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Spatial Interspecific Association Patterns of Mammal Communities in the Selin Co National Nature Reserve, Tibet

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Abstract

To elucidate the mammalian community structure and interspecific relationships within the alpine ecosystem of the Qinghai–Tibet Plateau, this study was conducted in the Selin co National Nature Reserve for Black-necked Cranes, Tibet. Based on infrared camera monitoring data collected from June 2023 to July 2024, we analyzed mammalian species diversity and their spatial association patterns. A total of 150 infrared cameras were deployed, of which 128 were effectively retrieved, yielding 13,301 effective camera-trap days and 31,170 photographs of mammals. In total, 21 mammal species were recorded, belonging to 5 orders, 9 families, and 17 genera. The species accumulation curve approached an asymptote, indicating adequate sampling effort. Relative abundance analysis showed that Bharal (*Pseudois nayaur*) was the dominant species (RAI = 13.72), followed by Plateau Pika (*Ochotona curzoniae*) (RAI = 8.44), Moupin Pika (*Ochotona thibetana*) (RAI = 5.93), and Red Fox (*Vulpes vulpes*) (RAI = 5.50), while Snow Leopard (*Panthera uncia*) exhibited a moderate abundance level (RAI = 3.69). Significant differences in species diversity were observed among habitat types. Alpine meadow and meadow–desert ecotone exhibited higher diversity indices, whereas alpine desert and alpine bare rock habitats showed lower diversity. Interspecific association analysis identified 30 significant species pairs ($p < 0.05$), among which positive associations accounted for 93.3% and negative associations for 6.7%. The constructed association network comprised 16 nodes and 30 edges, with Chiru (*Pantholops hodgsonii*), Snow Leopard, and Red Fox serving as key hub species. Predator–prey pairs exhibited clear spatial coupling, while positive associations among herbivores mainly reflected shared utilization of similar habitat resources. The association structure varied across habitats, being most complex in alpine meadow, whereas no significant associations were detected in alpine desert. Overall, the mammalian community in this region is characterized by "low species richness and high endemism," with interspecific relationships dominated by positive associations. Habitat heterogeneity plays a critical role in shaping the structure of the association network. These findings provide a scientific basis for biodiversity conservation and alpine ecosystem management on the Qinghai–Tibet Plateau.

Keywords: alpine ecosystem; mammal diversity; interspecific associations; habitat heterogeneity; Qinghai–Tibet Plateau Plateau

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1. Introduction

Biodiversity is a crucial measure of ecosystem health and resilience, playing a pivotal role in assessing the success of conservation efforts and ecological rehabilitation in protected

regions [1,2]. Within nature reserves, going beyond mere species lists to comprehend spatial distribution and interactions among different species is imperative for uncovering community structure and ecosystem resilience [3–6]. Consequently, analyzing species spatial associations offers a robust quantitative approach to delineate patterns of coexistence among species, shedding light on ecological mechanisms like niche sharing, competition for resources, and predator–prey dynamics [7,8].

The Qinghai–Tibet Plateau, a representative high-altitude ecosystem, is marked by severe climatic conditions, significant environmental heterogeneity, and heightened ecological sensitivity. Despite this, quantitative research on mammal community structure and interspecific relationships in the region is limited, primarily due to logistical constraints and environmental challenges [9,10]. Recently, camera trapping has emerged as a widely utilized method for long-term wildlife monitoring in alpine ecosystems, facilitating standardized data collection for community-level analyses [11]. Previous investigations have mainly concentrated on the population recovery and distribution patterns of flagship species, such as Chiru (*Pantholops hodgsonii*) and Wild Yak (*Bos mutus*), whose population increases reflect overall enhancements in regional ecological conditions [12,13]. However, studies focusing on community-level dynamics, particularly regarding spatial associations among mammal species, remain inadequate.

The Selin co National Nature Reserve is an important alpine ecosystem on the Qinghai–Tibet Plateau and provides critical habitats for many endemic and rare mammal species [14]. Recent studies have shown that community assembly and species coexistence patterns in alpine ecosystems are strongly influenced by environmental filtering, habitat heterogeneity, and resource availability [15]. Under harsh climatic conditions, species with similar ecological requirements often exhibit high spatial overlap due to limited suitable habitats and concentrated resources [16]. Consequently, interspecific spatial associations have become an important approach for understanding community structure, ecological interactions, and biodiversity maintenance in high-altitude ecosystems [16]. In recent years, camera-trapping technology has been increasingly applied to evaluate mammal community composition, habitat use, and species co-occurrence patterns, providing new insights into the ecological processes shaping alpine mammal communities [17].

The current study goes beyond conventional species diversity assessments by using long-term camera-trapping data to examine mammal community structure and interspecific spatial associations in the Selin co National Nature Reserve. Specifically, this study aimed to: (1) characterize mammal community composition and diversity patterns; (2) evaluate differences in mammal diversity and interspecific associations among habitat types; and (3) explore the potential ecological mechanisms shaping species co-occurrence patterns in alpine ecosystems. By integrating species diversity, habitat heterogeneity, and interspecific spatial associations, this study provides new insights into the ecological processes influencing community structure and biodiversity maintenance in high-altitude ecosystems of the Qinghai–Tibet Plateau. The findings are expected to improve the understanding of mammal community organization in alpine protected areas and provide a scientific basis for biodiversity conservation and ecosystem management in high-altitude regions.

2. Materials and Methods

2.1. Overview of the Study Area

The Selin Co National Nature Reserve for Black-necked Cranes is located in the northern Qinghai–Tibet Plateau within the Tibet Autonomous Region, China. It is the world's largest protected area established for the conservation of Black-necked Cranes and represents a typical alpine ecosystem of the central Tibetan Plateau. The reserve

supports rich biodiversity, including 376 species of seed plants belonging to 39 families, 23 mammal species belonging to 10 families, 92 bird species belonging to 25 families, 1 amphibian species, 3 reptile species belonging to 2 families, and 12 fish species belonging to 2 families [14].

Geographically, the reserve is divided into eastern and western sectors. The southern boundary follows the eastern Gangdise Mountains, whereas the northern boundary extends to the southern side of the Amdo–Shiquanhe Highway. The western boundary is delineated by the watershed between Zigui Lake and the Angzi Lake system, while the eastern boundary extends from the eastern shore of Co Na Lake to the confluence of the Nagqu and Mugqu rivers [15]. Administratively, the study area spans Xainza, Nyima, Baingoin, Amdo, and Seni District of Nagqu City.

The study area is characterized by a typical alpine plateau climate, with low temperatures, intense solar radiation, strong winds, and large diurnal temperature fluctuations. The vegetation is dominated by alpine meadow, alpine steppe, alpine desert, and wetland ecosystems, providing important habitats for a variety of endemic and high-altitude wildlife species [18,19].

