Ant (Hymenoptera: Formicidae) Species Diversity of the Western Sichuan Plateau in China[1]

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J. Entomol. Sci. 58(2): 142–165 (April 2023)
DOI: 10.18474/JES22-28

Abstract Ant (Hymenoptera: Formicidae) diversity, with respect to elevation and the similarity of different ant communities therein, was identified in the southern portion of the Western Sichuan Plateau in China. Thirty plots were established in four elevation zones to serve as sampling areas for ants. We collected 19,235 ants in the survey. Those represented 68 species, 23 genera, and 4 subfamilies (including 13 undetermined species). The three dominant species in terms of abundance were *Lasius himalayanus* Bingham, *Formica fusca* L., and *Myrmica kozlovi* Ruzsky. We also found that the number of species, population density, the diversity, and dominance indices of the ant communities displayed a multidomain effect with an increase in elevation. The similarity coefficient of ant communities in each zone of elevation ([*q*] 0.2239–0.5217, medium similar level [occupying 17%], medium dissimilar level [occupying 50%], and dissimilar level [occupying 33%]) showed that differences in elevation and in habitat heterogeneity had a large impact on ant communities in the study area. Ant species diversity at each elevation sampled was not disturbed by human activities. The similarity coefficient of ant communities at the different zones of elevation was low. Therefore, ant species diversity was relatively high, indicating a higher conservation value in Sichuan Province.

Key Words Formicidae, diversity, community composition, similarity, Western Sichuan Plateau

In recent years, global climate change and interference of human activities have decreased biodiversity, and its conservation on our planet is in crisis (Gao et al. 2020). Ecosystem function will change with alterations in biodiversity, resulting in increasingly severe environmental problems, leading to the extinction of many plant and animal species (Zhang et al. 2006). Insects are among the most diverse groups in the animal kingdom due to their species diversity, abundance, and widespread distribution. Protecting and managing their biodiversity to prevent loss is a global concern and effort (Li and Huang 2018).

Ants (Hymenoptera: Formicidae) are increasingly used as important indicators of biodiversity in ecosystem studies (Andersen 1990). Wilson et al. (1967) noted that

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ants are amenable as bioindicators because of their abundance, widespread distribution, ease of collection, sensitivity to environmental change, and ease of observation of community dynamics. The role ants play in ecosystems is considerable (Folgarait 1998), and includes decomposition of organic matter in the soil, the spread of plant seeds, decomposition of small animal carrion, and plant pollination (Xu 2002). However, a few species of ants also harm crops, spread diseases, and interfere with human activities (Xu 2002). Therefore, ants are closely related to human and ecosystem health, and it is important to conduct systematic classification and species diversity research on them.

The diversity of Formicidae in China has been mainly studied in Yunnan and Tibet, for example, southeast Yunnan (Zhu et al. 2019), northeast Yunnan (Huang et al. 2019), southwest Yunnan (Guo et al. 2021), near the Himalayas (Li et al. 2016, Liu et al. 2020, Zhang et al. 2018), southeast Tibet (Liu et al. 2011, 2017; Yu et al. 2012; Zhang et al. 2011), and Tibetan areas (Xu et al. 2021). Our research team also has conducted research on ant diversity in Sichuan, including the elevation gradient of ant species diversity of the Wanglang Nature Reserve and adjacent areas in Sichuan Province (Luo et al. 2019), Western Daliangshan in Sichuan Province (He et al. 2020), Middle Daliangshan in Sichuan (Chen et al. 2022), Anzihe Nature Reserve and adjacent areas in Sichuan Province (Qi et al. 2021), and Eastern Daliangshan, Sichuan Province (Han et al. 2021).

As a part of the southeastern margin of the Qinghai-Tibet Plateau and the Hengduan Mountains, the Western Sichuan Plateau is the transition zone of the first and second steps of China's physical geography, as well as the middle zone from the Qinghai-Tibet Plateau to the Sichuan Basin, which is characterized by changes in topography and elevation. The average elevation of the region is $>$3,500 m, with large seasonal and diurnal temperature differences, complex and diverse climatic conditions, a typical geological environment, and fragile surface ecology (Zeng et al. 2011). There are clear differences in geomorphology, rich ecosystem types, and unique plant resources. It is an important water source protection zone and national ecological security barrier in the upper reaches of the Yangtze and Yellow rivers, and is an ideal area for biodiversity research. Therefore, to better understand the role of ant species diversity in this region, we conducted a systematic survey in the southern part of the Western Sichuan Plateau to gather basic data for biodiversity conservation in this region.

Materials and Methods

Study area. From July to August 2021, we surveyed the ant species diversity in Jiulong, Litang, Daocheng, Xiangcheng, and Derong counties in the southern part of the Western Sichuan Plateau. Four zones of elevation were established in the range of 1,515 to 4,512 m, which were the southern slope of the Dardenna Village Pass, the northern slope of the Dardenna Village Pass, the southern slope of Zhongyongtong Village Pass, and the northern slope of Zhongyongtong Village Pass. Selection of sample plots was based mainly on the change in elevation. One 50×50-m sample plot was established for every 250-m increase in elevation for a total of 30 plots (Table 1). Owing to the complexity of the terrain and the limitations of vegetation conditions, there was a certain degree of deviation in the selection of typical sample sites. However, the error range was usually controlled within ±50 m.

