



Increased Temporal Overlap in Diel Activity Patterns Intensifies Interspecific Competition among Sympatric Large Carnivores in the Sanjiangyuan Region of China

Dong Wang^{1,2}, Quanbang Li^{2,3}, Jingyu Gao^{2,3}, Xu Su^{1,4,5,*} and Xinming Lian^{2,3,6,*}

¹ School of Geographical Science, Qinghai Normal University, Xining 810016, China; wangdong@nwipb.cas.cn (D.W.); xusu8527972@126.com (X.S.)

² Key Laboratory of Adaptation and Evolution of Plateau Biota, Northwest Institute of Plateau Biology, Chinese Academy of Sciences, Xining 810008, China; wangdong@nwipb.cas.cn (D.W.); liquanbang@nwipb.cas.cn (Q.L.); gaojingyu24@mails.ucas.ac.cn (J.G.); lianxinming@nwipb.cas.cn (X.L.)

³ University of Chinese Academy of Sciences, Beijing 100049, China

⁴ Key Laboratory of Biodiversity Formation Mechanism and Comprehensive Utilization of the Qinghai-Xizang Plateau in Qinghai Province, Qinghai Normal University, Xining, Qinghai 810008, China

⁵ Academy of Plateau Science and Sustainability, Qinghai Normal University, Xining, Qinghai 810016, China

⁶ Qinghai Provincial Key Laboratory of Animal Ecological Genomics, Xining 810008, China

* Correspondence: lianxinming@nwipb.cas.cn (X.L.); xusu8527972@126.com (X.S.)

Simple Summary: Direct competition for resources is particularly pronounced among apex predators, significantly influencing their fitness and functional roles within ecosystems. These competitive pressures are further intensified in complex predator guilds characterized by dominance hierarchies that clearly delineate winners and losers. In the Sanjiangyuan Region (SR) of Qinghai Province, China, a diverse array of apex predators is distributed. Their cryptic and elusive behaviors have resulted in limited understanding of their activity patterns and the extent of interspecific overlap. To investigate the intensity of interspecific competition among large carnivores in the SR from the perspective of temporal niche differentiation, we leveraged approximately a decade of data collected from infrared camera traps. This analysis focused on quantifying the degree of overlap in diurnal activity rhythms across all pairwise combinations of four large carnivore species. Our findings suggest that pairwise diel activity patterns exhibit moderate to high levels of overlap, potentially intensifying interspecific competition among these carnivore species within the region.

Abstract: Activity patterns constitute a critical adaptive trait in large carnivores, enabling them to manage interspecific competition, enhance foraging efficiency, and adapt to fluctuating environmental conditions. At the community level, elucidating the temporal activity allocation of sympatric large carnivores is essential for understanding species coexistence mechanisms. However, the activity patterns of most large carnivores remain inadequately explored. In this study, spanning the entire survey period from June 2014 to April 2024, we employed infrared camera technology to collect a total of 331,52, 240, and 79 independently validated photographs of snow leopards (*Panthera uncia*), wolves (*Canis lupus*), brown bears (*Ursus arctos*), and Eurasian lynx (*Lynx lynx*) respectively, across six distinct regions in the Sanjiangyuan Region (SR) and during various monitoring intervals. We utilized kernel density estimation and the coefficient of overlap to assess diel activity pattern overlap and competitive intensity through pairwise comparisons among four large carnivores: snow leopard, wolf, brown bear, and Eurasian lynx. Analysis of the diel activity rhythm curves revealed that all four large carnivores predominantly

Academic Editor: Firstname Last-name

Received: date

Revised: date

Accepted: date

Published: date

Citation: To be added by editorial staff during production.

Copyright: © 2025 by the authors. Submitted for possible open access publication under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

exhibited nocturnal behavior, albeit with notable differences in their peak activity periods. Notably, the diel activity rhythm overlap between each pair of species showed moderate to high intensity throughout the year ($0.5 \leq \Delta < 1$), including during both the cold and warm seasons. Specifically, the diel activity rhythms of snow leopards and wolves, snow leopards and Eurasian lynx, and wolves and Eurasian lynx exhibited high levels of overlap annually and during the cold season ($0.8 \leq \Delta < 1$), but only moderate overlap during the warm season ($0.5 \leq \Delta < 0.8$). Our findings suggested that the diel activity rhythms of these four large carnivore species exhibited considerable overlap, potentially intensifying interspecific competition. This study enhances our comprehension of competition and co-existence mechanisms among large carnivores in high-altitude mountainous ecosystems and provides valuable data for their conservation and management.

Keywords: large carnivores; infrared camera trap; activity time overlap; interspecific competition; Sanjiangyuan Region

1. Introduction

Large carnivores (body mass ≥ 15 kg), commonly referred to as apex predators, play a pivotal role in ecosystem conservation by serving as flagship species that enhance public awareness and support fundraising initiatives [1, 2]. The effects of apex predators often cascade through food chains and webs, influencing other faunal groups such as birds and invertebrates, and ultimately affecting plant abundance and distribution [3]. This influence permeates throughout the entire ecological community, contributing significantly to the maintenance and formation of biodiversity [4]. Consequently, understanding the behavioral ecology of large carnivores is fundamental to managing public perceptions, attitudes, and promoting human-large carnivore coexistence in multifunctional landscapes [5]. However, due to their wide-ranging distributions and cryptic behaviors, conducting reliable behavioral observations of large carnivores remains a significant challenge [6, 7].

Infrared camera technology has been widely adopted in the study of activity patterns and interspecific interactions among elusive, low-density large carnivores due to its high accuracy, long-term monitoring capability, concealment, and non-invasive sampling characteristics [8, 9]. Infrared cameras can precisely record the timing, frequency, and duration of animal presence, providing continuous and long-term data for analyzing activity patterns. Researchers typically define activity time as the period during which an animal is detected within the field of view of the camera lens, while activity level is quantified as the proportion of time spent in an active state [10]. These techniques are particularly valuable for investigating elusive species in remote or inaccessible habitats.

The Sanjiangyuan Region (SR) is distinguished by its representative ecosystems and the rich biodiversity of the Qinghai-Xizang Plateau [23]. It functions as a critical habitat and genetic resource repository for rare wildlife species endemic to the Qinghai-Xizang Plateau [24]. This region maintains a high level of wildlife authenticity and habitat integrity, supporting a diverse array of endemic and rare species characterized by their extensive distribution ranges, large population sizes, and predominantly plateau-specific endemism. Moreover, the SR hosts a thriving community of large carnivores, serving as a critical habitat for species such as the snow leopard (*Panthera uncia*), wolf (*Canis lupus*), brown bear (*Ursus arctos*), and Eurasian lynx (*Lynx lynx*) [25, 26]. Prior studies on the four sympatric large carnivores in the aforementioned SR have predominantly focused on dietary composition [27], predator-prey interspecific relationships [9, 28], human-carnivore conflict [26, 29], and population density [30]. However, there remains a notable gap in

research addressing the competitive intensity and regional coexistence mechanisms among these large carnivores from the perspective of temporal niche differentiation.

To enhance our understanding of interspecific competitive relationships among sympatric large carnivores in the SR and to provide robust scientific data for informing the management and development of conservation policies for local apex carnivores, this study leverages a decade-long dataset of infrared camera trap records (from June 2014 to April 2024). The focus is on analyzing the daily activity rhythm overlap between snow leopards, wolves, brown bears, and Eurasian lynx. Additionally, the study investigates the intensity of interspecific competition and the mechanisms of regional coexistence from the perspective of temporal niche differentiation.