2.2. Camera-Trap Survey Design

Field surveys were conducted in the Selin Co National Nature Reserve from June 2023 to July 2024. Owing to the complex environmental conditions and extensive spatial extent of the reserve, camera trapping was adopted as the primary monitoring method using Forsafe H885 (China) infrared cameras. Using ArcMap 10.8, the reserve was divided into 256 grid cells (10 km × 10 km) to ensure broad spatial coverage of the study area (Figure 1). The sampling design considered habitat representativeness, terrain accessibility, wildlife distribution patterns, and resource availability to maximize coverage of major habitat types and reduce potential sampling bias [20].

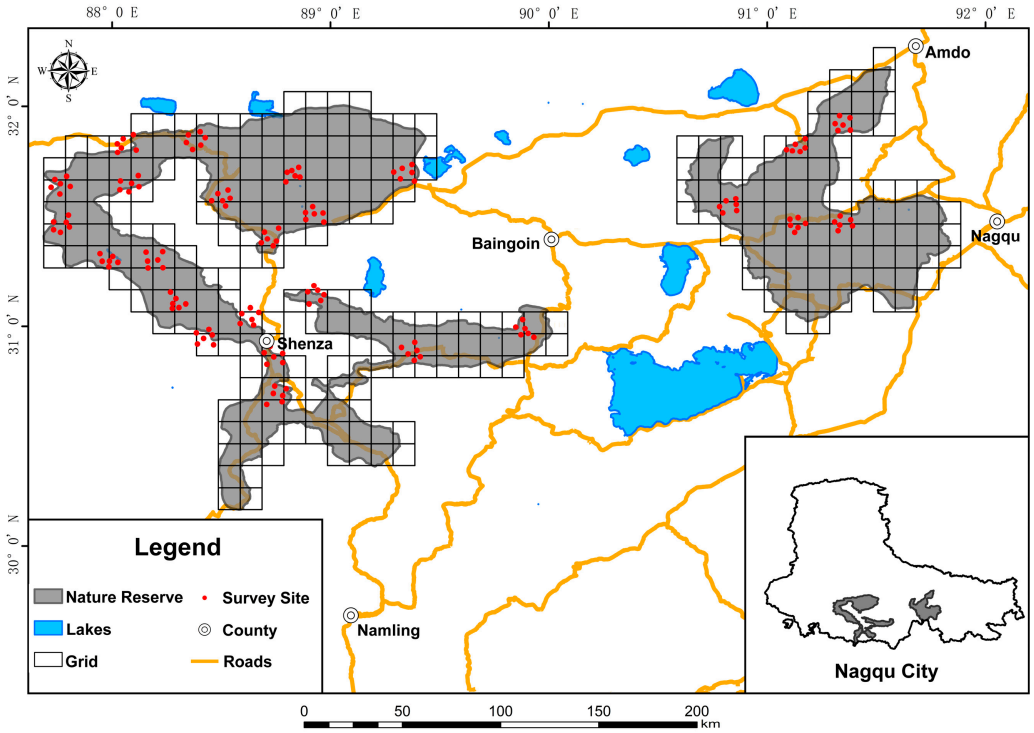


Figure 1. Geographic location of the Selin Co National Nature Reserve on the Qinghai–Tibet Plateau and spatial distribution of camera-trap sampling sites across different habitat types.

Among the grid cells, 25 were selected as monitoring units to ensure representative coverage of the main habitat types and geographic regions while maintaining logistical feasibility for long-term field monitoring. Within these grids, a total of 150 infrared cameras were deployed across five habitat types: marsh wetland, alpine meadow, alpine desert, meadow–desert ecotone, and alpine bare rock habitat (Figures 1 and 2). To ensure standardized comparisons among habitats, 30 cameras were assigned to each habitat type. Habitat classification was based on vegetation characteristics, topographic features, and land-cover information derived from field surveys and remote-sensing data.



Figure 2. Representative habitat types and camera-trap deployment conditions in the Selin Co National Nature Reserve. (**a**) Alpine meadow; (**b**) Alpine desert; (**c**) Marsh wetland; (**d**) Alpine bare rock; (**e**) Meadow–desert ecotone; (**f**) Work photo.

Camera locations were determined based on historical wildlife occurrence records and the field experience of local wildlife rangers, providing important local ecological knowledge for identifying areas with higher probabilities of mammal activity [21]. However, due to constraints related to terrain accessibility, logistical limitations, and installation safety, camera deployment could not be strictly uniform across space. As a result, camera distribution exhibited localized clustering in accessible areas, while some regions with extremely steep terrain or hazardous conditions remained unsampled.

Camera Trap Deployment and Maintenance

Cameras were mounted on rocks or wooden stakes at a height of approximately 40–60 cm, adjusted according to local terrain and vegetation structure. They were preferentially deployed along wildlife trails, ridge routes, valley corridors, water sources, and in areas with clear signs of mammal activity (e.g., tracks, feces, or feeding traces). To minimize

false triggers and image overexposure, cameras were oriented away from direct sunlight whenever possible, and vegetation immediately in front of the sensor was cleared.

All cameras were programmed to operate continuously (24 h/day) in a hybrid photo–video mode with high trigger sensitivity. Each trigger event generated three consecutive photographs followed by a 15 s video recording. Field inspections were performed every four months to replace batteries, retrieve memory cards, and assess equipment performance. All photographs were manually screened, and species identifications were independently verified by at least two trained researchers.

2.3. Camera-Trap Data Processing

Camera-trap data were systematically organized and preprocessed prior to analysis. Each camera site was assigned a unique geographic identifier in the format "SLCP-XXX" (reserve code + sequential number) to ensure spatial consistency across sampling locations. Image data were processed following a standardized spatiotemporal protocol.

To minimize pseudoreplication, consecutive photographs of the same species captured within a 60-s interval at the same camera site were merged into a single detection event. Independent detection events were defined as records of the same species separated by at least 30 min at the same camera site, following widely accepted criteria in camera-trapping studies [20]. Although shorter temporal thresholds may better capture fine-scale behavioral variation or multiple individuals in highly active species, a 30-min interval was adopted to ensure methodological consistency across species and sampling sites and to reduce repeated detections of the same individuals within short time periods [22,23].

Species identification was conducted using authoritative taxonomic references, including *A Guide to the Mammals of China* [24], *A Field Guide to the Mammals of China* [25], and *Illustrated Handbook of Chinese Mammals* [26]. Taxonomic nomenclature, species classification, and endemic status followed the standardized checklist provided in *A Catalogue of Mammals in China* [27].

2.4. Statistical Analysis

2.4.1. Species Accumulation Curve

Species accumulation curves were generated using the ggplot2 package in R version 4.2.1 to evaluate sampling completeness and assess whether the camera-trapping effort adequately captured mammalian species richness within the study area [28].

2.4.2. Species Diversity Index

To enhance the estimation of species relative abundance in the reserve, all infrared camera-captured photographs were aggregated, and the relative abundance index was computed utilizing camera-trap capture rates [29]. Mammalian diversity variations across the reserve were evaluated by quantifying species diversity through the Shannon-Wiener index, Simpson index, and Pielou's evenness index [30,31].