Survey method. We followed the protocols of Xu (2002) in our surveys. In each of the 30 plots, five 1 × 1-m squares were established 10 m apart along a diagonal across the plot. Each of these squares in each plot was sampled for soil composition, estimation of the area coverage by ants, and collection of ants. First, all ants that were not in a colony (nest) were collected and preserved in 95% ethyl alcohol. If an ant nest was found in the square, the numbers of ants were counted and up to 30 ants were collected and preserved in alcohol. The remaining ants were allowed to remain. Second, the soil layer in the square was excavated to a depth of 20 cm using a small hand tool. Ants in that soil sample were counted, collected, and preserved as previously described. Finally, the ants in the tree or shrub canopy in the plot were sampled using a shake-cloth method, so that all ants that fell on the cloth during shaking of the plant foliage could be counted, collected, and preserved. We then carefully examined each square for 1 h as described by Xu et al. (2011) for any additional ant specimens. The ground surface, deciduous layer, mosses and other ground plants, cow dung, rotting wood, stones, tree trunks, and other microhabitats in the sample plot were further searched for ant specimens. In these searches, observed ants were collected and preserved. When an ant nest was found, up to 30 ants were collected from the colony and preserved. For each plot, we recorded the geographical location, elevation, slope direction, soil type and water content, vegetation type, tree canopy, shrub coverage, ground cover and density, time of sampling, and name of the sampler. The plot was then photographed. All collected ant specimens were transported to the laboratory for identification and data analysis.

Specimen identification. According to the principles of "same nest" and "same morphology" (Xu 2002), the ant specimens collected in the field were grouped, numbered, and number of individuals recorded. Up to nine specimens from each group were mounted on card points for morphological examination and taxonomic identification. The remaining specimens from each group were preserved in vials of 95% ethyl alcohol. Specimens were identified according to available literature, professional websites, and photographs of type specimens (Wu and Wang 1995, Xu 2002, Zhou 2001). These specimens were verified by a taxonomic specialist in the Formicidae (Professor Zheng-Hui Xu, Southwest Forestry University), and identified specimens were deposited in the Southwest Forestry University Herbarium for future reference.

Community structure analysis. The species in sampled areas were divided into five classes based on the percentage of individual ant species relative to the total number. Using the method of Huang et al. (2019), these classes were: A with ≥10% dominant species; B with 5.0–9.9% common species; C with 1.0–4.9% relatively common species; D with relatively rare species; and E with <0.1% rare species.

Diversity index. To compare the composition, species richness, and diversity of ant communities in different elevation gradients in the zones, EstimateS 9.1.0 software was used to process the data (Li 2011). The ant species diversity was measured using five main indices: number of species (*S*), population density, Shannon–Wiener diversity index (*H*), Simpson dominance index (*C*), and Jaccard similarity coefficient (*q*) (Xu 2002, Xu et al. 2001). The iNEXT software toolkit in R

Table 1. Characteristics of sample plots of the ant community survey in the southern part of the Western Sichuan Plateau.

Sample Number	Sample Site	Elevation (m)	Slope Direction	Slope Gradient (°X)	Soil Type	Vegetation Type	Canopy Density	Coverage (%)			Litter Thickness (cm)
								Shrub	Herb	Litter	
1	Luobosigou Village, Xiaojinyizu Township, Jiulong County, Ganzi Prefecture, Sichuan Province	1,515	S	45	Brown soil	Conifer–broadleaf mixed forest	30	70	90	90	2–3
2	Xiongjiagou Village, Yandai Town, Jiulong County, Ganzi Prefecture, Sichuan Province	1,720	SE	30	Brown soil	Broad-leafed forest	20	30	90	60	2–3
3	Yanshijiangliangzi Village, Wulaxi Town, Jiulong County, Ganzi Prefecture, Sichuan Province	2,015	SE	40	Brown soil	Broad-leafed forest	20	20	70	30	1–2
4	Naiqu Village, Naiqu Town, Jiulong County, Ganzi Prefecture, Sichuan Province	2,266	SE	10	Cinnamon soil	Broad-leafed forest	30	45	95	10	1–2
5	Changcaoping Village, Naiqu Town, Jiulong County, Ganzi Prefecture, Sichuan Province	2,502	S	30	Cinnamon soil	Broad-leafed forest	50	40	90	5	1–2

Table 1. Continued.

Sample Number	Sample Site	Elevation (m)	Slope Direction	Slope Gradient (°X)	Soil Type	Vegetation Type	Canopy Density	Coverage (%)			Litter Thickness (cm)
								Shrub	Herb	Litter	
6	Maipu Village, Xiaer Town, Jiulong County, Ganzi Prefecture, Sichuan Province	2,783	SW	40	Brown soil	Broad-leafed forest	30	40	70	60	1
7	Huaqiu Village, Xiaer Town, Jiulong County, Ganzi Prefecture, Sichuan Province	3,043	NW	25	Brown soil	Coniferous forest	40	20	60	60	1–2
8	Tanggu Village, Tanggu Town, Jiulong County, Ganzi Prefecture, Sichuan Province	3,265	SE	15	Brown soil	Conifer–broadleaf mixed forest	90	30	90	30	1–2
9	Zhongu Village, Tanggu Town, Jiulong County, Ganzi Prefecture, Sichuan Province	3,500	SE	30	Cinnamon soil	Conifer–broadleaf mixed forest	85	30	90	70	2–3
10	Geta Village, Tanggu Town, Jiulong County, Ganzi Prefecture, Sichuan Province	3,778	S	15	Brown soil	Conifer–broadleaf mixed forest	50	30	30	20	3–4

Table 1. Continued.

