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The autumn activity patterns and time budgets of Forest musk deer (*Moschus berezovskii*) in captivity

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Abstract

Activity patterns and time budgets play a crucial role in the successful farming and management of animals. In this study, the behavior patterns of 53 forest musk deer (*Moschus berezovskii*) were analyzed from October 2nd to 16th, 2021, throughout the day and night. The results showed a distinct dawn–dusk activity rhythm in the captive forest musk deer with a peak activity observed at dawn (07:00 - 10:00) and dusk (16:00 - 19:00). Additionally, there were smaller activity peaks lasting less than an hour during the nighttime (00:00 - 04:00). Comparing behavior ratios between peak and off-peak periods, it was evident that all behaviors, except rumination (RU), showed significant differences. Furthermore, no significant differences were found in the behavior ratios of the forest musk deer between the daytime and night-time. During the daytime, the percentages of time spent performing locomotion (32.87 ± 3.38%), feeding (14.43 ± 1.81%), and RU (5.62 ± 1.46%) were slightly higher compared to the night-time. Based on these findings, it is important to match the management strategies for musk deer farming with the animals' activity patterns and behavioral rhythms. Doing so can enhance farming outputs and contribute to the welfare of captive forest musk deer.

Introduction

Musk deer (*Moschus* sp.) are critically endangered ungulates and they are in urgent need of conservation. Farming has been recognized as an effective *ex situ* conservation approach.[1] Musk deer farming has been carried out successfully in China since 1958, with forest musk deer (*Moschus berezovskii*) being the primary species reared in the captivity. Currently, captive rearing is considered one of the most important measures for the *ex situ* conservation of musk deer. Under artificial feeding conditions, the activity time allocation of captive musk deer differs from that of their wild counterparts and is influenced by various factors.[2] Some previous studies have reported the seasonal activity patterns of captive alpine musk deer (*Moschus chrysogaster*).[2]

Under captive conditions, alpine musk deer exhibit a distinct morning activity peak in the summer. However, this morning peak is not evident in autumn and winter. Instead, captive alpine musk deer show an activity peak around noon during these seasons.[2] Many other ungulate species live in one or more stable groups, and behaviors such as running or foraging are affected by the group dynamics. These behaviors often demonstrate certain degree of synchronization, which helps maintain group cohesion.[3-4] On the contrary, forest musk deer are solitary ungulates that predominantly inhabit high-altitude closed-cone coniferous and broad-leaved mixed forests.[5]

Activity time budgets are a fundamental biological characteristic of animals and reflect behavioral adaptations to the environment. The pattern of activity plays a crucial role in the life history strategies of both wild and domestic herbivores.[6,7] Studying the circadian

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rhythms of animals has always been a significant aspect of research in the field of behavioral ecology.[8,9] Research on animal circadian activity patterns and their influencing factors can broaden the understanding of animal behavior patterns,[10] and help clarify how animals adapt to their environment.[11-14] However, traditional methods, like manual scan sampling, have limitations in terms of time and data collection capabilities, as well as small sample sizes.

In this study, we used infrared cameras and scan sampling to explore the 24hr activity patterns and time budgets of a forest musk deer population after *ex-situ* conservation more effectively through data analysis. Autumn is just before the reproduction season for forest musk deer; therefore, it is crucial to know the activity patterns and time budgets of musk deer in autumn, which will benefit successful reproduction attempts, population increases, and *ex situ* conservation.

Materials and Methods

Research area. This study was carried out from October 2nd to 16th, 2021, at the Huailai Musk Deer Farm in Xinglinpu, Hebei Province, China. The farm is located in a mid-temperate semi-arid region known for its temperate continental monsoon climate, which exhibits significant temperature variations between day and night. The farm lies at the highest latitude of any musk deer farm in the world (E115°38′48″, N40°33′32″). In October, the local temperatures range from 0.00 to 30.00 ˚C, with average daily low and high temperatures of 5.00 and 17.00 ˚C, respectively. There were 3 days of precipitation during the study (October 3rd, 12th, and 16th). However, the amount of the rainfall was minimal with a little effect on the observations.

