et al., 2022). Influenced by complex topography and climate, the distribution of orchids in Yunnan shows pronounced regional differences: horizontally, it follows a pattern of "higher in the west and lower in the east, higher in the south and lower in the north," while vertically it exhibits a "mid-elevation bulge" pattern (Wang Ziyuan et al., 2022). Among these areas, orchid species are most abundant in northwestern Yunnan, southern Yunnan, and southeastern Yunnan, and they are distributed mainly in mountainous areas at elevations of 900–2,099 m; related studies have also been concentrated largely in these regions (Gao Jiangyun et al., 2014; Yang Xinkai et al., 2017), whereas northeastern Yunnan still lacks systematic research. Yunnan Wumeng Mountain National Nature Reserve (hereafter "Wumeng Mountain Reserve") is located in Zhaotong City, northeastern Yunnan, in the transitional zone from the Yunnan-Guizhou Plateau to the Sichuan Basin, and has a distinctive mountain ecosystem. The reserve preserves intact subtropical montane moist evergreen broad-leaved forest, providing critical habitat for numerous rare and endangered animals and plants (Lei Jiqin et al., 2025). The complex terrain, diverse microclimates, and rich vegetation types within the reserve provide potentially suitable habitats for the survival and reproduction of orchids. Although the second survey report on key protected wild plant resources in Yunnan Province recorded 13 orchid species in the reserve (Hua Chaolang, 2019), this figure may seriously underestimate the actual diversity of the area. Owing to the lack of systematic field surveys and

specimen collection, the species composition, distribution patterns, population status, and conservation status of orchids in the reserve remain unclear. Compared with other orchid hotspots in Yunnan, research on Wumeng Mountain Reserve is clearly lagging behind; comprehensive surveys are urgently needed to provide a scientific basis for orchid conservation in this region.

Based on the severe paucity of studies on Orchidaceae in northeastern Yunnan noted above, and on the marked ecological representativeness of Wumeng Mountain National Nature Reserve as a key ecological barrier and biodiversity hotspot in this region, this study employed a standardized quadrat-grid survey covering eight major vegetation subtypes within the reserve and spanning 1,000 m in elevation. This was combined with detailed species identification and specimen collection, and integrated with phylogenetic tree construction and endangered-status assessment, to examine in depth the following three key scientific questions: (1) species composition structure and population status: to comprehensively clarify the species checklist of Orchidaceae in Wumeng Mountain Nature Reserve and the basic status of their populations, thereby providing core data for accurately evaluating the baseline resources of Orchidaceae in the region; (2) elevational-gradient patterns of diversity and their driving mechanisms: to precisely characterize the distribution patterns of orchid species richness and phylogenetic diversity along the elevational gradient, and to reveal the key ecological factors influencing orchid distribution under the reserve's complex terrain; and (3) endangered status and conservation-priority assessment: based on field population survey data, together with the IUCN assessment framework and analysis of human disturbance, to systematically evaluate the degree of threat faced by orchids in the reserve and identify rare and endangered species and their key habitats in urgent need of priority conservation. This study will fill an important gap in knowledge of the geographical distribution of Orchidaceae in northeastern Yunnan. Its findings will directly provide a solid scientific basis and decision-making support for the reserve to formulate targeted in situ conservation strategies for orchids, habitat management measures, and priority conservation action plans for endangered species, and will have important theoretical and practical significance for maintaining the integrity of biodiversity in this region.

1 Study Area Overview and Research Methods

1.1 Overview of the Study Area

Wumeng Mountain Nature Reserve has complex and diverse geomorphic types, with a minimum elevation of 880 m, a maximum elevation of 2,454 m, and a relative elevation difference of 1,574 m. Its climate shows pronounced vertical differentiation and belongs to the subtropical humid monsoon climate zone. The reserve spans all of five counties—Yiliang, Daguan, Yongshan, Yanjin, and Weixin—with a total area of 26 186.65 hm^2, and consists of four independent sections: Sanjiangkou, Xiaocaoba, Haiziping, and Luohanba (Figure 1). Within the reserve there are 15 species of wild plants under national key protection,

including dove tree (*Davidia involucrata*), Chinese yew (*Taxus chinensis*), Fujian cypress (*Fokienia hodginsii*), katsura tree (*Cercidiphyllum japonicum*), *Emmenopterys henryi*, *Dipentodon sinicus*, *Tetracentron sinense*, golden hair dog fern (*Cibotium barometz*), and Chinese tree fern (*Alsophila costularis*). A total of 2 plant species under National Grade I key protection, 13 plant species under National Grade II key protection, and 15 plant species under Yunnan provincial key protection have been recorded in the reserve. In addition, 19 plant species are assessed on the International Union for Conservation of Nature (IUCN) Red List as Vulnerable (VU) or in higher threat categories, and 24 species are included in the protected list of Appendix I of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES).

Figure 1. Schematic map of the location of Wumeng Mountain National Nature Reserve

Fig. 1 Geographical location of the Wumeng Mountain National Nature Reserve

1.2 Research Methods

Within the principal functional zones (core zone, buffer zone, and experimental zone) of the Wumengshan Reserve, a field survey of Orchidaceae was carried out using a combination of quadrats and line transects, focusing on the main areas centered on the Haiziping, Sanjiangkou, Luohanba, and Xiaocaoba management stations. At the same time, interviews with management-station staff were conducted by using plant photographs and other materials. The survey routes covered different habitats, including valleys, flatlands, mountain slopes, mountain ridges, saddles, and summits, and different vegetation types, including evergreen broad-leaved forest, mixed evergreen–deciduous broad-leaved forest, deciduous broad-leaved forest, mixed coniferous–broad-leaved forest, coniferous forest, shrub thickets, and shrub–grass communities. Quadrats were established in representative sites for the distribution of Orchidaceae and in typical forest stands. Each quadrat was set at 5 m × 5 m, and a total of 178 quadrats were established. To account for different seasons, surveys of Orchidaceae in the main functional zones of the Wumengshan Reserve were conducted in June–July 2023 (rainy season) and September–October 2024 (dry season). Information recorded included orchid species, distribution, abundance, natural geographical background, forest-community type, threatening factors, main associated species, and GPS location; photographs taken during flowering were collected to further confirm species identifications.