Sample Number	Sample Site	Elevation (m)	Slope Direction	Slope Gradient (°X)	Soil Type	Vegetation Type	Canopy Density	Coverage (%)			Litter Thickness (cm)
								Shrub	Herb	Litter	
11	Xikelong Village, Tanggu Town, Jiulong County, Ganzi Prefecture, Sichuan Province	4,028	S	20	Cinnamon soil	Broad-leafed forest	70	15	75	60	1–2
12	Dardenna Village, Xiongba Township, Litang County, Ganzi Prefecture, Sichuan Province	4,270	NE	30	Brown soil	Shrub	0	30	95	90	1
13	Pass of Dardenna Village, Xiongba Township, Litang County, Ganzi Prefecture, Sichuan Province	4,512	SW	5	Yellow loam	Shrub	0	20	40	30	1
14	Lebuchacou Village, Sangdui Town, Daocheng County, Ganzi Prefecture, Sichuan Province	4,267	NW	20	Yellow loam	Meadow	0	0	95	30	1
15	Chaime Village, Sangdui Town, Daocheng County, Ganzi Prefecture, Sichuan Province	4,015	SE	20	Brown soil	Shrub	0	40	90	10	1

Table 1. Continued.

Sample Number	Sample Site	Elevation (m)	Slope Direction	Slope Gradient (°X)	Soil Type	Vegetation Type	Canopy Density	Coverage (%)			Litter Thickness (cm)
								Shrub	Herb	Litter	
16	Liange Village, Sangdui Town, Daocheng County, Ganzi Prefecture, Sichuan Province	3,758	E	15	Brown soil	Meadow	0	0	95	5	1
17	Tongdian Village, Shagong Township, Xiangcheng County, Ganzi Prefecture, Sichuan Province	3,520	SW	35	Yellow loam	Coniferous forest	75	40	20	70	3–4
18	Songantong Village, Shagong Township, Xiangcheng County, Ganzi Prefecture, Sichuan Province	3,252	SW	45	Yellow loam	Conifer–broadleaf mixed forest	70	20	95	10	1
19	Ganyong Village, Xiangbala Town, Xiangcheng County, Ganzi Prefecture, Sichuan Province	3,045	SE	30	Yellow loam	Coniferous forest	60	40	40	5	1
20	Lenglongyong Village, Xiangbala Town, Xiangcheng County, Ganzi Prefecture, Sichuan Province	3,285	SW	45	Yellow loam	Coniferous forest	20	75	15	30	2–3

Table 1. Continued.

Sample Number	Sample Site	Elevation (m)	Slope Direction	Slope Gradient (°X)	Soil Type	Vegetation Type	Canopy Density	Coverage (%)			Litter Thickness (cm)
								Shrub	Herb	Litter	
21	Lenglongyong Village, Xiangbala Town, Xiangcheng County, Ganzi Prefecture, Sichuan Province	3,548	SW	45	Yellow loam	Coniferous forest	30	60	15	30	2–3
22	Lenglongyong Village, Xiangbala Town, Xiangcheng County, Ganzi Prefecture, Sichuan Province	3,740	NW	45	Red loam	Coniferous forest	40	65	30	40	2–3
23	Zhongyongtong Village, Xiangbala Town, Xiangcheng County, Ganzi Prefecture, Sichuan Province	3,985	NW	420	Red loam	Coniferous forest	10	70	15	10	1
24	Maanshan Village, Xiangbala Town, Xiangcheng County, Ganzi Prefecture, Sichuan Province	3,737	SW	40	Red loam	Coniferous forest	50	60	70	30	2–3
25	Jasi Village, Reda Town, Xiangcheng County, Ganzi Prefecture, Sichuan Province	3,520	SW	20	Red loam	Coniferous forest	40	30	70	70	3–4

Table 1. Continued.

Sample Number	Sample Site	Elevation (m)	Slope Direction	Slope Gradient (°X)	Soil Type	Vegetation Type	Canopy Density	Coverage (%)			Litter Thickness (cm)
								Shrub	Herb	Litter	
26	Bierongyaka Village, Zhengdou Township, Xiangcheng County, Ganzi Prefecture, Sichuan Province	3,230	N	60	Cinnamon soil	Coniferous forest	40	25	25	75	2–3
27	Kerong Village, Zhengdou Township, Xiangcheng County, Ganzi Prefecture, Sichuan Province	3,035	NW	35	Yellow loam	Coniferous forest	15	30	70	5	1
28	Gongjigong Village, Baisong Town, Derong County, Ganzi Prefecture, Sichuan Province	2,770	NW	30	Yellow loam	Broad-leafed forest	10	50	50	10	1
29	Donggu Village, Taiyanggu Town, Derong County, Ganzi Prefecture, Sichuan Province	2,549	S	25	Yellow loam	Shrub	0	30	40	5	1
30	Silang Village, Bendu Township, Derong County, Ganzi Prefecture, Sichuan Province	2,250	NW	45	Yellow loam	Shrub	0	10	20	5	1

was used to draw the species sparsity and prediction curve based on the number of individuals (Bharti et al. 2013).

The population density was calculated using the density formula, $D = N/M$, where N is the total number of ants collected from five quadrats in each plot and M is the total area of five quadrats. The Shannon–Wiener diversity index was calculated as

$$H = \sum_{i=1}^{s} Pi \ln Pi,$$

where Pi is the ratio of the number of individuals of species i to the total number of individuals of all species in the community. The Simpson dominance index was calculated by

$$C = \sum_{i=1}^{s} (Pi)^2 = \sum_{i=]1}^{s} (Ni/N)^2,$$

where Ni is the number of individuals of the i species, S is the number of species, and N is the sum of the individuals of all species in the community. The Jaccard similarity coefficient was calculated by $q = c/(a + b - c)$, where c is the number of common species in two communities, and a and b are species in communities a and b, respectively.