2. Materials and Methods

2.1. Study Area

The SR (31°39' ~ 36°16' N, 89°24' ~ 102°23' E; Figure 1) located in the heart of the Qinghai-Xizang Plateau and spanning southern Qinghai Province, covering an area of approximately 396,000 km², serves as the source of the three major rivers in China: the Yangtze River, the Yellow River, and the Lancang River [31]. Additionally, it is recognized as a critical biodiversity hotspot and a key recharge zone for freshwater resources in China, earning the nickname “Water Tower of China”. Due to its unique geographical position and significant ecological roles, the SR acts as a vital ecological refuge not only for China but also for the broader Asian continent. The region exhibits complex topography, with an average elevation exceeding 4000 m. Its climate is characterized by plateau continental features, marked by small annual temperature ranges and large diurnal temperature variations. The mean annual temperature ranges from −5.6 °C to 3.8 °C, while annual precipitation varies between 262 mm and 772 mm, with 85 % occurring during the months of June to September [32]. Unlike regions with traditional four distinct seasons, this area is predominantly divided into cold and warm seasons. The main mountain ranges include the Tanggula, Bayan Har, East Kunlun, and Anyemaqen Mountains [33]. Grassland constitutes 74% of the SR, with meadows and steppes being the dominant vegetation types, accounting for 51% and 22% of the region, respectively [34]. The SR boasts rich faunal biodiversity, encompassing 85 species of wild mammals across 20 families and eight orders, 238 bird species across 41 families and 16 orders, and 15 species of amphibians and reptiles. Most of these species are classified as National Key Protected Wildlife in China.

2.2. Camera Trapping and Data Pre-processing

Between June 2014 and April 2024, six areas within the SR, characterized by frequent activity of snow leopards, wolves, brown bears, and Eurasian lynx, were selected for the deployment of infrared camera traps. Over the entire survey period, a total of 422 infrared cameras (L6210 MC, Shenzhen Ltl Acorn Electronics Co., Ltd; ERE-E1B, Shenzhen Ereagle Technology Co., Ltd) were deployed across these areas (Figure 1), covering approximately 2580 km², with monitoring altitudes ranging from 3924 m to 5078 m.

During the placement of camera traps, we first consulted ecological rangers and local herders with extensive knowledge of regional wildlife distributions to identify key areas frequently utilized by and preferred as habitats for the four large carnivore species. Camera deployment locations were determined based on a comprehensive consideration of terrain features and site accessibility. Cameras were primarily installed at strategic locations such as animal trails, saddles, ridge lines, river valleys, water sources, and the bases of large boulders, where encounters with the target species were most likely. Each infrared camera was securely anchored using ground stakes or rocks, maintaining a vertical height

of 50–80 cm above the ground [9], with lenses oriente horizontally to minimize direct sunlight exposure.

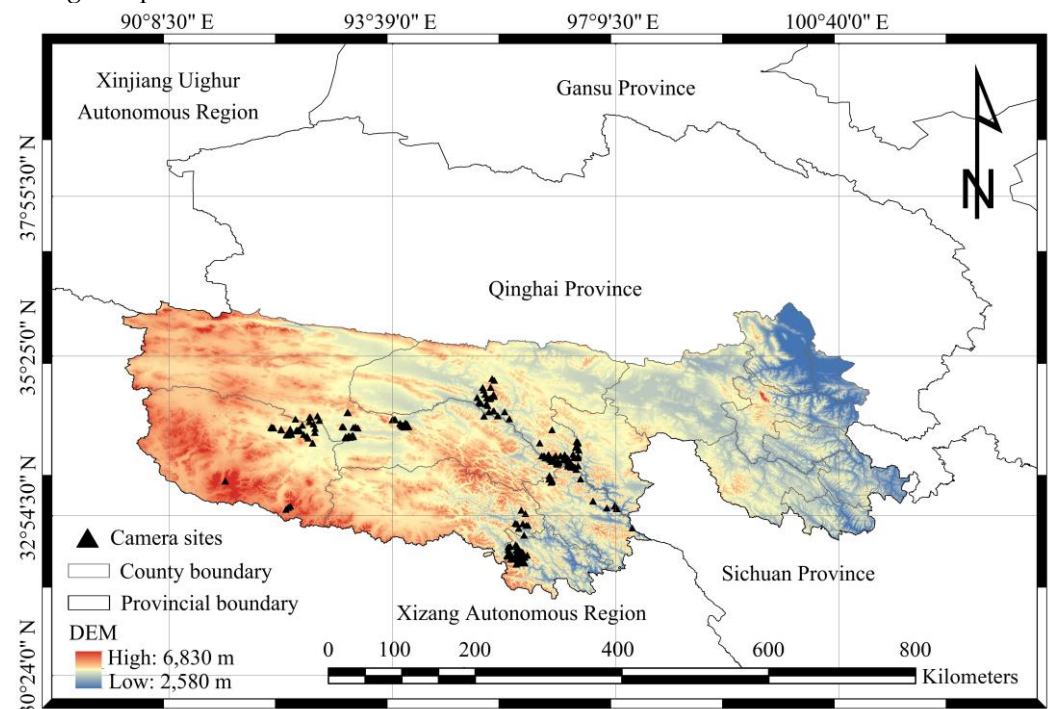


Figure 1. Locations of infrared camera trapping sites within the SR.

Additionally, detailed information including the unique identification number of each camera, its corresponding latitude and longitude coordinates, elevation, and surrounding habitat characteristics was meticulously recorded. To address potential spatial autocorrelation issues arising from excessive proximity between adjacent camera sites, we ensured that the straight-line distance between neighboring camera locations exceeded 500 m during deployment [35]. Following installation, camera data were retrieved and maintenance was performed at intervals of approximately three to four months.

After retrieving the infrared camera data, folders were systematically created for each camera site. The Bio-photo V 2.1 software was subsequently employed to automatically extract key information, including the identification number, capture date, and time, for each photograph and video. This information was then exported into an Excel spreadsheet for further processing. Thereafter, the captured photographs and videos were manually reviewed for individual identification, while simultaneously filtering the imagery to isolate records of snow leopards, wolves, brown bears, and Eurasian lynx. The criteria for defining independent events were established based on previous studies [36]. Specifically, photographs of the same species captured by the same camera site within a 30-minute interval were classified as a single independent and valid record for subsequent data analysis.

2.3. Daily Activity Pattern Analysis

This study employed kernel density estimation to quantify the activity intensity of snow leopards, wolves, brown bears, and lynx at each time point, thereby elucidating the diel activity patterns of these four large carnivores [37, 38]. The calculation formula is as follows:

$$f(x; v) = \frac{1}{n} \sum_{i=1}^n K_v [d(x, x_i)]$$

In this formula, K_v represents the probability density function of the von Mises distribution, $d(x, x_i)$ represents the angular distance between an arbitrary point x and sample

i , and the cumulative sum of activity intensities across all time points equals 1. The kernel density estimation method posits that the likelihood of an animal being captured by an infrared camera within a specific time period is proportional to its activity intensity. Therefore, the infrared camera data included in the analysis for the target species must be independent and valid records [38].

