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Effects of clearcutting on species composition and community renewal of *Rhododendron* shrubs in northwest Guizhou Province, China

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Tree base sprouting is the main reproduction and expansion mode of *Rhododendron* plants. By leveraging the plot survey method, the species composition, community renewal, and species diversity in three *Rhododendron* shrub communities in control, and before and after clearcutting (CK, D_{3yr}, and D_{6yr}, respectively) were studied. Moreover, the dissimilarity of *Rhododendron* communities in CK, D_{3yr} and D_{6yr} were analyzed. The results showed that there were 26 plant species belonging to 14 families and 22 genera, in 3 communities in total, with 19 species of shrub plants and 7 species of herbaceous plants. The number of species increased from 13 in CK to 23 in D_{3yr} and then decreased to 20 in D_{6yr}. The height and coverage of D_{3yr} and D_{6yr} reached 39.3% and 58.9% of that of CK, respectively. The relative height of CK, D_{3yr}, and D_{6yr} was 43.79%, 65.4%, and 58.54%, respectively. The coverage of D_{3yr} and D_{6yr} reached 60.8% and 114.70% of that of CK, respectively. The relative coverage of CK, D_{3yr}, and D_{6yr} was 19.05%, 83.24%, and 77.32%, respectively. The important value of *Rhododendron* plants in the communities increased from 0.42 in CK to 0.74 in D_{3yr}, and then decreased to 0.67 in D_{6yr}. The α diversity in the shrub layer of D_{3yr} and D_{6yr} were generally lower than those of CK except Pielou evenness index. The β diversity indicates that the similarity between CK and D_{3yr} was lower, that between CK and D_{6yr} was moderate, and that between D_{3yr} and D_{6yr} was higher. The sprouting height and coverage of *Rhododendron* plants was significantly correlated with age and sprouting time. The sprouting ability of *Rhododendron* plants increased first and then decreased with age, while the sprouting ability of *Rhododendron* plants with age of 10–12 years was the strongest. Clearcutting measures can improve the dominance of *Rhododendron* plants in the communities, promote the sprouting and renewal of *Rhododendron* population, and accelerate the succession rate of communities.

KEYWORDS

Rhododendron **shrub, clearcutting, species composition, species diversity, community renewal**

1 Introduction

Rhododendron is one of the largest genera of angiosperms with more than 1200 species worldwide, which have important ecological and socio-economic applications of ornamental, cultural, scientific, economic, and medicinal value (MacKay and Gardiner, 2017; Li et al., 2018; Ahmad et al., 2021). The genus is mostly distributed in subtropical evergreen broad-leaved mountain forests, mixed coniferous broad-leaved forests, coniferous forests, and dark coniferous forests at altitudes varying from 1000 to 3800 m (Fang and Min, 1995). It only forms a single species of *Rhododendron* shrub or *Rhododendron* dwarf forest in certain high mountains above the tree line (Sun, 2002). Guizhou Province is located at the edge of the distribution center of modern *Rhododendron* (Hengduan Mountain region in China) and its transition zone along the eastern distribution range (Dai et al., 2020). More than 110 species of *Rhododendron* plants are distributed naturally in Guizhou Province (Dai et al., 2020). Northwest Guizhou Province is a vital area for the distribution of *Rhododendron*, with six subgenera and more than fifty species accounting for approximately 50% of the total *Rhododendron* population in Guizhou. The Baili Rhododendron National Nature Reserve at the junction of Qianxi and Dafang counties is the most representative, with 43 species of *Rhododendron* plants (Wang et al., 2010; Chen et al., 2013). It is a typical representative of the largest and contiguously distributed natural wild *Rhododendron* communities in the world (Rong et al., 2009) which may play an important role in understanding *Rhododendron* shrub ecosystem processes, succession, and shrub management. However, both the quantity of seedlings and the renewal rate of *Rhododendron* plants are low (Yang et al., 2020a). Meanwhile, it is easy for *Rhododendron* plants to be replaced by highly competitive trees and other shrubs because of succession (Bian et al., 2006). Coupled with global changes in recent years, *Rhododendron* plants, particularly some narrowly distributed *Rhododendron* species, have begun to decline or even die (Ma et al., 2014; Liu et al., 2019; Yu et al., 2019; Bitayan et al., 2021).

Sprouting renewal primarily refers to dry base sprouting and underground stem sprouting (Lu et al., 2021). New plants are formed *via* dormant or adventitious buds from underground stems and stubble of trees to achieve forest renewal (Vesk and Westoby, 2004). Sprouting plants can use nutrients in the soil more effectively through their strong root system, which usually grows faster than seedlings and has stronger adaptability (Kauffman, 1991; Chen et al., 2019). Owing to the weak competitiveness and high canopy density of *Rhododendron* shrub communities in northwest Guizhou, seed renewal of the *Rhododendron* population is difficult, and tree-based sprouting renewal is the main mode of reproduction and expansion (Kong et al., 2019). At present, the primary measures to promote tree-based sprouting renewal are controlled forest fires, clearcutting and other natural disasters such as hurricane, mudslides (Li, 1992; Luoga et al., 2004; Subedi et al., 2019). However, forest fires are harmful as these reduce the sprouting ability of shrub communities (Tang et al., 2001). In contrast, planned clearcutting promotes the growth of shrub tillering branches, regenerates and rejuvenates plant clusters, and increases the canopy width and biomass (Shang et al., 2020). Following clearcutting, sprouting plants usually grow faster than seedlings (Vesk and Westoby, 2004).

Research on sprouting renewal of *Rhododendron* plants in global started late at present; further, research on sprouting and stress tolerance of wild *Rhododendron* plants is limited, decreasing the promotion and utilization of wild *Rhododendron* plants resources (MacKay and Gardiner, 2016). Although several studies have reported renewal of *Rhododendron* shrubs by disturbance, altitude, and climate changes (Singh et al., 2019; Choudhary et al., 2021; Jia et al., 2021), there is limited knowledge regarding the sprouting renewal of *Rhododendron* plants by clearcutting. In this study, the effects of rational clearcutting on the sprouting renewal of *Rhododendron* communities were studied to determine the effect of clearcutting–sprouting on the role of *Rhododendron* plants in *Rhododendron* shrub communities. The objectives were to (1) Can clearcutting promote the community renewal of *Rhododendron* shrubs? (2) Does age affect the response of *Rhododendron* shrubs to clearcutting? (3) Can the sprouting and regeneration of *Rhododendron* be predicted after clearcutting?