Animals. The study included a total of 53 captive forest musk deer (25 males and 28 females) in the Huailai musk deer farm. They were all born in captivity and descendant from the southern species of China. The study area consisted of six enclosures, each consisting of one 10.00 m^2 cell and 50.00 m^2 exercise area containing 6 - 10 deer (four enclosures each holding 10 forest musk deer; one enclosure holding six forest musk deer; and one enclosure holding seven forest musk deer). The enclosures featured a natural soil base that was covered with ground vegetation and trees. All deer were adults aged 3 years old, and were maintained by one deer-keeper and fed twice a day, at 08:00 and 18:00. The diet was supplemented with artificial feed containing approximately 40.00% corn, 25.00% wheat, and 25.00% beans, which was mixed onsite. Seasonal vegetables were also provided occasionally, and water was available *ad libitum*. Interaction with the human keeper was limited to 20 min per day, for feeding, cleaning, and other management duties. All deer were individually identified by a numbered plastic ear tag. This study was approved by the Academic Committee of the School of Environment and Natural Resources, Renmin University of China (No. 2021010 of proposal).

Behavioral sampling and data collection. Excessive ambient lighting at night can have an impact on animal behavior, such as causing over-expression and resulting in inaccurate data.[15,16] To minimize this interference, our study did not use any artificial lighting at night-time. Also, infrared cameras (Hikvision, Hangzhou, China) were installed on the diagonal of each barn to cover the entire barn area without blind spots. This allowed us to monitor the behavior 24 hr a day from October 2nd to October 16th with minimal environmental light interference for the captive forest muck deer, a particularly timid species. Scan sampling was used to record each individual's behavior at 30-min intervals. [4,17] Each scan was watched for up to 30 sec. The study ethogram was adapted from previous studies on the time allocation of alpine musk deer activities,[2,18] with the behaviors defined in Table 1. All behavioral sampling was performed by the same observer.

Statistical analysis. During the experiment, the maximum change in day duration was 34 min. To ensure the comparability of the incidence of behaviors between periods, the inter-variation of day duration was not considered when dividing periods. Hence, the daytime period remained fixed as 06:25 - 17:32 throughout the experiment, with the remaining time each day considered as night-time. Behavior samples were analyzed by individuals and, for each behavior, the behavior ratio was calculated (the duration of behavior was divided by the total sampling duration)[17] The average rate of the total population was then determined. The behaviors of locomotion (LO), rumination (RU) and feeding (FE) were merged to calculate the activity rate (the duration of these three behaviors was divided by the total sampling duration), and the period whose activity rate exceeded the average was defined as the activity peak. The Shapiro-Wilk test was used to assess the normality of data (behavior ratios). If the data were normally distributed, either an

Table 1. Ethogram of captive forest musk deer.

Behaviors	Abbreviations	Definition
Locomotion	LO	In locomotion, including walking, chasing, grooming, conflict behavior, and exploring the environment
Feeding	FE	Feeding or drinking water
Rumination	RU	Ruminating, including standing-ruminating and lying-ruminating
Lying still	LS	In a prone posture and resting although not ruminating, with the head on the shoulder or ground
Others	OT	Included other infrequent behaviors, such as excretion and tail-pasting

The observer was aware of the work protocol.

ANOVA (to explore the difference between different periods defined by activity rate) or a t-test (to explore the difference between daytime and night-time) was used to explore the difference. If the data were non-normally distributed, either the Kruskal-Wallis H test (to explore the difference between different periods defined by activity rate) or the Mann-Whitney U test (the difference between daytime and night-time) was used. Statistical analyses were completed using SPSS Software (version 25.0; IBM Corp., Armonk, USA) and all reported statistical probabilities were two-tailed at $p \leq 0.05$. Excel (version 2108; Microsoft Corp., Redmond, USA) was used to draw the diagrams.

