Community environment analysis of giant panda and red panda in Wolong Nature Reserve, China

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Abstract: In order to understand the community environment of giant panda *Ailuropoda melanoleuca* and red panda *Ailurus fulgens*, so as to increase the understanding of their ecological evolution and facilitate conservation and management. In our study, spatial data monitored by infrared camera from 2017 to 2018 in Wolong National Nature Reserve, China was used to analyze the spatial association network of terrestrial animals. The results show that a total of 35 terrestrial species is recorded, of which 20 species formed a spatial network including giant panda and red panda. In the network, giant panda and red panda are directly related, and 9 other species have direct spatial associations with them. Further analysis show that: (1) Giant panda and red panda already ate bamboo at the early stage of community evolution. Bamboo eating helps them blend into the community and coexist. (2) Giant panda had moderate niche separation with most of the species that have directly spatial associations, the same to red panda. There is a commensalism relationship between giant panda and red panda: red panda may create suitable habitat for giant panda to some extent, which is beneficial to the survival of giant panda. (3) In the existing community, giant panda has no natural enemies, and has a mutually beneficial relationship with golden snub-nosed monkey. (4) In the community, red panda has predator: the yellow-throated marten. Yellow-throated marten not only preys on red panda, but also may have evolved a unknown

counter-anti-predatory strategy to attract red panda, that can improve the chances of meeting and preying. The red panda also moderately creates suitable habitat for golden snub-nosed monkey, which is conducive to the survival of golden snub-nosed monkey. (5) In the community, commensalism, mutualism, and counter anti-predation strategies of predators enhanced inter-specific associations significant. Compared with giant panda, red panda has more interspecific associations and transfers more energy in the energy flow of the community. Therefore, the umbrella effect of red panda is more important in the community.

Key words: *Ailuropoda melanoleuca*; *Ailurus fulgens*; Interspecific association; Community analysis; Conservation; Wolong National Nature Reserve

INTRODUCTION

The giant panda *Ailuropoda melanoleuca* belongs to the genus *Ailuropoda* of the family Ursidea. They are endemic to China. The red panda *Ailurus fulgens* belongs to the genus *Ailurus* of the family Ailuridae. They are distributed in China, Nepal, Bhutan, India and Burma. In China, giant panda and red panda are mainly distributed in Sichuan province (Huang & Zhang, 2008). The two species have partial overlap in habitat selection and feeding habits (Huang & Zhang, 1984), and both of them have evolved pseudo thumbs adapted to bamboo feeding (Hua et al., 2017). The result of evolution is that the two species have achieved mutual adaptation and coexistence, and achieved niche separation in terms of microhabitat (Zhang et al., 2004), food resource utilization and activity rhythm (Wei et al., 1999b; Johnson. et al., 1988).

The giant panda was adjusted to vulnerable (VU) species in 2016 (Wei, Feng &

Wang, 1999; IUCN, 2011). The red panda has been listed as endangered (EN) species by IUCN (Huang & Zhang, 1984; Wei et al., 1999a). Theory of modern conservation biology holds that the ultimate goal of conservation is to allow species to live in healthy communities. In the community, ecological relations support the transfer of matter and energy flow among species to fulfill ecosystem functions (Odum & Saunders, 1953; Putman, 1999). Spatial correlation, as a quantitative relationship among the number and structural characteristics of species in a community (Greig-Smith, 1983). Inter-specific association is the basis for the construction of spatial network of species. Spatial network analysis of species contributes to a comprehensive understanding of the environmental basis of species survival and evolution. At present, the comparative studies on the giant panda and the red panda mostly focus on habitat selection, associated species, etc., and no papers have discussed their relationship in the community. Although China has devoted huge resources to conservation of giant panda, does giant panda live in a healthy community? Therefore, based on the infrared camera data, this paper calculates the inter-specific associations with the Phi coefficient 2*2 tables, and constructs the spatial association network of terrestrial species in Wolong, so as to analyze the community environment of giant panda and red panda. The aim of this paper is to answer this question.

MATERIALS AND METHODS

Study Area

The study was conducted in Wolong Nature Reserve Area, Sichuan Province, China

(102°52'-103°24'E, 30°45'-31°25'N), an area is 2000 km^2 (Fig.2-1), at an elevation of 1150-6250m. The terrain of Wolong sharply increases from southeast to northwest (Zhang, 1992). The study area belongs to the eastern Himalayas, where the Palearctic Realm animals are distributed from north to south along the high elevation, and the Indomalayan Realm animals are distributed from south to north along the low elevation, thus achieving mutual penetration. Famous endangered species include snow leopard *Panthera uncia*, giant panda, red panda and so on. Therefore, it is an important area for zoogeography and conservation biology research.

Data collection

In this study, infrared camera survey method is used for data acquisition. According to the boundary of Wolong Nature Reserve, the researchers used Arc GIS to generate a 1km×1km grid covering the reserve, and randomly selected 20 camera sites in each of the low, middle and high elevation areas, with a total of 60 sites (Figure 2-1). The working time of infrared camera is from February 2017 to April 2018. Species are classified and identified by looking at photos and videos one by one. The identification of species refers to *A Guide to the Mammals of China* (Smith & Xie, 2009) and *A Field Guide to the Birds of China* (Mackinnon et al., 2019).