Based on the specified climatic conditions in the SR, the study area was categorized into two distinct periods: the warm season (May to September) and the cold season (October to April of the following year) [39]. Additionally, considering the substantial variation in sunrise (ranging from 5:30 to 8:30, Beijing time) and sunset (ranging from 17:30 to 21:00, Beijing time) times throughout the year within the study area, all infrared camera capture times were standardized to solar time. This adjustment aimed to mitigate discrepancies in sunrise and sunset times across different seasons [40, 41]. The correlation analysis was performed using the “sunTime” function within the “overlap” statistical package in R software (R version 4.4.2).

2.4. Activity Time Overlap Analysis

The temporal overlaps between large carnivores were quantified using the overlap coefficient Δ , which is defined as the area under the two kernel density curves ranges from 0 (no overlap) to 1 (complete overlap) [37, 42]. The 95% confidence interval for the overlap coefficients was estimated through bootstrapping with 1,000 samples derived from the estimated probability density functions [43]. Additionally, we classified the degree of diel activity rhythm overlap among pairs of large carnivore species during the entire year, cold season, and warm season into three categories based on the magnitude of the overlap coefficient Δ . Specifically, $0 < \Delta < 0.5$ indicated low overlap, $0.5 \leq \Delta < 0.8$ denoted moderate overlap, and $0.8 \leq \Delta < 1$ signified high overlap [44]. These three overlap levels corresponded sequentially to low, moderate, and high levels of competitive intensity between the paired large carnivore species.

3. Results

From June 2014 to December 2024, a total of 102913 effective camera-days were accumulated across 422 camera sites in six distinct survey regions within the SR through the deployment of varying numbers of infrared cameras and monitoring for different durations (Table 1). Statistical analysis of the infrared camera data revealed that, during the survey period, a total of 3312 independent and valid records were obtained for snow leopards, 352 for wolves, 240 for brown bears, and 79 for Eurasian lynx.

Table 1. Table of survey information collected by infrared cameras across different regions and time periods in the SR from June 2014 to April 2024.

Investigating area	Survey duration	No. of camera sites	Survey area (km²)	Elevation range (m)	Camera days (d)
Yanzhanggua Valley	2014.06-2015.12	57	300	4125-5874	10434
Jianggudiru Glacier	2015.10-2016.10	13	10	5432-6393	2143
Bagan Town	2018.11-2022.09	171	925	3897-4900	68163
Longma Village	2022.04-2023.04	20	400	4102-5324	4781
Dongba township	2023.03-2024.03	40	135	3982-4794	3106
Tanggulashan Town (Period 1)	2017.09-2018.12	60	60	4478-4979	4288
Tanggulashan Town (Period 2)	2023.11-2024.04	61	750	4507-5070	9998

3.1. Degree of Daily Activity Rhythm Overlap Throughout the Year

The analysis of the annual diel activity rhythm curves indicated that all four large carnivores predominantly exhibit nocturnal behavior, with notable differences observed in their peak activity periods (Figure 2). Statistical evaluation of the annual diel activity rhythm overlap coefficient between pairwise species revealed that the highest overlap coefficient occurred between snow leopards and Eurasian lynx ($\Delta = 0.88$, 95% CI: 0.80–0.95, Figure 2c), followed by snow leopards and wolves ($\Delta = 0.86$, 95% CI: 0.82–0.90, Figure 2a), as well as wolves and Eurasian lynx ($\Delta = 0.83$, 95% CI: 0.74–0.92, Figure 2e). These three pairs of species exhibited a high level of overlap in their diel activity rhythms. Additionally, moderate diurnal activity rhythms between snow leopards and brown bears ($\Delta = 0.71$, 95% CI: 0.65–0.77, Figure 2b), wolves and brown bears ($\Delta = 0.67$, 95% CI: 0.60–0.74, Figure 2d), as well as brown bears and Eurasian lynx ($\Delta = 0.66$, 95% CI: 0.56–0.76, Figure 2f), demonstrate a moderate level of overlap for each pairwise species combination.

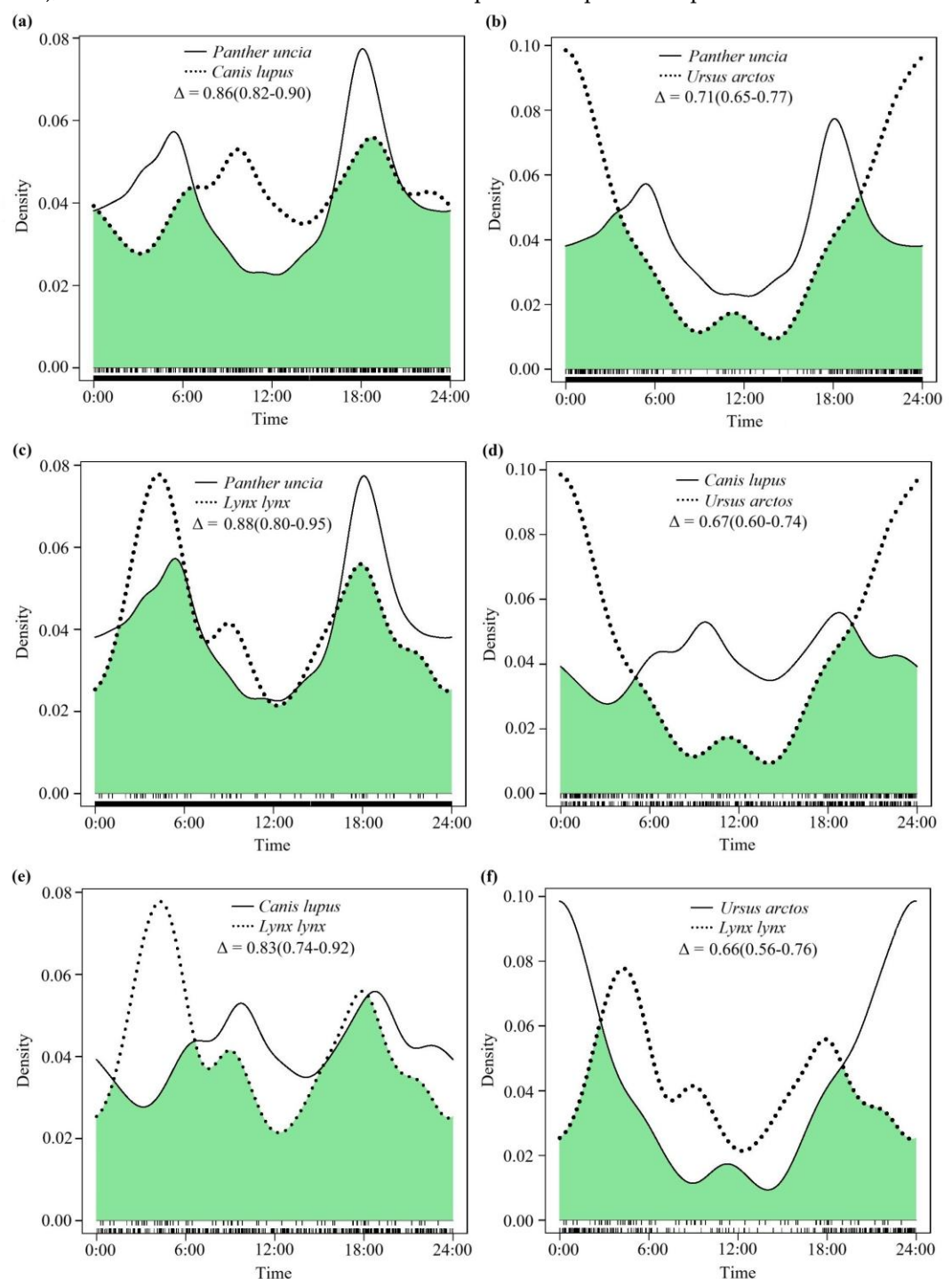


Figure 2. The comparative curves of diel activity rhythms between pairwise species among the four large carnivores throughout the year (January to December) in the SR. Δ represents the coefficient of overlap, while the numbers in parentheses represent the 95% confidence intervals for the coefficient of overlap (Δ).

