

Diversity and vertical distribution patterns of wildlife in Tianzhushan, Shaanxi Province, China

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Abstract

Biodiversity monitoring is an important means by which to evaluate management effectiveness and develop sound conservation plans. In this study, 52 cameras were installed in the study area of Tianzhushan to assess wildlife diversity and elevational patterns from 2018 to 2019. In total, 9541 independent photos were collected within 26565 camera-days. We analysed the relative abundance index (RAI), activity patterns and seasonal activity rhythms of the five most abundant species at 200-m elevational intervals throughout the study area (elevation range 1400–2000 m a.s.l.). Based on RAI results, the activity patterns of the five most abundant species (i.e. *Sus scrofa*, *Naemorhedus griseus*, *Muntiacus reevesi*, *Arctonyx collaris* and *Capricornis milneedwardsii*) were analysed. Amongst the detected wild mammals, *Sus scrofa* had the highest RAI value of 9.91, while the occurrence of *Tamias swinhoi* had the lowest RAI at 0.004. In addition, there were significant differences in species activity during the daytime and night-time. RAI of the ungulate community peaked at the 1600–1800 m a.s.l. elevational range, thus showing a mid-elevational peak pattern. Differences in vertical distribution patterns were detected for the five most abundant species. Mainland serows and wild boars preferred mid-elevation habitats (1600–1800 m a.s.l.), long-tailed gorals preferred mid- and high altitudes (1600–2000 m a.s.l.) elevation habitats and Chinese muntjacs and hog badgers preferred low elevation habitats (1400–1600 m a.s.l.). Taken together, this is the first study to reveal the five dominant species activity patterns in Tianzhushan, which is of importance for wildlife conservation.

Keywords

Qinling Mountains, infrared camera, ungulates, relative abundance index (RAI), activity patterns, elevational distribution, seasonal variation

Introduction

Biodiversity represents the richness of life forms in a certain region and includes ecosystem, genetic and species diversity. Species diversity reflects the complex relationships amongst organisms, biological resources and the environment. Wild animals are an important link between the energy flow and material circulation within an ecosystem (Jiang 2001) and are involved in the maintenance of normal ecosystem function. Due to their high diversity, wide distribution and sensitivity to changes in habitat, mammals are considered as a key indicator of biodiversity conservation and environmental assessment. Over the last several decades, rapid economic development, expanding urbanisation and increasing transportation networks have led to severe fragmentation of natural habitats, as well as illegal poaching of threatened mammals. In the face of declining mammal populations, it is particularly important to carry out animal monitoring to clarify living status, population dynamic changes and threatened status and to propose targeted protection measures.

Compared with traditional survey methods, camera-trapping techniques have obvious advantages in their ability to monitor and study large and medium-sized mammals. Camera traps provide continuous monitoring and real imaging of animals within potentially difficult habitats and, thus, can be used to evaluate animal resources and monitor endangered species with minimal disturbance. In recent years, an increasing number of studies have used infrared camera technology to explore animal species diversity and wildlife activity. For example, Azlan and Sharma (2006) used camera traps to explore the diversity and activity patterns of wild felids in the Jerangau Forest Reserve in Malaysia. Liu et al. (2013) analysed mammal diversity and activity rhythms in different habitats in Guanyin Mountain Nature Reserve in the Qinling Mountains of China. Peng et al. (2021) used infrared cameras to investigate the activity rhythms of artiodactyls in the Baishuihe National Nature Reserve in China. Mori et al. (2020) investigated the activity rhythms of invasive coypus (*Myocastor coypus*) using camera trapping. Scientists have also explored the vertical distribution of mammals using infrared cameras (Yan et al. 2019, Li et al. 2020). This technology has become a routine monitoring method for large- and medium-sized terrestrial mammals and birds (Rovero et al. 2010, Bridges and Noss 2011).

The Qinling Mountains not only form a dividing line between the Yangtze and Yellow River watersheds, but are also a transition zone between subtropical and warm-temperate climate zones. As such, they possess a rich and unique biodiversity and are of considerable research value. Tianzhushan Nature Reserve, which was initially established for the conservation of the forest musk deer (*Moschus berezovskii*) and its habitat, harbours a high species diversity. However, little is known about the status of mammalian biodiversity in this area of the Qinling Mountains. Thus, in the current study, we aimed to identify the dominant species in the study area, analyse their activity patterns and assess their elevational patterns. The results obtained in this study will

provide important information for ecological research and support for the development of conservation measures for the dominant species in the area.