2.4.3. Interspecific Association Analysis

Using camera-trap data, each camera location served as a sampling unit to construct a species presence–absence matrix, with "1" indicating detection and "0" indicating non-detection. Subsequently, species co-occurrence patterns were analyzed quantitatively. The Ochiai index was used to assess the degree of association between pairs of species, and chi-square (χ^2) tests were used to assess the statistical significance of these associations [32]. To mitigate Type I errors from multiple comparisons, all *p*-values were adjusted using the False Discovery Rate (FDR) method. Additionally, the Association Coefficient (AC) and the lambda coefficient (λ, LB) were used as supplementary measures to evaluate interspecific associations, enhancing the reliability and coherence of the findings [33,34].

It is crucial to note that the identified associations indicate spatial co-occurrence or segregation patterns rather than direct ecological interactions. These patterns can arise from various underlying processes, such as shared responses to environmental conditions (environmental filtering), niche differentiation, and stochastic processes. Therefore, ecological interpretations of these associations should be approached with caution and should take into account habitat characteristics and contextual ecological information.

3. Results

3.1. Sample Adequacy Results

A total of 150 infrared camera traps were deployed during the survey period. Of these, 9 cameras were damaged and 13 were lost, resulting in 128 successfully retrieved units. The total sampling effort reached 13,301 camera-trap days, yielding 31,170 mammal photographs. After species identification, a total of 21 mammal species belonging to 17 genera, 9 families, and 5 orders were recorded.

The species accumulation curve exhibited a rapid increase during the initial ~5000 camera-trap days and gradually stabilized, approaching an asymptote at approximately 10,000 camera-trap days (Figure S1). This asymptotic trend suggests that the sampling effort was sufficient to capture most mammalian species present in the study area, with only a limited number of additional species expected to be detected with further sampling effort.

3.2. Diversity of Mammal Species

3.2.1. Species Composition

A total of 150 infrared camera traps were deployed, of which 128 were successfully retrieved after field losses (9 damaged, 13 lost), resulting in 13,301 camera-trap days and 31,170 independent detections. A total of 21 mammal species belonging to 17 genera, 9 families, and 5 orders were recorded.

Sampling completeness was evaluated using species accumulation curves and asymptotic richness estimators. The accumulation curve reached a clear asymptote at ~10,000 camera-trap days, with no additional species detected thereafter. Observed richness closely matched estimated richness, indicating high sampling coverage of the mammal assemblage. Together, curve stabilization and estimator convergence provide strong evidence that sampling effort was sufficient to capture the majority of species present in the study area (Figure S1).

3.2.2. Species Relative Richness

During the survey, 21 mammal species were recorded. The species with the highest relative abundance index (RAI) was Bharal at 13.72, followed by Plateau Pika (*Ochotona curzoniae*) (RAI = 8.44), Moupin Pika (*Ochotona thibetana*) (RAI = 5.93), and Red Fox (*Vulpes vulpes*) (RAI = 5.50). Species with RAI values between 2.0 and 4.0 included Large-eared Pika (*Ochotona macrotis*) (RAI = 4.02), Woolly Hare (*Lepus oiostolus*) (RAI = 3.95), Snow Leopard (*Panthera uncia*; RAI = 3.69), and Himalayan Marmot (*Marmota himalayana*) (RAI = 2.29). Species showing relatively low relative abundance (RAI < 1.0) comprised Gray Wolf (*Canis lupus*) (RAI = 0.50), Tibetan Gazelle (*Procapra picticaudata*, RAI = 0.31), Tibetan Argali (*Ovis hodgsoni*) (RAI = 0.26), Eurasian Lynx (*Lynx lynx*) (RAI = 0.25), Steppe Polecat (*Mustela eversmanii*) (RAI = 0.20), Beech Marten (*Martes foina*) (RAI = 0.18), and Mountain Weasel (*Mustela altaica*) (RAI = 0.10) (Figure 3; Table 1; Figure S2).

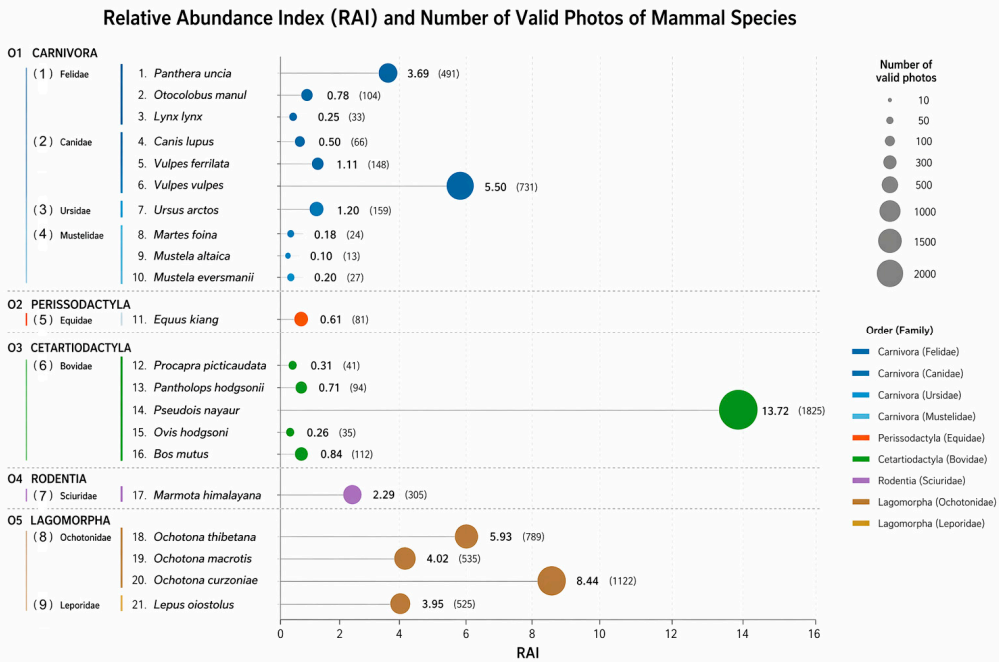


Figure 3. Relative Abundance Index (RAI) of 21 mammal species arranged by taxonomic order.

Table 1. Mammal species recorded by camera trapping in the Selin Co National Nature Reserve (June 2023–July 2024).