Results

Distribution pattern of autumn activities. The behavior data of LO, FE, and lying still, and the logarithmically transformed RU data, were all normally distributed ($p > 0.05$). Lying still (LS) accounted for the highest percentage of the time budget (50.10 ± 2.72%, n = 48), followed by LO (31.39 ± 2.08%, n = 48) and FE (12.14 ± 1.17%, n = 48). Rumination accounted for the lowest percentage of time amongst the four main behaviors (4.82 ± 0.83%, n = 48). The distribution of the percentage of each behavior exhibited by captive forest musk deer over 24 hr is shown in Figure 1 with LO and LS found to be the main behaviors of the forest musk deer and FE and ruminating behaviors presented together.

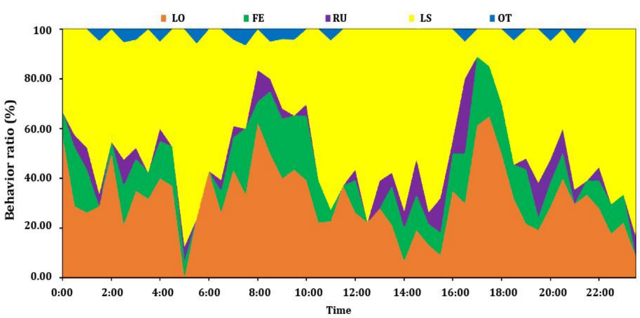

Fig. 1. The behavioral pattern of captive forest musk deer (LO: locomotion; FE: feeding; RU: ruminating; LS: lying still; OT: other behaviors).

Activity peak. As shown in Figure 2, throughout the study, the average daily activity rate was (43.53 ± 2.69%, n = 18). There were dawn activity peaks (07:00 ~ 10:00, 65.26 ± 2.35%, n = 18) and dusk activity peaks (16:00 ~ 19:00, 61.83 ± 7.27%, n = 18), and at midnight (0:00 ~ 04:00) there were multiple small, short-duration peaks of night activity. Among them, the activity peak duration at midnight (0:00 - 1:00) was relatively longer (1 hr), and its activity rate was (54.18 ± 6.75%, n = 18).

As shown in Table 2, the activity rates of the three peak periods of captive forest musk deer activities were significantly higher than those of the off-peak (rest) period (33.46 ± 2.19%, n = 30; F = 18.62, df = 3, $p < 0.001$).

Comparing the activity rate of peak periods, there were no significant differences between them ($p > 0.05$).

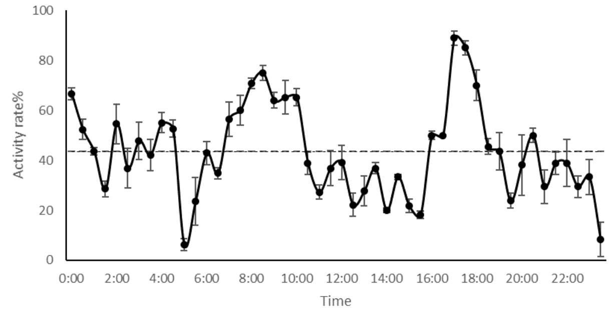

Fig 2. Autumn activity rate and activity peak of forest musk deer (the error bars are shown, and the dashed line indicates the average daily activity rate).

Table 2. The activity rate (mean ± SE) of forest musk deer in active and inactive periods.

Time	Activity rate (%)	Activity period
00:00 - 01:00	54.18 ± 6.75[a]	Midnight peak
07:00 - 10:00	65.26 ± 2.35[a]	Dawn peak
16:00 - 19:00	61.83 ± 7.27[a]	Dusk peak
Rest of time	33.46 ± 2.19[b]	Off-peak
All day average	43.53 ± 2.69[a]	-

[a] indicates non-significant difference ($p > 0.05$), and [b] indicates highly significant difference ($p < 0.01$).