Materials and methods

Research area

Tianzhushan Nature Reserve is located on the southern slopes of the Qinling Mountains (109°10'~110°03'E, 33°20'~33°23'N). Established in 2001, the Reserve covers a total area of 21 685 hectares, including a core area of 7 541 hectares. The reserve has a temperate monsoon sub-humid mountain climate, with an altitudinal range of 800–2 074 m a.s.l., average annual temperature of 10–13°C, average annual rainfall of > 700 mm and frost-free period of 200 days. The area contains three major forest types: i.e. conifer forest, mixed conifer-broadleaf forest and deciduous broadleaf forest.

Camera trapping

Three observation sites, suitable for large- and medium-sized mammals to hunt or forage for food, were selected. Two sites were located within the reserve and one was located outside the reserve (elevation 1 400–2 000 m a.s.l.). Each site covered an area of 20 km², with a distance of at least 3 km between sites. Each observation site was divided into 1 × 1 km² grids (20 grids for each sample site). The distance between two camera traps in the different grids was at least 500 m (Fig. 1).

In total, 52 cameras were fixed on trees about 60 cm above the ground. The camera sensor was parallel to the ground to avoid direct sunlight. Cameras were configured to capture events with 15 s and infrared sensor sensitivity was configured to 'medium'. Camera trapping data were downloaded every 3 months.

After the image data were collected, Bio-Photo v.2.1 was used to extract basic photo and video information. Excel data forms were exported for sorting and analysis. Images were classified and species were identified according to mammals, birds, livestock, poultry, staff and non-staff. Photos of the same species taken by the same camera after a 30-min interval were classified as an effective independent photo (Kawanishi et al. 1999, O'Brien et al. 2003). One camera working 24 h was regarded as a camera-day. We analysed two years of data collected between January 2018 and December 2019. In total, 5 991 independent photos of ungulates were collected over 26 565 camera-days.

Data analysis

Relative abundance analysis

The relative abundance index (RAI) is a standardised metric of how frequently a species appears on a camera (Botts et al. 2020). We calculated the RAI based on the following formula of O'Brien et al. (2003) and Botts et al. (2020):

$$\text{RAI} = A_i/N \times 100 \quad (1)$$

where A_i represents the total independent photos of a species and N is the total number of camera-days. We calculated RAI separately for the first (RAI-2018) and second years (RAI-2019).

Activity pattern analysis

Based on RAI, the activity patterns of the five most abundant species were analysed. Monthly RAI (MRAI) and seasonal RAI (SRAI) were used to analyse monthly and quarterly activity rhythms, respectively:

$$\text{MRAI} = M_i/T_i \times 100 \quad (2)$$

$$\text{SRAI} = N_j/T_j \times 100 \quad (3)$$

where M_i is the total number of independent photos of each of the five species detected each month ($i = 1 \dots 12$); N_j is the total number of independent photos of each of the five species detected each season ($j = \text{spring, summer, autumn and winter}$); T_i is the number of camera-days each month; and T_j is the number of camera-days each season.

The daily activity patterns of the five most abundant species were analysed using time-period RAI (TRAI), defined following Liu et al. (2013):

$$\text{TRAI} = T_{ij}/N_i \times 100 \quad (i = 1-5; j = 1-12) \quad (4)$$

where the whole day (24 h) is divided into 2 h periods; T_{ij} is the number of independent photos of a species in one of 12 time periods ($i = 1-5; j = 1-12$); and N_i is the total number of independent photos of a species over all time periods.

Vertical distribution pattern analysis

The vertical distribution patterns of the five most dominant species were also investigated. The study area (elevation range 1 400–2 000 m a.s.l.) was divided into three altitude ranges with vertical intervals of 200 m. The RAI of the target species within each altitude range was calculated using equation (1), where A_i is the independent photos of a species detected at one of three altitudes and N is the number of camera-days at one of three altitudes.

We next analysed the SRAI of each species detected at each altitude range, where N_{ij} is the number of independent photos of a species ($i = 1 \dots 5$) at one of three altitudes in each season ($j = \text{spring, summer, autumn and winter}$); and T_j is the number of camera-days at one of three altitudes in each season.