Results

Community structure. Ants collected from the 30 plots in the four elevation zones in the southern part of the Western Sichuan Plateau totaled 19,235. They were identified as representing 68 species belonging to 23 genera and 4 subfamilies, including 55 known species and 13 undetermined species. The three dominant species were *Lasius himalayanus* Bingham, *Formica fusca* L., and *Myrmica kozlovi* Ruzsky, accounting for 40% of the total species collected. Three common species were *Paraparatrechina aseta* (Forel), *Lasius talpa* Wilson, and *Tetramorium caespitum* (L.), accounting for 26% of the total species. Of the total species collected, the 11 relatively common species accounted for 26%, the 20 relatively rare species accounted for 7%, and the 31 rare species accounted for 1%. The rarest species were *Aphaenogaster* sp. 3, *Odontomachus monticola* Emery, *Hypoponera exoecata* (Wheeler), *Ponera paedericera* Zhou, *Myrmica margaritae* Emery, *Formica gagatoides* Ruzsky, and *Camponotus* sp. 2, with only one specimen of each species (Table 2).

Diversity index. The species accumulation curve (Fig. 1) reflects the adequacy of sampling in field surveys and guarantees the reliability of diversity index analysis. The solid line of the cumulative curve represents the actual number of species and individuals, whereas the dotted line represents the estimated number of species and individuals. In this analysis, a flat dotted line generally indicates that sampling is sufficient. As shown, each of the dashed lines of the four elevation zones show a slow increase which then flattens, indicating that sampling is sufficient for diversity analysis.

Ant species diversity. The richness of ant species in the four zones was as follows: the southern slope of Dardenna Village Pass (50 species) > northern

Table 2. Ant community composition by species in the southern part of the Western Sichuan Plateau.

Species	Number of Individuals	Percentage (%)	Dominance*
Lasius himalayanus Bingham, 1903	3,098	16.1061	A
Formica fusca Linnaeus, 1758	2,493	12.9607	A
Myrmica kozlovi Ruzsky, 1915	2,180	11.3335	A
Paraparatrechina aseta (Forel, 1902)	1,852	9.6283	B
Lasius talpa Wilson, 1955	1,701	8.8433	B
Tetramorium caespitum (Linnaeus, 1758)	1,360	7.0704	B
Formica candida Smith, 1878	898	4.6686	C
Formica sinensis Wheeler, 1913	687	3.5716	C
Pheidole nietneri Emery, 1901	656	3.4104	C
Aphaenogaster caeciliae Viehmeyer, 1922	580	3.0153	C
Temnothorax sp. 4	460	2.3915	C
Aphaenogaster famelica (Smith, 1874)	383	1.9912	C
Myrmica afghanica Radchenko & Elmes, 2003	382	1.9860	C
Camponotus sp. 3	259	1.3465	C
Tetramorium wroughtonii (Forel, 1902)	240	1.2477	C
Lasius nipponensis Forel, 1912	215	1.1178	C
Myrmica lobicornis Nylander, 1846	210	1.0918	C
Brachyponera luteipes (Mayr, 1862)	190	0.9878	D
Aphaenogaster sp. 1	178	0.9254	D
Temnothorax sp. 46	119	0.6187	D
Formica sentschuensis Ruzsky, 1915	112	0.5823	D
Myrmica pleiorhytida Radchenko & Elmes, 2009	96	0.4991	D
Hypoponera confinis (Roger, 1860)	83	0.4315	D
Plagiolepis pallescens Forel, 1889	83	0.4315	D

Table 2. Continued.

Species	Number of Individuals	Percentage (%)	Dominance*
Lasius umbratus (Nylander, 1846)	81	0.4211	D
Tetramorium kraepelini Forel, 1905	67	0.3483	D
Tapinoma geei Wheeler, 1927	55	0.2859	D
Aphaenogaster tibetana Donisthorpe, 1929	52	0.2703	D
Lasius coloratus Santschi, 1937	45	0.2339	D
Camponotus sp. 1	37	0.1924	D
Temnothorax sp. 28	36	0.1872	D
Formica manchu Wheeler, 1929	35	0.1820	D
Lordomyrma bhutanensis (Baroni Urbani, 1977)	30	0.1560	D
Temnothorax striatus Zhou et al., 2010	27	0.1404	D
Aphaenogaster sp. 2	25	0.1300	D
Brachyponera brevidorsa Xu, 1994	20	0.1040	D
Nylanderia taylori (Forel, 1894)	20	0.1040	D
Cardiocondyla kagutsuchi Terayama, 1999	19	0.0988	E
Pheidole zoceana Santschi, 1925	18	0.0936	E
Pheidole nodus Smith, 1874	18	0.0936	E
Crematogaster zoceensis Santschi, 1925	14	0.0728	E
Temnothorax sp. 31	13	0.0676	E
Temnothorax sp. 19	12	0.0624	E
Ochetellus glaber (Mayr, 1862)	11	0.0572	E
Tapinoma melanocephalum (Fabricius, 1793)	9	0.0468	E
Camponotus japonicus Mayr, 1866	7	0.0364	E
Aphaenogaster weigoldi Viehmeyer, 1922	6	0.0312	E
Carebara reticapita (Xu, 2003)	6	0.0312	E
Camponotus pseudolendus Wu & Wang, 1989	5	0.0260	E

Table 2. Continued.