Species	Number of Valid Photos	RAI
CARNIVORA		
Felidae		
Panthera uncia	491	3.69
Otocolobus manul	104	0.78
Lynx lynx	33	0.25
Canidae		
Canis lupus	66	0.50
Vulpes ferrilata	148	1.11
Vulpes vulpes	731	5.50
Ursidae		
Ursus arctos	159	1.20
Mustelidae		
Martes foina	24	0.18
Mustela altaica	13	0.10
Mustela eversmanii	27	0.20
PERISSODACTYLA		
Equidae		
Equus kiang	81	0.61
CETARTIODACTYLA		
Bovidae		
Procapra picticaudata	41	0.31
Pantholops hodgsonii	94	0.71
Pseudois nayaur	1825	13.72
Ovis hodgsoni	35	0.26
Bos mutus	112	0.84
RODENTIA		
Sciuridae		
Marmota himalayana	305	2.29

Table 1. *Cont.*

Species	Number of Valid Photos	RAI
LAGOMORPHA		
Ochotonidae		
Ochotona thibetana	789	5.93
Ochotona macrotis	535	4.02
Ochotona curzoniae	1122	8.44
Leporidae		
Lepus oiostolus	525	3.95

Note: Taxonomy follows A Catalogue of Mammals in China. All species names are presented in standardized binomial Latin nomenclature. Independent detections refer to temporally independent camera-trap records, defined as consecutive detections of the same species separated by ≥30 min at the same camera site to reduce pseudoreplication. RAI (relative abundance index) was expressed as the number of independent detections standardized per 100 camera-trap days. All indices were standardized by sampling effort, ensuring comparability across species and habitats.

3.3. Differences in Biodiversity Across Habitat Types

Significant variation in diversity indices (Shannon–Wiener, Simpson, and Pielou's evenness) was observed among the five habitat types within the reserve, including marsh wetland, alpine bare land, alpine desert, alpine meadow, and meadow–desert ecotone. Alpine meadow exhibited the highest diversity, with a Shannon–Wiener index of 2.44 and Simpson index of 0.88, closely followed by meadow–desert ecotone (2.26 and 0.87, respectively). Marsh wetland showed intermediate diversity (Shannon–Wiener = 2.12, Simpson = 0.83), whereas alpine bare land and alpine desert displayed consistently lower values across indices (Shannon–Wiener = 1.51 and 1.30; Simpson = 0.70 and 0.55, respectively). Pielou's evenness showed a similar gradient, ranging from 0.32 in alpine meadow to 0.19 in alpine desert. Species richness and Shannon diversity exhibited consistent spatial patterns across habitats, with alpine meadow and meadow–desert ecotone showing the highest values and alpine desert and alpine bare land the lowest (Table 2).

Table 2. Diversity indices in different habitats.

Index / Habitat	Shannon-Wiener	Simpson	Pielou
marsh wetland	2.12	0.83	0.28
alpine bare land	1.51	0.70	0.23
alpine desert	1.30	0.55	0.19
alpine meadow	2.44	0.88	0.32
Meadow–desert ecotone	2.26	0.87	0.30

3.4. Species Association Results

3.4.1. Interspecific Association of Mammals

A total of 190 potential species pairs were formed among all recorded mammal species, with 30 pairs showing statistically significant associations ($\chi^2 \geq 3.84$, $p < 0.05$). Of these significant associations, positive associations dominated, accounting for 28 pairs (93.3%), while negative associations accounted for two pairs (6.7%), indicating a strong tendency toward spatial co-occurrence within the community.

The species association network, constructed based on significant pairwise relationships, comprised 16 nodes and 30 edges, with a network density of 0.25, indicating moderate connectivity. Degree centrality analysis identified Chiru, Snow Leopard, and Red Fox as key hub species, connecting 12, 10, and 9 species, respectively. From a functional perspective, herbivores exhibited widespread positive associations. Representative pairs

included Kiang–Tibetan Gazelle (*Equus kiang*–*Procapra picticaudata*, Φ = 0.73) and Chiru–Bharal (Φ = 0.48). Clear predator–prey spatial coupling was also observed, such as Snow Leopard–Bharal (Φ = 0.60) and Snow Leopard–Woolly Hare (Φ = 0.58). Negative associations were limited, with the strongest observed between Wild Yak (*Bos mutus*)–Bharal (Φ = −0.41). Additional weak negative associations involved Brown Bear (*Ursus arctos*) with smaller carnivores, including Tibetan Fox (*Vulpes ferrilata*) and Red Fox (Figures 4 and 5).

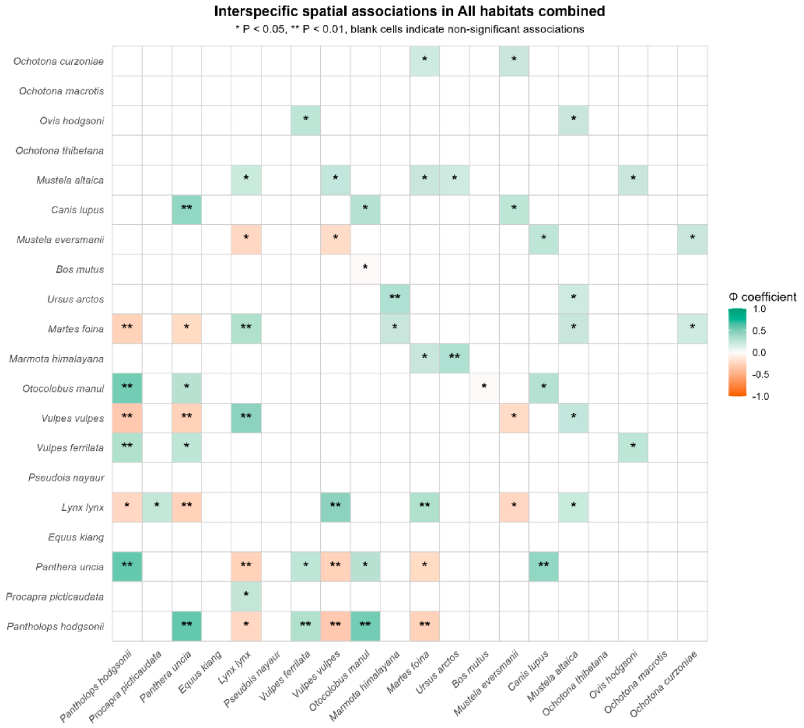


Figure 4. Heatmap of significant interspecific associations among mammals.

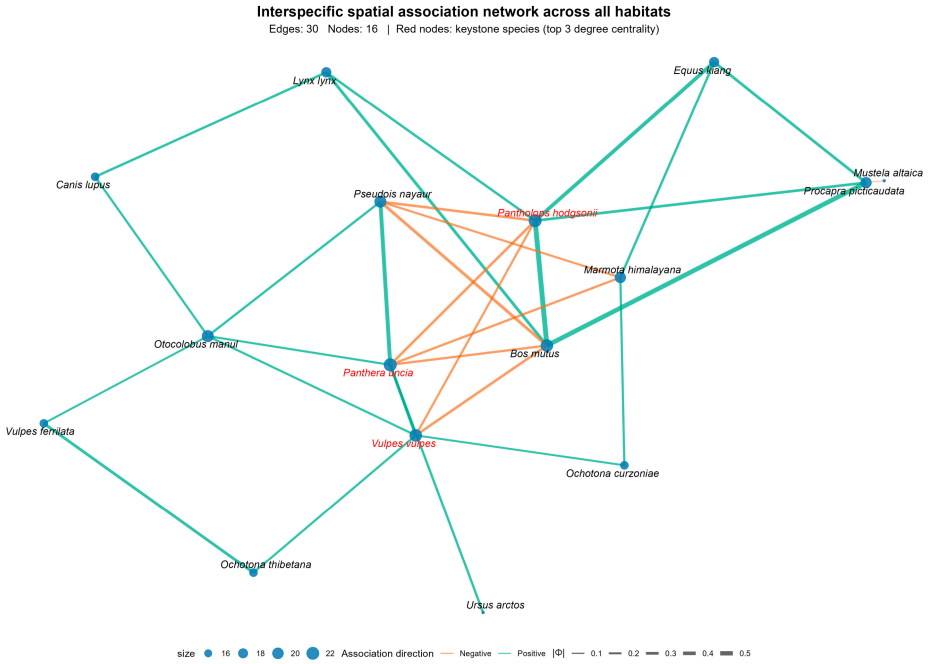


Figure 5. Overall network of significant spatial associations among mammals.