Results

Relative abundance of mammals

Between January 2018 and December 2019, 14 species of mammals were detected at the 52 infrared camera sites. Species included the forest musk deer, which is a Class I

National Protected Species in China and listed as endangered on the IUCN Red List, as well as the long-tailed goral (*Naemorhedus griseus*), mainland serow (*Capricornis milneedwardsii*) and yellow-throated marten (*Martes flavigula*), which are listed as Class II National Protected Species. The wild boar was detected most often (RAI = 9.91), followed by the long-tailed goral (RAI = 6.73), Chinese muntjac (*Muntiacus reevesi*, RAI = 5.18), hog badger (*Arctonyx collaris*, RAI = 4.49) and mainland serow (RAI = 3.33), with the forest musk deer (RAI = 0.01) and swinhoe's striped squirrel (*Tamiops swinhoei*, RAI = 0.004) found at the lowest rates. RAI values for the first (RAI-2018) and second year (RAI-2019) differed somewhat (Fig. 2), suggesting temporal changes in the relative abundance of various species.

Daily activity patterns of five most abundant species

The daily activity patterns of the five most abundant species in Tianzhushan were analysed, based on TRAI (Fig. 3). Results showed that daily activity of the long-tailed gorals peaked at 06:00–08:00 and remained active continuously from 09:00 to 20:00 after the morning peak. The Chinese muntjacs were more active between 06:00 and 08:00 and between 16:00 and 20:00. Wild boars and mainland serows were more active from 06:00 to 20:00 and the highest activity period for wild boars appeared from 14:00 to 16:00. Hog badgers showed the opposite pattern, with lower activity during the day (lowest period between 10:00 and 12:00) and higher activity at night, peaking at 20:00–22:00 and 04:00–06:00.

Annual activity patterns of five most abundant species

The annual activity patterns of the five most abundant species are shown in Fig. 4. Results showed that wild boars were more active from September to November, with a peak in October. Long-tailed gorals were most active in July, with low activity from November to April (winter season). Chinese muntjacs showed activity peaks in July and November. Hog badgers showed two activity peaks in May and August. Mainland serows displayed a different pattern, with activity peaks in May, July and October.

Vertical distribution patterns of five most abundant species

The RAI values of forest ungulates were calculated at 200 m elevational intervals throughout the study area (elevation range 1 400–2 000 m a.s.l.). Results showed that the relative abundance of forest ungulates was higher within the 1 600–1 800 m a.s.l. range than at other elevations (Fig. 5). We next calculated the RAI of the five most abundant species at each elevational gradient (Fig. 6). All five species were found at all elevational gradients. Mainland serows and wild boars preferred mid-elevation habitats (1 600–1 800 m a.s.l.). For long-tailed gorals, RAI was higher at mid- and high altitudes (1 600–2 000 m a.s.l.) and lower at low altitude. For Chinese muntjacs, RAI decreased with elevation, with a peak at 1 400–1 600 m a.s.l. For hog badgers, the RAI was lowest at mid-altitude (1 600–1 800 m a.s.l.).

Vertical distribution patterns of five most abundant species in Tianzhushan by season

We performed comparative analyses of vertical distribution patterns of the dominant species by season (Fig. 7). Mainland serows showed similar vertical distribution patterns in all four seasons, with the highest RAI at the mid-altitude range (1 600–1 800 m a.s.l.). Wild boars showed a consistent vertical distribution pattern in all four seasons, with the highest population found at the 1 600–1 800 m a.s.l. elevation range and autumn recorded much higher RAI for wild boars. Hog badgers showed a similar vertical distribution pattern in spring, summer and winter and the populations of hog badger inhabiting the altitude of 1 600 to 1 800 m a.s.l. is lower than those in other altitudes, but in autumn, it is lower at 1 800–2 000 m a.s.l.. Long-tailed goral populations were highest at 1 800–2 000 m a.s.l. in autumn, spring and winter and lowest at 1 400–1 600 m a.s.l.. In contrast, the summer long-tailed goral population was highest at 1 600–1 800 m a.s.l.. Chinese muntjacs showed a similar vertical distribution pattern in autumn and spring (preferring mid-elevation habitats at 1 600–1 800 m a.s.l.) and a similar pattern in summer and winter (preferring low elevation habitats at 1 400–1 600 m a.s.l.).