2 Material and methods

2.1 Overview of the study area

The study area is in the Tiaohuapo Scenic Spot in the Baili Rhododendron National Nature Reserve, Guizhou Province, China (27°23′22′′N and 105°51′52′′E), near the Jiaozi Mountain, at an altitude of 1700–1900 m. The climate of the region can be characterized as subtropical humid monsoon climate, with an annual average temperature and precipitation of 11.8°C, and 1150.4 mm, respectively, a frost-free period of 257 days, and an annual sunshine duration of 1335.5 h. Zonal vegetation is dominated by the evergreen broad-leaved mountain forest. The existing vegetation is primarily *Rhododendron* shrub species exhibiting succession and transitional characteristics (Li and Chen, 2005; Jiang et al., 2015). Among *Rhododendron* shrubs, *R. delavayi*, *R. annae*, and *Lyonia ovalifolia* are the main dominant species. The soil type is primarily yellow soil with an acidic pH (4.61–5.32).

2.2 Plot setting and survey

In August 2015, three 20 m × 20 m fixed quadrats were set in the study area to represent the control community (CK), and three 5 m × 5 m survey quadrats were set diagonally in each quadrat. The species, plant number, branch number, height, and canopy width of the shrubs as well as the species and number of the herbaceous plants in the quadrats were recorded. Each *Rhododendron* shrub in the fixed quadrat was labelled.

In conjunction with the guidelines of Management Office of the Baili Rhododendron National Nature Reserve, all plants in the fixed quadrat were deforested and recovered. The shrubs in the fixed quadrat were deforested in December 2015 and the stubble height was recorded as approximately 15 cm. The number of stubbles was also recorded. The age of shrubs was determined based on the rings of the main pile of shrubs. All other plants were deforested and eliminated.

The same method was used to survey and record the sprouting number, height, and canopy width of *Rhododendron* shrubs in August 2018 and August 2021. Moreover, the species number, height, and canopy width of other shrubs, as well as the species and number of herbaceous plants in the quadrats, were also surveyed. The communities surveyed in 2018 and 2021 were denoted as D_{3yr} (Community 3 years after clearcutting) and D_{6yr} (Community 6 years after clearcutting), respectively.

2.3 Data analyses

2.3.1 Importance value

IV of the shrub layer for plant species in the three annual communities (CK, D_{3yr}, and D_{6yr}) was calculated using the equation (Wang et al., 2023)

$$IV = (RH + RC + RD)/3 \quad (1)$$

where *RH* denotes the relative height, *RC* denotes the relative coverage, and *RD* denotes the relative density.

2.3.2 α-Diversity

The Margalef richness index (*R*), Simpson diversity index (*D*), Shannon–Wiener diversity index (*H*), and Pielou evenness index (*J*) were determined to measure the α-diversity of the three communities using the equations (Zhang et al., 2017)

$$R = (S - 1)/lnN \quad (2)$$

$$D = 1 - \sum_{i=1}^{S} P_i^2 \quad (3)$$

$$H = -\sum_{i=1}^{S} P_I \quad lnI \quad (4)$$

$$J = H/lnS \quad (5)$$

where P_i denotes the relative IV of the ith species, *S* denotes the number of species, and *N* denotes the number of individual plants in the quadrat.

2.3.3 β-Diversity

The Cody index (β_c), Whittaker index (β_{ws}), Jaccard index (C_j), and Sorenson index (C_s) were determined to measure the β-diversity of the three communities before and after clearcutting using the equations (Baselga, 2010)

$$\beta_c = [g(H) + L(H)]/2 \quad (6)$$

$$\beta_{ws} = ms/ma - 1 \quad (7)$$

$$Cj = j/(a + b - j) \quad (8)$$

$$Cs = 2j/(a + b) \quad (9)$$

where β_c and β_{ws} denote the dissimilarity measures, C_j and C_s denote the similarity measures, $g(H)$ denotes the number of species increased along the time gradient *H*, $L(H)$ denotes the number of plant species existing in the previous community but lost in the next community, *ms* denotes the total number of species recorded in the three communities, *ma* denotes the average number of species in each community, *a* denotes the number of species in community A, *b* denotes the number of species in community B, and *j* denotes the number of species shared by communities A and B.

2.3.4 Sprouting status

The ratio between the number of *Rhododendron* sprouts and stumps after clearcutting was determined to measure the ability of *Rhododendron* plant to rejuvenate and renew using the equation

$$RS = ES/NS \quad (10)$$

where *RS* denotes sprouting ability, *ES* denotes the number of sprouts, and *NS* denotes the number of stubbles.

2.4 Data processing and statistical analyses

SPSS 26.0 software was used to measure the correlation (*Pearson correlation*) and linear regression analysis between the height and coverage as well as clearcutting time and age of *Rhododendron*. Analysis of variance was performed ($p < 0.05$ indicates significant differences) to determine the difference in IV of community species and biodiversity indices between the different stages of *Rhododendron* shrubs. All plots were prepared using SigmaPlot 14.0.

3 Results

3.1 Effects of clearcutting on *Rhododendron* shrub community characteristics

The three communities comprised 26 species, including nineteen species of shrubs and seven species of herbaceous plants, belonging to 14 families and 22 genera (Tables 1, 2). Ericaceae, Rosaceae, and Theaceae accounted for the highest number of species, specifically 19.23%, 15.38%, and 11.54% of the total, respectively. Three species of *Rhododendron* plants accounted for 11.54% of the total species.

CK comprised 13 species belonging to seven families (including Ericaceae, Lauraceae, Theaceae, and Poaceae) and 11 genera. Four species were identified in the herbaceous layer and nine in the shrub layer of which five viz., *R. delavayi*, *L. ovalifolia*, *R. annae*, and *P. japonica* of Ericaceae and *L. pungens* of Lauraceae exhibited IVs > 0.1 (0.31, 0.17, 0.12, 0.12, and 0.12, respectively). *R. delavayi* was the dominant species in the shrub layer of CK, and *L. ovalifolia* was the subdominant species.

TABLE 1 Effects of clearcutting on species composition of *Rhododendron* shrub communities.