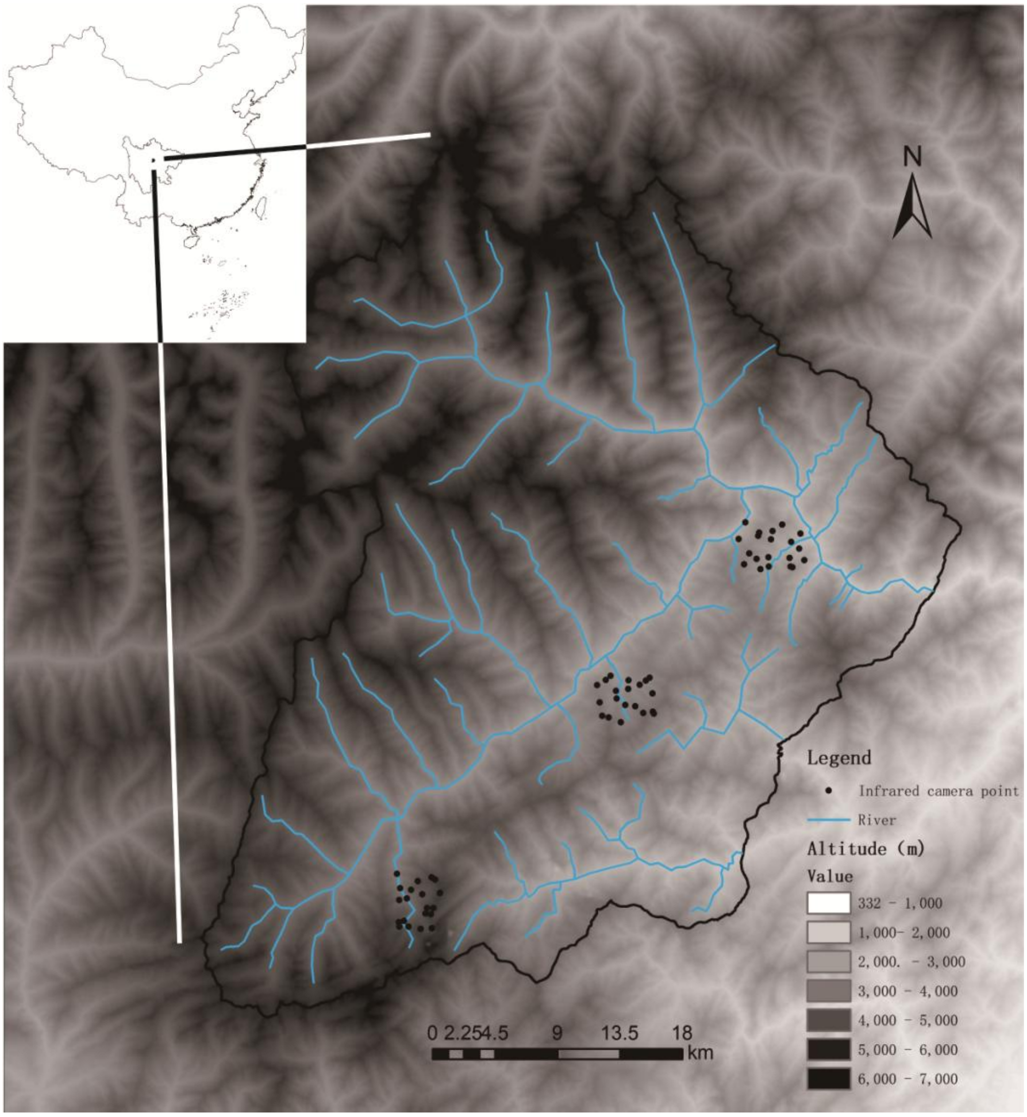

Fig.2-1 Locations of Wolong Nature Reserve and infrared cameras

Due to the delay of infrared trigger and poor resolution of night images, the images taken by the camera can only be used for the species identification rather than individual identification. Therefore, the effective photo number (He et al., 2016) cannot be used for inter-specific comparison of population density. Accordingly, the data from each camera on the presence or absence of a particular species is dichotomous.

Data analysis

Correlation analysis of pairs

In the correlation analysis of species pairs, the species in which spatial overlap occurs do not necessarily have ecological relationships. Many accidental factors can lead to spatial overlap between different species. Only regular spatial overlap can reflect inter-specific ecological relationships. In order to exclude the spatial overlap caused by accidental factors, this study adopted statistical methods of mathematical demonstration to measure the correlation of species pairs, and selected species pairs with significant positive correlation for analysis. Since the data obtained by each infrared camera are dichotomous, the correlation coefficients among species are calculated using the Phicoefficient 2*2 tables $r_{ø}$ (Li & Liu, 2018) . The calculation process is as follows(Li & Liu, 2018) :

$$r_{ø}=\frac{|\mathrm{ad}-\mathrm{bc}|}{\sqrt{(a+b)(b+c)(a+c)(b+d)}}$$

In the formula, “a” is the number of cameras in which both species in the species pair appear, “b” is the number of cameras in which only species X appears, “c” is the number of cameras in which only species Y appears, and “d” is the number of cameras in which neither species appears. The value range of $r_{ø}$ is [0,1], and the number of the value indicates the strength of the correlation between species. The positive and negative values of “ad-bc” were used to determine the correlation between species pairs. Negative values indicate that two species are spatially repulsive, while positive values indicate that they tend to occur in the same geographic space.

After the “$r_{ø}$” is calculated, a significance test is required. First, calculate the “χ^2” as follows:

$$\chi^2 = \frac{N\left(|ad - bc| - 0.5N\right)^2}{(a+b)(c+d)(a+c)(b+d)}$$

In the formula, "N" represents the total number of cameras, while "a", "b", "c" and "d" have the same meanings as the formula for calculating the Phicoefficient 2*2 tables. When $\chi^2<3.841$, $p > 0.05$, the result "$r_ø$" is not significant, and there is no correlation between related species pairs. When $3.841\leqslant\chi^2\leqslant6.635$, $0.01< p < 0.05$, "$r_ø$" is significant, indicating that the species pairs are correlated. When $\chi^2>6.635$, $p < 0.01$, the correlation coefficient is very significant.

Construction of spatial association network

Based on the above calculations, species pairs with significant positive associations are retained. Taking each species as the node, these species pairs are linked together to construct a species association network including red panda and giant panda.

Test of asymmetric relations

In communities, ecological relationships between species can be divided into two categories: symmetrical and asymmetric. When there is no benefit in the ecological relationship between the two species, the ecological relationship is symmetric. In terms of spatial distribution, the two species are symmetrically correlated. For example, two species have access to the same habitat resources, but the resources are abundant and there is no competition among the species. When ecological relationships result in commensalism, that is, one party gains and the other party doesn't gain or even loses, so the inter-specific relationships are asymmetrical. In the asymmetric relationship, the gainer tends to distribute its individual based on the appearance of the other party due to the bias of profit, thus showing the asymmetric spatial correlation. In order to investigate the asymmetrical correlation, the Lambda statistic is used to test the asymmetrical correlation between species pairs due to the dichotomy of the data (Li & Liu, 2018). In the calculation of the Lambda statistic, the contingency table is first established as follows:

Tab.2-1 Contingency table of the Lambda statistic

Species A / **Species B**	**A_1**	**A_2**	**Total**
B_1	n_{11}	n_{12}	R_1
B_2	n_{21}	n_{22}	R_2
Total	C_1	C_2	N

In the contingency table, the first row is species A, "A_1" represents the presence of the species and "A_2" represents the absence of the species. The first column is species B, with "B_1" indicating the presence of the species and "B_2" indicating the absence of the species. "N_{11}" is the number of camera positions in which species A and B appear simultaneously; "N_{12}" is the number of camera positions in which species A does not appear but species B does; "N_{21}" is the number of camera positions in which species A appears but species B does not; and "N_{22}" is the number of camera positions in which neither species A nor B appears. "R_i (i=1, 2)" and "C_j (j=1, 2)" are the total number of camera sites in each column and each row of contingency table, respectively. "N" represents the total number of camera sites.