Discussion

This study is the first to monitor the Tianzhushan Nature Reserve in Shaanxi Province via infrared camera. In total, 14 mammal species were detected, including one endangered Class I National Protected Species and three Class II National Protected Species. The five species with the highest RAI were *Sus scrofa*, *Naemorhedus griseus*, *Muntiacus reevesi*, *Arctonyx collaris* and *Capricornis milneedwardsii*. The RAI of the wild boars was significantly higher than that of the other species. Strong environmental adaptability, high reproduction rate and widespread lack of large predators in the reserve have likely contributed to the higher wild boar populations (Frauendorf et al. 2016, Johann et al. 2020). Although it is a key protected animal in the reserve, the RAI of the forest musk deers was relatively low, which may be related to the significant decline in wild forest musk deer populations due to habitat loss and overexploitation (Yang et al. 2003, Fan et al. 2018). Swinhoe's striped squirrels had the lowest RAI value, which is likely due to the low record of small mammals in the study area and limited camera coverage. Another reason for the low record could be related to the fact that swinhoe's striped squirrels are an arboreal species.

Animal activity intensity in different time periods is positively correlated with the probability of being captured by the cameras. The higher the activity intensity index, the more active animals are at this time (Azlan and Sharma 2006). According to the daily activity rhythms of the five most abundant species, Chinese muntjacs were more active from 06:00 to 08:00 and 16:00 to 20:00, indicating higher activity at dawn and dusk, consistent with reports in different areas of the Qinling Mountains (Jia et al. 2014). This daily activity pattern is essential for herbivores as morning foraging on dew-covered plants can provide additional water and evening activity can reduce sun exposure to avoid water loss. In addition, the low light at dawn and dusk can reduce the risk of predation (Yuan and Kong 2011). Our results also showed that long-tailed gorals were more active from 06:00 to 20:00, suggesting that they are a diurnal species, as reported

in previous research (Jia et al. 2014). In our study area, wild boars were more active during the day than at night. This is similar to results reported in Guanyinshan Nature Reserve in Shaanxi, China (Liu et al. 2013) and in Saskatchewan, Canada (Stolle et al. 2015), but different from research in south-western Germany (Johann et al. 2020) and the Mediterranean (Russo et al. 1997), which reported predominantly nocturnal activity. The different results between regions in terms of daily activity patterns may be due to local environmental conditions. Our results also showed that mainland serows were predominantly active during the day, whereas hog badgers showed obvious nocturnal habits.

Analysis of the annual activity patterns showed that activity intensity for the five most abundant species fluctuated seasonally, which may be related to the different distribution of food resources (Chen and Hu 2012), as well as changes in temperature, light and water availability at different times of the year (Wang et al. 2008). In winter, the relative abundance and activity intensity of the five species were low, which coincided with the lowest levels of food availability, shortest sunshine hours and lowest temperatures. Wild boars were more active in September and October, corresponding to their breeding season when the frequency and range of activities increase in order to find a mate. Mainland serows, Chinese muntjacs and long-tailed gorals were highly active in the summer month of July, coinciding with the increase in food abundance and, thus, foraging activity. Mainland serows activity also peaked in May, which may be due to the increase in food resources in spring, especially the stems and buds of favoured plants. Mainland serows were also active in October, which may be related to their breeding behaviour. For hog badgers, it was already reported to have a period of winter torpor or (semi-) hibernation from November to March in central and northern China (Wang and Fuller 2003, Zhou et al. 2015). This may explain the fact that hog badgers were more active from March to October.

The spatial patterns of species richness and diversity are of major interest in ecology and biogeography. Species diversity distribution is affected by many ecological gradients (Gaston 2000, Morin 2000), with highest species diversity found at mid-altitudes (Rickart 2010). Here, we calculated the RAI for all forest ungulates at different elevations and found

that the spatial distribution of forest ungulates was highest at mid-elevation (1 600–1 800 m a.s.l.), thus showing a mid-peak model, in accordance with the prediction of the mid-domain effect hypothesis. This model is consistent with the results of Zeng et al. (2005) and Li et al. (2014) in different regions of the Qinling Mountains. Our results also showed that hog badgers preferred low elevation habitats (1 400–1 600 m a.s.l.), mainland serows and wild boars preferred mid-elevation habitats (1 600–1 800 m a.s.l.), long-tailed gorals preferred mid- and high-altitude areas (1 600–2 000 m a.s.l.) and Chinese muntjacs preferred low to mid-altitude habitats (1 400–1 800 m a.s.l.). Species preferring different elevation habitats may be a response to differences in habitat adaptability (SÁnchez-Cordero 2001).