Species	Number of Individuals	Percentage (%)	Dominance*
Cardiocondyla itsukii Seifert et al., 2017	5	0.0260	E
Prenolepis angularis Zhou, 2001	5	0.0260	E
Aphaenogaster pumilopuncta Zhou, 2001	5	0.0260	E
Nylanderia bourbonica (Forel, 1886)	4	0.0208	E
Ectomomyrmex sauteri (Forel, 1912)	4	0.0208	E
Tapinoma rectinotum Wheeler, 1927	4	0.0208	E
Myrmica heterorhytida Radchenko & Elmes, 2009	4	0.0208	E
Lasius flavus (Fabricius, 1782)	3	0.0156	E
Temnothorax sp. 18	3	0.0156	E
Myrmica tibetana Mayr, 1889	3	0.0156	E
Camponotus anningensis Wu & Wang, 1989	3	0.0156	E
Temnothorax sp. 1	2	0.0104	E
Aphaenogaster sp. 3	1	0.0052	E
Odontomachus monticola Emery, 1892	1	0.0052	E
Hypoponera exoecata (Wheeler, 1928)	1	0.0052	E
Ponera paedericera Zhou, 2001	1	0.0052	E
Myrmica margaritae Emery, 1889	1	0.0052	E
Formica gagatoides Ruzsky, 1904	1	0.0052	E
Camponotus sp. 2	1	0.0052	E

* Dominance categories: A, ≥10% dominant species; B, 5.0–9.9% common species; C, 1.0–4.9% relatively common species; D, 0.1–0.9% relatively rare species; E, <0.1% rare species.

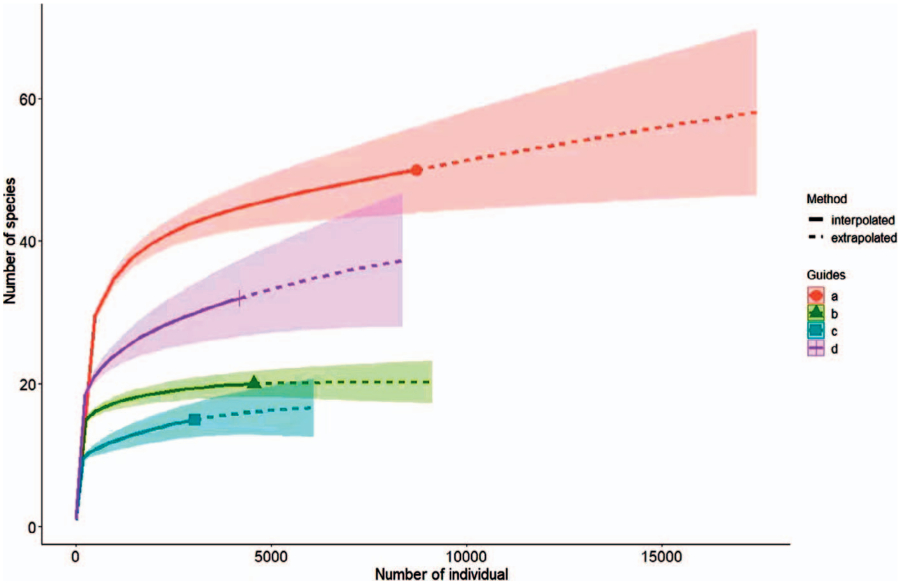

Fig. 1. Accumulation curves for the observed and estimated number of ant species in the southern part of the Western Sichuan Plateau. Note: a–d, four zones of elevation: the southern slope of the Dardenna Village Pass, the northern slope of the Dardenna Village Pass, the southern slope of the Zhongyongtong Village Pass, and the northern slope of the Zhongyongtong Village Pass.

slope of Zhongyongtong Village Pass (32 species) > northern slope of Dardenna Village Pass (20 species) > southern slope of Zhongyongtong Village Pass (15 species) (Table 3). Areas with large elevation differences yielded more ant species, while areas with small elevation differences yielded fewer ant species (Table 3). In the zone of the southern slope of the Dardenna Village Pass, the lowest number of species was found in shrub vegetation at 4,512 m (1 species), and the highest was in the broad-leafed forest at 1,720 m (18 species) (Table 3).

The number of ant species increased in the broad-leafed forest at 1,720 m and in the coniferous forest at 3,043 m on the southern slope of the Dardenna Village Pass, in the coniferous forest at 3,520 m on the northern slope of the Dardenna Village Pass, and in the coniferous forest at 3,548 m and the coniferous forest at 3,985 m on the southern slope of the Zhongyongtong Village Pass, likely due to low canopy density. There was a broad-leafed forest at 2,015 m and a conifer–broadleaf mixed forest at 3,265 m on the southern slope of the Dardenna Village Pass, a conifer–broadleaf mixed forest at 3,252 m on the northern slope of the Dardenna Village Pass, a meadow at 3,758 m, and a coniferous forest at 3,740 m on the southern slope of the Zhongyongtong Village Pass, a coniferous forest at 3,285 m on the northern slope of the Zhongyongtong Village Pass, and a coniferous forest at

Table 3. Main indices of ant communities in the southern part of the Western Sichuan Plateau.