Layer	Family	Species name	Community		
			CK	D_{3yr}	D_{6yr}
Shrub	Ericaceae	*R. delavayi*	1	1	1
		R. annae	1	1	1
		R. lilacinum	1	1	1
		Lyonia ovalifolia	1	1	1
		Pieris japonica	1	1	1
	Rosaceae	*Rubus trianthus*	NA	1	1
		R. corchorifolius	NA	1	1
		Cotoneaster horizontalis	NA	1	1
		Pyracantha fortuneana	NA	NA	1
	Lauraceae	*Litsea pungens*	1	1	1
		Machilus pingii	1	NA	NA
	Theaceae	*Eurya japonica*	1	1	1
		E. loquaiana	NA	1	1
		Camellia oleifera	NA	1	1
	Salicaceae	*Populus adenopoda*	NA	1	1
		Salix matsudana	NA	1	1
	Pinaceae	*Pinus armandii*	1	NA	NA
	Fagaceae	*Castanea seguinii*	NA	1	1
	Smilacaceae	*Smilax china*	NA	1	1
Herbaceous	Poaceae	*Miscanthus floridulus*	1	1	1
		Fargesia spathacea	1	1	1
	Thelypteridaceae	*Macrothelypteris oligophlebia*	NA	1	NA
	Rosaceae	*Duchesnea indica*	NA	1	1
	Cyperaceae	*Cyperus rotundus*	1	1	NA
	Juncaceae	*Juncus effusus*	1	1	NA
	Asteraceae	*Elephantopus scaber*	NA	1	NA
Total	14	26	13	23	20

"NA" indicates that the species did not appear in the community, and "1" indicates that the species appeared in the community. CK, Community before clearcutting; D_{3yr}, Community 3 years after clearcutting; D_{6yr}, Community 6 years after clearcutting.

D_{3yr} comprised the highest number of species, with 23 species from 12 families (including Ericaceae, Rosaceae, Theaceae, and Poaceae) and 19 genera. There were seven species in the herbaceous layer and 16 in the shrub layer of which two, *R. delavayi* and *R. annae* of Ericaceae, exhibited IVs of > 0.1 (0.53 and 0.19, respectively). *R. delavayi* was the dominant species in the shrub layer of D_{3yr}, and *R. annae* was the subdominant species.

D_{6yr} comprised 20 species belonging to nine families (including Ericaceae, Rosaceae, Theaceae, and Poaceae) and 16 genera. There were three species in the herbaceous layer and seventeen in the shrub layer. Consistent with D_{3yr}, two species in the shrub layer, *R. delavayi* and *R. annae*, exhibited IVs > 0.1 (0.46 and 0.18, respectively). *R. delavayi* was the dominant species in the shrub layer of D_{6yr}, and *R. annae* was the subdominant species.

In the CK→D_{3yr}→D_{6yr} community sequence, the height and coverage of *Rhododendron* shrubs first decreased and then increased (Figure 1). The height decreased significantly from 191.87 cm in CK to 75.61 cm in D_{3yr} and then recovered to 116.71 cm in D_{6yr}. The coverage decreased significantly from 68.46% in CK to 37.89% in D_{3yr} and then increased significantly to 73.28% in D_{6yr}. The relative height increased from 43.79% in CK to 65.40% in D_{3yr} and then decreased to 58.54% in D_{6yr}. The relative coverage increased from 49.05% in CK to 83.24% in D_{3yr} and then decreased to 77.32% in D_{6yr}. The height of *Rhododendron* species in

TABLE 2 Effects of clearcutting on importance values (IVs) of species in the shrub layer of *Rhododendron* shrub communities.

Species name	IV		
	CK	D_{3yr}	D_{6yr}
R. delavayi	0.31	0.53	0.46
R. annae	0.12	0.19	0.18
R. lilacinum	0.02	0.02	0.02
Lyonia ovalifolia	0.17	0.04	0.07
Pieris japonica	0.12	0.02	0.03
Rubus trianthus	NA	0.03	0.04
R. corchorifolius	NA	0.01	0.01
Cotoneaster horizontalis	NA	0.03	0.04
Pyracantha fortuneana	NA	NA	0.00
Litsea pungens	0.12	0.01	0.02
Machilus pingii	0.09	NA	NA
Eurya japonica	0.04	0.04	0.05
E. loquaiana	NA	0.02	0.01
Camellia japonica	NA	0.00	0.01
Populus adenopoda	NA	0.01	0.01
Salix matsudana	NA	0.03	0.03
Pinus armandii	0.01	NA	NA
Castanea seguinii	NA	0.01	0.01
Smilax china	NA	0.01	0.01
Total: 19	9	16	17

"NA" indicates that the species did not appear in the community. CK, Community before clearcutting; D_{3yr}, Community 3 years after clearcutting; D_{6yr}, Community 6 years after clearcutting.

the three communities were significantly different ($p < 0.05$). The coverage in D_{3yr} was significantly different from that in CK and D_{6yr} ($p < 0.05$). The relative height and coverage in CK were both significantly different from those in D_{3yr} and D_{6yr} ($p < 0.05$).

3.2 Effects of clearcutting on the diversity of species in *Rhododendron* shrub communities

The Margalef richness index values of species in the shrub layers of the three communities were significantly different ($p < 0.05$) (Figure 2). However, the differences in the Simpson diversity, Shannon–Wiener diversity, and Pielou evenness indices were not significant ($p > 0.05$). The values of all four indices were the highest in CK and lowest in D_{3yr}. The values of the Margalef richness, Simpson diversity, Shannon–Wiener diversity, and Pielou evenness indices of species in D_{3yr} were 61.15%, 80.30%, 84.79%, and 96.61% of that of species in CK, respectively.

As CK→D_{3yr}→D_{6yr} progressed, the dissimilarity coefficients of the three communities showed a decreasing trend (Table 3). Both Cody and Whittaker indices were the highest in CK and D_{3yr} (3.83 and 1.65, respectively) and the lowest in D_{3yr} and D_{6yr} (0.83 and 1.20, respectively). The similarity indices, the Jaccard and Sorenson indices, were the highest in D_{3yr} and D_{6yr} (0.87 and 0.93, respectively) and the lowest in CK and D_{3yr} (0.38 and 0.55, respectively). The similarity between CK and D_{3yr} was low, that between CK and D_{6yr} was moderate, and that between D_{3yr} and D_{6yr} was high.

3.3 Effects of clearcutting on the renewal of *Rhododendron* shrub communities

The height and coverage as well as the sprouting time and age of *Rhododendron* shrubs were significantly and positively correlated ($p < 0.01$). The correlation degree of sprouting time was higher than that of the age of *Rhododendron* shrubs (Table 4).

