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Temporal Niche Overlap of Medium Sized Herbivores in the Seoraksan and Jirisan National Parks, South Korea

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ETK and SJR designed the study and wrote the manuscript. JKL, DHL, HKB, HK, KJK and SCJ performed the field work. ETK, JKL, JHL and SJR analyzed the data.

Key words
Activity pattern, Camera trap, Deer, Goral, Temporal niche

ABSTRACT

Studies on the daily activity patterns of species can contribute to gaining an understanding of community ecology. During the warm seasons of the years 2019 to 2021, we used camera traps to monitor the activity patterns of water deer *Hydropotes inermis*, roe deer *Capreolus pygargus*, and Amur goral *Naemorhedus caudatus* in the Seoraksan and Jirisan National Parks, South Korea. We compared activity patterns among pairs of sympatric species in each area, as well as those of water deer and roe deer populations inhabiting the two parks. Overlaps in activity patterns were estimated based on kernel density function and overlap coefficient analyses, and activity pattern distributions were compared using Watson's two-sample test. We detected an overlap of the activity patterns of sympatric species and established that there were no significant differences in the distribution of activity patterns in the two areas. However, we detected differences between the Seoraksan and Jirisan sites with respect to the activity patterns of water deer particularly their patterns of nocturnal activity, which could be attributable to differences in community inter-specific interactions and food resources for water deer inhabiting the Seoraksan and Jirisan National Parks.

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INTRODUCTION

In many areas of the world, there have been recent expansions in the range of size of deer populations (Kaji *et al*., 2010). As with most animals, a thorough understanding of deer ecology is essential for the conservation of these mammals, as well as their habitats (Rhim, 2019). In this regard, both intra and interspecific interactions, such as competition and predation, can have pronounced influences on habitat use by deer (Ratikainen *et al*., 2007; Lone *et al*., 2014). Competition among species, for example, can occur when commonly exploited resources are limited, and such competition may thus give rise to niche partitioning and differential resource use (Gaudiano *et al*., 2021; Lee *et al*., 2021).

In areas where multiple species coexist, an assessment of activity patterns can provide valuable insights with respect to identifying the potential interactions among species (Banjade *et al*., 2121). The activity patterns of deer are determined to a large extent by environmental conditions (Ikeda *et al*., 2015), the responses to which may be modified according to behavioral traits, hormonal state, and reproductive status (Mysterud and Ostbye, 1999; Bourgoin *et al*., 2011).

Determining the circadian activity patterns of species can provide important clues for elucidating key aspects of community ecology (Frey *et al*., 2017; Gaudiano *et al*., 2021), and interspecific interactions can play a prominent role in shaping the daily activity patterns of species. For example, temporal niche partitioning can arise among competitors (Marinho *et al*., 2020), and prey species can switch their activity patterns to reduce the risk of predation (Jasińska *et al*., 2021). Accordingly, the temporal segregation is considered an important factor contributing to the coexistence of species with similar ecological niches (Di Bitetti *et al*., 2010; Monterroso *et al*., 2014; Cho *et al*., 2021).

In South Korea, water deer *Hydropotes inermis*, roe deer *Capreolus pygargus*, and Amur goral *Naemorhedus caudatus* are considered representative of the native herbivores fauna. These mammals are medium-sized herbivores with similar ecologies, among which interspecific interactions can occur, particularly in the case of water deer and roe deer, both of which are browsers that have similar habitats and exploit common resources (Jo *et al*., 2018).

According to IUCN Red List, Amur goral and roe

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deer are Vulnerable, whereas water deer is Least Concern. In addition, Amur goral is a designated endangered species that is currently the target of a restoration project by Korean government (Korea National Park Service, 2005). However, although all three species are relatively well studied, there is currently limited information regarding their respective patterns of activity (Banjade *et al*., 2021).