Behavior rate comparison. In the distribution of behavior ratios between peak and off-peak periods throughout the day, LO and FE exhibited significant differences in each time (Table 3). The further comparison found that the incidence of LO in the three peak periods was significantly higher than that in the off-peak period (F = 7.21, df = 3, $p < 0.001$). There was no significant difference in LO between the three peaks ($p > 0.05$), with the highest behavior ratio occurring within three hr of the peak at dawn (44.56 ± 3.55%). Similarly, FE was significantly higher during the peak periods than in the off-peak periods (F = 14.12, df = 3, $p < 0.001$), although there was no significant difference between peaks. However, RU with a lower behavior ratio exhibited no significant difference between different periods ($p > 0.05$) and peaked (5.62 ± 4.15%) in the time from 1.5 hr before to 1.5 hr after sunset. In addition, for inactive behavior LS, there were significant differences between periods (F = 20.85, df = 3, $p < 0.001$), and LS during off-peak periods (60.44 ± 2.20%) was much higher than that of peak periods.

Daytime and night-time differences in behaviors. The average behavior ratios are shown in Table 4. Deer LS values during the daytime (45.62 ± 4.63%) were slightly lower than that at night (54.22 ± 2.88%); however, the difference was not significant ($p > 0.05$). Other behaviors were slightly higher during the daytime but showed no significant difference.

Table 3. Incidence of various behaviors in active and inactive periods. Data are presented as mean ± SE.

Time	Locomotion (%)	Feeding (%)	Ruminating (%)	Lying still (%)
00:00-01:00	37.27 ± 9.96^a	16.91 ± 4.13^a	4.49 ± 2.51^a	41.34 ± 4.25^a
07:00-10:00	44.56 ± 3.55^a	20.70 ± 2.70^a	4.31 ± 1.58^a	26.95 ± 2.99^a
16:00-19:00	42.10 ± 6.30^a	19.74 ± 1.75^a	5.62 ± 4.15^a	31.18 ± 6.75^a
Rest of time	25.43 ± 2.01^b	8.03 ± 1.05^b	4.79 ± 0.85^a	60.44 ± 2.20^b

^{a} indicates non-significant difference ($p > 0.05$) and ^{b} indicates highly significant difference ($p < 0.01$).

Table 4. Statistical analysis of day-night differences in behaviors. Data are presented as mean ± SE.

Time	Locomotion (%)	Feeding (%)	Ruminating (%)	Lying still (%)
Daytime	32.87 ± 3.38	14.43 ± 1.81	5.62 ± 1.46	45.62 ± 4.63
Night-time	30.04 ± 2.55	10.03 ± 1.41	4.09 ± 0.86	54.22 ± 2.88
All day average	31.39 ± 2.08	12.14 ± 1.17	4.82 ± 0.83	50.10 ± 2.72

There are non-significant differences among the data ($p > 0.05$).

Discussion

In this study, the 24h activity budgets showed that there was a dawn-dusk activity peak in captive forest musk deer in autumn. The activity rate at dawn (7:00 - 10:00) and dusk (16:00 - 19:00) were significantly higher than that in off-peak periods. Moreover, forest musk deer seem to have a clear schedule that distinguishes between activity and rest time. The activity rhythms of animals mainly include diurnal, nocturnal, and crepuscular activity, and they can also be affected by environmental factors, such as the photoperiod and temperature. This is closely related to the individual's internal physiological processes such as eating, digestion, ruminating, and hunger/satisfaction.[19] Animals use activity time allocation to achieve a balance between foraging and predation risks[20] and to avoid excessive water and energy consumption.[21]

The dawn and dusk peaks were close to the local sunrise (06:15 - 06:29) and sunset (17:59-17:37) times during the study. Similar bimodal activity patterns with obvious dawn–dusk peaks have been identified for most free-range ungulates in the northern hemisphere, such as goat antelope*(Rupicapra rupicapra*), white-tailed deer (*Odocoileus virginianus*),[22] red deer (*Cervus elaphus*),[3,8,23,24] Spanish ibex (*Capra pyrenaica*),[25] moose (*Alces alces*),[26,27] and Rocky Mountain elk (*Cervus elaphus*).[24,28] Two activity peaks found in this study were of relatively long duration, both reaching three hours, and the related activities were mainly LO and FE. The stable and long-term high frequency of activities indicated that the high frequency of activities during this period was due to group behaviors rather than a fixed individual habit. During the observation, we also found that the continuity of activity peaks may have been due to alternate eating in the musk group, which means taking turns in a certain order.[18] This order conforms to the habits of musk deer FE, ruminating, re-eating, and re-ruminating.[2] The FE time at the musk deer farm was close to the set sunrise and sunset times; thus, there was a peak in activity under the combined action of the two, and related issues still need to be further studied.