3.4.2. Species Association Results Across Habitat Types

In the meadow–desert ecotone, five significant positive associations were detected, indicating a relatively simple but structured interaction network. The strongest association was observed between Snow Leopard and Woolly Hare ($\Phi = 0.66$, $p < 0.01$). Additional significant positive associations included Tibetan Fox ($\Phi = 0.58$, $p < 0.01$), Red Fox–Woolly Hare ($\Phi = 0.58$, $p < 0.01$), Snow Leopard–Red Fox ($\Phi = 0.55$, $p < 0.05$), and Gray Wolf–Woolly Hare ($\Phi = 0.47$, $p < 0.05$).

The alpine meadow exhibited a more complex association structure. Positive associations were primarily observed among ungulates, including Tibetan Gazelle–Kiang ($\Phi = 0.93$, $p < 0.01$), Kiang–Chiru ($\Phi = 0.62$, $p < 0.01$), and Tibetan Gazelle–Chiru ($\Phi = 0.55$, $p < 0.05$). A positive association was also detected between Snow Leopard and Bharal ($\Phi = 0.51$, $p < 0.05$). Among carnivores, positive associations included Gray Wolf–Tibetan Fox ($\Phi = 0.51$, $p < 0.05$) and Red Fox–Pallas's Cat (*Otocolobus manul*, $\Phi = 0.44$, $p < 0.05$). A single significant negative association was observed between Wild Yak–Bharal ($\Phi = -0.41$, $p < 0.05$).

In marsh wetland habitat, positive associations were observed among Kiang–Chiru ($\Phi = 0.55$, $p < 0.05$), Himalayan Marmot–Chiru ($\Phi = 0.52$, $p < 0.05$), and Kiang–Tibetan Gazelle ($\Phi = 0.48$, $p < 0.05$). In alpine bare land, a significant positive association was detected between Snow Leopard and Bharal ($\Phi = 0.60$, $p < 0.05$). In contrast, no statistically significant interspecific associations were detected in the alpine desert habitat despite the presence of 12 recorded species (Figures 6 and 7).

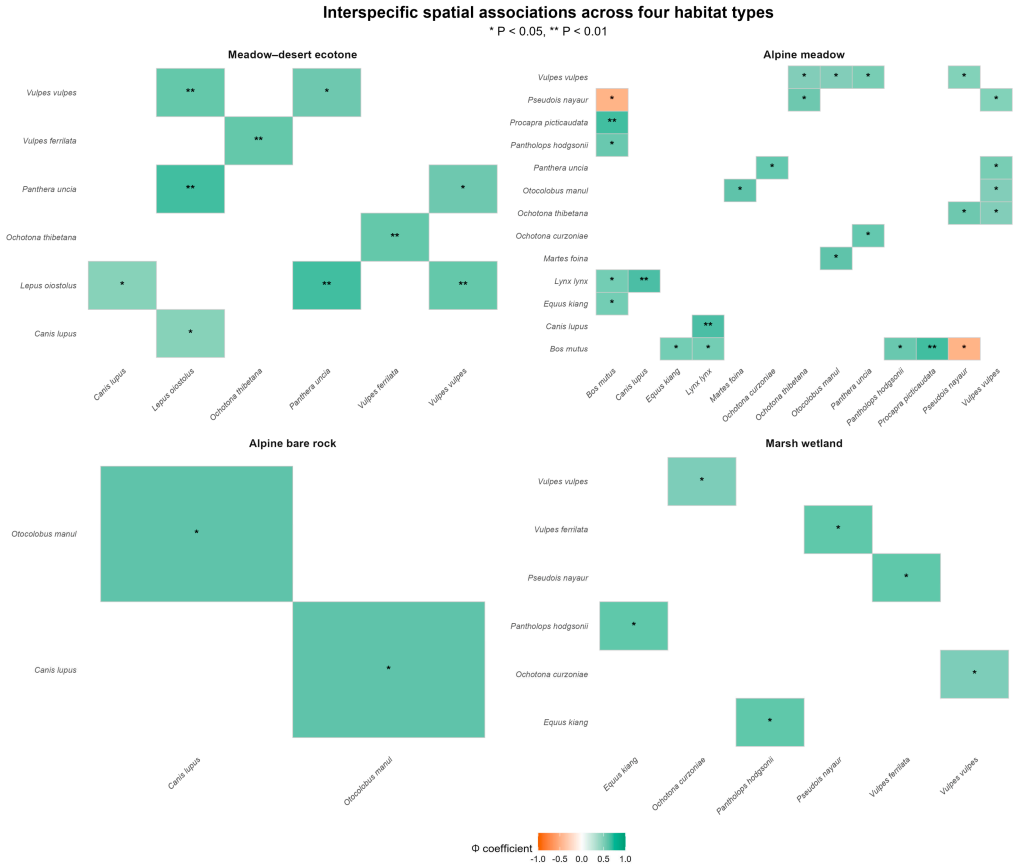


Figure 6. Heatmap of significant spatial associations among species across different habitats.