Vegetation Type	Elevation (m)	Number of Species (*S*)	Population Density (population m^{-2})	Simpson Index (*C*)	Shannon–Wiener Index (*H*)
Conifer–broadleaf mixed forest	1,515	15	66.8	0.3249	1.4030
Broad-leafed forest	1,720	18	16.2	0.7244	1.6918
Broad-leafed forest	2,015	14	60.2	0.1938	1.8463
Broad-leafed forest	2,266	10	150.0	0.2957	1.5100
Broad-leafed forest	2,502	7	92.6	0.5409	0.9246
Broad-leafed forest	2,783	7	65.8	0.5715	0.9277
Coniferous forest	3,043	10	10.4	0.2288	1.6693
Conifer–broadleaf mixed forest	3,265	9	45.6	0.2341	1.6171
Conifer–broadleaf mixed forest	3,500	9	175.2	0.2937	1.4858
Conifer–broadleaf mixed forest	3,778	5	94.0	0.4995	0.9093
Broad-leafed forest	4,028	4	45.8	0.4564	0.6726
Shrub	4,270	4	115.8	0.7121	0.5631
Shrub	4,512	1	0.2	1.0000	0.0000
Southern slope of the Dardenna Village Pass	—	50	72.2	0.1125	2.5739
Average value of southern slope of the Dardenna Village Pass	3,015	9	78.2	0.4674	1.1708
Shrub	4,512	1	0.2	1.0000	0.0000
Meadow	4,267	7	34.8	0.6558	0.7670
Shrub	4,015	7	166.0	0.6219	1.3227
Meadow	3,758	4	12.2	0.7546	0.5256
Coniferous forest	3,520	7	110.8	0.3376	1.2294
Conifer–broadleaf mixed forest	3,252	5	87.6	0.4641	1.0188

Table 3. Continued.

Vegetation Type	Elevation (m)	Number of Species (S)	Population Density (population m^{-2})	Simpson Index (C)	Shannon–Wiener Index (H)
Coniferous forest	3,045	6	153.4	0.4044	1.1641
Northern slope of the Dardenna Village Pass	—	20	—	0.1487	2.1953
Average value of northern slope of the Dardenna Village Pass	3,767	5	80.7	0.6055	0.8611
Coniferous forest	3,045	6	153.4	0.4044	1.1641
Coniferous forest	3,285	8	32.8	0.3184	1.3137
Coniferous forest	3,548	9	167.4	0.4822	1.0501
Coniferous forest	3,740	3	48.8	0.5358	0.7819
Coniferous forest	3,985	5	6.4	0.4674	1.0040
Southern slope of the Zhongyongtong Village Pass	—	15	—	0.1899	1.8188
Average value of southern slope of the Zhongyongtong Village Pass	3,521	6	81.8	0.4416	1.0628
Coniferous forest	3,985	5	6.4	0.4674	1.0040
Coniferous forest	3,737	9	8.6	0.3570	1.3082
Coniferous forest	3,520	14	113.0	0.2998	1.5508
Coniferous forest	3,230	12	196.6	0.5797	0.9107
Coniferous forest	3,035	8	31.0	0.5181	1.0044
Broad-leafed forest	2,770	7	98.8	0.4338	1.0849
Shrub	2,549	7	4.8	0.4150	1.2204
Shrub	2,250	4	2.4	0.2634	1.3594

Table 3. Continued.

Vegetation Type	Elevation (m)	Number of Species (*S*)	Population Density (population m^{-2})	Simpson Index (*C*)	Shannon–Wiener Index (*H*)
Northern slope of the Zhongyongtong Village Pass	—	32	—	0.1363	2.3211
Average value of northern slope of the Zhongyongtong Village Pass	3,135	8	57.7	0.4168	1.1804
Southern part of the Western Sichuan Plateau	—	68	—	0.0855	2.8401
Average value of the southern part of the Western Sichuan Plateau	3,223	8	73.8	0.4662	1.1279

* A dash (—) indicates that no data were available.

3,737 m on the northern slope of Zhongyongtong Village Pass, likely due to higher canopy density, lower light intensity, and lower ant species richness (Table 3; Fig. 2), Therefore, ant species were more abundant in wildwood with lower canopy density.

Population density. The population density of ant species in the four zones in the southern part of the Western Sichuan Plateau ranged from 0.2 to 196.6 m^{-2}, with an average of 73.8 m^{-2} (Table 3). The order of the average ant population density was the southern slope of the Zhongyongtong Village Pass (81.8 m^{-2}) > the northern slope of the Dardenna Village Pass (80.7 m^{-2}) > southern slope of the Dardenna Village Pass (72.2 m^{-2}) > northern slope of the Zhongyongtong Village Pass (57.7m^{-2}). The highest population density (196.6 m^{-2}) was found in the coniferous forest at 3,230 m on the northern slope of the Yongtong Village Pass, and the shrub vegetation at 4,512 m on the southern slope of the Dardenna Village Pass was the lowest (Table 3; Fig. 2).