Considering the seasonal vertical migration behaviour of ungulates (Herrero et al. 1996), we analysed the vertical distribution patterns of the five most abundant species in the

different seasons. In the four seasons, there was no change in the vertical distribution pattern of mainland serows and wild boars, suggesting they had no obvious vertical migration behaviour. The spatial distribution of artiodactyls varies in different regions (Gonzalez 1985). For example, different from our results, mainland serows migrate downwards in spring and upwards in summer in the Cibaigou Nature Reserve in Tibet (Wu and Zhang 2004). It is possible that, due to the elevation range (1 580–5 000 m a.s.l.) being much higher there, the habitat heterogeneity is much more marked in Cibaigou Nature Reserve in Tibet than in our study area, which may contribute to this difference. However, the real reason still needs more study in the future. Zhou et al. (2015) and Kaneko et al. (2006) had reported strong seasonal variations in the diet composition of hog badgers in a Chinese subtropical forest and Japanese badgers in Hinode, Japan. They reported that, during spring and summer, earthworms were the predominant food category and badgers exhibited switched from worms when fruit became abundant in autumn. Thus, the vertical distribution of hog badgers in autumn was different to that in other seasons, which may be related to seasonal changes in food availability. The long-tailed gorals preferred mid-elevation habitats in summer, but migrated upwards in spring and winter. This may be due to animals travelling to higher altitudes in winter and spring to gain more solar radiation in cold environments (Zeng et al. 2010). The Chinese muntjacs were primarily distributed at mid-elevation in spring, at low elevation in summer and winter and at both during autumn. This seasonal variation in the vertical distribution could be attributed to the seasonal changes in food resources.

Conclusions

In conclusion, our data revealed the survival status and activity rhythms of five most abundant species in Tianzhushan, thus providing a strong basis for the efficient monitoring, protection and management of ungulates. However, further research is needed to understand the dominant factors affecting ungulates activity rhythms and the relationship between ungulates and predators.

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Grant title

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Hosting institution

Shaanxi Institute of Zoology

Ethics and security

All procedures and experiments were approved by the Animal Care and Use Committee of the Shaanxi Institute of Zoology.

Conflicts of interest

The authors declare that they have no conflict of interest.

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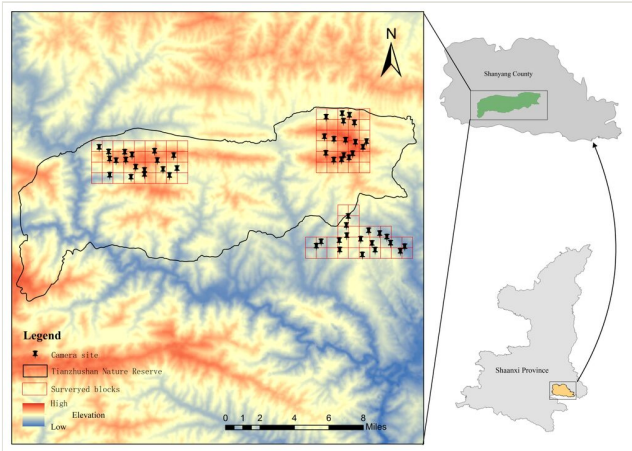


Figure 1.
Camera trapping sites in Tianzhushan, Shaanxi Province, China.

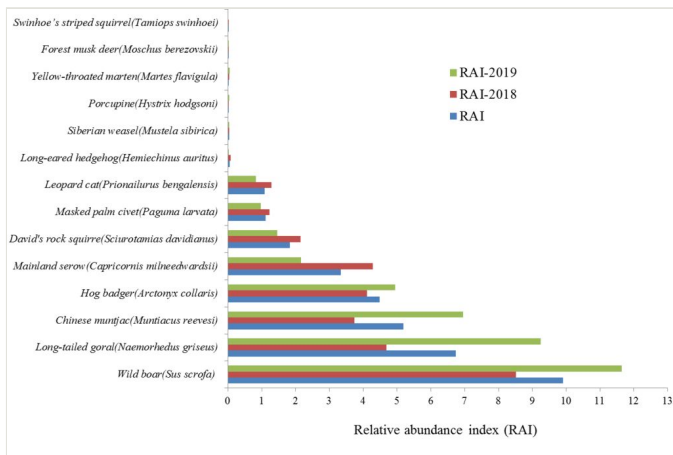


Figure 2. Relative abundance index (RAI) of ungulate species detected at infrared camera trap sites (RAI: Entire study period; RAI-2018: January–December 2018; RAI-2019: January–December 2019).