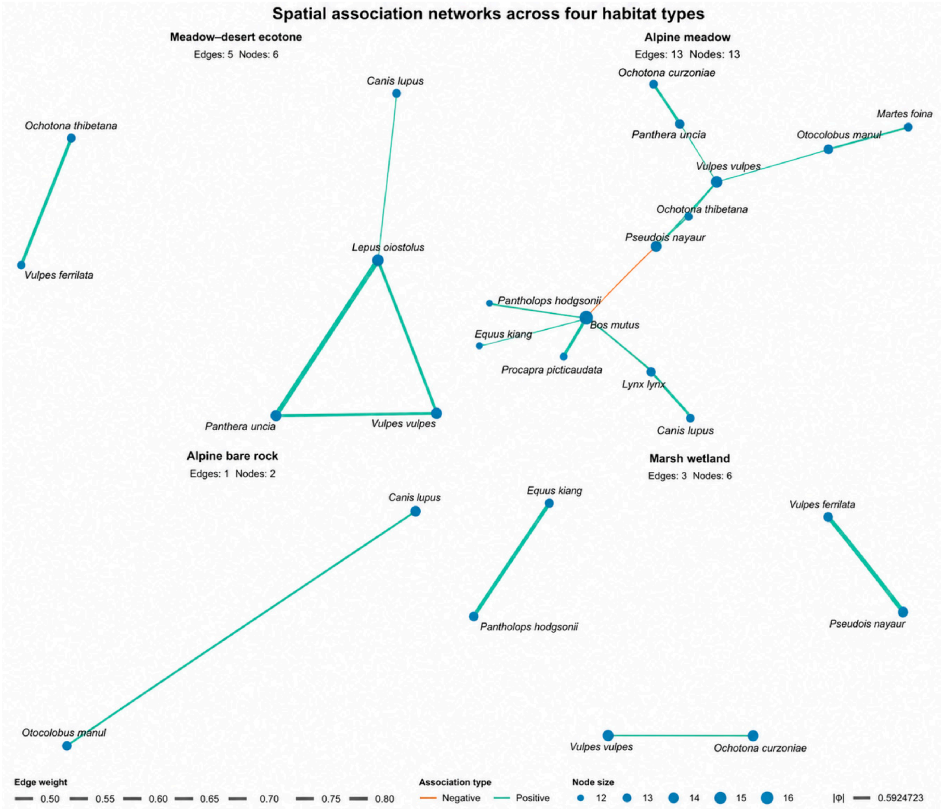


Figure 7. Spatial association networks of species in different habitats.

4. Discussion

4.1. Mammalian Community Composition and Characteristics

The mammal community recorded in this study was characterized by relatively low species richness but high dominance of alpine-adapted taxa, with Bharal, Plateau Pika, Moupin Pika, and Red Fox exhibiting comparatively high relative activity intensity. Similar assemblage structures have been widely reported across alpine ecosystems of the Qinghai–Tibet Plateau, where pika species, Blue Sheep, and Himalayan Marmot commonly dominate under harsh climatic conditions [11,35].

The Selin Co region is characterized by low temperature, hypoxia, low primary productivity, and short growing seasons, imposing strong abiotic constraints on mammalian persistence. Consequently, the regional fauna is dominated by cold-adapted and endemic taxa, forming a typical pattern of low species richness but high ecological specialization. Environmental filtering therefore likely plays a key role in structuring mammalian assemblages in this high-altitude ecosystem [36–39].

The high relative abundance of Bharal likely reflects the suitability of alpine meadow and rocky habitats that provide both forage resources and refuge conditions. In contrast, apex predators such as Snow Leopard and Eurasian Lynx were recorded less frequently, likely reflecting low population densities and species-specific detectability in camera-trap surveys. Camera-trap detection probability is known to vary with body size, movement behavior, and habitat structure. Accordingly, the Relative Abundance Index should be interpreted as a proxy of relative activity intensity rather than absolute population density [40]. The continuous detection of flagship species, including Snow Leopard, Gray Wolf, and Brown Bear, further indicates that the Selin Co ecosystem retains relatively high ecological integrity and conservation value [41–43].

4.2. Habitat Heterogeneity and Mammalian Diversity Patterns

Differences in mammalian diversity among habitat types likely reflect variation in vegetation structure, hydrothermal conditions, and resource availability. Previous studies have shown that vegetation productivity, topographic complexity, and climate are important drivers of mammalian habitat selection and community composition in alpine ecosystems [44–47].

In the Selin Co region, alpine meadows and meadow–desert ecotones generally provide higher soil moisture, greater vegetation cover, and more abundant forage resources than alpine desert habitats. These relatively productive habitat patches may support higher densities of herbivorous mammals and subsequently attract predators, thereby promoting multispecies coexistence and increasing mammalian diversity.

In contrast, alpine desert and bare-rock habitats are characterized by sparse vegetation, strong wind exposure, and limited food resources. Under such harsh environmental conditions, only species with specialized adaptations to cold and arid environments can persist, resulting in lower species richness and simpler community structure [48].

The coexistence of wetlands, meadows, desert areas, and rocky habitats within the reserve forms a heterogeneous habitat mosaic, which may facilitate niche partitioning and contribute to the maintenance of mammalian diversity in this alpine ecosystem [8].

4.3. Spatial Co-Occurrence Patterns of Mammal Species

Positive spatial associations prevailed among significantly associated species pairs, indicating extensive habitat overlap driven by patchily distributed resources (water, forage, shelter) in this alpine ecosystem. Herbivore positive associations (e.g., Kiang, Tibetan Gazelle, Chiru, Bharal) reflect shared selection for productive grasslands, meadows, and wetland margins. Snow Leopard–prey (Bharal, Woolly Hare) associations suggest predator aggregation in prey-rich patches [8,47]. Mesocarnivores (Tibetan Fox, Red Fox, Pallas's Cat) also exhibited positive associations, likely coexisting through dietary, temporal, and microhabitat niche partitioning despite spatial overlap [15]. Association patterns varied by habitat: alpine meadows and meadow–desert ecotones showed more frequent positive associations, likely due to higher productivity and vegetation cover, whereas alpine deserts yielded no significant associations, where harsh conditions and dispersed resources may amplify stochastic processes [49]. Observed co-occurrence primarily reflects spatial overlap, potentially confounded by habitat heterogeneity and detection probability [50]. Given ongoing climate change and anthropogenic disturbance [51], long-term monitoring and conservation of meadows, wetland margins, and ecotones are crucial for sustaining mammalian diversity in the Selin Co region.

4.4. Study Limitations and Conservation Implications

This study was based on a one-year camera-trapping survey and therefore may not fully capture long-term temporal dynamics or interannual variation in mammalian community structure. Seasonal migration, breeding behavior, and climate-driven environmental fluctuations may influence species occurrence and co-occurrence patterns in alpine ecosystems. In addition, the observed associations mainly reflect spatial overlap rather than direct ecological interactions.

Despite these limitations, this study provides important baseline information on mammalian diversity and spatial co-occurrence patterns in the Selin Co National Nature Reserve. Alpine meadows, wetland margins, and meadow–desert ecotones supported relatively high mammalian diversity and frequent species co-occurrence, highlighting their importance for biodiversity conservation on the central Qinghai–Tibet Plateau. Strengthening long-term ecological monitoring and prioritizing the conservation of heterogeneous habitats will be

important for maintaining ecosystem stability under ongoing climate change and increasing human disturbance.

5. Conclusions

This study presents a one-year camera-trapping survey (2023–2024) of mammalian communities in the Selin Co National Nature Reserve, during which 21 mammal species belonging to 5 orders were recorded. Species accumulation curves approached an asymptote, indicating that the sampling effort was generally sufficient to reflect the mammalian community structure of the study area.