The Lambda statistic is:

$$L_B = \frac{\sum_{j=1}^{k} n_{Mj} - \max(R_i)}{N - \max(R_i)}$$

In the formula, "n_{Mj}" is the maximum column frequency of column "j"; "Max (Ri)" is the maximum row sum. "L_B" represents the predictability of species A (which does not benefit from the bias, or even suffers injury) over species B (which benefits from the bias). After the Lambda statistic is calculated, its significance test is carried out. First, the variability of "L_B" is calculated as follows:

$$\mathrm{var}(L_B) = \frac{\left(N-\sum_{j=1}^{k} n_{Mj}\right)\left(\sum_{j=1}^{k} n_{mj}+\max(R_i)-2\sum' n_{iM}\right)}{[N-\max(R_i)]^3}$$

In the formula, $\sum' n_{iM}$ is the sum of the frequencies of the largest columns falling on the row where "max (R_i)" is. If the maximum column frequency on the row is only one, then $\sum' n_{iM}=n_{Mj}$.

Finally calculated "z",

$$z=\frac{L_B-\lambda_{B0}}{\sqrt{\mathrm{var}(L_B)}}$$

"λ_{B0}" is the decrease in the error rate of species B predicted to be equal to a specific value. "λ_{B0}" ranges from 0 to 1, and the number will affect the significance level of the statistical value. The null hypothesis "H_0" of this test is $\lambda_B = \lambda_{B0}$. Find out the probability that the null hypothesis is true by calculating the Z-value. The value of "λ_{B0}" was selected based on the significance level, which was used as the lower limit and the "L_B" value as the upper limit to estimate the predictability of species A to species B.

RESULTS

A total of 35 species of terrestrial wildlife were recorded in the field work. The list is as follows:

Tab.3-1 Species List of Terrestrial Animal in Wolong (Yang et al., 2021)

Orders	Family	Species
Rodentia	Sciuridae	Himalayan Marmot (*Marmota himalayana)*
	Hystricidae	Chinese Porcupine (*Hystrix hodgsoni)*
Lagomorpha	Ochotonidae	Moupin Pika (*Ochotona thibetana)*
Primates	Cercopithecidae	Tibetan Macaque (*Macaca thibetana)*
		Golden Snub-nosed Monkey (*Rhinopithecus roxellanae)*
Carnivora	Canidae	Wolf (*Canis lupus*）
		Red Fox (*Vulpes vulpes)*
	Ursidae	Black Bear (*Ursus thibetanus)*
		Giant Panda (*Ailuropoda melanoleuca)*
	Ailuridae	Red Panda (*Ailurus Ailurus)*
	Mustelidae	Yellow-thraoted Marten (*Martes flavigula)*
		Stone Marten (*Martes foina)*
		Siberian Weasel (*Mustela sibirica)*
		Altai Weasel (*Mustela altaica)*
		Northern Hog Badger (*Arctonyx collaris)*
	Viverridae	Masked Palm Civet (*Paguma larvata)*
	Felidae	Leopard Cat (*Prionailurus bengalensis)*
		Snow leopard (*Panthera uncia)*
Cetartiodactyla	Suidae	Wild Boar (*Sus scrofa)*
	Moschidae	Forest Musk Deer (*Moschus berezovskii)*
	Cervidae	Tufted Deer (*Elaphodus cephalophus)*
		Sambar (*Rusa unicolor)*
	Bovidae	Takin (*Budorcas taxicolor*)
		Chinese Serow (*Capricornis milneedwardsii*)
		Chinese Goral (*Naemorhedus griseus*)
		Blue Sheep (*Pseudois nayaur)*
Galliformes	Phasianidae	Snow Partridge (*Lerwa lerwa)*
		Chestnut-throated Partridge (*Tetraophasis obscurus)*
		Tibetan Snowcock (*Tetraogallus tibetanus)*
		Blood Pheasant (*Ithaginis cruentus)*
		Temminck's Tragopan (*Tragopan temminckii)*
		Koklass Pheasant (*Pucrasia macrolopha)*
		Chinese Monal (*Lophophorus lhuysii)*
		White Eared-pheasant (*Crossoptilon crossoptilon)*
		Golden Pheasant (*Chrysolophus pictus)*

Interspecific association and vertical distribution

Among the 34 species of terrestrial wild animals, 6 species were directly and significantly correlated with the giant panda, they were tufted deer ($r_{ø}$=0.35，χ^2=5.83，$p<0.05$)、the yellow-throated marten ($r_{ø}$=0.40，χ^2=7.96，$p<0.01$)、sambar ($r_{ø}$=0.39，

χ^2=7.42，$p<0.01$）、the red panda ($r_ø$=0.49，χ^2=12.34，$p<0.01$）、black bear ($r_ø$=0.33，χ^2=4.68，$p<0.05$)and golden snub-nosed monkey ($r_ø$=0.72，χ^2=27.68，$p<0.01$）. To further calculate other species that are significantly correlated with these species.

Using the same method, the species with direct significance correlation with giant panda were identified as tufted deer（$r_ø$=0.33，χ^2=5.04，$p<0.05$）、the yellow-throated marten（$r_ø$=0.59，χ^2=18.08，$p<0.01$）、the sambar（$r_ø$=0.38，χ^2=6.77，$p<0.01$）、the giant panda（$r_ø$=0.49，χ^2=12.34，$p<0.01$）、the wild boar（$r_ø$=0.32，χ^2=4.85，$p<0.05$）、temminck's tragopan （$r_ø$=0.31，χ^2=4.52，$p<0.05$）、takin（$r_ø$=0.39，χ^2=7.23，$p<0.01$）、the forest Musk Deer（$r_ø$=0.36，χ^2=6.06，$p<0.05$）and the golden snub-nosed monkey（$r_ø$=0.46，χ^2=10.53，$p<0.01$）. Other species mentioned above are indirectly significantly associated with the red panda.