The sprouting time (t) and age (a) are the two main factors that affect clearcutting sprouting of *Rhododendron* shrubs. The linear relationships between sprouting height (h), sprouting coverage (c), sprouting time (t), and age (a) of *Rhododendron* shrubs after clearcutting were well fitted ($R^2 = 0.65$, $p < 0.01$ and $R^2 = 0.50$, $p < 0.01$, respectively) (Table 5).

The height of *Rhododendron* shrubs in CK, D_{3yr}, and D_{6yr} showed a gradual increasing trend with age (Figure 3). Compared with CK, the height of *Rhododendron* shrubs in D_{3yr} and D_{6yr} was lesser and increased slowly. The coverage rates of *Rhododendron* shrubs in the three communities also increased gradually with increasing age. The coverage rates of *Rhododendron* shrubs in D_{3yr} and D_{6yr} at the early stage were higher than those in CK.

To determine the sprouting ability at different ages, the age of *Rhododendron* shrubs was divided into three classes (I, II, and III). The sprouting ability of *Rhododendron* shrubs first increased and then decreased with age (Figure 4). Class II *Rhododendron* shrubs had the strongest sprouting ability. Moreover, the sprouting ability of class III *Rhododendron* shrubs was significantly different from that of classes I and II shrubs ($p < 0.05$).

4 Discussion

4.1 Effects of clearcutting on species composition and community characteristics of *Rhododendron* shrubs

Species composition reflects the structure, dynamic changes, and succession characteristics of a community and plays a decisive role in community diversity (Gilliam, 2007; Liu et al., 2020). In this study, 26 species belonging to 14 families and 22 genera were identified in the three communities studied (Table 1). The number of species in CK was the lowest probably because the canopy density of *Rhododendron* shrubs was high and the litter layer was thick, which reduced the migration and colonisation of *Rubus trianthus*, *Cotoneaster horizontalis*, *Eurya loquaiana*, *Populus adenopoda*, belonging to the Rosaceae, Theaceae, Salicaceae, as well as herbaceous plants. However, clearcutting weakened interspecies

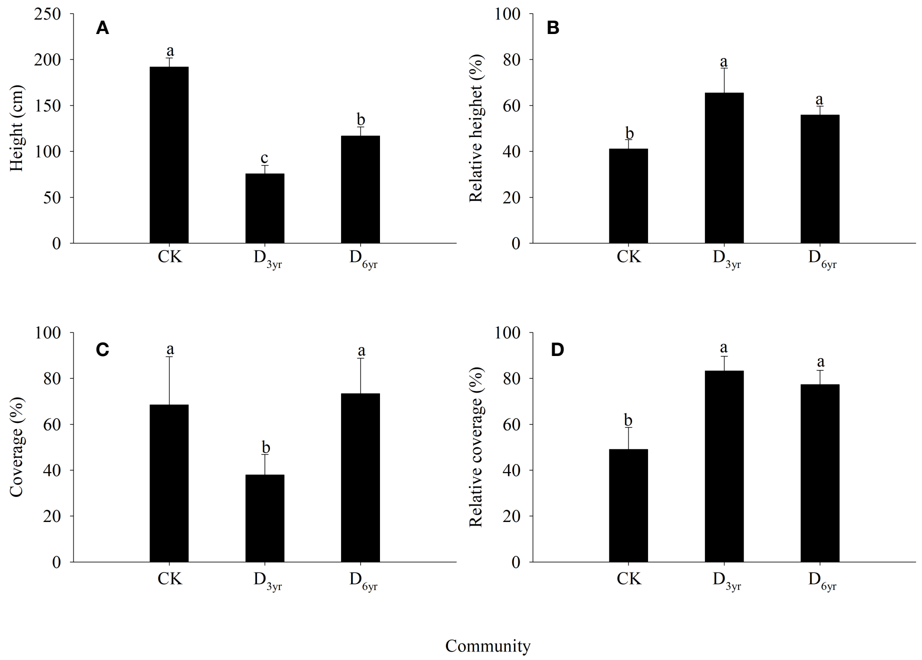

FIGURE 1
Effects of clearcutting on the height and coverage of *Rhododendron* shrubs. Height **(A)**; Relative height **(B)**; Coverage **(C)**; Relative coverage **(D)**. **(A–C)** indicate significant difference (p< 0.05). CK, control; D_{3yr}, community in 2018; D_{6yr}, community in 2021.

competition by reducing canopy density (Jones et al., 2019). Consequently, a large number of herbaceous plants, and species belonging to Rosaceae, Theaceae, and Salicaceae migrated; thus, D_{3yr} had the highest number of species. Subsequently, *Rhododendron* shrubs gradually occupied the upper space, the canopy density increased, and herbaceous plants gradually disappeared. Therefore, the number of species in D_{6yr} was lower compared with that in D_{3yr}.

The height and coverage of plants in communities are important indicators for evaluating the plant growth status (Chen et al., 2014). In this study, the height and coverage of plants in communities after clearcutting were significantly higher than those of plants in the seed

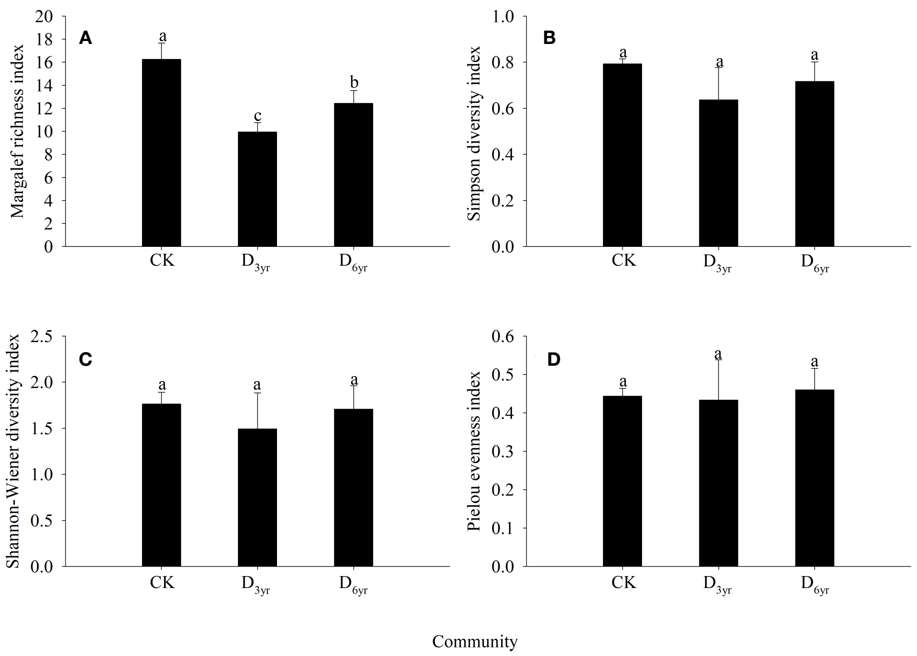

FIGURE 2
Effects of clearcutting on α-diversity of *Rhododendron* shrub communities. Margalef richness index **(A)**; Simpson diversity index **(B)**; Shannon–Wiener diversity index **(C)**; Pielou evenness index **(D)**. **(A–C)** significant difference (p< 0.05). CK, control; D_{3yr}, community in 2018; D_{6yr}, community in 2021.