In this study, with a view toward gaining an understanding of community ecology, we sought to determine the activity patterns of these three deer species, the study was conducted in two national parks located in South Korea, namely, the Seoraksan and Jirisan National Parks. The Seoraksan National Park was selected as being representative of areas inhibited by populations of Amur goral, in which interspecific competition among water deer, roe deer, and Amur goral is predicted to occur. The Jirisan National Park is the focus of restoration program for Asiatic black bear *Ursus thibetanus*, which was inaugurated 2001. This has included reintroducing bears to the parks, and currently their population is being sustainably maintained (Kim *et al*., 1999). We anticipate that these large predators would also influence the ecologies of water deer and roe deer in this park.

To clarify the overlaps in the temporal niches of the three focal deer species, we monitored animals using camera traps and evaluated daily activity patterns in both protected areas. Our objectives were to gain an understanding of daily patterns and thereby obtain basic information for the conservation of medium-sized herbivores and their habitats.

MATERIALS AND METHODS

As study area, we selected the Seoraksan (38°00′–15′N, 128°15′–34′E) and Jirisan (35°17′–21′N, 127°35′–41′E) National Parks, located in the northern and southern regions of South Korea, respectively. The Seoraksan National Park is located in the northern part of Gangwon-do Province, covering an area of 398 km^2 at altitudes ranging from 200 to 1700 m above sea level. The annual mean temperature of the region is 13.5°C (range: -16.1°C to 36.1°C), and annual precipitation is 1743.1 mm (Korea Meteorological Administration, 2021). The park is home to three medium-sized herbivores, namely, water deer, roe deer, and Amur goral (National Institute of Forest Science, 2020), and their primary predator is yellow-throated marten *Martes flavigula*.

The 483 km^2 Jirisan National Park is located in a region straddling the provinces of Jeollanam-do and Gyeongsangnam-do at altitudes ranging from 200 to 1900 m above sea level. The mean annual temperature of the region is 13.5°C (range: -19.7°C to 35.4°C) and the annual precipitation is 1682.3 mm (Korea Meteorological Administration, 2021). The park is populated by two medium-sized herbivores, the water deer and roe deer (National Institute of Forest Science, 2020), with the yellow-throated marten and Asiatic black bear being considered their primary predators. A reintroduction program for Asiatic black bear has been ongoing at Jirisan since 2001, and the park currently supports more than 63 individuals (Kim *et al*., 1999).

For the purposes of this study, we monitored the activities of animals using camera traps incorporating heat and motion sensors (Trel 20J; GISupply, Inc.). Camera traps surveys were conducted in the warmer months (May–September) from 2019 to 2021, with four cameras installed at different sites in each of the two parks (8 camera sites in total). In both parks, the 4 camera sites were selected according to altitude with one, two, and on being installed at 400, 800, and 1200 m above sea level, respectively. The cameras were fixed at a height of 50 cm above ground level in the absence any baits or lures, and were set to record videos of 10-s duration.

We compared the activity patterns of pairs of sympatric species within each of the Seoraksan and Jirisan parks, and differences in the activities of the same species (water deer and roe deer) between the two parks. To estimate the overlap in activities between the two samples, we used the kernel density function. In this regard, Ridout and Linkie (2009) have defined the overlap coefficient as the overlapping area under the curves of kernel density estimates from two samples, with coefficient values ranging from 0 (no overlapping area) to 1 (overlap of the total area). In the present study, we used the overlap coefficient $\Delta 4$ for comparison of the activity patterns of water deer pattern between Seoraksan and Jirisan, whereas other paired samples were assessed using overlap coefficient $\Delta 1$ for small sample size (< 75 records). The 95% confidence interval and mean of the overlap coefficients were calculated based on 1000 bootstrap samples (Meredith and Ridout, 2021). The degree of overlap can be classified as follows: low ($\Delta \leq 0.5$), moderately high ($0.5 < \Delta \leq 0.75$), and very high ($0.75 < \Delta$) (Monterroso *et al*., 2014). Furthermore, we assessed the significance of differences between the distributions of two samples using Watson's two-sample test. All statistical analyses were performed using the overlap package of R statistical software Ver. 0.3.4 (Meredith and Ridout, 2021).