According to the above calculations, the members of the species network that includes red panda is the same as that of giant panda. This indicates that the two species are live in the same species network (Figure 3-1).

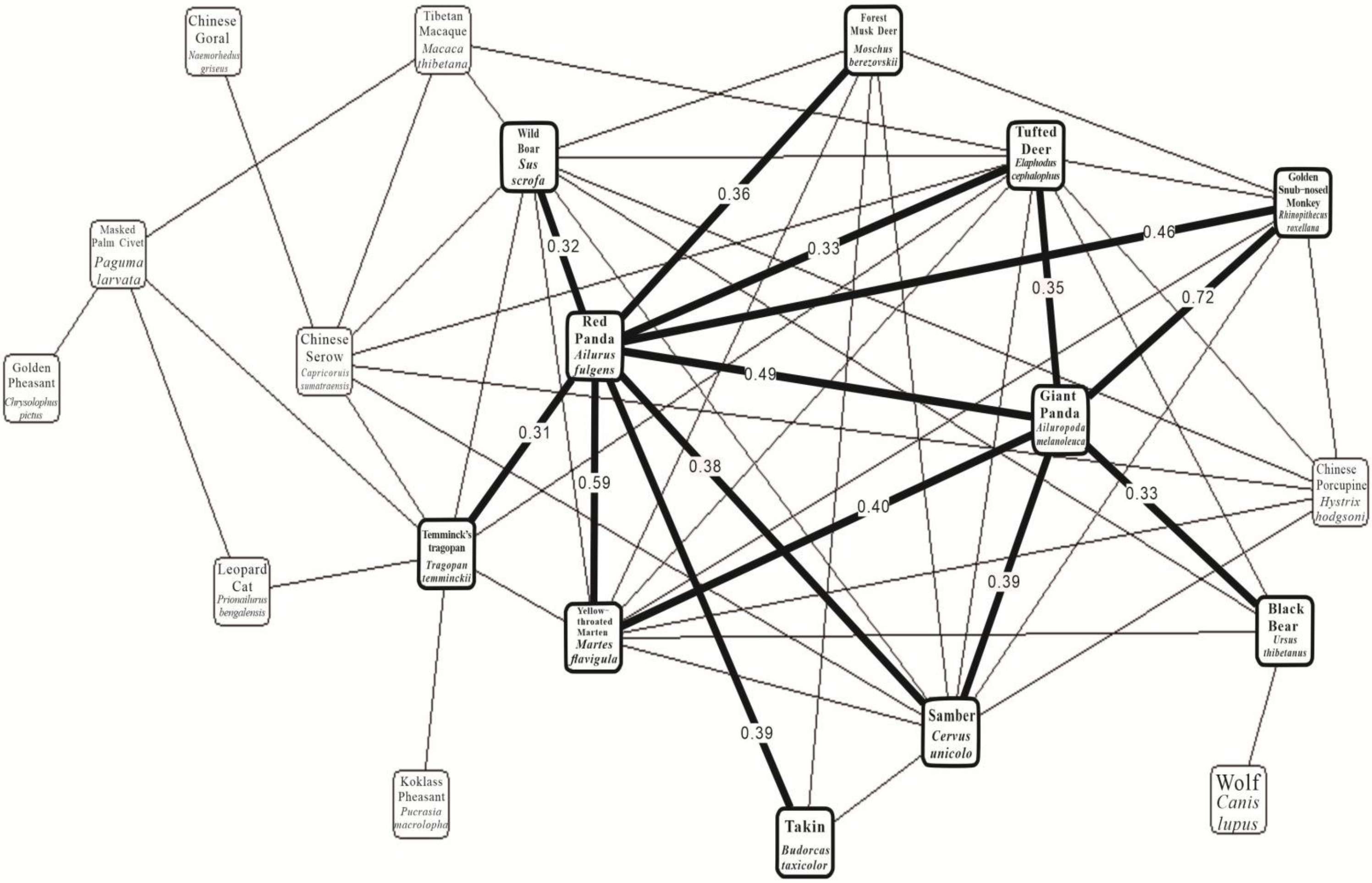

Fig.3-1 Spatial association network structure diagram

Ecological factor correlation

According to the distribution frequency, the ecological factors were combined into different habitat types :(1) The main distribution areas of temminck's tragopan are the low elevation, the slope of 6 °-20 °, the vegetation coverage of 0-24%, ridge and middle slope habitats. (2) The main distribution areas of sambar, tufted deer and wild boar are the middle and low elevations, the gentle slopes of 0 °-5 °and steep slopes of 21 °-30 °, the vegetation coverage of 0-24%, the habitats on ridges and in the middle slopes habitats. (3) The main distribution areas of black bear are the middle and low altitudes, the slope of 0°-20°, the vegetation coverage of 25-100%, the ridges, the upper slopes and the valley habitats. (4) The main distribution areas of giant panda are the middle elevation, the slope of 0°-5°, the vegetation coverage of 0-24%, ridges and upper slope habitats. (5) The main distribution areas of red panda are the middle elevation, the slope of 0°-30°, the vegetation coverage of 0-24%, the middle ridge slope and the valley habitats. (6) The main distribution areas of takin are the middle elevation, the gentle slope of 0°-5° and steep slope of 21°-30°, the vegetation coverage of 0-24% and 50%-100% vegetation coverage, the ridge and lower slope habitats. (7) The main distribution areas of golden snub-nosed monkey are the middle elevation, gentle slope of 0°-5° and steep slope of 21°-30°, vegetation coverage of 0-49%, mountain ridges, middle and lower slopes habitats. (8) The main distribution area of yellow-throated marten and forest musk deer are the middle elevation, the gentle slope 0°-5° and steep slope 21°-30°, the vegetation coverage 0-24% habitats, in which yellow-throated marten is mainly distributed in the ridge and valley area, and forest musk deer is mainly distributed in the ridge and the middle slope area.