TABLE 3 Effects of clearcutting on the β-diversity index of species in *Rhododendron* shrub communities.

Index	Community	CK	D_{3yr}	D_{6yr}
β_c	CK	0.00	3.83	3.50
	D_{3yr}	3.83	0.00	0.83
	D_{6yr}	3.50	0.83	0.00
β_{ws}	CK	0.00	1.65	1.55
	D_{3yr}	1.65	0.00	1.20
	D_{6yr}	1.55	1.20	0.00
C_j	CK	1.00	0.38	0.45
	D_{3yr}	0.38	1.00	0.87
	D_{6yr}	0.45	0.87	1.00
C_s	CK	1.00	0.55	0.62
	D_{3yr}	0.55	1.00	0.93
	D_{6yr}	0.62	0.93	1.00

β_c denotes the Cody index, β_{ws} denotes the Whittaker index, C_j denotes the Jaccard index, and C_s denotes the Sorensen index. CK, Community before clearcutting; D_{3yr}, Community 3 years after clearcutting; D_{6yr}, Community 6 years after clearcutting.

renewal communities (Figure 1), primarily because the large number of sprouting branches produced by *Rhododendron* shrubs could occupy more space by utilizing the resources, hence promoting rapid formation of community hierarchy. Post clearcutting, the sprouting coverage of *Rhododendron* shrubs in D_{6yr} was higher than that of shrubs in CK, primarily because clearcutting promoted shrub tillering and expanded individual canopy width. After clearcutting, the relative height of *Rhododendron* shrubs in D_{3yr} and D_{6yr} also increased significantly, probably because *Rhododendron* shrubs occupied the upper space of the whole shrub community after clearcutting, playing a dominant role in light absorption and utilization. The absence of other tall trees and shrub vegetation enabled *Rhododendron* plants roots to utilize soil nutrients more effectively. Therefore, clearcutting resulted in the domination of *Rhododendron* plants in the community, with vigorous population renewal and a stronger self-sustaining ability of the population.

4.2 Effects of clearcutting on the diversity of *Rhododendron* shrub communities

As a basic feature of a community, biodiversity is a key factor driving the dynamics and processes of an ecosystem and can indicate the habitat status, composition structure, and distribution pattern of a community (Liu and Bra, 1998; Tilman et al., 2012). In

TABLE 4 Correlation between sprouting height and coverage and time and age of *Rhododendron* shrubs.

	Height	Coverage
Time	0.69**	0.62**
Age	0.42**	0.37**

** indicates significant correlation at the 0.01 level.

TABLE 5 Regression model of sprouting height, sprouting coverage, and sprouting time of *Rhododendron* shrubs.

	Regression equation	R^2
Height	$h = 13.55t + 8.15a - 44.60$	0.65**
Coverage	$c = 0.60t + 0.37a - 3.43$	0.50**

** indicates significant correlation at the 0.01 level. h, sprouting height; t, sprouting time; a, age; and c, sprouting coverage.

this study, the evenness index of the communities changed after clearcutting (Figure 2). The index value was relatively large, indicating that the heterogeneity of the study area was poor. This was also determined by the characteristics of the sprouting branches of *Rhododendron* shrubs. Although clearcutting increased the number of species, the α-diversity was still lower than that in CK before clearcutting. This may be because *Rhododendron* plants has a strong sprouting ability. After clearcutting, *Rhododendron* plants is likely to occupy space in the form of sprouting branches to inhibit the migration and colonisation of foreign species (Grant and Loneragan, 1999; Kruger and Midgley, 2001). Therefore, *Rhododendron* plants with its strong sprouting abilities can reduce species diversity and species turnover in the community to a certain extent.

β-Diversity is usually expressed as the turnover rate of biological species in different habitats. A high β-diversity index indicates a low level of species similarity between different habitats or ecosystems (Yang et al., 2020b). The results showed that the similarity between CK and D_{3yr} was low, that between CK and D_{6yr} was moderate, and that between D_{3yr} and D_{6yr} was high (Table 3). The Cody and Whittaker indices were higher before and after clearcutting, whereas the Jaccard and Sorenson indices were lower, indicating that clearcutting changed the species composition and community structure of *Rhododendron*. The similarity between CK and D_{3yr} was low but that between CK and D_{6yr} was moderate, indicating that with the progression of CK→D_{3yr}→D_{6yr}, the number of common plant species first decreased and then increased. Subsequently, the similarity among species composition also first decreased and then increased, indicating that *Rhododendron* plants could recover to the pre-clearcutting community level in a short time through clearcutting–sprouting renewal.

4.3 Effects of clearcutting on the renewal of *Rhododendron* shrub communities

In *Rhododendron* shrub communities, both seedlings and sprouting seedlings can undergo population renewal. Nevertheless, sprouting seedlings are an important source of population dynamics (Vesk and Westoby, 2004). Due to the strong sprouting ability of *Rhododendron* plants, deforested communities rapidly self-substitute, which not only affects the community structure but also has an important impact on population dynamics. Clearcutting–sprouting renewal avoids the problems of very low sprouting and survival rates as well as weak seedling competitiveness. The results of this study similarly showed that the dominance of the *Rhododendron* population in D_{3yr} and D_{6yr} after sprouting was greater than that