Based on the survey data, a checklist of Orchidaceae in the Wumengshan Reserve was compiled, and the species and distribution of Orchidaceae within the reserve were basically determined. According to differences in living substrate, the orchids were divided into three life-form types: terrestrial orchids, epiphytic orchids, and saprophytic orchids. According to GPS location information, the vertical distribution was divided into five elevational gradients: H1

(1 100–1 300 m), H2 (1 300–1 500 m), H3 (1 500–1 700 m), H4 (1 700–1 900 m), and H5 (1 900–2 100 m). Meanwhile, the relative abundance (RA) and relative frequency (RF) of orchid species were calculated. The Shannon–Wiener index (H'), Simpson dominance index (λ), and Margalef richness index (D_{MG}) were used to quantitatively describe the diversity characteristics of Orchidaceae in the study area. The calculation formulas were as follows:

$$RA\ (\%) = \frac{\text{number of individuals (clumps) of a given species}}{\text{total number of individuals (clumps) of all species}};$$

$$RF\ (\%) = \frac{\text{frequency of a given species}}{\text{sum of frequencies of all species}};$$

$$H' = -\sum P_i \ln P_i, \quad P_i = N_i/N \quad \text{(Shannon \& Weaver, 1949)};$$

$$\lambda = 1 - \sum P_i^2, \quad P_i^2 = n_i(n_i - 1)/N(N - 1) \quad \text{(Greenberg, 1959)};$$

$$D_{\mathrm{MG}} = (S - 1)/\ln N \quad \text{(Margalef, 1958)}.$$

In the formulas, S denotes species richness, expressed as the number of species; N_i denotes species abundance, representing the abundance of the ith species; N denotes the total number of individuals of all species; and n_i is the number of individuals of the ith species.

The open-source R package V.PhyloMaker was used to construct a phylogenetic tree of Orchidaceae in the Wumengshan Reserve (Jin & Qian, 2019). V.PhyloMaker is an R package designed specifically to generate phylogenetic trees of vascular plants. It uses "GBOTB.extended.tre" as the background phylogenetic tree and "phylo.maker"as the core function for generating phylogenetic trees. After excluding data that could not be identified to species, a list of 30 orchid species in the Wumengshan Reserve was compiled. The orchid species names from the Wumengshan Reserve were bound to the background phylogenetic tree to generate a phylogenetic tree of Orchidaceae for this region. On this basis, the generated phylogenetic tree was visualized with the aid of the "ggtree" package. Finally, the topology of the tree was checked for rationality and, as needed, optimized and adjusted to obtain an accurate and reliable phylogenetic tree.

2 Results and Analysis

2.1 Species composition of Orchidaceae

A total of 22 genera and 33 species of Orchidaceae were recorded in the Wumengshan Reserve (Table 1), dominated by *Habenaria* (4 species), *Platanthera*

(4 species), and *Calanthe* (3 species). At the species level, the analysis of relative abundance (RA) showed that *Goodyera henryi* had a significant advantage ($RA = 25.86\%$), followed by *Liparis campylostalix* ($RA = 11.60\%$) and *Odontochilus elwesii* ($RA = 10.41\%$); together, these three accounted for 47.87% of the total number of individuals. In contrast, the population sizes of more than 67% of the orchid species were below 50 individuals (Fig. 2: A), indicating a clear pattern of dominance by rare species. Analysis of relative frequency (RF) further revealed the spatial distribution characteristics of the species. *Calanthe puberula* showed the widest distribution range ($RF = 11.82\%$), followed by *Liparis campylostalix* ($RF = 10.05\%$) and *Neottia nanchuanica* ($RF = 7.76\%$). Notably, although *Goodyera henryi* had the largest number of individuals, its distribution frequency was relatively low ($RF = 5.02\%$), indicating that this species may form locally high-density populations. The study also found that more than 70% of the orchid species occurred in no more than five quadrats (Fig. 2: B). Together with the relative-abundance analysis, this result confirms that the distribution pattern of Orchidaceae in the reserve is characterized by "a small number of widely distributed species plus a large number of localized species." In addition, in terms of life forms, terrestrial orchids in the Wumengshan Reserve had an absolute advantage (28 species). Saprophytic species were relatively abundant, with four species recorded: *Cyrtosia septentrionalis*, *Galeola lindleyana*, *Gastrodia elata*, and *Epipogium taiwanense*, but epiphytic

Only one species, *Pleione yunnanensis*, occurs.

Table 1 Checklist of orchids in the Wumeng Mountain National Nature Reserve

Genus	Species	Typical habitat in the reserve	Endangered status	Protection level
Gold-thread orchid genus *Anoectochilus*	Emei gold-thread orchid *A. emeiensis*	In crevices among stones under the forest beside streams	Critically endangered (CR)	National Second-Class
Shrimp-spine orchid genus *Calanthe*	Curved-spur shrimp-spine orchid *C. arcuata*	Under the forest or on rocks covered with a thin layer of soil in mountain valleys	Vulnerable (VU)	

Genus	Species	Typical habitat in the reserve	Endangered status	Protection level
Shrimp-spine orchid genus *Calanthe*	Small-flowered shrimp-spine orchid *C. mannii*	Under the forest on hillsides	Least concern (LC)	
Shrimp-spine orchid genus *Calanthe*	Sickle-sepal shrimp-spine orchid *C. puberula*	Under evergreen broad-leaved forest	Least concern (LC)	
Helleborine genus *Epipactis*	Helleborine *E. helleborine*	Under the forest, in grasslands, or beside valleys on hillsides	Near threatened (NT)	
Helleborine genus *Epipactis*	Large-leaved helleborine *E. mairei*	In moist meadows or at forest edges	Near threatened (NT)	
Rattlesnake-plantain genus *Goodyera*	Spotted-leaf orchid *G. schlechten-daliana*	Under broad-leaved forest on hillsides or in valleys	Near threatened (NT)	
Rattlesnake-plantain genus *Goodyera*	Henry' s spotted-leaf orchid *G. henryi*	In shady and moist places under the forest	Vulnerable (VU)	
Beak orchid genus *Collabium*	Chinese beak orchid *C. chinense*	In shady and moist places under dense forest in valleys, or on moist rocks in valleys	Least concern (LC)	
Cremastra genus *Cremastra*	Appendiculate cremastra *C. appendiculata*	In wetlands under the forest or in wetlands beside ditches	Critically endangered (CR)	National Second-Class

Genus	Species	Typical habitat in the reserve	Endangered status	Protection level
Cymbidium genus *Cymbidium*	Spring orchid *C. goeringii*	Under the forest on hillsides or beside streams	Vulnerable (VU)	National Second-Class
Cyrtosia genus *Cyrtosia*	Blood-red fleshy-fruited orchid *C. septentrion-alis*	Under high-mountain pine forest, on rocky substrates	Vulnerable	

Genus	Species	Habitat	Conservation status
		rocks	(VU)
Tiger-tongue orchid genus *Epipogium*	Taiwan tiger-tongue orchid *E. taiwanensis*	Shaded sites under forest or along valleys	Data Deficient (DD)
Mountain-coral orchid genus *Galeola*	Lindley' s mountain-coral orchid *G. lindleyana*	Under sparse forest, in sparse shrublands, or in moist, rocky, humus-rich places beside valleys	Least Concern (LC)
Gastrodia genus *Gastrodia*	Tianma *G. elata*	Under sparse forest, in forest clearings, or at the edges of shrublands along forest margins	National Class II
Jade-phoenix orchid genus *Habenaria*	Thin-leaved jade-phoenix orchid *H. austrosinensis*	Shady, moist places under forest in valleys	Vulnerable (VU)
Jade-phoenix orchid genus *Habenaria*	Long-spurred jade-phoenix orchid *H. davidii*	Under forest, under shrubs, or in meadows on hillsides	Near Threatened (NT)