Tab.3-2 Occurring frequencies of animal species at different parts of ecological factors.

"F": frequency; "P": Percentage.

Species / Ecological factor			Giant panda	Red panda	Sambar	Tufted deer	Yellow throated marten	Golden snub-nosed monkey	Black bear	Forest musk deer	Takin	Temminck's tragopan	Wild boar
Elevation (m)	Lower	**F**	5	3	21	21	8	6	5	3	2	10	17
	1749-2649	P	26%	17%	47%	54%	38%	26%	45%	23%	10%	59%	53%
	Middle	**F**	14	14	20	17	13	17	6	8	13	6	15
	2650-3549	P	74%	78%	44%	44%	62%	74%	55%	62%	65%	35%	47%
	High	**F**	0	1	4	1	0	0	0	2	5	1	0
	3550-4449	P	0%	5%	9%	2%	0%	0%	0%	15%	25%	6%	0%
Slope	Ridge	F	7	5	10	8	7	7	3	5	5	5	8

		P	37%	28%	22%	21%	33%	30%	27%	39%	25%	30%	25%
	Upper	F	5	4	8	6	4	5	3	2	4	3	5
		P	26%	22%	18%	15%	19%	22%	27%	15%	20%	17%	16%
	Middle	F	4	2	11	12	4	5	2	3	2	5	9
		P	21%	11%	24%	31%	19%	22%	19%	23%	10%	30%	28%
	Lower	F	2	3	9	7	1	4	0	2	5	1	4
		P	11%	17%	20%	18%	5%	17%	0%	15%	25%	6%	12%
	Valley	F	1	4	7	6	5	2	3	1	4	3	6
		P	5%	22%	16%	15%	24%	9%	27%	8%	20%	17%	19%
Slopes (°)	0-5	**F**	7	8	14	11	8	9	5	5	8	4	11
		P	37%	44%	31%	28%	38%	39%	46%	38%	40%	24%	34%
	6-20	**F**	5	5	10	8	5	4	4	2	2	6	7
		P	26%	28%	22%	21%	24%	17%	36%	15%	10%	35%	22%
	21-30	**F**	5	5	15	13	7	6	1	5	8	4	10
		P	26%	28%	33%	33%	33%	27%	9%	38%	40%	24%	31%
	31-40	**F**	2	0	6	7	1	4	1	1	2	3	4
		P	11%	0%	14%	18%	5%	17%	9%	8%	10%	18%	13%
Vegetation coverage (%)	0-24	**F**	8	8	19	17	9	11	3	5	8	7	14
		P	42%	45%	42%	43%	43%	48%	28%	38%	40%	42%	44%
	25-49	**F**	6	4	13	11	5	8	4	4	5	5	8
		P	32%	22%	29%	28%	24%	35%	36%	31%	25%	29%	25%
	50-100	**F**	5	6	13	11	7	4	4	4	7	5	10
		P	26%	33%	29%	29%	33%	17%	36%	31%	35%	29%	31%

Asymmetric relation

Among the above species that have direct spatial correlation with red panda and giant panda, the following species pairs have asymmetric spatial correlation (Table 3-3) :(1) Red panda has a prediction rate of 23%-48% for yellow-throated marten; (2) Red panda has a prediction rate of 1%-32% for giant panda; (3) Red panda has a prediction rate of 10%-35% for golden snub-nosed monkey; (4) Giant panda has a prediction rate of 47%-65% for golden snub-nosed monkey; (5) Golden snub-nosed monkey has a prediction rate of 31%-58% for giant panda; (6) Yellow-throated marten has a prediction rate of 6%-39% for red panda.

Tab.3-3 Prediction of other directly related species by giant panda and red panda (the Lambda statistic). "-" means that there is no significant correlation between the predicting species and the predicted species, so the asymmetric relationship cannot be calculated. "*" indicates that P value is less than or equal to 0.05, it is significant.

predicted species / predicting species		Giant panda	Red panda	Tufted deer	Sambar	Yellow throated marten	Golden snub-nosed monkey	Takin	Forest musk deer	Temminck's tragopan	Wild boar	Black bear
Giant panda	L_B(upper)	-	0.28	0	0	0.24	0.65*	-	-	-	-	0
	λ_B(lower)	-	＜0	＜0	＜0	＜0	0.47*	-	-	-	-	＜0
Red panda	L_B(upper)	0.32*	-	0	0	0.48*	0.35*	0.2	0	0	0.21	-
	λ_B(lower)	0.01*	-	＜0	＜0	0.23*	0.10*	＜0	＜0	＜0	＜0	-

predicting species / predicted species		Giant panda	Red panda	Tufted deer	Sambar	Yellow throated marten	Golden snub-nosed monkey	Takin	Forest musk deer	Temminck's tragopan	Wild boar	Black bear
Giant panda	L_B(upper)	-	0.32*	0	0	0.16	0.58*	-	-	-	-	0.16
	λ_B(lower)	-	0.01*	＜0	＜0	＜0	0.31*	-	-	-	-	＜0
Red panda	L_B(upper)	0.28	-	0	0	0.39*	0.17	0.11	0.17	0.06	0	-
	λ_B(lower)	＜0	-	＜0	＜0	0.06*	＜0	＜0	＜0	＜0	＜0	-

DISCUSSION

Preliminary Study on Community Evolution

This study shows that in the communities where giant panda lived, the carnivore species include red panda, black bear, wolf, yellow-throat marten, leopard cat, masked palm civet and giant panda. These fauna species is characterized by a single family, a single genus and a single specie. It is differentiated at the family level. Only giant panda and black bear differentiate at the subfamily level. This monomorphism in the community helps to reduce internal competition and promote the prosperity of each group when different species groups meet at Wolong. According to Zhaoyuan Li 's (Writing, 2021) collation of literature and fossil database data, the earliest Felidae fossils were found in Oligocene Asia (Kazakhstan, 28.4-23.0 mya) and North America (South Dakota, 30.8 mya), and the earliest Viverridar fossils were found in Early