3.2. Degree of Daily Activity Rhythm Overlap During the Cold Season

From the perspective of the cold season, the diel activity rhythm curves of the pairwise species pairs between snow leopards and wolves ($\Delta = 0.86$, 95% CI: 0.82–0.91, Figure 3a), snow leopards and Eurasian lynx ($\Delta = 0.86$, 95% CI: 0.78–0.94, Figure 3c), and wolves and Eurasian lynx ($\Delta = 0.85$, 95% CI: 0.75–0.94, Figure 2e) still exhibited high-density overlap. In comparison with the annual pattern, the degree of overlap in the diurnal activity rhythms between snow leopards and brown bears ($\Delta = 0.70$, 95% CI: 0.62–0.77, Figure 3b), wolves and brown bears ($\Delta = 0.65$, 95% CI: 0.55–0.74, Figure 3d), as well as brown bears and Eurasian lynx ($\Delta = 0.60$, 95% CI: 0.48–0.72, Figure 3f) during the cold season shows a slight decline, yet all still fall within the range of moderate overlap.

3.3. Degree of Daily Activity Rhythm Overlap During the Warm Season

It is noteworthy that all species pairs exhibited moderate overlap in their diurnal activity rhythms during the warm season (Figure 4). When compared with the degrees of overlap in diurnal activity rhythms throughout the year and during the cold season, the overlap coefficients between snow leopards and wolves ($\Delta = 0.79$, 95% CI: 0.70–0.87, Figure 4a), snow leopards and Eurasian lynx ($\Delta = 0.73$, 95% CI: 0.55–0.88, Figure 4c), as well as wolves and Eurasian lynx ($\Delta = 0.66$, 95% CI: 0.47–0.84, Figure 4e) during the warm season have all decreased. There is little change in the overlap of diurnal activity rhythm curves between snow leopards and brown bears ($\Delta = 0.69$, 95% CI: 0.61–0.77, Figure 4b), wolves and brown bears ($\Delta = 0.61$, 95% CI: 0.50–0.72, Figure 4d), as well as brown bears and Eurasian lynx ($\Delta = 0.69$, 95% CI: 0.51–0.85, Figure 4f) during the warm season, when compared with the overlaps throughout the year and during the cold season.

4. Discussion

Globally, large carnivore populations are limited by their inherently low population densities [45]. As human activities, such as livestock grazing and logging operations, continues to expand spatially, the amount of suitable habitat available for large carnivores has been progressively diminished [46]. High-altitude mountain ecosystems, despite often harboring high levels of biodiversity and endemism, present significant challenges for large carnivores due to harsh environmental conditions, low productivity, scarce resources, and anthropogenic habitat compression. These factors may result in reduced ecological niche space among sympatric species [47, 48]. Consequently, investigating how sympatric carnivores partition and utilize limited alpine resources, as well as examining their interspecific interactions and coexistence mechanisms, is critical for understanding the structuring and long-term persistence of biodiversity within these unique ecosystems.

This study utilized an extensive network of camera traps deployed across the SR within the hinterland of the Qinghai-Xizang Plateau over multiple years, systematically collecting activity data on four large carnivore species: snow leopards, wolves, brown bears, and Eurasian lynx. We analyzed the degree of overlap in diurnal activity rhythm among these species to assess the intensity of competition among sympatric large carnivore from the perspective of temporal niche differentiation. These findings might inform practical conservation and management strategies for maintaining the ecological integrity of the large carnivore guild in this region. Despite moderate or high overlap in pairwise comparisons of diel activity rhythms among the four species, our results indicated considerable variation in their peak activity periods. This variation partially alleviated

potential interspecific competition along the temporal niche dimension. Based on existing literature, the activity rhythms of large carnivores were primarily **influence** by the activity patterns of their primary prey [49]. Moreover, differences in prey activity patterns represented a key factor shaping the variations in carnivore activity rhythms [50, 51]. Therefore, we hypothesized that the distinct diurnal activity peaks observed among the four carnivore species may be linked to differences in the activity patterns of their preferred prey.