The mammalian community was dominated by alpine-adapted species, particularly Bharal, Plateau Pika, Moupin Pika, and Red Fox, whereas large carnivores and several mesocarnivores showed relatively low detection frequencies. Mammalian diversity varied considerably among habitat types, with alpine meadows and meadow–desert ecotones supporting higher diversity than alpine desert and alpine bare-rock habitats, highlighting the importance of habitat heterogeneity in shaping community structure.

Positive spatial associations dominated the mammalian community, suggesting that many species shared similar habitat preferences and resource-use patterns under the harsh environmental conditions of the Qinghai–Tibet Plateau. Species association patterns also differed among habitat types, whereas no significant associations were detected in alpine desert habitats despite the presence of multiple species.

Overall, this study provides important baseline information on mammalian diversity and spatial co-occurrence patterns in the Selin Co National Nature Reserve and offers scientific support for biodiversity conservation and long-term ecological monitoring on the central Qinghai–Tibet Plateau.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/d18060312/s1, Figure S1. Species accumulation curve of mammals detected by camera trapping in the Selin Co National Nature Reserve from June 2023 to July 2024. Figure S2. Representative camera-trap photographs of selected mammal species recorded in the Selin Co National Nature Reserve, Tibet.

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References

1. Díaz, S.; Zafra-Calvo, N.; Purvis, A.; Verburg, P.H.; Obura, D.; Leadley, P.; Chaplin-Kramer, R.; De Meester, L.; Dulloo, E.; Martín-López, B.; et al. Set ambitious goals for biodiversity and sustainability. *Science* **2020**, *370*, 411–413. [CrossRef] [PubMed]

2. Watson, J.E.M.; Evans, T.; Venter, O.; Williams, B.; Tulloch, A.; Stewart, C.; Thompson, I.; Ray, J.C.; Murray, K.; Salazar, A.; et al. The exceptional value of intact forest ecosystems. *Nat. Ecol. Evol.* **2018**, *2*, 599–606. [CrossRef]
3. Tian, S.R.; Li, H.W.; Jiang, B.W.; Zhang, Z.J.; Wang, C.Y.; Yang, H.Y.; Liu, J.; Zhou, Q.; Luo, X.B. Spatiotemporal patterns of mammalian diversity in Hupingshan National Nature Reserve, Hunan Province, China. *Acta Theriol. Sin.* **2020**, *40*, 87–95.
4. IPBES. *Summary for Policymakers of the Thematic Assessment Report on the Interlinkages Among Biodiversity, Water, Food and Health*; IPBES Secretariat: Bonn, Germany, 2024.
5. Ministry of Ecology and Environment of China. *China Biodiversity Conservation Strategy and Action Plan (2023–2030)*; Ministry of Ecology and Environment of China: Beijing, China, 2024.
6. Hu, S.W.; Yang, Y.C.; Jin, C. Urban forest biodiversity and its influencing factors in China: A review. *J. Chin. Urban For.* **2022**, *20*, 1–8.
7. Xu, Z.; Chau, S.N.; Chen, X.; Zhang, J.; Li, Y.; Dietz, T.; Wang, J.; Winkler, J.A.; Fan, F.; Huang, B.; et al. Assessing progress towards sustainable development over space and time. *Nature* **2020**, *577*, 74–78. [CrossRef]
8. Li, Z.; Tang, Z.; Xu, Y.; Wang, Y.; Duan, Z.; Liu, X.; Wang, P.; Yang, J.; Chen, W.; Prins, H.H.T. Habitat use and activity patterns of mammals and birds in relation to temperature and vegetation cover in an alpine ecosystem of southwestern China using camera trapping. *Animals* **2021**, *11*, 3377. [CrossRef]
9. Harris, D.J. Inferring species interactions from co-occurrence data with Markov networks. *Ecology* **2016**, *97*, 3308–3314. [CrossRef]
10. Rovero, F.; Tobler, M.; Sanderson, J. Camera trapping for inventorying terrestrial vertebrates. In *Camera Traps in Animal Ecology*; Springer: Berlin/Heidelberg, Germany, 2010; pp. 1–21.
11. Li, S.Q.; Li, Y.; Xiang, Y.; Tang, W.Y.; Li, S.Q. Diversity and spatiotemporal distribution patterns of medium and large mammals in eastern Qinghai–Tibet Plateau. *Sichuan For. Sci. Technol.* **2024**, *45*, 48–62.
12. Tibet Forestry and Grassland Administration. Joint Conference on Wildlife Protection and "Qingfeng Action 2023". 4 March 2023. Available online: https://news.jstv.com/a/20230304/1677901237705.shtml (accessed on 21 April 2026).
13. Jiang, D.; Zhao, X.; López-Pujol, J.; Wang, Z.; Qu, Y.; Zhang, Y.; Zhang, T.; Li, D.; Jiang, K.; Wang, B.; et al. Effects of climate change and anthropogenic activity on ranges of vertebrate species endemic to the Qinghai–Tibet Plateau over 40 years. *Conserv. Biol.* **2023**, *37*, e14069. [CrossRef]
14. Lv, J.E.; Ma, L.; Gao, H.J. Lake evolution in Selin Co National Nature Reserve over the past 30 years. *For. Inventory Plan.* **2024**, *49*, 51–57.
15. Song, W.-Y.; Onditi, K.O.; Li, X.-Y.; Chen, Z.-Z.; He, S.-W.; Li, Q.; Jiang, X.-L. Decomposing niche components reveals simultaneous effects of opposite deterministic processes structuring alpine small mammal assembly. *Front. Ecol. Evol.* **2023**, *10*, 999573. [CrossRef]
16. Gotelli, N.J.; McCabe, D.J. Species co-occurrence: A meta-analysis of J.M. Diamond's assembly rules model. *Ecology* **2002**, *83*, 2091–2096. [CrossRef]
17. Burton, A.C.; Neilson, E.; Moreira, D.; Ladle, A.; Steenweg, R.; Fisher, J.T.; Bayne, E.; Boutin, S. Wildlife camera trapping: A review and recommendations for linking surveys to ecological processes. *J. Appl. Ecol.* **2015**, *52*, 675–685. [CrossRef]
18. Wang, K.X.; Zhang, Y.S.; Zhang, T.; Yu, K.L.; Guo, Y.H.; Ma, N. Climate change in the Selin Co basin on the Qinghai–Tibet Plateau from 1979 to 2017. *Arid Zone Res.* **2020**, *37*, 652–662.
19. Wang, B.Q.; Chen, K.; Zhu, R. Threats to and conservation of biodiversity in the Siling Co National Nature Reserve, Tibetan Plateau, China. *Eco Mont* **2024**, *16*, 47. [CrossRef]
20. Tang, M.; Liao, J.H.; Qin, H.F. Avifauna and diversity of Selin Co National Nature Reserve, Tibet. *J. Mianyang Norm. Univ.* **2021**, *40*, 57–63.
21. Yang, C.M.; Dou, L.; Xu, H.L.; Li, Y.; Ma, J.Z. Habitat suitability assessment of Vulpes vulpes based on camera trapping in Seda County. *Chin. J. Wildl.* **2025**, *46*, 1–10.
22. Li, S.; Wang, D.J.; Xiao, Z.S.; Li, X.H.; Wang, T.M.; Feng, L.M.; Wang, Y. Application of camera trapping in wildlife monitoring in China: Problems and limitations. *Biodivers. Sci.* **2014**, *22*, 696–703.
23. Zhao, T. Mammalian Diversity in Badagongshan National Nature Reserve Based on Camera Trapping. Master's Thesis, Central South University of Forestry and Technology, Changsha, China, 2021.
24. China Wildlife Conservation. (Ed.) *Illustrated Handbook of Mammals in China*; Henan Science and Technology Press: Zhengzhou, China, 2005.
25. Smith, A.T. (Ed.) *A Guide to the Mammals of China*; Hunan Education Press: Changsha, China, 2009.
26. Liu, S.Y.; Wu, Y.; Li, S. (Eds.) *Mammals of China*, 3rd ed.; Strait Publishing House: Fuzhou, China, 2022.
27. Wei, F.W. (Ed.) *Classification and Distribution of Mammals in China*; Science Press: Beijing, China, 2022.
28. Bebber, D.P. Species accumulation curves: A tool for assessing sampling adequacy in biodiversity surveys. *Methods Ecol. Evol.* **2024**, *15*, 482–494.
29. Roswell, M.; Dushoff, J.; Winfree, R. A conceptual guide to measuring species diversity. *Ecol. Monogr.* **2023**, *93*, e1591. [CrossRef]