Eocene England (55.8-48.6 mya). The earliest Mustelidae fossils were found in the late Eocene (37.2-33.9 mya) in Montana, USA. The earliest Canidae fossils were found in the late Eocene (39 mya) in North America, and the earliest Ailuridae fossils were found in the middle Oligocene (28.4 mya) in Pakistan. The earliest fossil of the genus *Ailuropoda* was found in the late Pliocene in Liucheng, Guangxi, China (Jin et al., 2007) : *Ailuropoda microta*. According to this space-time distribution pattern, only the origin of family Ailuridae (Pakistan) is close to Wolong. According to the results of molecular biology (Hosoda et al., 2000), the yellow-throated marten first differentiated in the Middle Miocene (10-14mya) in Russia, while other species differentiated later. It is speculated that the yellow-throated marten may have existed in Wolong area in Pliocene and lived in the same community as red panda. The giant panda was still in Liucheng, China, before the Pleistocene spread throughout China, as well as to Vietnam and Burma. Black bear already existed in the Pliocene, but it was far away in Europe and did not arrive in Asia until the Pleistocene. This time series suggested that the present-day Wolong community did not form all at once, but evolved gradually as different species arrived at different times. When giant panda (living or their ancestors) and black bear arrived at Wolong during the Pleistocene, the tricky problem was how to interact with red panda and yellow-throated marten to get into the communities of these species. After entering the group, giant panda, red panda and other species faced the problem of interacting with leopard cat, black bear, masked palm civet and wolf. The species composition of this Pliocene community is unknown due to the lack of fossil data. Based on the results of this study, the formation of ecological relationship between giant panda and red panda, yellow-throated marten, wolf, masked palm civet, leopard cat and black bear is preliminary discussed here.

Formation of ecological relationship between giant panda and red panda

The earliest red panda - *Simocyon batalleri* was found in Early Miocene Europe (Spain). Fossils of the genus *Ailurus* had not been reported, but its relative specie, *Parailurus*, has been widely distributed in Europe, Asia (Japan) and North America during the Pliocene (Wallace, 2011; Kundrat, 2011). Thus, the family Ailuridae originated in Asia and then spread out, and the populations that arrived in Europe divided into the subfamily Ailurinae in the Miocene and spread back to Asia. The Asian Ailurinae may have split into the genus *Ailurus* in the Pliocene Himalaya-Hengduan Mountains, and had appeared in Wolong. Therefore, the genus *Ailurus* may have appeared in Wolong in the Pliocene. And red panda had already eaten bamboo at this time(Ogino et al., 2009). Giant panda in Liucheng had also eaten bamboo (Jin et al., 2007). Therefore, when giant panda met red panda, since both species fed on bamboo, they moved into the same habitat and may compete for food and habitat. Ecological studies have found that giant panda likes to feed on bamboo stems, while red panda prefers to feed shorter branches (Wei et al., 1999b). This food niche separation may promote their coexistence in the community. The results of this study show that the correlation coefficient between red panda and giant panda reaches 0.49, and red panda is predictive to giant panda (the prediction rate is 1.1%-31.6%), which indicates that giant panda tends to follow the distribution of red panda.

Ecological studies have found that giant panda prefers bamboo forests with moderate density, while red panda prefers dense bamboo forests (Wei, Feng & Wang, 1999). The movement and feeding of red panda affect the growth and density of bamboo forests, It makes dense forests become sparse forests (Wang et al., 2001; Zhang et al., 2008). This is good for giant panda's activities.

Formation of ecological relationship between giant panda and yellow-throated marten, black bear, leopard cat, masked palm civet, wolf

According to the above speculation, yellow-throated marten may be one of the earliest species in the Wolong area. Yellow-throated marten is an omnivorous species, but mainly eats meat. Due to the huge body size difference, yellow-throated marten is impossible to pose a threat to the adult giant panda. Ecological studies have found that yellow-throated marten can pose a threat to panda cubs around 1 year old (Hu & Wu, 2007). Giant panda has a behavior of holding their cubs on their chests and hiding them near the feeding grounds (Hu, 2016). It is impossible to determine the geological age of the occurrence of such behavior. If this behavior was already present in the Liucheng giant panda, then giant panda could easily get along with yellow-throated marten when they met at Wolong. If they only appeared after meeting in Hengduan Mountain area, it is the behavioral characteristics evolved by giant panda under the predation pressure. This behavior effectively solves the problem of predation pressure faced by giant panda from yellow-throated marten and other predatory species. Therefore, there is no asymmetric spatial relationship between giant panda and yellow-throated marten (Table 3-7). In the backwoods, giant panda tends to share the habitat with yellow-throated marten, and both prefer the original forest with certain tree canopy density (Yang et al, 2006).

The earliest black bear fossils were found in Pliocene (5.332 mya) in Europe, and widely distributed in Eurasia during Pleistocene. The earliest fossils of the genus *Prionailurus* were found in Indonesia (100-800 kya) in the late Pleistocene, and the earliest fossils of the genus *Paguma* were found in Guangdong (126 kya) in the late Pleistocene (Fossilworks, data in May 2021). In the late Pleistocene (300 kya), wolf was widely dispersed in Eurasia after crossing the Beringian land bridge into Asia (Nowak, 1992; Chambers et al., 2012). Therefore, black bear may arrive in Wolong earlier or at the same time as giant panda, while masked palm civet, leopard cat and wolf should all arrive later than giant panda.

By the time they arrived at Wolong, black bear was already a highly omnivorous species in an environment where food was plentiful. Black bear is unlikely to take great risks to prey on giant panda. There is no predation relationship between black bear and giant panda (L_B=0, p>0.05). In addition, black bear mainly lives in broad-leaved forests or mixed coniferous and broad-leaved forests, preferring the habitat of trees and shrubs with moderate density (Lu & Hu, 2003). They only feed on bamboo shoots during the season of shoot sprout(Hu & Wu, 2007). Therefore, black bear has food and ecological niche separation for the giant panda. There is a spatial correlation between the two species due to bamboo shoot feeding（r_ϕ=0.33, χ^2=4.68, p<0.05）. Leopard cat, masked palm civet and wolf may have arrived at Wolong in the late Pleistocene, when the environment of Wolong was already close to modern times.