RESULTS

In this study, with the exception prolonged observations of the same individuals, we used only independent records. In total, we analyzed 272 camera trap records obtained over 2330 camera trap-days, 145 of which were collected in the Seoraksan National Park

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[water deer (n = 77), roe deer (n = 36), and Amur goral (n = 32)] and 127 were obtained in the Jirisan National Park [water deer (n = 85) and roe deer (n = 42)].

Comparisons of the daily activities of water deer, roe deer, and Amur goral in Seoraksan revealed that these three species were generally most active at dusk (Fig. 1, Table I). In contrast to the other two species, however, the peak in roe deer activity was recorded between 07:00 and 11:00. Pairwise comparisons revealed a very high overlap of the respective activity patterns of water deer and Amur goral (overlap coefficient $\Delta 1 = 0.79$, CI 95% = 0.70–0.90), whereas the overlap between roe deer activity and that of these two species tended to be moderate (water deer and roe deer: $\Delta 1 = 0.68$, CI 95% = 0.52–0.82, roe deer and Amur goral: $\Delta 1 = 0.62$, CI 95%= 0.48–0.78). Moreover, we detected no significant differences in the distribution of activity patterns in any of the pairwise combinations of sympatric species (Watson's two-sample test: $U^2 < 0.09$, $P > 0.10$).

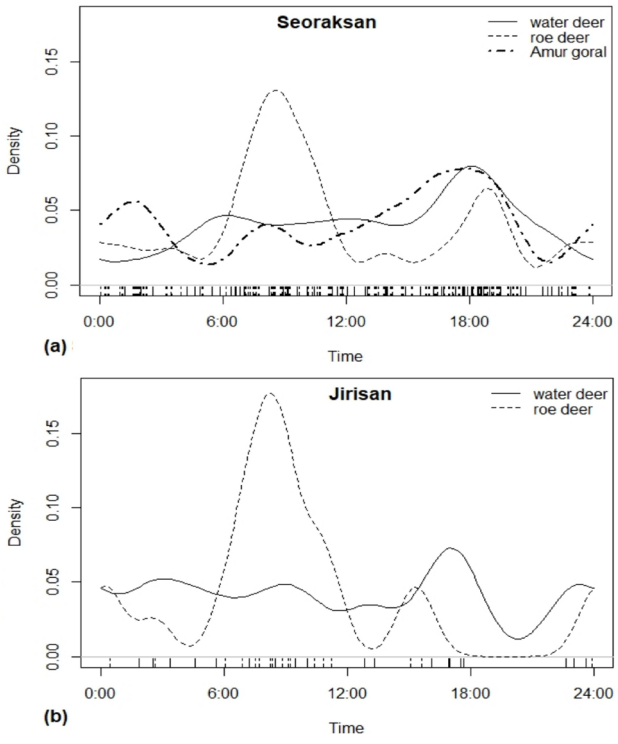

Fig. 1. Overlap of the daily activity rhythms of water deer, roe deer, and Amur goral shown as kernel density estimates throughout a 24-h cycle in the Seoraksan (a) and Jirisan (b) National Parks.

In Jirisan, we found that overlaps in the activity patterns of water deer and roe deer were not as pronounced as those determined for the Seoraksan populations of these species (water deer and roe deer: $\Delta 1 = 0.51$, CI 95% = 0.31–0.74). With the exception of dusk, water deer inhabiting Jirisan were found to be active throughout the day, tending to be most active prior to dusk and least active thereafter. Roe deer in Jirisan were most active from dawn to noon and were not observed between 18:00 and 11:00. Moreover, we detected no significant differences in the distribution of the activity patterns of water deer and roe deer in Jirisan ($U^2 < 0.12$, $P > 0.10$).