30. Chao, A.; Chiu, C.H. Measuring and estimating species diversity and related indices. In *Encyclopedia of Biodiversity*, 3rd ed.; Academic Press: Cambridge, MA, USA, 2023.
31. Li, X.Y.; Bleisch, W.V.; Hu, W.Q.; Wang, X.H.; Yang, Y.C.; Xiao, Z.S. Human disturbance increases spatiotemporal associations among mountain forest mammals. *eLife* **2024**, *13*, RP93567.
32. De Cáceres, M.; Legendre, P. Associations between species and groups of sites: An overview of statistical methods. *Ecol. Monogr.* **2023**, *93*, e1567.
33. Ferrari, R.; Hordley, K.A.; Gill, J.A.; Potts, P.M. Multiple hypothesis testing in ecology: Controlling false discovery rates. *Methods Ecol. Evol.* **2023**, *14*, 2789–2801.
34. Li, Z.Y.; Liu, P. *Applied Statistical Methods*; Science Press: Beijing, China, 2018.
35. Shi, X.Y.; Li, X.Y.; Wei, C.Y. Bird and mammal diversity and altitudinal distribution in the Yarlung Zangbo Grand Canyon. *Biodivers. Sci.* **2023**, *31*, 23150. [CrossRef]
36. Zhang, R.M.; Zhang, Q.; Yang, X. Spatiotemporal patterns of mammalian diversity in alpine ecosystems: A case study of Xuebaoding area. *Acta Theriol. Sin.* **2023**, *43*, 533–543.
37. LI, C.Y.; Lv, C.Y.; Liu, X.D.; Jin, K. Conservation status and prospects of endangered wildlife in China. *World For. Res.* **2014**, *27*, 51–56.
38. Chai, Y.H.; Mao, X.N.; Gama, C.L.Q.J. Spatiotemporal relationships of leopard and sympatric carnivores in Sanjiangyuan. *Acta Theriol. Sin.* **2024**, *44*, 706–716.
39. Song, Y.; Shan, L.S.; Yang, J. Effects of habitat heterogeneity on plant diversity in desert ecosystems. *J. Gansu Agric. Univ.* **2023**, *58*, 136–144.
40. D'Amen, M.; Mod, H.K.; Gotelli, N.J.; Guisan, A. Disentangling biotic interactions, environmental filters, and dispersal limitation as drivers of species co-occurrence. *Ecography* **2018**, *41*, 1233–1244. [CrossRef]
41. Poggiato, G.; Randin, T.M.O.; Broennimann, O.; Dubuis, A.K.; Guisan, A. On the interpretation of co-occurrence networks. *Ecol. Lett.* **2021**, *24*, 2651–2662.
42. Wang, Y.; Li, J.; Liu, Y.; Yin, Z.; Li, D.; Stenhouse, J.A. Free-ranging livestock affected the spatiotemporal behavior of Panthera uncia. *Ecol. Evol.* **2023**, *13*, e9992.
43. Marco, S.; Valentina, O.; Claudio, A.; Miha, K.; Francesco, R. Effects of free-ranging livestock on mammalian community interactions. *Ecol. Appl.* **2022**, *32*, e2644.
44. Li, X.Y.; He, Y.J.; Chen, X.E. Distribution and niche relationships of large carnivores in Tibet. *Acta Theriol. Sin.* **2024**, *44*, 681–694.
45. Franchini, M.; Atzeni, L.; Lovari, S.; Nasanbat, B.; Ravchig, S.; Herrador, F.C.; Bombieri, G.; Augugliaro, C. Spatiotemporal behavior of predators and prey in Central Asia. *Curr. Zool.* **2023**, *69*, 670–681. [CrossRef]
46. Wang, D.; Saiqinggaowa; Wang, Z.H. Spatiotemporal overlap among *Otocolobus manul*, *Vulpes ferrilata*, and *Vulpes vulpes*. *Biodivers. Sci.* **2022**, *30*, 123–132.
47. Carvajal, D.E.; Loayza, A.P.; Squeo, F.A. Functional diversity and spatial associations along an aridity gradient. *Sci. Rep.* **2023**, *13*, 18523. [CrossRef]
48. Blanchet, F.G.; Cazelles, K.; Gravel, D. Co-occurrence is not evidence of ecological interactions. *Ecol. Lett.* **2020**, *23*, 1050–1063. [CrossRef]
49. Koju, N.P.; Maharjan, B.; Budha, M.; Thapamagar, A.; Pokhrel, N.; Lee, M.; Khanal, L.; Buzzard, P.; Jiang, X.; Kyes, R.C. Niche partitioning facilitates coexistence of three apex predators in the Central Himalaya, Nepal. *PLoS ONE* **2026**, *21*, e0344947. [CrossRef] [PubMed]
50. Bison, M.; Yoccoz, N.G.; Carlson, B.Z.; Bayle, A.; Delestrade, A. Camera traps reveal seasonal variation in activity and occupancy of the Alpine mountain hare Lepus timidus varronis. *Wildl. Biol.* **2024**, *2024*, e01186. [CrossRef]
51. Crosta, A.; Valle, B.; Caccianiga, M.; Gobbi, M.; Ficetola, F.G.; Pittino, F.; Franzetti, A.; Azzoni, R.S.; Lencioni, V.; Senese, A.; et al. Ecological interactions in glacier environments: A review of studies on a model Alpine glacier. *Biol. Rev.* **2025**, *100*, 227–244. [CrossRef] [PubMed]

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