Leopard cat is a small animal. Facing the giant panda, the best survival strategy of leopard cat is to avoid it. This study shows that there is no direct spatial correlation between leopard cat and giant panda (Figure 3-1). Masked palm civet is omnivorous, mainly eating fruits, snakes, insects and plant roots(Mu & Chen, 1993). As a small animal, faced with giant panda, in an environment with sufficient food, the best strategy is to choose to stay away from giant panda. The results of this study show that there is no spatial correlation between masked palm civet and giant panda. Wolf is basically carnivore. The results of this study show that wolf is only spatially correlated with black bear (Figure 3-1), and has no correlation with any other species. Meanwhile, there is no predation relationship between wolf and black bear （$L_B=0.182$, $\lambda_B<0$, $p>0.05$）. The reason for this may be that wolf’s population density is so low, and the ecological relationship between wolf and the species in the community has been broken. Therefore, the evolution of its ecological relationship with giant panda cannot be discussed at present.

Formation of ecological relationship between red panda and yellow-throated marten, black bear, leopard cat, masked palm civet

Red panda, which is much smaller than giant panda, may face different challenges from other species. Inter-specific interactions between red panda and yellow-throated marten may precede other species and have begun in the Pliocene Wolong community. According to the morphological characteristics of teeth, the canine teeth of red panda are conical, without obvious cleft teeth (Gao, 1987), while yellow-throated marten's canine teeth are curved and conical, with obvious cleft teeth (Li, 1987), and it is more predatory. The weight of red panda is similar to yellow-throated marten (Smith & Xie, 2009). It is therefore inferred that yellow-throated marten preys on red panda and there is a predator-prey relationship between the two species. The results showed that there was a strong spatial correlation between yellow-throated marten and red panda ($r_{ø}$ = 0.59，χ^2=18.08，p＜0.01), and there was an asymmetric correlation between red panda and yellow-throated marten (L_B=0.476, λ_{B}=0.234, $p \leq 0.05$), with a prediction rate as high as 23.4%-47.6%. This suggests that yellow-throated marten often follows and preys on red panda. Yellow-throated marten prefers conifer and broad-leaved mixed forest and likes to walk on fallen wood (Zhu et al., 2019). It is similar to red panda(Wei et al., 2004).

As one of the first Carnivore species in Wolong, red panda has adapted to the ecological environment of Wolong in the long evolutionary process, and faces the problem of getting along with the later Carnivore species in Wolong. Black bear was diffused and distributed in Wolong during the Pleistocene, and their diet was highly omnivorous, and plant food accounted for a very high proportion of black bears' diet (Lu & Hu, 2003). However, red panda tends to choose the area with high density of bamboo forest and some fallen trees and tree stumps for foraging (Wei, Feng & Wang, 1999; Wei et al., 2004), which is a habitat avoided by black bear (Lu & Hu, 2003). The results of this study also show that there is no spatial correlation between black bear and red panda. Leopard cat and masked palm civet arrived in Wolong later. Leopard cat is a small carnivore. It prefers the areas with high grassland coverage and close to the water source, and avoids the forests with high tree canopy density (Choi et al., 2012), which is separated from the main habitat of red panda. This study also shows that there is no direct spatial correlation between leopard cat and red panda (Figure 3-1). Masked palm civet tends to forage in areas close to settlements, greater disturbance and lower bamboo coverage (Zeng et al., 2010; Wang et al., 2009). The results of this study show that there is no spatial correlation between masked palm civet and red panda, which is similar to that of leopard cat.

In this study, we find that there is mutual prediction of spatial distribution between red panda and yellow-throated marten and between giant panda and golden snub-nosed monkey, suggesting that the two pairs of species are mutually attracted to each other. Maybe there are two mechanisms for the formation of mutual attraction: (1) Yellow-throated marten forms a counter-anti-predatory strategy based on the anti-predatory strategy of red panda, namely, it attracts red panda to approach by the unknown strategy to improve the food availability of yellow-throated marten. (2) Yellow-throated marten attracts the third species, which in turn attracts red panda, thus achieving yellow-throated marten's attraction to red panda. However, the results of this study did not find any asymmetrical association about any species other than yellow-throated marten and red panda (Table 3-3). Therefore, the relationship between yellow-throated marten and red panda is more likely to be the result of predation and the counter-anti-predation strategy that is not yet understood.

There was a high correlation coefficient between giant panda and golden snub-nosed monkey (r_{ϕ}=0.72, χ^2=27.68, $p < 0.01$), and the prediction rate of them is also high(Table 3-3). This suggests that golden snub-nosed monkey can benefit from the relationship with giant panda. Both giant panda and golden snub-nosed monkey prefer to choose mixed coniferous and broad-leaved forest, with a demand for shrubs (Li et al., 2017; Wang et al., 2013). In such habitats, golden snub-nosed monkey mainly lives in the canopy of trees (Tie et al, 2009), while giant panda lives mainly in the undergrowth of shrubs. The active bases of the two species are actually separated and there is no competition between them. The principle food of golden snub-nosed monkey is abundant in the arbor forests in the active areas of giant panda (Li et al., 2013; Zhou et al., 2003). However, due to different feeding habits, there is no competitive relationship between the two species in terms of food. As the symbiotic species, the growth of bamboo will inhibit the growth of tree seedlings (Qin & Taylor, 1996). The feeding of giant panda will reduce the density of bamboo forests (Wang et al., 2001), thereby promoting the growth of trees and being good for golden snub-nosed monkey, which leads to a favorable ecological relationship between giant panda and golden snub-nosed monkey. So giant panda may be creating a suitable habitat for golden snub-nosed monkey. This has led to giant panda's attraction to golden snub-nosed monkey. In the coniferous and broad-leaved mixed forest, the coniferous forest with too high canopy density will hinder the growth of Arrow Bamboo, while the deciduous forest with low canopy density in spring and autumn will make Arrow Bamboo taller and denser (Wang et al, 2007). Golden snub-nosed monkey mainly feeds on leaves, buds and bark of trees (Li et al., 2012; Li et al., 2013). This will reduce the canopy density of the trees, but it is conducive to the growth of bamboo, so as to provide more abundant food resources for giant panda. This has led to golden snub-nosed monkey's attraction to giant panda.

Present community environment of giant panda

The results showed that, in addition to red panda, black bear and yellow-throated marten, there are also tufted deer and sambar which have direct spatial association with giant panda.