Genus	Species	Habitat	Conservation status
Jade-phoenix orchid genus*Habenaria*	Goose-feather jade-phoenix orchid*H. dentata*	Under forest on hillsides or beside valleys	Least Concern (LC)
Jade-phoenix orchid genus*Habenaria*	An unidentified species of jade-phoenix orchid*Habenaria* sp.	Under forest, under shrubs, or in meadows on hillsides	
Horn-disk orchid genus*Herminium*	Tibetan horn-disk orchid*H. orbiculare*	In high-altitude moist meadows, under forest, or in rock crevices	Near Threatened (NT)
Horn-disk orchid genus*Herminium*	An unidentified species of horn-disk orchid*Herminium* sp.	Under forest, under shrubs, or in meadows on hillsides	
Sheep-ear orchid genus*Liparis*	Sheep-ear orchid*L. campylostalix*	Under forest, in valleys, or in rock crevices	
Opposite-leaved orchid genus*Listera*	Nanchuan opposite-leaved orchid*N. nanchuanica*	Under forest, beside streams, or in rock crevices	Endangered (EN)
Toothed-lip orchid genus*Odontochilus*	Southwestern toothed-lip orchid*O. elwesii*	In moist forests or valley areas with sufficient water and appropriate shade	
Mountain-orchid genus*Oreorchis*	Narrow-leaved mountain orchid*O. micrantha*	In high-altitude areas, in rock crevices with good drainage and some shade, or under forest	Least Concern (LC)

Genus	Species	Habitat	Conservation status	Protection category
Platanthera	Two-leaved *PlatantheraP. chlorantha*	In high-altitude moist meadows or under the forest	Least concern(LC)	
Platanthera	Small *PlatantheraP. minor*	Under the forest, meadows, or swamp areas	Least concern(LC)	
Platanthera	*Platanthera latilabrisP. latilabris*	In the lower layers of moist forests with sufficient shade	Least concern(LC)	
Platanthera	A species of *Platan-theraPlatanthera* sp.	In moist meadows or at the edge of forests		
Pleione	Yunnan *PleioneP. yunnanensis*	In mountain forests, in shady and moist places under the forest, or beside streams	Vulnerable(VU)	National Second-Class
Rhomboda	White-ribbed *RhombodaR. tokioi*	In alpine meadows and under the forest	Vulnerable(VU)	
Spiranthes	Chinese ladies' -tresses*S. sinensis*	Under the forest in the mountains, in environments that are relatively shaded, moist, and rich in humus	Least concern(LC)	

Figure 2. Horizontal bar charts showing orchid abundance and frequency in the Wumeng Mountain National Nature Reserve. Panel A: number of individuals; Panel B: number of plots. The species labels include *Goodyera henryi*, *Liparis campylostalix*, *Odontochilus elwesii*, *Calanthe puberula*, *Neottia nanchuanica*, *Cremastra appendiculata*, *Collabium chinense*, *Herminium orbiculare*, *Calanthe arcuata*, *Pleione yunnanensis*, *Epipactis helleborine*, *Habenaria dentata*, *Epipactis mairei*, *Platanthera latilabris*, *Spiranthes sinensis*, *Cymbidium goeringii*, *Rhomboda tokioi*, *Tainia dunnii*, *Anoectochilus emeiensis*, *Platanthera minor*, *Calanthe mannii*, *Oreorchis micrantha*, *Habenaria davidii*, *Herminium* sp., *Habenaria austrosinensis*, *Cyrtosia septentrionalis*, *Gastrodia elata*, *Habenaria* sp., *Platanthera chlorantha*, *Epipogium taiwanense*, *Galeola lindleyana*, *Platanthera* sp., and *Goodyera schlechtendaliana*.

Figure 1: Figure 2. Horizontal bar charts showing orchid abundance and frequency in the Wumeng Mountain National Nature Reserve. Panel A: number of individuals; Panel B: number of plots. The species labels include *Goodyera henryi*, *Liparis campylostalix*, *Odontochilus elwesii*, *Calanthe puberula*, *Neottia nanchuanica*, *Cremastra appendiculata*, *Collabium chinense*, *Herminium orbiculare*, *Calanthe arcuata*, *Pleione yunnanensis*, *Epipactis helleborine*, *Habenaria dentata*, *Epipactis mairei*, *Platanthera latilabris*, *Spiranthes sinensis*, *Cymbidium goeringii*, *Rhomboda tokioi*, *Tainia dunnii*, *Anoectochilus emeiensis*, *Platanthera minor*, *Calanthe mannii*, *Oreorchis micrantha*, *Habenaria davidii*, *Herminium* sp., *Habenaria austrosinensis*, *Cyrtosia septentrionalis*, *Gastrodia elata*, *Habenaria* sp., *Platanthera chlorantha*, *Epipogium taiwanense*, *Galeola lindleyana*, *Platanthera* sp., and *Goodyera schlechtendaliana*.

Genus	Species	Habitat	Conservation status	Protection category
Tainia	*Tainia dunnii T. dunnii*	Under the forest in the mountains, in environments that are relatively shaded, moist, and rich in humus	Near threatened(NT)	

A. The number of individuals of each species; **B.** The number of plots of each species.

Fig. 2 The abundance and frequency of orchids in the Wumeng Mountain National Nature Reserve

2.2 Distribution pattern of Orchidaceae species

In terms of horizontal distribution characteristics, the species composition and abundance of Orchidaceae differed markedly among the four sub-reserves managed by the Wumengshan Reserve (Haiziping, Luohanba, Sanjiangkou, and Xiaocaoba). As shown in Figure 3A, the Haiziping sub-reserve contained a total of 6 species, with *Goodyera henryi* as the dominant species; the Xiaocaoba sub-reserve contained 17 species, with *Pleione yunnanensis* as the dominant species; the Sanjiangkou sub-reserve contained 18 species, with *Liparis campylostalix* and *Pleione yunnanensis* as the dominant species; and the Luohanba sub-reserve contained 14 species, but the numbers of individuals of each species were relatively low, with *Calanthe arcuata*, *Calanthe puberula*, and *Cremastra appendiculata* being comparatively dominant.