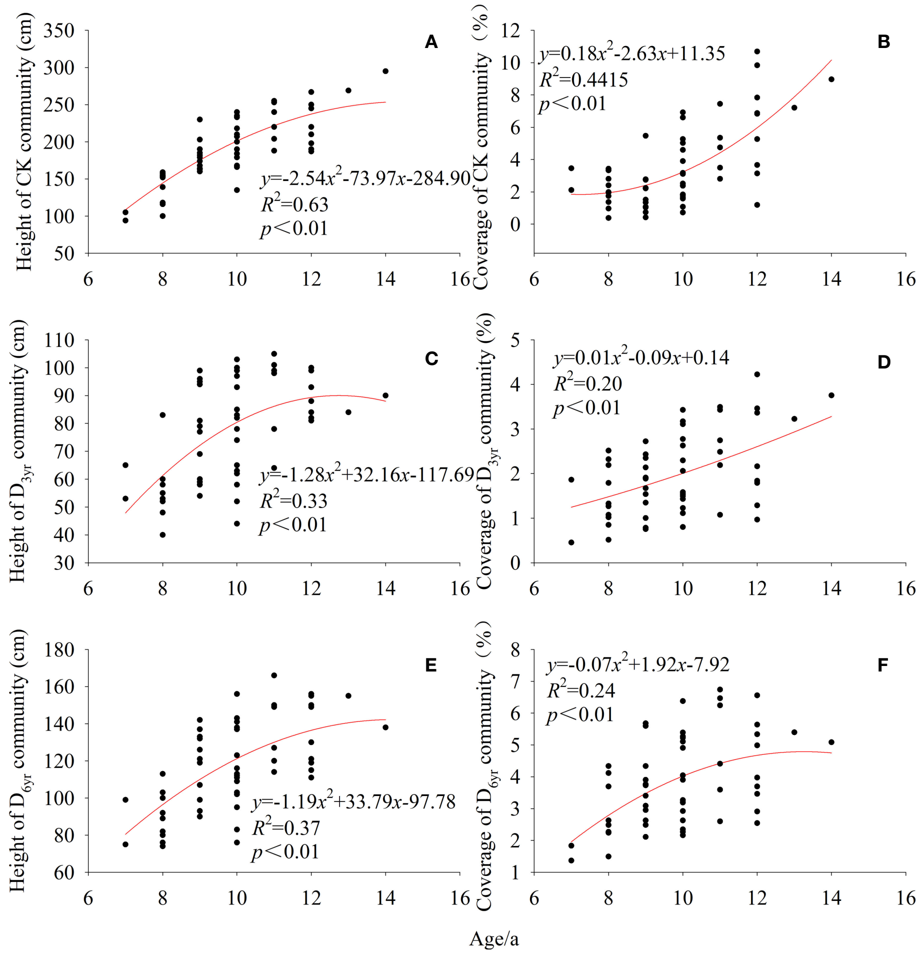

FIGURE 3
Variation in height and coverage of *Rhododendron* shrubs with age. Height of CK community **(A)**; Coverage of CK community **(B)**; Height of D_{3yr} community **(C)**; Coverage of D_{3yr} community **(D)**; Height of D_{6yr} community **(E)**; Coverage of D_{6yr} community **(F)**. CK, control; D_{3yr}, community in 2018; D_{6yr}, community in 2021.

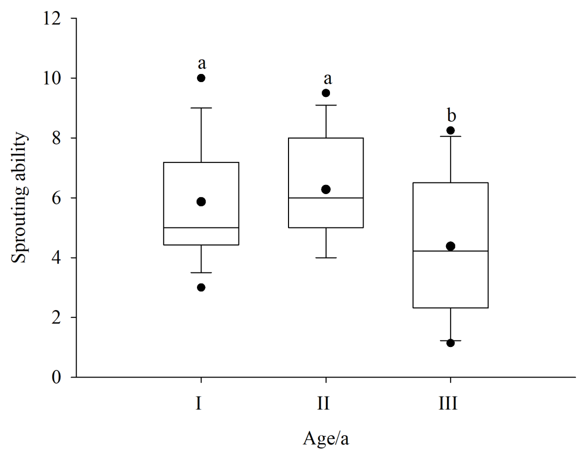

FIGURE 4
Effect of age of *Rhododendron* shrubs on sprouting ability. I, 7–9 years; II, 10–12 years; and III, > 12 years. a and b denote significant difference (p < 0.05).

in CK before clearcutting. The growth recovery of *Rhododendron* plants after clearcutting is completely dependent on the amount of stubble, root tiller, and rhizome, whereas the number of sprouts is a common index to characterize the strength of sprouting (Chi et al., 2019). Although the sprouting ability of *Rhododendron* plants was strong in this study, the recovery ability first increased and then decreased with the age of the *Rhododendron* shrubs. The sprouting ability of *Rhododendron* shrubs of age 10–12 years was the strongest (Figure 4). This may be associated with the aging of plants, an excessively large root system, and a lack of rhizome growth, which led to partial necrosis of the underground root system.

The community succession of *Rhododendron* plants does not deviate far from the original direction because of its strong sprouting ability and the effect of the ecological niche after clearcutting (Ahmad et al., 2021). However, the communities in this study had a high number and proportion of *Rhododendron* shrubs initially, which were *in situ* substituted with a similarly high number, accelerating the recovery to the original structure and succession rate of the community. Therefore, the shrub layer of *Rhododendron* communities after clearcutting was primarily composed of sprouting branches of *Rhododendron*, and the final direction of succession was subtropical evergreen broad-leaved forest. Compared with seed renewal and succession, the clearcutting–sprouting succession of *Rhododendron* plants takes a shorter time to achieve maturity (Loucks, 1970; Chen et al., 2019).

5 Conclusions

In total, 26 species from 22 genera and 14 families were found in the three communities. Clearcutting promoted the migration and colonisation of the families Rosaceae, Theaceae, and Salicaceae and other herbaceous plants, whereas the relative height and coverage of shrubs in the communities increased significantly. After clearcutting, there was a slight change in community evenness and a decrease in the α-diversity. The β-diversity showed that clearcutting improved the dominance of *Rhododendron* plants in the community and promoted sprouting renewal of *Rhododendron* populations. Moreover, the sprouting ability of *Rhododendron* shrubs of age 10–12 years was the strongest. Clearcutting did not affect the direction of community succession, but could accelerate the succession rate. Owing to the short observation period of clearcutting and sprouting of *Rhododendron* communities in this study, it was not possible to accurately predict the rate of population renewal and community succession of *Rhododendron* shrubs. In subsequent studies, multiple clearcutting modes and *Rhododendron* population succession stages will be established in combination with the competitive ability of the *Rhododendron* population.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

YZ, XZ, and LW contributed to the conception and design of the study. HS confirmed and guided the study. ZW, BJ, and HS carried out the experiments. YW performed the statistical analysis and wrote the first draft of the manuscript. YZ, XZ, and CC guided writing sections of the manuscript. All authors contributed to manuscript revision, read, 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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References