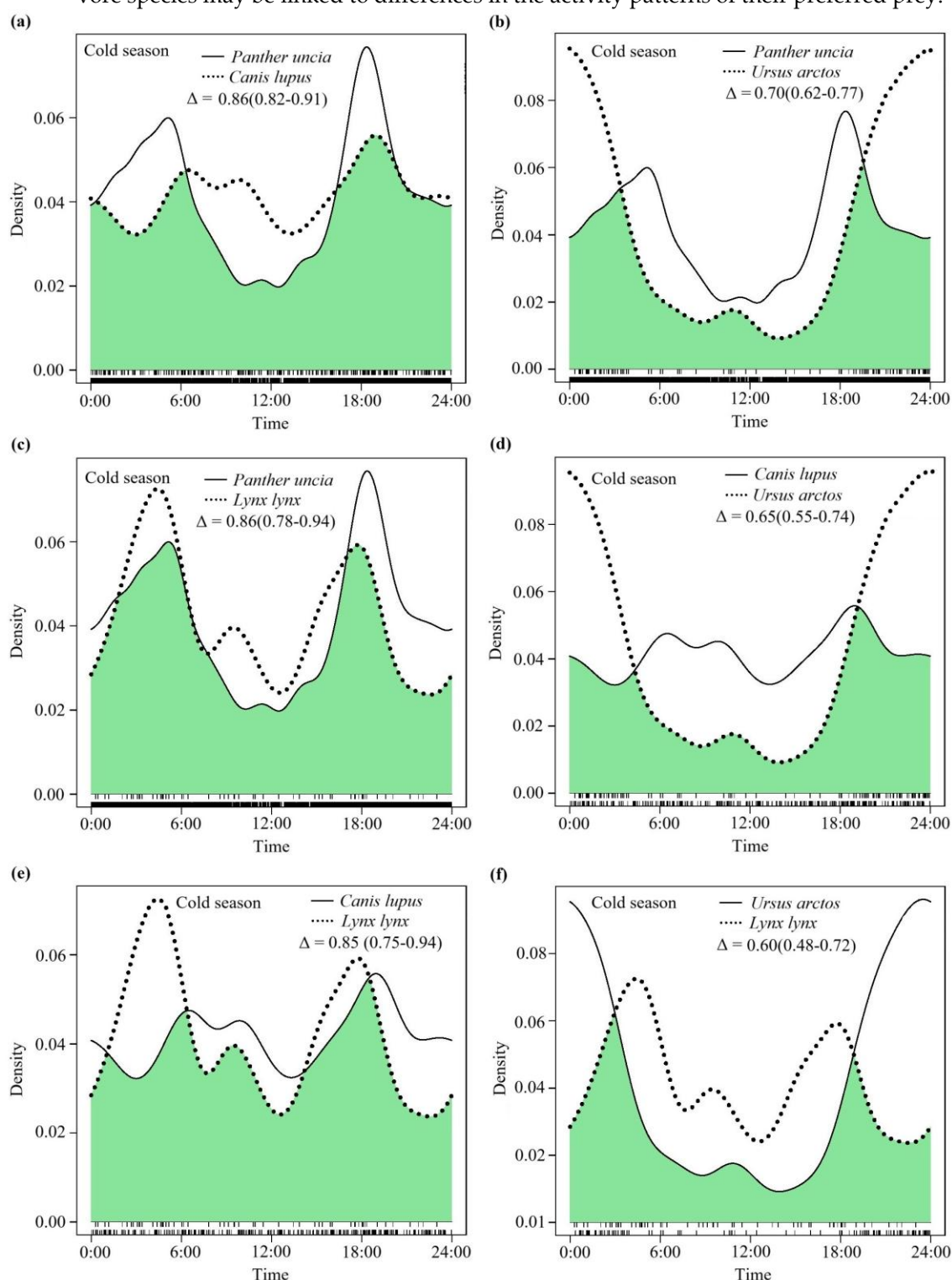


Figure 3. The comparative curves of diel activity rhythms in pairwise species among four large carnivores during the cold season (October to April of the following year) in the SR.

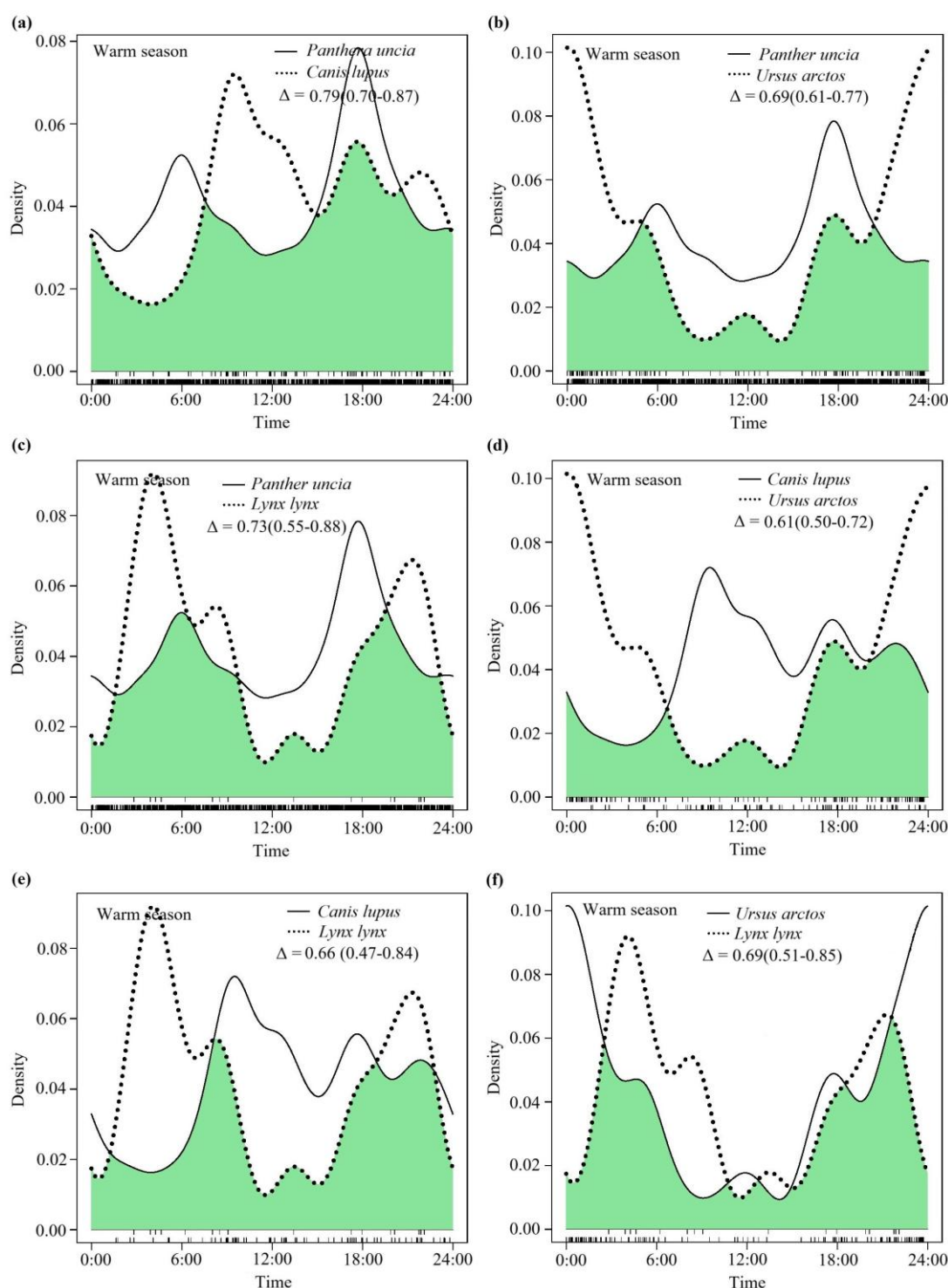


Figure 4. The comparative curves of diel activity rhythms in pairwise species among four large carnivores during the warm season (May to September) in the SR.

Research has indicated that interspecific competition was a primarily driver of resource partitioning across three niche dimensions: spatial, temporal, and trophic [8, 21]. A species can enhance its persistence stability within a community by differentiating along at least one of these niche dimensions [52]. Compared to spatial and trophic niche differentiation, temporal niche differentiation exhibits greater flexibility and adaptability [22], effectively reducing competitive suppression among sympatric carnivores with overlapping ecological traits [50]. In this study, snow leopards and Eurasian lynx exhibited the highest degree of overlap in their diurnal activity rhythms ($\Delta = 0.88$). Both species displayed peak activity around sunrise and sunset, indicating substantial potential for

interspecific interference in terms of temporal niche utilization. However, while high niche overlap serves as an indicator of potential competition intensity between species within a community, it does not fully equate to the actual strength of interactions. Significant temporal overlap primarily reflects an increased likelihood of encounters between sympatric carnivore species within the same area but does not necessarily imply synchrony in their activity patterns [53, 54]. Although snow leopards and Eurasian lynx shared similar peak activity periods, the lynx exhibited a more prolonged activity peak, with its sunrise-related activity distinctly delayed relative to the snow leopard. This temporal segregation likely functions to alleviate direct competition between the two species.

Predators, like their prey, inhabit a landscape of fear where body size significantly influences predation risk. Typically, smaller species face a greater likelihood of being killed by other carnivores [51, 55]. In competitive interactions among carnivores, body size plays a decisive role, with larger individuals gaining a significant competitive advantage [56]. Among the four large carnivore species examined in this study, adult brown bears (body mass = 125–225 kg) exhibit the largest body size, followed by snow leopards (body mass = 38–75 kg), wolves (body mass = 28–40 kg), and Eurasian lynx (body mass = 18–38 kg) [57]. This suggests that brown bears hold an absolute dominance in interspecific competition. Nevertheless, the four sympatrically distributed large carnivores achieved coexistence through differentiation in daily activity patterns, spatial utilization, and prey selection.