Diversity index. The total diversity index of the ant community in the southern part of the Western Sichuan Plateau was 2.8401, with an average of 1.1279 (Table 3). The diversity index of the four zones was as follows: the southern slope of the Dardenna Village Pass (2.5739) > northern slope of the Zhongyongtong Village Pass (2.3211) > northern slope of the Dardenna Village Pass (2.1953) > southern

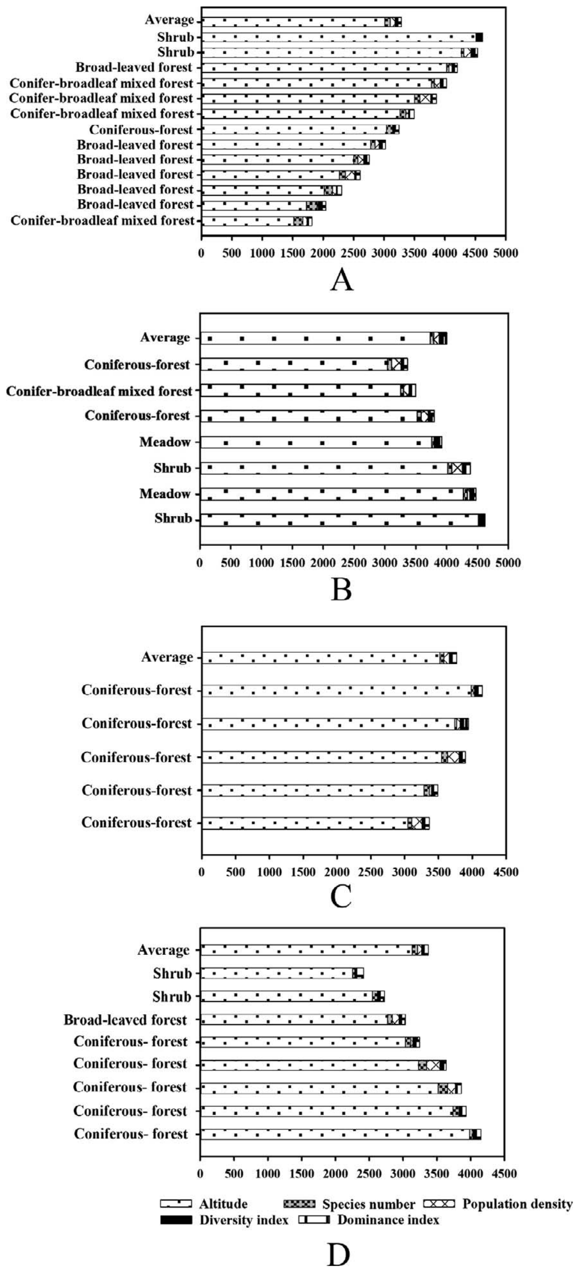

Fig. 2. Variations in main indices of ant communities from different zones of elevation: (A) southern slope of Dardenna Village pass; (B) northern slope of Dardenna Village Pass; (C) southern slope of Zhongyongtong Village Pass; and (D) northern slope of Zhongyongtong Village Pass. In order to present the differences of the main community indexes more clearly, the number of species is magnified 10 times, and diversity index and dominance index are multiplied 100 times.

slope of the Zhongyongtong Village Pass (1.8188). The ant community diversity index was the highest on the southern slope of the Dardenna Village Pass and the lowest on the southern slope of the Zhongyongtong Village Pass, where areas with large elevation differences yielded more ant species, whereas areas with small elevation differences yielded fewer ant species.

The diversity indices ranged from 0.0000 to 1.8463, among which the diversity index of shrub community at 4,512 m on the southern slope of the Dardenna Village Pass was the lowest (0.0000), and the diversity index of the broad-leafed forest at 2,015 m on the southern slope of the Dardenna Village Pass was the highest (1.8463), where there were two peak values with an increase in elevation, presenting a multidomain effect. The diversity index of the northern slope of the Dardenna Village Pass ranged from 0.0000 to 1.3227, with three peak values showing a multidomain effect; the diversity index of the southern slope of the Zhongyongtong Village Pass ranged from 0.7819 to 1.3137, with two peak values showing a multidomain effect; and the diversity index of the northern slope of the Zhongyongtong Village Pass ranged from 0.9107 to 1.5508, with two peak values showing a multidomain effect (Table 3; Fig. 2).

Dominance index. The total ant community dominance index of the southern part of the Western Sichuan Plateau was 0.0855, with an average of 0.4662. The dominance index of the four zones was in the order of: the southern slope of the Zhongyongtong Village Pass (0.1899) > northern slope of the Dardenna Village Pass (0.1487) > northern slope of the Zhongyongtong Village Pass (0.1363) > southern slope of the Dardenna Village Pass (0.1125) (Table 3).

The dominance index of the southern slope of the Dardenna Village Pass ranged from 0.1938 to 1.0000, with four peak values with the increase of elevation, representing a multidomain effect. The dominance index of the northern slope of the Dardenna Village Pass ranged from 0.3376 to 1.0000, and there were three peak values with the increase of elevation, representing a multidomain effect; the dominance index of the southern slope of the Zhongyongtong Village Pass ranged from 0.3184 to 0.5358, with two peak values and a multidomain effect. The dominance index of the northern slope of the Zhongyongtong Village Pass ranged from 0.2634 to 0.5797, and there were two peaks with the increase of elevation, representing a multidomain effect (Table 3; Fig. 2).

Community similarity. The similarity coefficient (q) of the ant communities in each zone in the southern part of the Western Sichuan Plateau ranged from 0.2239 to 0.5217 (Table 4). The similarity coefficient of the zone of the northern slope of the Dardenna Village Pass and the southern slope of the Zhongyongtong Village Pass were the highest and reached the moderately similar level. The similarity coefficient of the elevation zone from the southern slope of the Dardenna Village Pass and the northern slope of the Zhongyongtong Village Pass were the lowest, which was at the extremely dissimilar level. The similarity coefficient of ant communities between the zones of elevation accounted for 17% at moderately similar levels, 50% at moderately dissimilar levels, and 33% at extremely dissimilar levels, indicating that the species in this elevation zone differ from those in the altitudinal belt, which has a high conservation value.