Ahmad, P. I., Puni, L., Pandey, R., Pala, N. A., Rather, M. M., Rashid, M., et al. (2021). Influence of different treatments and techniques on rooting behaviour of *Rhododendron arboreum* Sm. In Indian Himalayas. *Acta Ecol. Sin.* 41 (4), 332–335. doi: 10.1016/j.chnaes.2021.01.001

Baselga, A. (2010). Partitioning the turnover and nestedness components of beta diversity. *Glob. Ecol. Biogeogr.* 19 (1), 134–143. doi: 10.1111/j.1466-8238.2009.00490.x

Bian, C. M., Jin, Z. X., Zhang, J. H., and Jin, J. D. (2006). Response of seed germination of *Rhododendron fortunei* to drought stress. *Bull. Bot. Res.* 26 (6), 718–721. doi: 10.7525/j.issn.1673-5102.2006.06.016

Bitayan, M., Cervantes, S. S., and Napaldet, J. T. (2021). Morpho-anatomical characterization of *Rhododendron* subsessile Rendle, an endangered species of the Cordillera Central Range, Philippines. *J. For. Res.* 32, 241–247. doi: 10.1007/s11676-019-01087-5

Chen, Z. G., Batu, N. C., Xu, Z. Y., and Hu, Y. F. (2014). Measuring grassland vegetation cover using digital camera images. *Acta Pratac. Sin.* 23 (6), 20–27. doi: 10.11686/cyxb20140603

Chen, X., Huang, J. Y., Huang, C. L., and Chen, X. (2013). Study on the macromorphological characters of *Rhododendron* (Ericaceae) in Northwestern Guizhou. *Seed.* 32 (8), 51–55. doi: 10.16590/j.cnki.1001-4705.2013.08.077

Chen, S. Q., Wei, X. L., An, M. T., and Kong, D. M. (2019). Species diversity of plant communities at different succession stages in Baili *Rhododendron* Nature Reserve of Guizhou. *Acta Bot. Boreali-Occident. Sin.* 39 (7), 1298–1306. doi: 10.7606/j.issn.1000-4025.2019.07.1298

Chi, X. L., Wang, Q. G., Guo, Q., Yang, X., and Tang, Z. Y. (2019). Sprouting characteristics of communities during succession in an ever-green broad-leaved forest on Gutian Mountain, East China. *Biodivers. Sci.* 27 (1), 24–32. doi: 10.17520/biods.2018222

Choudhary, S., Thakur, S., Majeed, A., and Bhardwaj, P. (2021). Adaptability of *Rhododendrons* in high altitude habitats. *J. For. Res.* 32 (2), 449–460. doi: 10.1007/s11676-019-01081-x

Dai, X. Y., Yang, C. H., Yang, B., Chen, P., and Ma, Y. P. (2020). A new species of *Rhododendron* (Ericaceae) from Guizhou, China. *Phytokeys.* 146 (10), 53–59. doi: 10.3897/phytokeys.146.51342

Fang, R. Z., and Min, T. L. (1995). The floristic study on the genus *Rhododendron*. *Plant Divers.* 17 (4), 359–379. doi: ir.kib.ac.cn:8080/handle/151853/12313

Gilliam, F. S. (2007). The ecological significance of the herbaceous layer in temperate forest ecosystems. *BioScience.* 57 (10), 845–858. doi: 10.1641/B571007

Grant, C. D., and Loneragan, W. A. (1999). The effects of burning on the understorey composition of 11–13-year-old rehabilitated bauxite mines in Western Australia–Vegetation characteristics. *Plant Ecol.* 145, 291–305. doi: 10.1023/A:1009821128075

Jia, Z. Z., Li, W. J., Tian, A., and Wang, J. G. (2021). Ecological influence of tourism disturbance on the characteristics of different communities in Baili *Rhododendron* Forest. *Acta Ecol. Sin.* 41 (11), 4641–4649. doi: 10.5846/stxb201907021387

Jiang, H., He, B., and Luo, Q. (2015). A study of the relationship between the distribution of bryophytes and the environmental factors in Baili Azalea National Forest Park. *Ecol. Sci.* 34 (4), 31–36. doi: 10.14108/j.cnki.1008-8873.2015.04.006

Jones, G. L., Tomlinson, M., Owen, R., Scullion, J., Winters, A., Jenkins, T., et al. (2019). Shrub establishment favoured and grass dominance reduced in acid heath grassland systems cleared of invasive *Rhododendron pontic*. *Sci. Rep.* 9, 2239. doi: 10.1038/s41598-019-38573-z

Kauffman, J. B. (1991). Survival by sprouting following fire in tropical forests of the eastern amazon. *Biotropica* 23 (3), 219–224. doi: 10.2307/2388198

Kong, D. M., Ran, J. C., An, M. T., Cui, X. Y., and Chen, S. Q. (2019). Analysis on structure characteristics and regeneration trend of typical *Rhododendron* communities at Baili Rhododendron Nature Reserve. *Non-wood For. Res.* 37 (4), 112–119. doi: 10.14067/j.cnki.1003-8981.2019.04.015

Kruger, L. M., and Midgley, J. J. (2001). The influence of resprouting forest canopy species on richness in Southern Cape forests, South Africa. *Glob. Ecol. Biogeogr.* 10, 567–572. doi: 10.1046/j.1466-822x.2001.00264.x

Li, J. W. (1992). *Forest Ecology* (BeiJing: China Forestry Publishing House).

Li, W. J., and Chen, X. A. (2005). Preliminary study on structure and regeneration of *Rhododendron delavayi* population in Baili Azalea Forest Park. *Guizhou Sci.* 23 (3), 46–49. doi: 10.3969/j.issn.1003-6563.2005.03.011

Li, T. Q., Liu, X. F., Li, Z. H., Ma, H., Wan, Y. M., Liu, X. X., et al. (2018). Study on reproductive biology of *Rhododendron longipedicellatum*: a newly discovered and special threatened plant surviving in limestone habitat in southeast Yunnan China. *Front. Plant Sci.* 9 (1). doi: 10.3389/fpls.2018.00033

Liu, Q., and Bra, S. (1998). Long-term effects of clear-felling on vegetation dynamics and species diversity in a boreal pine forest. *Biodivers. Conserv.* 7 (2), 207–220. doi: 10.1023/A:1008836502640

Liu, D., Guo, Z. L., Cui, X. Y., and Fan, C. N. (2020). Comparison of five associations of Taxus cuspidata and their species diversity. *Biodivers. Sci.* 28 (3), 340–349. doi: 10.17520/biods.2019112