Based on existing literature, spatial utilization varies markedly among these species [58–62]. Snow leopards predominantly occupy high-altitude ecosystems above 3000 m elevation, showing a strong preference for steep terrains such as ridge lines, narrow mountain passes, and canyons [58, 59]. Wolves, as the most widely distributed large carnivore globally, exhibit remarkable adaptability and are commonly found across diverse ecosystems, including forests, shrublands, grasslands, wetlands, bare rock areas, and deserts [60]. Brown bears, as opportunistic foragers, typically select habitats such as large rocks or natural dens on hillsides to enhance hunting success [61]. Eurasian lynx is highly adapted to cold climates at high altitudes and primarily inhabits various habitats, including forests, river valleys, grasslands, and deserts [62]. In terms of prey utilization, although all four large carnivores primarily prey on ungulates, they differ significantly in prey species selection and proportional utilization [8, 27, 63]. Wolves, employing a group-hunting strategy, captured the largest prey, while brown bears, acting as opportunistic predators with omnivorous diets, target smaller prey [27]. These differences collectively contribute to trophic niche differentiation among the four species, enabling their coexistence in sympatry.

Research demonstrates that large carnivores frequently exhibit substantial overlap in their activity patterns, and interspecific competition is primarily alleviated through spatial niche differentiation among species, thereby enabling regional coexistence [8]. This aligns with the findings of the present study, which revealed a high degree of overlap in diel activity rhythms among the four investigated large carnivore species. Regional coexistence among carnivores represents a relatively stable state achieved through long-term natural selection during evolutionary process. Consequently, no single mechanism can fully account for the assembly mechanisms of diverse species communities. Although this study acquired extensive infrared camera data via multi-year monitoring, a comprehensive understanding of the mechanisms underlying large carnivore competition and coexistence cannot be achieved solely based on temporal niche differentiation. Future research should integrate investigations into spatial and trophic niche differentiation while considering factors such as prey abundance and community composition, habitat quality and distribution, and the types and intensities of anthropogenic disturbances affecting species'

temporal, spatial, and trophic niches. Such an approach will enable a holistic understanding of the regional coexistence mechanisms of large carnivores in high-altitude ecosystems.

5. Conclusions

Currently, approximately 71% of large carnivore populations globally are experiencing continuous declines, and 60% of these species now occupy less than half of their historical ranges, thereby increasing the risks of local or global extinction [1]. When large carnivore population decline and locally extirpated, it inevitably results in the simplification of food web structure and compromises the stability of ecological communities [64]. However, limited understanding of the activity patterns of large carnivores has hindered comprehensive research into their interspecific relationships. Through multi-year monitoring, this study demonstrated that snow leopards, wolves, brown bears, and lynx predominantly exhibited nocturnal activity, yet significant differences existed in their peak activity periods. Furthermore, while there was considerable overlap in diel activity rhythms between each pair of these species ($0.5 \leq \Delta < 1$), the disparities in their peak activity times might partially alleviate interspecific competition and interference. These findings enhance our understanding of interspecific relationships among sympatric species in the Qinghai-Xizang Plateau region and provide a scientific foundation for the conservation and management of large carnivores.

Author Contributions: Conceptualization, D.W. and X.L.; Data curation, D.W., Q.L., J.G., X.S. and X.L.; Methodology, D.W., Q.L., J.G., X.S. and X.L.; Formal analysis: D.W., Q.L. and X.L.; Writing—original draft preparation, D.W. and X.L.; Writing—review and editing, X.S. and X.L.; Supervision, X.L.; Funding acquisition, X.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Joint Funds of the National Natural Science Foundation of China (U24A20361) and the National Key Research and Development Program of China (2023YFF1305003).

Institutional Review Board Statement: Ethical review and approval were waived because infrared camera survey and data collection totally non-invasive.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data are available upon reasonable request from the corresponding author (Xinming Lian).

Conflicts of Interest: The authors have no conflicts of interest to declare.

References

- Ripple, W.J.; Estes, J.A.; Beschta, R.L.; Wilmers, C.C.; Ritchie, E.G.; Hebblewhite, M.; Berger, J.; Elmhagen, B.; Letnic, M.; Nelson, M.P.; et al. Status and ecological effects of the world's largest carnivores. *Science* **2014**, *343*, 1241484.
- Clucas, B.; Mchugh, K.; Caro, T. Flagship species on covers of US conservation and nature magazines. *Biodivers Conserv* **2008**, *17*, 1517–1528.
- Suraci, J.P.; Clinchy, M.; Dill, L.M.; Roberts, D.; Zanette, L.Y. Fear of large carnivores causes a trophic cascade. *Nat Commun* **2016**, *7*, 10698.
- Ford, A.T.; Goheen, J.R.; Augustine, D.J.; Kinnaird, M.F.; O'Brien, T.G.; Palmer, T.M.; Pringle, R.M.; Woodroffe, R. Recovery of African wild dogs suppresses prey but does not trigger a trophic cascade. *Ecology* **2015**, *96*, 2705–2714.
- Kuijper, D.P.J.; Churski, M.; Trouwborst, A.; Heurich, M.; Cromsigt, J.P.G.M. Keep the wolf from the door: How to conserve wolves in Europe's human-dominated landscapes? *Biol Conserv* **2019**, *235*, 102–111.
- Karanth, K.U.; Gopalaswamy, A.M.; Kumar, N.S.; Vaidyanathan, S.; Nichols, J.D.; Mackenzie, D.I. Monitoring carnivore populations at the landscape scale: occupancy modelling of tigers from sign surveys. *J Appl Ecol* **2011**, *48*, 1048–1056.
- Suryawanshi, K.; Reddy, A.; Sharma, M.; Khanyari, M.; Bijoor, A.; Rathore, D.; Jaggi, H.; Khara, A.; Malgaonkar, A.; Ghoshal, A. Estimating snow leopard and prey populations at large spatial scales. *Ecol Solut Evid* **2021**, *2*, e12115.