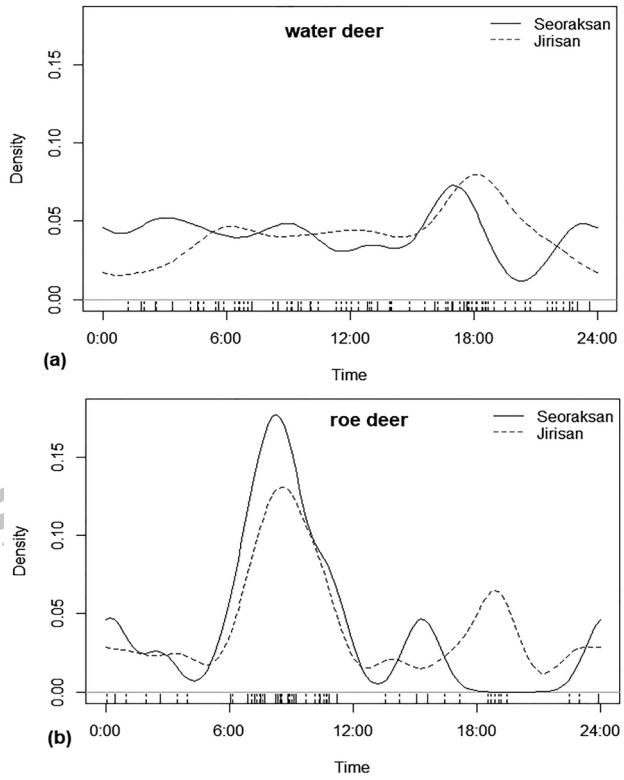

Fig. 2. Comparison of the daily activity patterns of water deer (a) and roe deer (b) between the Seoraksan and Jirisan National Parks.

Having assessed the activities of the deer species in each of the two national parks, we went on to compare the activity of water deer and roe deer between the Seoraksan and Jirisan sites (Fig. 2, Table II). In both parks, roe deer activity was observed to peak during the hours from 07:00 to 11:00, and the overlap was moderately high (Seoraksan and Jirisan: $\Delta 1 = 0.66$, CI 95% = 0.59–0.85). However, we detected no significant differences between Seoraksan and Jirisan populations with respect to the distribution of activity patterns ($U^2 = 0.08$, $P > 0.10$). In contrast, the distribution of water deer activity patterns was found to differ significantly between Seoraksan and Jirisan ($U^2 = 0.20$, $P < 0.05$), although in common with roe deer, we detected a moderately high overlap of water deer activity between the two study areas (Seoraksan and Jirisan: $\Delta 4 = 0.71$, CI 95% = 0.64–0.91).

Table I. Summary of overlap coefficient and Watson's two-sample test analyses of the daily activity patterns of sympatric species in the Seoraksan and Jirisan National Parks.

Study areas	Species pairs	Overlap coefficient			Watson's two-sample test	
		Mean	95% CI	Degree	U^2	P
Seoraksan[a]	Water deer–roe deer	0.68	0.52-0.82	moderately high	0.09	> 0.10
	Water deer–Amur goral	0.79	0.70-0.90	very high	0.06	> 0.10
	Roe deer–Amur goral	0.62	0.48-0.78	moderately high	0.04	> 0.10
Jirisan[a]	Water deer–roe deer	0.51	0.31-0.74	moderately high	0.12	> 0.10

[a]Δ1

Table II. Summary of overlap coefficient and Watson's two-sample test analyses of the daily activity patterns of water deer and roe deer between the Seoraksan and Jirisan National Parks.