In addition, the study found that there were many short midnight peaks in the activity of forest musk deer, with narrow peaks and frequent alternation, of which the midnight (00:00 - 01:00) small peak was particularly significant. Animal activity can be divided into nocturnal, diurnal, and twilight activity, as well as some transitional forms in its activity. The midnight peak may be the deer's adaptation to the season or environment. Similar results have been shown in previous studies. Red deer have demonstrated a constant small peak of midnight activity, in addition to the normal peaks of morning and evening activity.[19] Meng *et al.* reported that captive alpine musk deer were active in the morning and evening, and also had a small peak of midnight activity.[2] Some scholars have attempted to prove that forest musk deer also have a midnight activity peak, but definitive evidence has not yet been found.[18] The current study confirms that forest musk deer also have this habit. In our study, we performed a full review of these periods and found that forest musk deer's activities were not just ordinary walking or exploring the environment during these midnight peaks, but mainly social behaviors such as chasing, grooming, and conflict behavior. Also, the midnight peak is also a manifestation of the self-protection mechanism of some herbivores in special ecological systems, whose levels of alertness are higher at night than during the day, meaning that activity disturbance activities are greater. The duration and positioning of animal activity peaks may be affected by a variety of factors;[29] therefore, further control studies should be conducted to determine the influences on captive forest musk deer caused by more potential factors.

Day-night differences in activities of captive forest musk deer were investigated in this study. Results showed that there were no significant differences in the activity patterns between daytime and night-time in autumn. Furthermore, no long-lasting behaviors were observed either at night-time or during the daytime. A study by Xue *et al.* on the daytime and night-time activities of forest musk deer in spring showed that the intensity of night activity of forest musk deer in spring was higher than that in the daytime, [18] which is similar to that of captive alpine musk deer in summer.[2] Activity is essential for animals to adapt to ambient temperature,[30-32] and individuals demonstrate flexibility to temperature.[33] It has been reported that the shorter activity cycle in moose (*Alces alces*) is related to the increase in temperature at noon.[34-35] Additionally, this study found that the activity intensity of forest musk deer was greatly influenced by temperature change. At high temperatures, musk deer usually rest as a means of thermoregulation. Even though the temperature at night was lower than the daytime, the temperature at the musk deer farm was relatively mild in the early autumn and the forest musk deer showed midnight activity peaks, which may have led to the lack of significant differences in behavior ratios between daytime and night-time.

This study also found that, under captive conditions, musk deer had short rest times at night, between 0.5 and 1 hr, with a high frequency of changes in their resting positions. This relates to variations among individuals in the group. Forest musk deer in wild environments are highly solitary; however, when socially enclosed in musk deer farms, the interactions among individuals will mutually influence the whole group. Individual LO at night disturbs others and lead to group disturbance, which could explain why the LO behavior was not significantly reduced. In addition, due to the fixed FE time (08:00 and 18:00), there may not have been enough food after midnight (00:00), causing the forest musk deer to actively search for food in the enclosure and eat sporadic turf or food residues. This could also be a reason for the increased activity. After eating at night, individuals often expressed certain RU behaviors. During the FE process, musk deer often stood with vigilance for a short time (about 5 min) before continuing to feed, which may indicate that, after captive breeding and multigenerational reproduction, the forest musk deer born on the farm still expressed the same alertness behaviors developed in wild musk deer. This study was conducted outside of the mating season of captive forest musk deer, and the most active behaviors observed were related to foraging and FE. It is recommended that, in the management of musk deer farming practices, population size, stock density, and sufficient food provision should be taken into consideration in order to maintain stable and active populations.

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Conflict of interest

The authors declare no financial or conflict of interest that could inappropriately influence this study.

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