8. Cong, W.; Li, J.; Hacker, C.E.; Li, Y.; Zhang, Y.; Jin, L.X.; Zhang, Y.; Li, D.Q.; Xue, Y.D.; Zhang, Y.G. Different coexistence patterns between apex carnivores and mesocarnivores based on temporal, spatial, and dietary niche partitioning analysis in Qilian Mountain National Park, China. *elife* **2024**, *13*, RP90559. 384–386
9. Wang, D.; Li, Q.B.; Hou, L.Y.; Su, X.; Lian, X.M. Spatiotemporal overlap among snow leopard, bharal, and free-ranging livestock: Suggestions on mitigating human-snow leopard conflict. *Glob Ecol Conserv* **2024**, *53*, e03029. 387–388
10. Rowcliffe, J.M.; Kays, R.; Kranstauber, B.; Carbone, C.; Jansen, P.A.; Fisher, D. Quantifying levels of animal activity using camera trap data. *Methods Ecol Evol* **2014**, *5*, 1170–1179. 389–390
11. Bennie, J.J.; Duffy, J.P.; Inger, R.; Gaston, K.J. Biogeography of time partitioning in mammals. *PNAS* **2014**, *111*, 13727–13732. 391
12. Kronfeld-Schor, N.; Dayan, T. Partitioning of time as an ecological resource. *Annu Rev Ecol Evol S* **2003**, *34*, 153–181. 392
13. Valeix, M.; Simon, C.J.; Hervé, F. Interference competition and temporal niche shifts: elephants and herbivore communities at waterholes. *Oecologia* **2007**, *153*, 739–748. 393–394
14. Marinho, P.H.; Fonseca, C.R.; Sarmiento, P.; Fonseca, C.; Venticinque, E.M. Temporal niche overlap among mesocarnivores in a Caatinga dry forest. *Eur J Wildlife Res* **2020**, *66*, 1–13. 395–396
15. Marneweck, C.; Marneweck, D.G.; Schalkwyk, O.L.V.; Beverley, G.; Parker, D.M. Spatial partitioning by a subordinate carnivore is mediated by conspecific overlap. *Oecologia* **2019**, *191*, 531–540. 397–398
16. Cardillo, M.; Mace, G.M.; Jones, K.E.; Bielby, J.; Bininda-Emonds, O.; Sechrest, W.; Orme, C.D.L.; Purvis, A. Multiple causes of high extinction risk in large mammal species. *Science* **2005**, *309*, 1239–1241. 399–400
17. Smith, A.F.; Kasper, K.; Lazzeri, L.; Schulte, M.; Kudrenko, S.; Say-Sallaz, E.; Churski, M.; Shamovich, D.; Obrizan, S.; Domashevsky, S.; et al. Reduced human disturbance increases diurnal activity in wolves, but not Eurasian lynx. *Glob Ecol Conserv* **2024**, *53*, e02985. 401–403
18. Mondal, K.; Gupta, S.; Bhattacharjee, S.; Qureshi, Q.; Sankar, K. Response of leopards to re-introduced tigers in Sariska Tiger Reserve, Western India. *Int J Biodivers Conserv* **2012**, *4*, 228–236. 404–405
19. Hayward, M.W.; Slotow, R. Temporal partitioning of activity in large African carnivores: Tests of multiple hypotheses. *S Afr J Wildl Res* **2009**, *39*, 109–125. 406–407
20. Kronfeld-Schor, N.; Dayan, T. Partitioning of time as an ecological resource. *Annu Rev Ecol Evol S* **2003**, *34*, 153–181. 408
21. Schoener, T.W. Resource partitioning in ecological communities. *Science* **1974**, *185*, 27–39. 409
22. Andersen, G.E.; Johnson, C.N.; Jones, M.E. Space use and temporal partitioning of sympatric Tasmanian devils and spotted-tailed quolls. *Austral Ecol* **2020**, *45*, 355–365. 410–411
23. Jin, Z.N.; Zhuang, Q.L.; He, J.S.; Luo, T.X.; Shi, Y. Phenology shift from 1989 to 2008 on the Tibetan Plateau: An analysis with a process-based soil physical model and remote sensing data. *Climatic Change* **2013**, *119*, 435–449. 412–413
24. Ma, B.R.; Xie, Y.X.; Zhang, T.Z.; Zeng, W.H.; Hu, G.Z. Identification of conflict between wildlife living spaces and human activity spaces and adjustments in/around protected areas under climate change: A case study in the Three-River Source Region. *J Environ Manage* **2020**, *262*, 110322. 414–416
25. Cai, Z.Y.; Qin, W.; Gao, H.M.; Wu, T.; Chi, X.W.; Yang, J.D.; Miao, Z.Y.; Zhang, J.J.; Song, P.F.; Lian, X.M.; et al. Species diversity and fauna of mammals in Sanjiangyuan National Park. *Acta Theriologica Sinica* **2019**, *39*, 410–420. 417–418
26. Li, J.; Yin, H.; Wang, D.J.; Jiagong, Z.L.; Lu, Z. Human-snow leopard conflicts in the Sanjiangyuan Region of the Tibetan Plateau. *Biol Conserv* **2013**, *166*, 118–123. 419–420
27. Lu, Q.; Cheng, C.; Xiao, L.Y.; Li, J.; Li, X.Y.; Zhao, X.; Lu, Z.; Zhao, J.D.; Yao, M. Food webs reveal coexistence mechanisms and community organization in carnivores. *Curr Biol* **2023**, *33*, 647–659. 421–422
28. Chai, Y.H.; Mao, X.N.; Gama, C.L.Q.J.; Li, G.G.; Sun, N. Spatiotemporal niche relationship between leopard and its sympatric carnivores in the forest of Baizha, Qinghai Province. *Acta Ecologica Sinica* **2024**, *44*, 706–716. 423–424
29. Dai, Y.C.; Li, D.Q.; Hacker, C.E.; Zhang, Y.G.; Zhang, Y.; Liu, F.; Li, D.Q. Human-carnivore conflicts and mitigation options in Qinghai Province, China. *J Nat Conserv* **2020**, *53*, 125776. 425–426
30. Chu, M.Y.; Liang, S.J.; Li, P.Y.; Jia, D.; Maierdiyali, A.; Li, X.Y.; Jiang, N.; Zhao, X.; Li, F.X.; Xiao, L.Y.; et al. Population dynamic of snow leopard (*Panthera uncia*) based on camera trap monitoring in Yunta, Sanjiangyuan National Nature Reserve, China. *Biodiv Sci* **2022**, *30*, 22157. 427–429
31. Dai, Y.C.; Hacker, C.E.; Cao, Y.; Cao, H.N.; Xue, Y.D.; Ma, X.D.; Liu, H.D.; Zahoor, B.; Zhang, Y.G.; Li, D.Q. Implementing a comprehensive approach to study the causes of human-bear (*Ursus arctos pruinosus*) conflicts in the Sanjiangyuan region, China. *Sci Total Environ* **2021**, *772*, 145012. 430–432
32. Mahmood, R.; Jia, S.F.; Lv, A.F.; Babel, M.S. An integrative analysis of hydroclimatic elements in the three-river source region for historical and future periods: Shift toward an intensified hydrological cycle. *ISWCR* **2025**, *13*, 43–66. 433–434