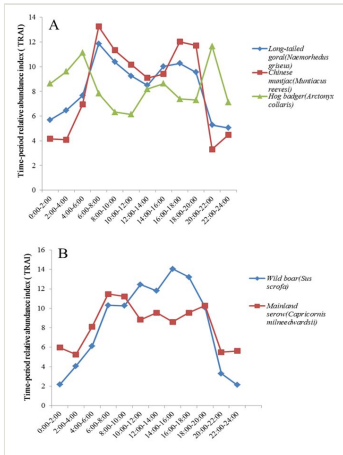


Figure 3. Daily activity patterns of five most abundant species at Tianzhushan. **A** Long-tailed goral, Chinese muntjac and Hog badger; **B** Wild boar and Mainland serow.

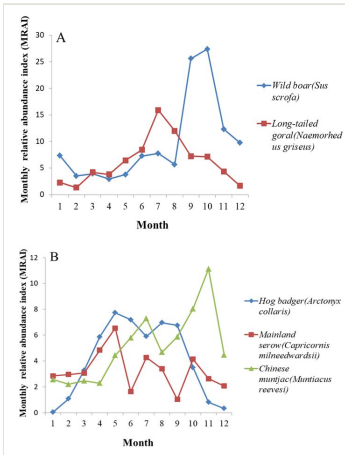


Figure 4.

Annual activity patterns of five most abundant species at Tianzhushan. **A** Long-tailed goral and wild boar; **B** Hog badger, Chinese muntjac and Mainland serow.

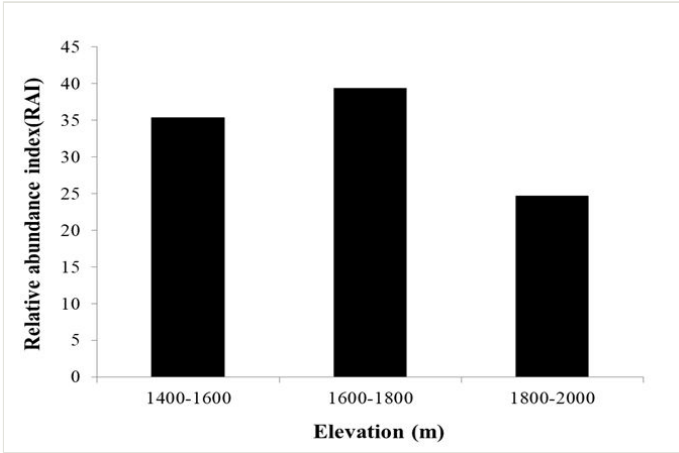


Figure 5.
RAI of ungulates at Tianzhushan along the elevational gradient.

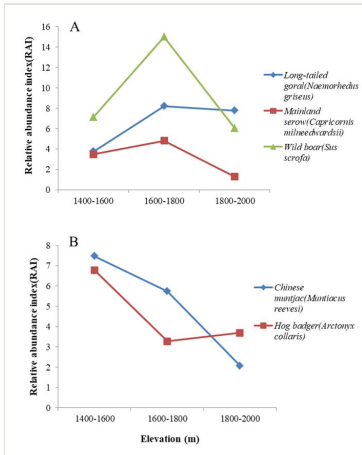


Figure 6. RAI of five most abundant species at each elevational gradient at Tianzhushan. **A** Long-tailed goral, Mainland serow and Wild boar; **B** Hog badger and Chinese muntjac.

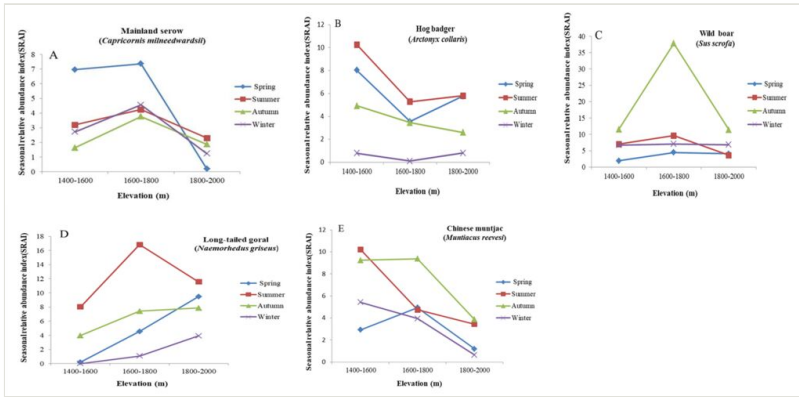


Figure 7.

Vertical distribution patterns of five most abundant species by season at Tianzhushan. **A** Mainland serow; **B** Hog badger; **C** Wild boar; **D** Long-tailed goral; **E** Chinese muntjac.