In terms of vertical distribution characteristics, overall species richness of Orchidaceae in the reserve showed a "mid- to high-elevation aggregation phenomenon" (Figure 3B). Specifically, only 11 Orchidaceae species were recorded across the three elevation bands H1–H3 (1,100–1,700 m), whereas species diversity was highest in the H4 elevation band (1,700–1,900 m), where 28 Orchidaceae species were recorded, accounting for approximately 85% of the total number of Orchidaceae species in the reserve. However, in the highest elevation band, H5 (1,900–2,100 m), the number of species declined to 13. In addition, the dominant Orchidaceae assemblages differed among elevation bands. In the H1 elevation band, *Odontochilus elwesii* was dominant; in H2, dominance shifted to *Goodyera henryi*; in H3, *Cremastra appendiculata* predominated; in H4, communities dominated by *Pleione yunnanensis* were formed; and in H5, mixed communities co-dominated by *Pleione yunnanensis*, *Liparis campylostalix*, and *Goodyera henryi* occurred.

Figure 3, visible in-figure text

A

- Y-axis: Species abundance
- X-axis: Sub-reserves
- Sub-reserves: Haiziping (HZP); Xiaocaoba (XCB); Sanjiangkou (SJK); Luohanba (LHB)
- Legend title: Species name
- Species listed in the legend:
  - *Pleione yunnanensis*
  - *Herminium orbiculare*
  - *Calanthe puberula*
  - *Cremastra appendiculata*
  - *Epipactis mairei*
  - *Neottia nanchuanica*

  - *Platanthera latilabris*
  - *Epipactis helleborine*
  - *Liparis campylostalix*
  - *Platanthera minor*
  - *Spiranthes sinensis*
  - *Habenaria davidii*
  - *Herminium* sp.
  - *Cyrtosia septentrionalis*
  - *Habenaria dentata*
  - *Galeola lindleyana*
  - *Goodyera henryi*
  - *Odontochilus elwesii*
  - *Collabium chinense*
  - *Rhomboda tokioi*
  - *Anoectochilus emeiensis*
  - *Tainia dunnii*
  - *Calanthe arcuata*
  - *Calanthe mannii*
  - *Oreorchis micrantha*
  - *Cymbidium goeringii*
  - *Habenaria austrosinensis*
  - *Gastrodia elata*
  - *Platanthera chlorantha*
  - *Habenaria* sp.
  - *Platanthera* sp.
  - *Epipogium taiwanense*
  - *Goodyera schlechtendaliana*

B

- Y-axis: Species abundance
- X-axis: Altitude zone
- Altitude zones:
  - H1 (1,100–1,300 m)
  - H2 (1,300–1,500 m)
  - H3 (1,500–1,700 m)
  - H4 (1,700–1,900 m)
  - H5 (1,900–2,100 m)

A. Distribution of orchids in different sub-reserves (**HZP.** Haiziping; **XCB.** Xiaocaoba; **SJK.** Sanjiangkou; **LHB.** Luohanba); **B.** Distribution of orchids at different altitudes.

A. Distribution of orchids in different sub-reserves (**HZP.** Haiziping; **XCB.** Xiaocaoba; **SJK.** Sanjiangkou; **LHB.** Luohanba); **B.** Distribution of orchids in different altitude zones.

Fig. 3 Species abundance patterns of Orchidaceae across sub-reserves and altitudinal zones in the Wumeng Mountain National Nature Reserve

Fig. 3 Species abundance patterns of Orchidaceae across sub-reserves and altitudinal zones in the Wumeng Mountain National Nature Reserve

At the species level, the altitudinal distribution pattern of Orchidaceae in the Wumeng Mountain Reserve shows clear ecological adaptive differentiation. As shown in Fig. 4, approximately 67% (22 species) of orchid species exhibit evident mid- to high-altitude adaptation characteristics: their distributions are restricted to areas above 1,700 m, and most of their altitudinal ranges are less than 400 m. Among them, 10 species, including spring orchid (*Cymbidium goeringii*), broad-leaved helleborine (*Epipactis mairei*), and *Herminium orbiculare*, form a typical "mid- to high-altitude cluster," being concentrated in the 1,700–1,900 m zone and showing a high degree of adaptation to specific altitudinal environments. At the same time, some species, such as *Rhomboda tokioi*, *Odontochilus elwesii*, *Anoectochilus emeiensis*, and *Collabium chinense*, occur only in the low-altitude zone of 1,100–1,400 m, indicating a special dependence on low-altitude habitats. However, a few species have relatively broad distribution ranges: for example, *Tainia dunnii* extends from 1,100 m to 1,900 m, whereas *Goodyera henryi* extends from 1,300 m to 2,100 m, showing relatively strong ecological plasticity.

Fig. 4 plot labels:
Y-axis: Species name
X-axis: Altitude (m)

Species labels shown in Fig. 4: *Galeola lindleyana*; *Goodyera schlechtendaliana*; *Oreorchis micrantha*; *Platanthera chlorantha*; *Calanthe mannii*; *Gastrodia elata*; *Habenaria austrosinensis*; *Pleione yunnanensis*; *Habenaria* sp.; *Herminium orbiculare*; *Epipogium taiwanense*; *Herminium* sp.; *Platanthera* sp.; *Calanthe arcuata*; *Spiranthes sinensis*; *Habenaria davidii*; *Epipactis mairei*; *Neottia nanchuanica*; *Cyrtosia septentrionalis*; *Habenaria dentata*; *Cymbidium goeringii*; *Platanthera minor*; *Epipactis helleborine*; *Platanthera latilabris*; *Cremastra appendiculata*; *Calanthe puberula*; *Liparis campylostalix*; *Goodyera henryi*; *Collabium chinense*; *Tainia dunnii*; *Rhomboda tokioi*; *Odontochilus elwesii*; *Anoectochilus emeiensis*.

Fig. 4 Distribution ranges of orchids along the altitudinal gradient in the Wumeng Mountain National Nature Reserve

Fig. 4 Distribution ranges of orchids along the altitudinal gradient in the Wumeng Mountain National Nature Reserve

Analysis of the relationship between orchid phylogeny and altitudinal distribution patterns in the Wumeng Mountain Reserve shows (Fig. 5) that different phylogenetic branches exhibit significant specificity in altitudinal distribution. Within the Orchidoideae branch, species of the closely related genera *Habenaria*, *Herminium*, and *Platanthera* in Branch 1 are all specialized in the mid- to high-

altitude belt of 1,700–1,900 m (H4), suggesting that this branch may have undergone shared adaptive evolution to high elevations. Branch 2 presents two adaptive patterns: species of *Odontochilus*, *Anoectochilus*, and *Rhomboda* are strictly distributed in the low-altitude belt of 1,100–1,300 m (H1), whereas *Spiranthes* is distributed in the mid- to high-altitude belt of 1,700–2,100 m (H4–H5),

However, *Goodyera* shows a cross-altitudinal distribution, occurring both at low altitude (H2) and at mid-to-high altitude (H4–H5). In the Epidendroideae branch, clade 3 shows clear ecological differentiation: except for species of *Collabium* and *Tainia*, which are concentrated at 1,100–1,500 m (H1–H2), the other groups are concentrated at 1,700–1,900 m (H4). Clade 4 exhibits strict specialization to mid-to-high altitudes: *Epipogium taiwanense* and *Gastrodia elata* both occur in the same altitudinal band, 1,700–1,900 m. Clade 5 shows a relatively broad altitudinal adaptation range, with species of *Epipactis* and *Neottia* concentrated at 1,700–2,100 m (H4–H5). As a basal group, Vanilloideae also shows specialization to mid-to-high altitudes, with *Cyrtosia septentrionalis* and *Galeola lindleyana* concentrated at 1,700–1,900 m (H4).