Species	Overlap coefficient			Watson's two-sample test	
	Mean	95% CI	Degree	U^2	P
Water deer[a]	0.71	0.64–0.91	moderately high	0.20	< 0.05
Roe deer[b]	0.66	0.59–0.85	moderately high	0.08	> 0.10

[a]Δ4, [b]Δ1

DISCUSSION

It is well established that deer partition their daily activity according to the requirements of movement, feeding, rumination, and rest. Moreover, time budgets and patterns of habitat use are often species-specific (Beier and McCullough, 1990). Environmental factor such as resource availability and quality can also influence the activity patterns of ruminants (Pagon *et al.*, 2013). Ruminants typically partition rumination time into discrete intervals, which tends to be manifested as repeated sequences of activity and rest. Moreover, dietary composition can also influence the patterns of feeding and ruminating bouts (van Soest, 1994).

In this study, we monitored the daily activity patterns of three medium-sized herbivores in the Seoraksan and Jirisan National Parks, based on a camera trap survey. With respect to the daily activity of roe deer, our observations were generally consistent with previously published data (Pagon *et al.*, 2013; Bonnot *et al.*, 2019), which have indicated a bimodal activity pattern with activity peaking around dawn. Similar bimodal patterns of activity have also been reported for sika deer *Cervus nippon* (Banjade *et al.*, 2021), elk *Cervus canadensis* (Green and Bear, 1990), and white-tailed deer *Odocoileus virginicanus* (Beier and McCullough, 1990). Contrastingly, water deer and Amur goral were found to be active throughout the day, with activity peaking at dusk, and were generally inactive during the night. The day/ night activity cycles of such medium-sized herbivores have been proposed to reflect the patterns of feeding and ruminating in these animals (Berger *et al.*, 2002).

Interestingly, we found that the water deer populations in Seoraksan is characterized by a diurnal pattern of activity that peaks at dusk, whereas the water deer found at Jirisan tend to be active throughout the day, with the exception of the period around dusk. These observations thus indicate that these deer can modify their patterns of activity in response to local conditions. Although we detected a moderately high overlap of water deer activity between the two study areas, it should be noted that whereas the overlap coefficient can explain the degree of overlap between two patterns, it does not necessarily reflect the similarity of activity patterns. Nevertheless, we presume that differences in the Seoraksan and Jirisan populations of water deer could be attributed to differences in the extent of interspecific interactions, such as predation and competition.

Our examination of the activity patterns of sympatric species revealed a moderate overlap of temporal niche partitioning, with no significant differences being detected among the activity patterns of sympatric species. These findings might imply that the activity of medium-sized herbivores in Korea is not determined to any appreciable degree by the temporal niches of potential competitors. This would be a reasonable assumption, given that of herbivores, the availability and quality of food resources in Korea is generally not influenced by temporal factors, but only a spatial variation in habitat (Eom *et al.*, 2020; Gaudiano *et al.*, 2021). Moreover, an abundance of food

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resource would reduce the degree of competitive stress.

The activity rhythms of animals can be affected by a diverse range of environmental, ecological, and endogenous factors (Pagon *et al*., 2013; Petrov *et al*., 2016), and we speculate that observed differences in the activity pattern of water deer in the Seoraksan and Jirisan National Parks could be attributable to ecological factors, notably predations. We assume that the presence of Asiatic black bears in Jirisan, as well as yellow-throated martens, would pose a heightened predatory risk for these deer, and that these herbivores accordingly modify their activity patterns in response to predator diurnal activity.

In this study, we also detected certain fluctuations in the patterns of water deer, roe deer, and Amur goral activity, and in this regard, it is conceivable that the difference in the flora of the Seoraksan and Jirisan regions influence the diet and behavior of water deer and roe deer. To date, however, there have been no detailed studies of the dietary composition of medium-sized herbivores in Korea, highlighting the need for further studies on the diet and habitat use of these mammals. Moreover, studies on seasonal and sexual differences in activity patterns would enable us to gain a more in-depth understanding of medium-sized herbivore ecology and their habitats.

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Statement of conflict of interest

The authors declare that they have no conflicts of interest.

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