Liu, D. T., Sun, W. B., Ma, Y. P., and Fang, Z. D. (2019). Rediscovery and conservation of the Critically Endangered *Rhododendron griersonianum* in Yunnan, China. *Oryx* 53 (1), 14. doi: 10.1017/S0030605318001278

Loucks, O. L. (1970). Evolution of diversity, efficiency, and community stability. *Am. Zool.* 10 (1), 17–25. doi: 10.1093/icb/10.1.17

Lu, M. Z., Du, H., Song, T. Q., Peng, W. X., Liu, K. P., Su, L., et al. (2021). Characteristics of sprouting in woody plants in evergreen-deciduous broadleaf karst forest in Mulun National Nature Reserve. *Acta Ecol. Sin.* 41 (15), 6182–6190. doi: 10.5846/stxb202004291045

Luoga, E. J., Witkowski, E., and Balkwill, K. (2004). Regeneration by coppicing (resprouting) of miombo (African savanna) trees in relation to land use. *For. Ecol. Manage.* 189 (1-3), 23–35. doi: 10.1016/j.foreco.2003.02.001

Ma, Y. P., Nielsen, J., Chamberlain, D. F., and Li, X. Y. (2014). The conservation of *Rhododendrons* is of greater urgency than has been previously acknowledged in China. *Biodivers. Conserv.* 23 (12), 3149–3154. doi: 10.1007/s10531-014-0764-9

MacKay, M., and Gardiner, S. E. (2016). A model for determining ex situ conservation priorities in big genera is provided by analysis of the subgenera of *Rhododendron* (Ericaceae). *Biodivers. Conserv.* 26 (1), 189–208. doi: 10.1007/s10531-016-1237-0

MacKay, M., and Gardiner, S. E. (2017). Geographic analysis of Red List *Rhododendron* (Ericaceae) taxa by country of origin identifies priorities for ex situ conservation. *Blumea* 62 (2), 103–120. doi: 10.3767/blumea.2017.62.02.05

Rong, L., Chen, X., and Wang, X. C. (2009). Leaf anatomical characters and its ecological adaptation of 13 species of *Rhododendron* in Baili Azalea Area. *J. Anhui Agric. Sci.* 37 (3), 1084–1088. doi: 10.13989/j.cnki.0517-6611.2009.03.113

Shang, K. K., Zhang, G. W., and Song, N. N. (2020). Effects of different cutting intensities on phytoremediation of heavy metal for flowering shrubs. *J. Northeast For. Univ.* 48 (5), 50–54+61. doi: 10.13759/j.cnki.dlxb.2020.05.010

Singh, N., Ram, J., Tewari, A., and Yadav, R. (2019). Phenological events along the elevation gradient and effect of climate change on *Rhododendron Arboreum* Sm. in Kumaun Himalaya. *BioScience* 37 (4), 112–119. doi: 10.18520/CS/V108/I1/106-110

Subedi, S. C., Ross, M. S., Sah, J. P., Redwine, J., and Baraloto, C. (2019). Trait-based community assembly pattern along a forest succession gradient in a seasonally dry tropical forest. *Ecosphere* 10 (4), e02719. doi: 10.1002/ecs2.2719

Sun, H. (2002). Tethys retreat and Himalayas-Hengduanshan Mountains uplift and their significance on the origin and development of the Sino-Himalayan elements and Alpine flora. *Acta Bot. Yunnanica* 24 (6), 671–688. doi: 10.3969/j.issn.2095-0845.2002.06.001

Tang, Y., Fong, Z. L., and Cao, M. (2001). Forest regeneration by sprouting in slash and burn field, Xishuangbanna. *J. Northeast For. Univ.* 2001 (4), 64–66. doi: 10.3969/j.issn.1000-5382.2001.04.019

Tilman, D., Reich, P. B., and Isbell, F. (2012). Biodiversity impacts ecosystem productivity as much as resources, disturbance, or herbivory. *Proc. Natl. Acad. Sci. U. S. A.* 109 (26), 10394–10397. doi: 10.1073/pnas.1208240109

Vesk, P. A., and Westoby, M. (2004). Sprouting ability across diverse disturbances and vegetation types worldwide. *J. Ecol.* 92 (2), 310–320. doi: 10.1111/j.0022-0477.2004.00871.x

Wang, Z. C., Chen, X., Ren, Z. M., Zhou, J. W., Chen, X., An, M., et al. (2010). Analysis on phylogenesis of *Rhododendron* L. plant located in hundred *Rhododendron* protection zone of Guizhou and flowering characteristics in molecular level. *Seed* 29 (12), 72–76. doi: 10.16590/j.cnki.1001-4705.2010.12.076

Wang, Z. Y., Wang, L. J., Tian, X. L., Zhang, Q., Wang, J. G., Shuai, H. G., et al. (2023). Characteristics and species diversity of different *Rhododendron* shrub communities in northwest Guizhou. *Acta Ecol. Sin.* 43 (2), 693–701. doi: 10.5846/stxb202101310336

Yang, J. W., Liu, X. Q., Peng, X. H., Wang, M., Zhen, L. Y., Liu, S., et al. (2020b). Plant diversity and soil physical properties in different degree of rocky desertification in northern Hubei Province. *Res. Soil Water Conserv.* 27 (6), 100–106+115. doi: 10.13869/j.cnki.rswc.2020.06.015

Yang, B., Yuan, C. J., Dai, X. Y., Yang, C. H., Chen, Z. P., Guo, Y., et al. (2020a). Characteristics of wild populations and their communities of endemic plant Rhododendron bailiense in Guizhou Province. *J. Plant Resour. Environ.* 29 (4), 61–68. doi: 10.3969/j.issn.1674-7895.2020.04.08

Yu, F. Y., Wang, T. J., Groen, T. A., Skidmore, A. K., Yang, X. F., Ma, K. P., et al. (2019). Climate and land use changes will degrade the distribution of *Rhododendrons* in China. *Sci. Total Environ.* 659, 515–528. doi: 10.1016/j.scitotenv.2018.12.223

Zhang, R. Y., Wang, Z. W., Han, J. D., Pan, Z. L., Liu, F., Wu, Q., et al. (2017). The response of plant alpha diversity to different grazer stocking rate in a *Stipa breviflora.* desert steppe. *Acta Ecol. Sin.* 37 (3), 906–914. doi: 10.5846/stxb201508191729