Figure 5 Association between phylogenetic structure and altitudinal distribution of orchids in the Wumeng Mountain National Nature Reserve

Fig. 5 Association between phylogenetic structure and altitudinal distribution of orchids in the Wumeng Mountain National Nature Reserve

2.3 Diversity indices of Orchidaceae

This study used three diversity indices to describe the diversity pattern of Orchidaceae in the reserve (Table 2). For the reserve as a whole, the Margalef richness index (D_{MG}) of Orchidaceae reached 4.0356, the Shannon–Wiener diversity index (H') was 2.6228, and the Simpson dominance index (λ) was only 0.1136. This indicates that, overall, the reserve has relatively high species richness and a comparatively balanced community structure, with no single species occupying an absolute dominant position. As shown in Table 2, the four sub-reserves—Sanjiangkou, Luohanba, Xiaocaoba, and Haiziping—exhibit marked spatial heterogeneity. Species richness is highest in the Sanjiangkou sub-reserve ($D_{\mathrm{MG}} = 2.4639$), while the Luohanba sub-reserve has the highest level of diversity ($H' = 2.1445$). By contrast, although the Xiaocaoba and Haiziping sub-reserves contain fewer species, they show pronounced dominant-population characteristics (λ values of 0.3706 and 0.3950, respectively), reflecting relatively simple community structures in these areas. From the perspective of vertical distribution, Orchidaceae show the most pronounced species aggregation in the mid-to-high altitudinal band (H4), where both the Margalef richness index ($D_{\mathrm{MG}} = 3.6397$) and the Shannon–Wiener diversity index ($H' = 2.2353$) reach their maximum values. However, the Simpson dominance index shows a vertical pattern opposite to that of the diversity indices: the dominance in-

dex is abnormally high in the mid-to-low altitudinal band (H2) ($\lambda = 0.8481$), indicating a clear monopolization by dominant species in this band. In the high-diversity altitudinal bands (H4, H5), the dominance indices are both below 0.2, reflecting the evenness of the community structure. This negative relationship of "high diversity–low dominance" verifies the applicability of niche theory along the vertical gradient.

Table 2 Diversity indices of Orchidaceae across sub-reserves and altitude zones in the Wumeng Mountain National Nature Reserve

Table 2 Diversity indices of Orchidaceae across sub-reserves and altitude zones in the Wumeng Mountain National Nature Reserve

Item	Item	Number of species	Number of individuals	Margalef richness index (D_{MG})	Shannon-Wiener diversity index (H')	Simpson dominance index (λ)
Reserve	Total	33	2 776	4.035 9	2.622 8	0.113 6
Sub-reserve	SanjiangkouSJK	18	992	2.463 9	2.137 6	0.154 9
Sub-reserve	LuohanbaLHB	14	362	2.206 5	2.144 5	0.140 2
Sub-reserve	XiaocaobaXCB	17	1 077	2.291 6	1.626 5	0.370 6
Sub-reserve	HaizipingHZP	6	1 058	0.718 0	1.162 8	0.395 0
Altitude zone	H11 100~1 300 m	7	437	0.986 9	1.281 5	0.378 5
Altitude zone	H21 300~1 500 m	3	649	0.308 9	1.192 3	0.848 1
Altitude zone	H31 500~1 700 m	5	88	0.893 4	1.108 6	0.421 9
Altitude zone	H41 700~1 900 m	28	1 666	3.639 7	2.235 3	0.185 6
Altitude zone	H51 900~2 100 m	13	644	1.855 4	1.956 3	0.185 0

2.4 Threat status of orchids

The assessment of the threat status of orchids in the Wumeng Mountain Reserve shows (Table 1) that orchids in this region face severe survival pressure. Based on the IUCN Red List assessment criteria, and with reference to the *China Species Red List* (Wang Song and Xie Yan, 2004) and the *List of Threatened Species of Higher Plants in China* (Qin Haining et al., 2017), this study found 10 threatened orchid species in the reserve, accounting for 30% of all species surveyed. Among them, there were 2 Critically Endangered (CR) species (Emei jewel orchid and Dujuan orchid), 1 Endangered (EN) species (Nanchuan tway-blade), and 7 Vulnerable (VU) species. Notably, within the reserve, Emei jewel orchid was distributed only within the narrow elevational range of 1 120~1 140 m, and only 21 individuals were recorded, indicating an extremely fragile population status. In terms of spatial distribution, the threat status of orchids differed among sub-reserves: for example, Sanjiangkou had 7 threatened species (39%), Luohanba had 4 species (29%), Xiaocaoba had 4 species (24%), and Haiziping had 3 species (50%). Along the elevational gradient, the proportion of threatened species in low-elevation areas (43%) was significantly higher than that in middle- and high-elevation areas. These results not only reveal the current threatened status of orchids in the reserve, but also highlight the urgency of giving priority protection to Critically Endangered species and low-elevation areas.

3 Discussion and conclusion

3.1 Species composition and species diversity of orchids in the Wumeng Mountain Reserve

The Wumeng Mountain Reserve is located in the transitional zone from the Yunnan-Guizhou Plateau to the Sichuan Basin. Although its orchid diversity (22 genera and 33 species) is lower than that of hotspot regions such as southwestern Yunnan (Wang Yubing and Du Fan, 2007), the region' s distinctive transitional climatic features make it an ideal site for studying adaptive differentiation and niche limitation in orchids. This study found that orchids in the Wumeng Mountain Reserve are dominated by *Habenaria*, *Calanthe*, and *Platanthera*, while mono- or oligospecific genera account for as much as 73%, indicating that orchid species differentiation in the reserve is relatively low and that lineages are comparatively impoverished. This phenomenon reflects the limitations imposed by the cold climate on orchid growth and differentiation.

a limiting effect. In terms of life form, wild orchids in China as a whole are dominated by terrestrial and epiphytic orchids (Zhang Dianbo et al., 2015), but in the Wumengshan Reserve there is only one epiphytic orchid species, *Pleione yunnanensis*. In addition to climatic factors, the extensive distribution of moso bamboo and Indocalamus in the reserve has led to a scarcity of epiphytic habitats (Lei Jiqin et al., 2025), which may be an important reason for the low

number of epiphytic orchid species.