Table 4. Similarity coefficients (*q*) among ant communities from zones of elevation in the southern part of the Western Sichuan Plateau.

Zone Name	Zone Name*: Southern slope of the Dardenna Village Pass	Northern slope of the Dardenna Village Pass	Southern slope of the Zhongyongtong Village Pass	Northern slope of the Zhongyongtong Village Pass
Southern slope of the Dardenna Village pass	—	—	—	—
Northern slope of the Dardenna Village Pass	0.2281	—	—	—
Southern slope of the Zhongyongtong Village Pass	0.2264	0.5217	—	—
Northern slope of the Zhongyongtong Village Pass	0.2239	0.4444	0.4375	—

* A *q* value of 0.00–0.24 indicates that the two communities are extremely dissimilar; 0.25–0.49 indicates that the two communities are moderately dissimilar; 0.50–0.74 indicates that the two communities are moderately similar; and 0.75–1.00 indicates that the two communities are extremely similar.

Discussion

A total of 19,235 ants belonging to 68 species of 23 genera and 4 subfamilies, including 55 known species and 13 undetermined species, were collected from four zones of elevation in the southern part of the Western Sichuan Plateau. The species richness in this region was significantly lower than that in the neighboring regions, for example, the eastern part of Daliangshan, Sichuan Province (135 species, 43 genera, 6 subfamilies) (Han et al. 2021), the middle part of Daliang Mountain (115 species, 44 genera, 6 subfamilies) (Chen et al. 2022), the western part of Daliang Mountain (95 species, 37 genera, 8 subfamilies) (He et al. 2020), Wanglang Nature Reserve, and adjacent areas in Sichuan Province (77 species, 37 genera, 5 subfamilies) (Luo et al. 2019), and similar to ant species richness in Anzihe Nature Reserve and adjacent areas (62 species, 32 genera, 6 subfamilies) (Qi et al. 2021). Previous studies have shown that ant species richness decreases with increasing latitude (Gotelli and Ellison 2002, Kaspari et al. 2004, Shen et al. 2016). However, the latitude of the southern part of the Western Sichuan Plateau is higher than that of Daliangshan, and lower than the Sichuan Wanglang Nature Reserve and adjacent areas, and the Sichuan Anzihe Nature Reserve and adjacent areas. Ant species richness was consistent with the results of previous studies. In addition, we believe that the habitat of ant species, elevation, and latitude are highly correlated. Similar to latitude, the lower the elevation, the higher the species abundance. Thus, latitude and elevation were the main factors affecting the species richness.

Previous studies have shown that the species diversity of ants usually shows a bottom-domain effect (Eidmann 1941, Xu et al. 2001). However, the results of this study showed that the species diversity index of ants in the southern part of the Western Sichuan Plateau showed a middomain or multidomain effect with the change of altitude. According to our analysis, this phenomenon is mainly influenced by the forest gap effect (Wang and Xue 2016). In other words, the aggregation of species adapted to different climate types occurred on different elevation gradients, and the aggregation effect of ant species was apparent (Liu et al. 2017). On the northern slope of the Zhongyongtong Village Pass, there was a midregion effect because only forest structure or vegetation type was present (coniferous forest). Excessive human exploitation and utilization interfered with the natural environment, resulting in a corresponding decrease in the number of ant species.

In terms of community similarity, the elevation zone was moderately similar (17%), moderately dissimilar (50%), and extremely dissimilar (33%). The northern slope of the Dardenna Village Pass and the southern slope of the Zhongyongtong Village Pass had similar elevation gradients; therefore, they reached moderately similar levels. However, the extremely dissimilar levels between the southern slope of the Dardenna Village Pass and the northern slope of the Dardenna Village pass, the southern slope of the Dardenna Village pass, and the southern slope of the Zhongyongtong Village Pass, and the southern slope of the Dardenna Village Pass and the northern slope of the Zhongyongtong Village Pass were caused by changes in elevation, and the elevation difference ranges between zones were too large. The habitats in the southern part of the Western Sichuan Plateau have complex and diverse vegetation types, mainly coniferous forests, broad-leafed forests, mixed coniferous and broad-leafed forests, and shrubs. The climatic conditions are diverse, the geological environments are typical, and ecosystem types are rich, resulting in high overall species richness.

In addition, in this survey, some of the sample sites had relatively more ant species than other sites. The uneven distribution of individual numbers would also lead to a decrease in the diversity of the sample sites. Therefore, the number of species of individual distribution also affected ant species diversity.

In conclusion, through the systematic investigation and analysis of four zones of elevation in the southern part of the Western Sichuan Plateau, it was found that the elevation difference in this area is large, the maximum is 2,997 m (1,515–4,512 m). The ants were distributed across the four zones of elevation, and the dominant species were *L. himalayanus*, *F. fusca*, and *M. kozlovi*. The diversity and dominance indices of ants showed a multidomain effect with the increase of elevation. The similarity level of ant communities in each zone of elevation was moderately similar to extremely dissimilar. Although the ecological environment of each zone of elevation was disturbed to various degrees, a large area of natural forest remains, leading to significant differences in diversity indices in different zones of elevation. This aids in preserving the rich ant diversity, which is of high conservation value.

Acknowledgments

This research was supported by the National Natural Science Foundation of China (32060122, 31760633, 31860615, 31860166), Emergency Management Project of National Natural Science Foundation of China Subproject (31750002), and Yunnan Provincial Science and Technology Department–Applied Basic Research Joint Special Funds of Agriculture (202101BD070001-057).

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