The tufted deer mainly feeds on herbs. They eat bamboo and bamboo shoots in winter and spring, and prefer to eat old bamboo shoots. They tend to choose bamboo forest activities with low density at middle and low altitudes (Zhang et al., 2007; Zhang et al., 2004). These habits are similar to those of giant panda. However, tufted deer is not undivided to feed on bamboo, and forages more often in areas outside the bamboo distribution area. Therefore, the spatial correlation between the two species is not strong ($r_ø$ = 0.35, χ^2=5.83, p＜0.05), and the ecological niche is separated.

Both sambar deer and giant panda prefer the area with gentle slope and high shrub coverage (Hu et al., 2018; Wang et al., 2018). Since the most common shrubs under the Wolong Nature Reserve are cold arrow bamboo *Bashania fangiana* and crabstick bamboo *Fargesia robusta* forest, the bamboo forest provides shelter and food conditions for sambar (Hu et al., 2018). Sambar has a wide diet (Zhang et al., 2020), but in winter, due to the loss of woody herbaceous plants and the shortage of food, the evergreen bamboo forest becomes the food source for sambar to overwinter (Guan et al., 2020). These habits are similar to those of giant panda. However, due to the differences in micro-habitat (Proulx et al., 2005) and feeding habits, the two species generally have good niche separation, and the spatial correlation between the two species is not strong ($r_{\varnothing}$ = 0.39, χ^2=7.42, p＜0.01).

The above discussion shows that giant panda has a harmonious inter-specific ecological relationship in the existing community because of its high bamboo eating ability. There is no natural enemy, and giant panda does not become the natural enemy of other species and has a mutualism relationship with golden snub-nosed monkey. Red panda creates a certain suitable habitat for giant panda. Giant panda creates a suitable habitat for golden snub-nosed monkey. There is a good niche separation between giant panda and black bear, yellow-throated marten, tufted deer and sambar.

Present community environment of red panda

The results showed that in addition to giant panda and yellow-throated marten, seven species are directly related to red panda, including tufted deer, sambar, wild boar, temminck's tragopan, forest musk deer, takin and golden snub-nosed monkey.

Tufted deer will feed on bamboo and bamboo shoots in winter and spring (Zhang & Wei, 2007). Tufted deer needs to feed on high places in the shrubs with the help of fallen wood and tree stumps due to the small size. It leads to a certain overlap of spatial distribution between tufted deer and red panda(Liu & Hu, 2008). The correlation coefficient is only 0.33.

Sambar prefers to choose areas with high shrub coverage (Hu et al., 2018; Wang et al., 2018). In Wolong, this area is usually the bamboo forest of *Bashania fangiana* and *Fargesia robusta*, which are the active areas of red panda. Sambar can obtain shelter and food resources from the bamboo forest (Hu et al., 2018), so the two species have the spatial overlap. But the spatial correlation between the two species is weak

(r_{ϕ}=0.38, χ^2= 27.68, p＜0.01).

Wild boar mainly nests in shrubs with low tree density and herb coverage. Their habitat selection is the same as red panda. They prefer mixed conifer and broad-leaved forest and live on sunny slopes in the middle and lower slopes (Zhou et al., 2014; Lu et al., 2007). Temminck's tragopan is active in the same forest type and tends to the middle and lower slope position. In order to avoid the enemy, they choose the area with higher slope and higher bamboo coverage as their habitats (Li et al., 2011). Forest musk deer is timid and agile, and chooses the bamboo forest with moderate density and steep slope under the coniferous and broad-leaved mixed forest as its activity area (Guo et al., 2001). There are many blow-down in its active area (Yang et al., 2011). Takin usually lives and forages in the mixed coniferous and broad-leaved mixed forest or broad-leaved deciduous forest in the middle and lower slopes with moderate elevation, sparse trees and moderate slope (Wu & Hu, 2001; Chen et al, 2019). These habitat types are integral parts of red panda's living space. Therefore, in terms of habitat utilization, these species compete with red panda to a certain extent, but there are good spatial niche and food ecology separations among species. The spatial correlation strength is weak.

In contrast, the correlation coefficient between golden snub-nosed monkey and red panda is higher (r_{ϕ}=0.46, χ^2=10.53, p＜0.01), and there is an asymmetric correlation (L_B = 0.348, λ_B=0.102, p ≤ 0.05). The prediction rate of red panda for golden snub-nosed monkey is 10.2%-34.8%. Both golden snub-nosed monkey and red panda prefer to choose the undergrowth shrub of mixed coniferous-broadleaf forest (Li et al., 2017; Wang et al., 2013). However, the active base of the two species is different: golden snub-nosed monkey mainly lives in arbor forests (Tie et al., 2009), while red panda mainly lives in bamboo forests. The feeding of red panda can reduce the density of bamboo forest (Zhou et al., 2011) and promote the growth of trees, which is beneficial to golden snub-nosed monkey. So golden snub-nosed monkey tends to follow red panda.

The above discussion suggests that red panda has a natural enemy: yellow-throated marten in the existing community, but red panda does not become a natural enemy of other species. The existence of red panda directly creates a certain suitable habitat for giant panda and golden snub-nosed monkey. There are good niche separations between red panda and tufted deer, sambar, wild boar, forest musk deer, takin and temminck's tragopan. Although there are low degree of competitions for food and habitat among the species, the overall relationship is harmonious without intense mutual exclusion.

Ecological relationship and spatial correlation degree

The above analysis shows that in giant panda’s and red panda’s inter-specific relationship, the formation of the dominance of the ecological relationship between spatial correlation intensity is weak, Phicoefficient 2*2 tables $r_{\phi} \leq 0.4$, even there is no direct spatial association. Preferential relationships enhance inter-specific associations. This phenomenon may be caused by the fact that the beneficiaries in the commensalism relationship follow the distribution of the other party in pursuit of evolutionary benefits, and the two parties in the mutualism relationship approach the other party actively, and the carnivorous species deceive the prey into approaching them in the counter anti-predation, thus increasing the overlap probability of the two species in the same geographical space.

CONCLUSIONS

Fig. 3-1 shows that giant panda only has direct spatial association with 6 species, while red panda has direct spatial association with 9 species in the community. The above discussion suggests that the ecological relationship between red panda and other species in the community is more complex than that of giant panda. In terms of umbrella protection, the protection of red panda could be beneficial to many more species, including giant panda. Therefore, the role of red panda umbrella protection is greater than giant panda.

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Data Accessibility:

- Data of the occurrence of different species at each camera site and Species List of Terrestrial Animal in Wolong: Dryad

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