Further community analysis showed that the species richness index of orchids in the Wumengshan Reserve ($D_{MG} = 4.035\,6$) was generally low (Zhou Kang, 2021; Liu et al., 2023), the community structure was relatively simple, and no obvious dominant species had yet formed. The Shannon–Wiener diversity index ($H' = 2.622\,8$) and Simpson dominance index ($\lambda = 0.113\,6$) also indicated that the species distribution of the orchid community in the reserve was relatively even and lacked dominant groups occupying a leading position (Wang Bing et al., 2008). This phenomenon may be closely related to differences in the distribution of orchids among different sections of the reserve and along the altitudinal gradient. Notably, the diversity and dominance characteristics of the orchid community in the Wumengshan Reserve are highly consistent with research results from nearby protected areas with similar habitats, such as the Guizhou Fanjingshan National Nature Reserve and the Fodingshan National Nature Reserve (Zhang Yuwu, 2008; Liu Feng et al., 2022). This suggests that, within this geographical region, the assembly of orchid communities may be jointly driven by similar ecological limiting factors.

3.2 Altitudinal Distribution Pattern of Orchids in the Wumengshan Reserve

The vertical distribution pattern of orchids in the Wumengshan Reserve showed a significant aggregation in the middle to high elevations. The 1,700–2,100 m elevational zone contained more than 80% of the orchid species in the reserve. This distributional characteristic is consistent with the overall altitudinal distribution pattern of orchids in Yunnan Province, while also reflecting regional specificity. For example, the altitudinal distribution of orchids in Yunnan Province is mainly concentrated at 900–2,099 m (Wang Ziyuan et al., 2022), whereas in northwestern Yunnan orchid species diversity is relatively high within the 1,051–3,000 m elevational range (Liu Yang et al., 2012). Studies have shown that, in addition to elevation range, vegetation conditions and temperature seasonality are also major environmental factors influencing orchid distribution (Zhang et al., 2015). In the Wumengshan Reserve, the 1,700–2,100 m elevational zone is the main area where evergreen broad-leaved forests, evergreen–deciduous broad-leaved mixed forests, and bamboo forests are distributed (Hu Jinyao et al., 2003); vegetation types are rich and human disturbance is relatively low. Compared with the insufficient hydrothermal conditions at high elevations and the stronger human disturbance at low elevations (Liu Guangfu et al., 2010; Dong Quanying, 2013; Wang Xilong et al., 2016; Ai et al., 2023), the suitable hydrothermal combination and stable microenvironment in the middle-elevation zone provide ideal survival conditions for orchids (Tang & Ohsawa, 1997; Chang Xuexiang et al., 2004). In addition, because the four sections under the jurisdiction of the reserve differ in elevation and vegetation type, there are also obvious differences in orchid species. Among them, the Sanjiangkou section has a relatively high elevation and the best vegetation protection, with the number of orchid species

reaching 18; the Xiaocaoba section spans a wide elevational range, and a total of 17 orchid species were recorded; the Haiziping section has the lowest elevation and frequent human activities, with vegetation types dominated by secondary forests and economic forests, and orchid distribution is seriously affected, with only 6 species recorded. The results of this study emphasize the key role of middle- to high-elevation areas in orchid conservation.

In the phylogenetic tree of orchids in the Wumengshan Reserve, closely related species usually clustered within similar elevational ranges, supporting the niche conservatism hypothesis; that is, closely related species inherited similar environmental adaptive traits retained from their ancestors (Wiens et al., 2010; Yin et al., 2021). By contrast, the more distantly related saprophytic *Cyrtosia haematodes* and *Gastrodia elata* were both distributed only under *Chimonobambusa* forests, possibly because both orchid species strictly depend on the saprophytic fungal networks unique to *Chimonobambusa* forests (Sun Yue et al., 2017; Cadotte et al., 2019; Zhao et al., 2021). In addition, habitat differentiation among closely related species was observed in *Spiranthes* and *Goodyera*, which is likely related to pollinator-mediated competitive exclusion or significant differentiation of fungal communities (Jacquemyn et al., 2015). Studies have shown that when closely related species exhibit phylogenetic clustering, it may reflect environmental filtering of species with similar adaptive traits. Conversely, when closely related species in a community show phylogenetic overdispersion, it may result from excessive divergence of conserved traits caused by competition, or from environmental filtering of ecologically important convergent traits (Webb et al., 2002; Wiens & Graham, 2005). On this basis, the orchid distribution pattern presented in this study may be jointly shaped by phylogenetic history and ecological interactions.

3.3 Endangerment Status of Orchids in the Wumengshan National Nature Reserve

Because orchids have mycorrhizal specificity, pollinator specialization, and limited germination rates, most orchids have narrow distributions in specific habitats and, compared with other plants, are extremely sensitive to habitat disturbance (Zhang et al., 2015). At present, all orchids are included within the scope of protection of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) (Zhou et al., 2021), reflecting the international community' s high level of attention to and urgent need for orchid conservation. China possesses abundant wild orchid resources, with a total of 187 genera and 1,447 species (Zhang Dianbo et al., 2015), among which medicinal orchids comprise as many as 87 genera and 327 species (Yu Jiali et al., 2025). However, under the dual pressures of habitat degradation and human collection, many orchid species

populations are gradually declining and even disappearing. The results of this study show that, among the 33 orchid species recorded in the Wumengshan Reserve, about 30% are threatened. Among them, Emei golden-thread orchid,

dujuan orchid, Yunnan single-bulb orchid, and spring orchid have long been over-collected because of their important medicinal and ornamental value, resulting in sharp declines in wild populations. In addition, the mechanisms underlying the threatened status of species such as Nanchuan twin-leaf orchid, arc-spurred calanthe, smooth-calyx spotted-leaf orchid, blood-red fleshy-fruited orchid, thin-leaved Habenaria, and white-ribbed rhomboda are more complex. The threats these species may face also include habitat loss, low fruit-setting rates caused by the absence of pollinating insects during reproduction, and limitations on seed germination due to dependence on mycorrhizal fungi (Shang Weixuan, 2023). These factors act together and further aggravate the endangered status of these orchids. Therefore, it is recommended that a long-term monitoring mechanism for key species be established in the reserve, that habitat protection for critically endangered species such as Emei golden-thread orchid be strengthened in particular, and that conservation and reproductive-ecology studies be carried out for important groups and endangered species.

In summary, a total of 33 orchid species belonging to 22 genera, including *Habenaria*, *Platanthera*, and *Calanthe*, were recorded in the Wumengshan Reserve, of which about one-third are threatened. In terms of vertical distribution, orchids in the reserve show a typical pattern of "mid- to high-elevation aggregation," with more than 80% of the species concentrated within the elevational range of 1 700–2 100 m. Combined with phylogenetic-tree analysis, this distribution pattern may have been jointly shaped by evolutionary history and ecological interactions. Although this study fills a gap in research on orchid diversity in northeastern Yunnan by revealing the distribution patterns and population status of orchids in the reserve, some limitations remain. For example, detailed observations of climatic factors and comprehensive integration of vegetation factors in this region are still lacking. Future studies could further combine climatic data with vegetation-type analyses to explore in depth the environmental drivers affecting orchid distribution. In addition, based on the results of this study, it is recommended that priority be given to the conservation of critically endangered species (Emei golden-thread orchid and dujuan orchid), that management and protection in low-elevation areas be strengthened, and that the distribution dynamics of native vegetation in the reserve (evergreen broad-leaved forest and bamboo forest) be monitored. These measures will help better conserve orchid resources in the Wumengshan Reserve and promote their sustainable development.