33. Zheng, X.K.; Liang, S.H.; Yan, D.Z.; Kuang, X.X.; Wan, L. Mechanisms of climate-induced lake dynamics in the Source Region of Three Rivers, Tibetan Plateau. *J Hydrol-Reg Stud* **2025**, *59*, 102323. 435
34. Zheng, K.; Liu, X.; Zou, X.Y.; Wang, Z.Q. Impacts of climate variations and human activities on the net primary productivity of different grassland types in the Three-River Headwaters Region. *Remote Sens-Basel* **2025**, *17*, 471. 436
35. Liu, X.H.; Wu, P.F.; Songer, M.; Cai, Q.; He, X.B.; Zhu, Y.; Shao, X.M. Monitoring wildlife abundance and diversity with infrared camera traps in Guanyinshan Nature Reserve of Shaanxi Province, China. *Ecol Indic* **2013**, *33*, 121–128. 437
36. Ohashi, H.; Saito, M.; Horie, R.; Tsunoda, H.; Noba, H.; Ishii, H.; Kuwabara, T.; Hiroshige, Y.; Koike, S.; Hoshino, Y. Differences in the activity pattern of the wild boar *Sus scrofa* related to human disturbance. *Eur J Wildlife Res* **2013**, *59*, 167–177. 438
37. Ridout, M.S.; Linkie, M. Estimating overlap of daily activity patterns from camera trap data. *J Agr Biol Envir St* **2009**, *14*, 322–337. 439
38. Linkie, M.; Ridout, M.S. Assessing tiger–prey interactions in Sumatran rainforests. *J Zool* **2011**, *3*, 224–229. 440
39. Yang, Y.; Chen, R.S.; Ding, Y.J.; Zhao, Q.D.; Li, H.Y.; Liu, Z.W. Variation in the hydrological cycle in the Three-River headwaters region based on multi-source data. *Front Env Sci* **2022**, *10*, 1088467. 441
40. Nouvellet, P.; Rasmussen, G.S.A.; Macdonald, D.W.; Courchamp, F. Noisy clocks and silent sunrises: measurement methods of daily activity pattern. *J Zool* **2012**, *286*, 179–184. 442
41. Vazquez, C.; Rowcliffe, J.M.; Spoelstra, K.; Jansen, P.A. Comparing diel activity patterns of wildlife across latitudes and seasons: Time transformations using day length. *Methods Ecol Evol* **2019**, *10*, 2057–2066. 443
42. Azevedo, F.C.; Lemos, F.G.; Freitas-Junior, M.C.; Rocha, D.G.; Azevedo, F.C.C. Puma activity patterns and temporal overlap with prey in a human-modified landscape at Southeastern Brazil. *J Zool* **2018**, *305*, 246–255. 444
43. Franchini, M.; Atzeni, L.; Lovari, S.; Nasanbat, B.; Ravchig, S.; Herrador, F.C.; Bombieri, G.; Augugliaro, C. Spatiotemporal behavior of predators and prey in an arid environment of Central Asia. *Curr Zool* **2024**, *70*, 670–681. 445
44. Tian, C.; Zhang, Y.Y.; Liu, Z.X.; Dayananda, B.; Fu, X.B.; Yuan, D.; Tu, Z.B.; Luo, C.P.; Li, J.Q. Temporal niche patterns of large mammals in Wanglang National Nature Reserve, China. *Glob Ecol Conserv* **2020**, *22*, e01015. 446
45. Hong, Y.; Zhang, M.H.; Cheng, Y.H.; Bian, X.X.; Tan, Y.C.; Shi, X.G.; Zhang, J.D.; Hull, V. Spatio-temporal interactions between snow leopards, prey, and livestock implications for coexistence. *Biol Conserv* **2025**, *308*, 111253. 447
46. Fernández-Sepúlveda, J.; Martín, C.A. Conservation status of the world's carnivorous mammals (order Carnivora). *Mamm Biol* **2022**, *102*, 1911–1925. 448
47. Xiao, L.Y.; Hua, F.; Knops, J.M.H.; Zhao, X.; Mishra, C.; Lovari, S.; Alexander, J.S.; Weckworth, B.; Lu, Z. Spatial separation of prey from livestock facilitates coexistence of a specialized large carnivore with human land use. *Anim Conserv* **2022**, *25*, 628–638. 449
48. Sunarto, S.; Kelly, M.J.; Parakkasi, K.; Hutajulu, M.B. Cat coexistence in central Sumatra: ecological characteristics, spatial and temporal overlap, and implications for management. *J Zool* **2015**, *296*, 104–115. 450
49. Ramesh, T.; Kalle, R.; Sankar, K.; Qureshi, Q. Spatio-temporal partitioning among large carnivores in relation to major prey species in Western Ghats. *J Zool* **2012**, *287*, 269–275. 451
50. Li, Z.L.; Wang, T.M.; Smith, J.L.D.; Feng, R.N.; Feng, L.M.; Mou, P.; Ge, J.P. Coexistence of two sympatric flagship carnivores in the human-dominated forest landscapes of Northeast Asia. *Landscape Ecol* **2019**, *34*, 291–301. 452
51. Bischof, R.; Ali, H.; Kabir, M.; Hameed, S.; Nawaz, M.A. Being the underdog: an elusive small carnivore uses space with prey and time without enemies. *J Zool* **2014**, *293*, 40–48. 453
52. Caceres, N.C.; Machado, A.F. Spatial, dietary and temporal niche dimensions in ecological segregation of two sympatric, congeneric marsupial species. *Open Ecol J* **2013**, *6*, 10–23. 454
53. Farris, Z.J.; Gerber, B.D.; Karpanty, S.; Murphy, A.; Wampole, E.; Ratelolahy, F.; Kelly, M.J. Exploring and interpreting spatio-temporal interactions between native and invasive carnivores across a gradient of rainforest degradation. *Biol Invasions* **2020**, *22*, 2033–2047. 455
54. Li, Z.L.; Duo, L.A.; Li, S.; Wang, T.M. Competition and coexistence among terrestrial mammalian carnivores. *Biodiv Sci* **2021**, *29*, 81–97. 456
55. Palomarest, F.; Caro, T.M. Interspecific killing among mammalian carnivores. *Am Nat* **1999**, *153*, 492–492. 457
56. Odden, M.; Wegge, P.; Fredriksen, T. Do tigers displace leopards? If so, why? *Ecol Res* **2010**, *25*, 875–881. 458
57. Ding, C.C.; Liang, D.N.; Xin, W.P.; Li, C.W.; Ameca, E.I.; Jiang, Z.G. A dataset on the morphological, life-history and ecological traits of the mammals in China. *Biodiv Sci* **2022**, *30*, 21520. 459
58. McCarthy, T.M.; Fuller, T.K.; Munkhtsog, B. Movements and activities of snow leopards in Southwestern Mongolia. *Biol Conserv* **2005**, *124*, 527–537. 460

59. Li, X.H.; Ma, L.M.; Hu, D.Z.; Ma, D.F.; Li, R.Q.; Sun, Y.H.; Gao, E.H. Potential range shift of snow leopard in future climate change scenarios. *Sustainability* **2022**, *14*, 1115. 485
60. Qiao, J.; Gong, X.L.; Jia, W.; Jia, G.Q.; Jiang, Y.; Zhou, H.M.; Li, J.Q.; Wen, A.X.; Wang, J. Distribution, group size and activity rhythm of wolves (*Canis lupus*) in the Gongga Mountains, Sichuan Province. *Acta Ecologica Sinica* **2023**, *43*, 248–257. 486
61. Dai, Y.C.; Hacker, C.E.; Zhang, Y.G.; Li, W.W.; Li, D.Q. Identifying climate refugia and its potential impact on Tibetan brown bear (*Ursus arctos pruinosus*) in Sanjiangyuan National Park, China. *Ecol Evol* **2019**, *9*, 13278–13293. 487
62. Liu, K.; Liu, Y.L.; Li, S. The current distribution and prediction of suitable habitat of Eurasian lynx (*Lynx lynx*) in China. *Acta Theriologica Sinica* **2023**, *43*, 652–663. 488
63. Cong, W.; Zhang, Y.; Huang, T.F.; Li, J.; Xu, J.Q.; Zhang, S.F.; Li, H.; Xue, Y.D.; Zhang, Y.G. Dietary composition and niche partitioning of sympatric carnivores in Altun Mountain National Nature Reserve. *Acta Ecologica Sinica* **2024**, *44*, 695–705. 489
64. Pringle, R.M.; Kartzinel, T.R.; Palmer, T.M.; Thurman, T.J.; Fox-Dobbs, K.; Xu, C.C.Y.; Hutchinson, M.C.; Coverdale, T.C.; Daskin, J.H.; Evangelista, D.A.; et al. Predator-induced collapse of niche structure and species coexistence. *Nature* **2019**, *570*, 58–64. 490

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content. 491

492

493

494

495

496

497

498

499