Acknowledgments: We thank the leadership of the Administration Bureau of Yunnan Wumengshan National Nature Reserve for their support, and the staff of the management stations for their full assistance during field investigations. We thank Dr. Xing Haitao of Yunnan Forestry Technological College for his guidance in map preparation.

References:

AI YY, LIU Q, HU HX, et al., 2023. Terrestrial and epiphytic orchids exhibit different diversity and distribution patterns along an elevation gradient of Mt.

Victoria, Myanmar [J]. Global Ecology and Conservation, 42: e02408.

CADOTTE MW, CARBONI M, SI X, et al., 2019. Do traits and phylogeny support congruent community diversity patterns and assembly inferences? [J]. Journal of Ecology, 107(5): 2065-2077.

CHANG XX, ZHAO WZ, ZHAO AF, 2004. Species diversity of pasture community at different altitude levels in Qilian mountains [J]. Chinese Journal of Applied Ecology, 15(9): 1599-1603. [CHANG XX, ZHAO WZ, ZHAO AF, 2004. Species diversity of grassland communities at different elevations in the Qilian Mountains [J]. Chinese Journal of Applied Ecology, 15(9): 1599-1603.]

CRIBB PJ, KEU SP, DIXON KW, et al., 2003. Orchid conservation [M]. Sabah: Natural History Publications, 4(1): 21-30.

DONG QY, 2013. Ecological habit of epiphytic orchids in Wuzhi Mountain National Nature Reserve, Hainan Island, China [D]. Shanghai: East China Normal University: 3-15. [DONG QY, 2013. Study on the ecological habits of epiphytic orchids in Wuzhi Mountain National Nature Reserve, Hainan [D]. Shanghai: East China Normal University: 3-15.]

GAO JY, LIU Q, YU DL, 2014. Orchids of Xishuangbanna: diversity and conservation [M]. Beijing: China Forestry Press. [GAO JY, LIU Q, YU DL, 2014. Orchids of Xishuangbanna: diversity and conservation [M]. Beijing: China Forestry Press.]

GREENBERG BJ, 1959. Race relations and American law [M]. New York: Columbia University Press.

GUSTAVO AR, 1996. The orchid family[M]// IUCN/SSC Orchid specialist group. Orchids- status survey and conservation action plan [M]. UK: IUCN, Gland, Switzerland and Cambridge: 3-4.

HU JY, SU ZX, LI YX, 2003. Research advance on dovetree biology [J]. Chinese Wild Plant

Resources, 22(4): 15–19. [HU Jinyao, SU Zhixian, LI Yunxiang, 2003. Research progress in *Erythrophleum fordii* biology [J]. Chinese Wild Plant Resources, 22(4): 15–19.]

HUA ZL, 2019. The second investigation report of key protected wild plant resources in Yunnan Province [R]. Kunming: Yunnan Forestry Survey and Planning Institute. [HUA Chaolang, 2019. Report on the second survey of key protected wild plant resources in Yunnan Province [R]. Kunming: Yunnan Forestry Survey and Planning Institute.]

JIN Y, QIAN H, 2019. V. PhyloMaker: an R package that can generate very large phylogenies for vascular plants [J]. Ecography, 42(8): 1353–1359.

JACQUEMYN H, BRYS R, WAUD M, et al., 2015. Mycorrhizal networks and coexistence in species-rich orchid communities [J]. New Phytologist, 206(3): 1127–1134.

LEI JQ, FANG J, FU YH, et al., 2025. Challenges and strategies for forest resource conservation in Wumengshan National Nature Reserve, Yunnan [J]. South China Agriculture, 19(5): 233–239. [LEI Jiqin, FAN Jia, FU Yihong, et al., 2025. Current problems and countermeasures in forest resource management and protection in Wumengshan National Nature Reserve, Yunnan [J]. South China Agriculture, 19(5): 233–239.]

LI DC, SONG XQ, ZHANG Z, et al., 2010. Strategies for conservation and priority monitoring of key orchid plants in Hainan Tropical Rainforest National Park [J]. Journal of Tropical Biology, 13(2): 136–148. [LI Dacheng, SONG Xiqiang, ZHANG Zhe, et al., 2022. Conservation and priority monitoring strategies for key orchid plants in Hainan Tropical Rainforest National Park [J]. Journal of Tropical Biology, 13(2): 136–148.]

LIU F, YANG Y, AN MT, et al., 2022. Diversity and conservation research of orchids in Foding Mountain National Nature Reserve of Guizhou Province [J]. Northern Horticulture(2): 67–70. [LIU Feng, YANG Yi, AN Mingtai, et al., 2022. Diversity of orchids and their conservation in Foding Mountain National Nature Reserve, Guizhou [J]. Northern Horticulture(2): 62–70.]

LIU GF, ZANG RG, DING Y, et al., 2010. Diversity and distribution of epiphytic orchids in different types of old-growth tropical forests in Bawangling National Nature Reserve, Hainan Island, China [J]. Chinese Journal of Plant Ecology, 34(4): 396–408. [LIU Guangfu, ZANG Runguo, DING Yi, et al., 2010. Diversity and distribution of epiphytic orchids in different forest types in Bawangling, Hainan [J]. Chinese Journal of Plant Ecology, 34(4): 396–408.]

LIU Q, WU XF, XING HT, et al., 2023. Orchid diversity and distribution pattern in karst forests in eastern Yunnan Province, China [J]. Forest Ecosystems, 10(3): 348–356.

LIU Y, DU F, LI RN, et al., 2012. Altitudinal distribution pattern of orchid plants in Northwest of Yunnan Province [J]. Journal of Southwest Forestry University, 32(3): 40–46. [LIU Yang, DU Fan, LI Ruinian, et al., 2012. Altitudinal distribution pattern of orchids in northwestern Yunnan [J]. Journal of Southwest Forestry University, 32(3): 40–46.]

MARGALEF R, 1958. Temporal succession and spatial heterogeneity in phytoplankton [M]//BUZZATI-TRAVERSO AA. Perspectives in Marine Biology. Berkeley: University of California Press: 323–349.

QIN HN, YANG Y, DONG SY, et al., 2017. Threatened species list of China' s higher plants [J]. Biodiversity Science, 25(7): 696–744. [QIN Haining, YANG Yong, DONG Shiyong, et al., 2017. List of threatened species of China' s higher plants [J]. Biodiversity Science, 25(7): 696–744.]

SHANNON C E, WEAVER W, 1949. The mathematical theory of communication [M]. Urbana: University of Illinois Press.

SHANG WX, 2023. Impacts of natural environment and anthropogenic activi-

ties on the distribution of threatened orchid species in China [D]. Inner Mongolia: Inner Mongolia University. [SHANG Weixuan, 2023. Effects of the natural environment and human activities on the distribution of threatened orchid species in China [D]. Hohhot: Inner Mongolia University.]

SUN Y, LI B, GUO SX, 2017. Research progress of saprophytic orchids [J]. Guihaia, 37(2): 191-203. [SUN Yue, LI Biao, GUO Shunxing, 2017. Research progress on saprophytic orchids [J]. Guihaia, 37(2): 191-203.]

SWARTS ND, DIXON KW, 2009. Terrestrial orchid conservation in the age of extinction [J]. Annals

of Botany, 104(3): 543-56.

TANG CQ, OHSAWAM, 1997. Zonal transition of evergreen, deciduous, and coniferous forests along the altitudinal gradient on a humid subtropical mountain, Mt. Emei, Sichuan, China [J]. Plant Ecology, 133: 63-78.

WANG B, ZHENG QH, GUO J, 2008. Economic value assessment of forest species diversity conservation in China based on the Shannon-Wiener [J]. Forest Research, 21(2): 268-274. [Wang Bing, Zheng Qiuhong, Guo Hao, 2008. An assessment method for the conservation value of forest species diversity in China based on the Shannon-Wiener index [J]. Forest Research, 21(2): 268-274.]

WANG XL, LIU Q, YU DL, et al., 2016. Diversity of epiphytic orchids in fragmental limestone forests in Xishuangbanna, China [J]. Guihaia, 36(2): 162-169. [Wang Xilong, Liu Qiang, Yu Dongli, et al., 2016. Diversity of epiphytic Orchidaceae plants in fragmented limestone forests in Xishuangbanna [J]. Guihaia, 36(2): 162-169.]

WANG YB, DU F, 2007. Orchid diversity and conservation in Xiaoheishan Nature Reserve, Yunnan Province [J]. Journal of Wuhan Botanical Research, 25(1): 59-64. [Wang Yubing, Du Fan, 2007. Diversity and conservation evaluation of Orchidaceae plants in Xiaoheishan Nature Reserve, Yunnan Province [J]. Journal of Wuhan Botanical Research, 25(1): 59-64.]

WANG S, XIE Y, 2004. China species red list: Vol. 1. Red list [M]. Beijing: Higher Education Press. [Wang Song, Xie Yan, 2004. China Species Red List: Volume 1, Red List [M]. Beijing: Higher Education Press.]

WANG ZY, LIU XY, WANG WC, et al., 2022. Diversity and spatial distribution of Orchidaceae plants in Yunnan Province [J]. Seed, 41(12): 66-77. [Wang Ziyuan, Liu Xingyue, Wang Weichao, et al., 2022. Diversity of Orchidaceae plants in Yunnan Province and their spatial distribution characteristics [J]. Seed, 41(12): 66-77.]

WEBB CO, ACKERLY DD, MCPEEK MA, et al., 2002. Phylogenies and community ecology. Annual Review of Ecology, Evolution, and Systematics, 33(1): 475-505.

WIENS JJ, ACKERLY DD, ALLEN A P, et al., 2010. Niche conservatism as

an emerging principle in ecology and conservation biology [J]. Ecology Letters, 13(10): 1310-1324.

WIENS JJ, GRAHAM CH, 2005. Niche conservatism: integrating evolution, ecology, and conservation biology [J]. Annual Review of Ecology, Evolution, and Systematics, 36: 519-539.

YANG XK, YANG ZH, JIANG H, 2017. Wild *Dendrobium* species in Dehong [M]. Kunming: Yunnan Science and Technology Press. [Yang Xinkai, Yang Zhenghua, Jiang Hong, eds., 2017. *Dendrobium* of Dehong [M]. Kunming: Yunnan Science and Technology Press.]

YIN X, JARVIE S, GUO WY, et al., 2021. Niche overlap and divergence times support niche conservatism in eastern Asia–eastern North America disjunct plants [J]. Global Ecology and Biogeography, 30(10): 1990-2003.

YU JL, CHANG ML, MA L, et al., 2025. Collection and sorting of resource information of Orchidaceae medicinal plants in China [J]. Wuyi Science Journal, 41(1): 52-59. [Yu Jiali, Chang Menglin, Ma Liang, et al., 2025. Collection and organization of resource information on medicinal Orchidaceae plants in China [J]. Wuyi Science Journal, 41(1): 52-59.]

ZHANG JK, CHEN WD, LIN PC, et al., 2024. Diversity investigation and distribution characteristics of wild species of Orchidaceae in Qinghai Province [J]. Journal of Plant Resources and Environment, 33(6): 102-105. [Zhang Jinkui, Chen Weidong, Lin Pengcheng, et al., 2024. Investigation of the diversity and distribution characteristics of wild Orchidaceae plants in Qinghai Province [J]. Journal of Plant Resources and Environment, 33(6): 102-105.]

ZHANG YB, DU HD, JIN XH, et al., 2015. Species diversity and geographic distribution of wild Orchidaceae in China [J]. China Science Bulletin, 60(2): 179-188. [Zhang Yinbo, Du Haodong, Jin Xiaohua, et al., 2015. Species diversity and geographical distribution of wild Orchidaceae plants in China [J]. Chinese Science Bulletin, 60(2): 179-188.]

ZHANG WY, 2007. A list of the orchid plants in Fanjing Mountain National Nature Reserve, Guizhou, China [J]. Guizhou Science, 25(1): 43-53. [Zhang Yuwu, 2007. Orchidaceae plants of Fanjingshan National Nature Reserve, Guizhou [J]. Guizhou Science, 25(1): 43-53.]

ZHANG ZJ, YAN YJ, TIAN Y, et al., 2015. Distribution and conservation of orchid species richness in China [J]. Biological Conservation, 181: 64-72.

ZHAO ZT, LI XJ, LIU MF, et al., 2021. Specificity of assemblage, not fungal partner species, explains mycorrhizal partnerships of mycoheterotrophic *Burmannia* plants [J]. *The ISME Journal*, 15(6): 1614–1627.

ZHOU K, 2021. Diversity of orchid in Hainan Tropical Rainforest National Park and its priority protection strategy [D]. Haikou: Hainan University. [Zhou Kang, 2021. Diversity of Orchidaceae plants in Hainan Tropical Rainforest National Park and its priority protection strategy [D]. Haikou: Hainan University.]

ZHOU ZH, SHI RH, ZHANG Y, et al., 2021. Orchid conservation in China from 2000 to 2020: Achievements and perspectives [J]. *Plant Diversity*, 43(5): 343-349.

Note: Figure translations are in progress. See original paper for figures.