

## The effect of temperature and other factors on roosting times of Szechenyi Monal Partridges *Tetraophasis szechenyii* during the breeding season

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In response to low temperatures, birds can choose between reducing their activity to minimize heat loss and increasing it in the hope of higher heat production. In this study, these aspects were evaluated in the rare Szechenyi Monal Partridges *Tetraophasis szechenyii* by examining the timing of breeding-season roosting. The partridges arrived at roost sites 54.7 ± 3.0 min before sunset ( $n = 78$ ), perched on branches 22.9 ± 1.8 min before sunset ( $n = 78$ ), and departed 7.3 ± 0.1 min after sunrise ( $n = 91$ ). Generalized linear mixed modelling with temperature and several other environmental variables (e.g. day length, cloud cover and precipitation) included as factors, showed that – all other things being equal – the partridges perched earlier and departed later on cold days. This result suggests that Szechenyi Monal Partridges reduce their activity to minimize heat loss in low temperatures. However, the partridges did not arrive early at roost sites on cold days, and the effects of low temperature on departure times were less than those on perching times: temperature had a partial coefficient of  $-0.89$  for departure times versus  $-1.29$  for perching times. Thus, we argue that the amplitude of these temperature effects may depend on food availability, or the birds level of hunger.



## 1. Introduction

Although daily activity of birds follows an endogenous or circadian rhythm, the exact time of it may vary from day to day. This variation is not random, but may be related to concurrent changes in environmental factors, reflecting that birds can alter their behavior in response to a changing environment (Reebs 1986, Tester 1987). Thus, by understanding the behavioral decisions made by individuals it is possible to predict their behavior in novel environments, such as those resulting from current or future environmental changes. Such conservation issues should be solved by applying soundly-performed scientific research (Sutherland 1998).

Temperature is the most extensively studied factor in this regard. To cope with cold days, diurnal birds can choose between reducing their activity to minimize heat loss and increasing it in the hope of higher heat production (Morse 1980, Doucette & Reebs 1994). Most bird species adopt the former strategy; examples include European Starling *Sturnus vulgaris* (Jumber 1956), Canada Goose *Branta canadensis* (Raveling et al. 1972), Black-capped Chickadee *Poecile atricapillus* (Kessel 1976), Carolina Chickadee *Poecile carolinensis* (Pitts 1976), Chimney Swift *Chaetura pelagica* (Zammuto & Franks 1981), Black Duck *Anas rupripes* (Brodsky & Weatherhead 1984), Black-billed Magpie *Pica pica* (Reebs 1986), Black-crowned Night Heron *Nycticorax nycticorax* (Perlmutter 1992), Merlin *Falco columbarius* (Warkentin 1986), House Crow *Corvus splendens* (Peh 2002), and Torresian Crow *Corvus orru* (Everding & Jones 2006). Only few birds are known to adopt the latter strategy: Snow Bunting *Plectrophenax nivalis* (Morse 1956), Redpolls *Carduelis* spp. (Brooks 1968) and Mourning Dove *Zenaida macroura* (Doucette & Reebs 1994)]. Why do birds prefer reducing rather than increasing their activity to maximize their thermoregulation benefits on cold days? This is probably because most birds have specific body structures, they can occupy sheltered roosting sites, or are able to adopt particular ways of roosting or body postures (Morse 1980, Doucette & Reebs 1994). Under cold conditions, the energy birds can save by remaining inactive is more than that which would be gained by actively foraging. Few spe-

cies, such as Mourning Dove whose body structures (e.g. thin foot papillae) or roosting behavior (e.g. a roosting posture in which the bill is not buried under the scapular feathers) are disadvantages for saving energy, must increase their activity levels. Furthermore, geographic area may also affect the selection of a particular strategy (Doucette & Reebs 1994). In many if not most areas, birds can first gather the minimum energy resources needed to survive the upcoming night, thus reducing their activity in cold weather. For species that spend the winter at high latitudes, such as Snow Bunting and Redpoll, the raised minimum level of energy required owing to longer and colder nights necessitates increased food intake and, consequently, prolonged foraging activity.

There are few published quantitative studies about temperature effects on general activity in Galliformes. In the present study, this aspect was evaluated in the rare Szechenyi Monal Partridges *Tetraophasis szechenyii* by examining the breeding-season roosting times. The partridge is restricted to western China and inhabits coniferous forests, alpine shrubberies and tundra above the treeline at 3,350–4,600 m a.s.l. Although it is listed as a first-grade protected species in the Red Book of China (Mackinnon et al. 2000, Madge & McGowan 2002, Wang & Xie 2004), its autecology remains poorly studied. Therefore, this research also aimed to provide information that is applicable for conservation of this species.

## 2. Material and methods

Field work was conducted in the Pumuling Mountain (30°06' N, 101°11' E; Fig. 1), Yajiang County, Ganzi Tibetan Autonomous Prefecture, Sichuan, China, from April to October 2006, and from March to May, 2007. The area of the study site was 339.75 ha and the elevation ranged from 3,900 m to 4,200 m. The climate was the sub-humid climate of the Qinghai-Xizang plateau. Five habitat types, based on vegetation characteristics, were distinguished: (1) Flaky fir forest = dense-branch azalea (*Abies squamata* and *Rhododendron fastigiatum*), comprising 27.6% of the study site; (2) Flaky fir forest = spiffy azalea (*A. squamata* and *R. calophytum*), accounting for 11.2% of the study site; (3) Hollyleaf alpine oak forest (*Quercus aquif-*

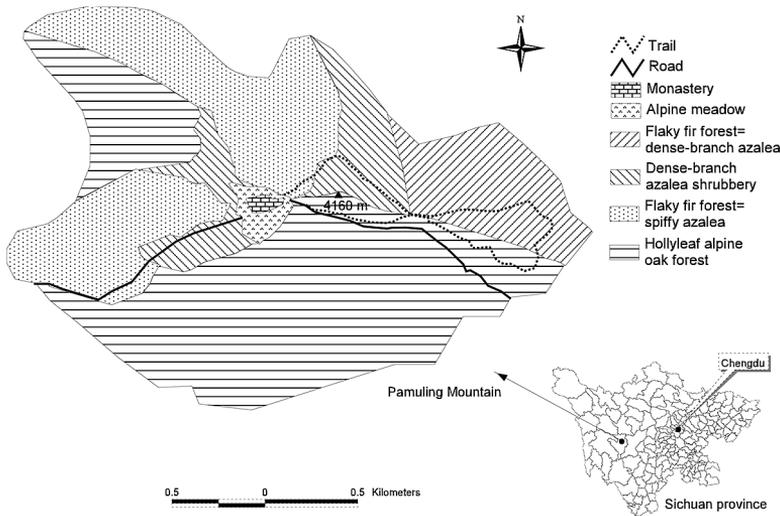


Fig. 1. The study site and habitat types in Sichuan, China, during 2006–2007.

*folioides*), accounting for 49.5% of the study site; (4) Dense-branch azalea shrubbery (*R. fastigiatum*), accounting for 10.5% of the study site; and (5) Alpine meadow, comprising 1.2% of the study site (Fig. 1).

Partridges were captured using drop-netting. Eight individuals were color ringed, but several individuals were also recognizable by their unique plumages. Two male individuals were fitted with radio-collar transmitters. Locations of individuals with transmitters were determined by triangulation technique, using a hand-held 3-element Yagi antenna with an ATS receiver (R1000, 148–174 MHz, made in Japan). Other individuals were located by cues such as calls, feeding traces and footprints observed while the researchers walked along roads or trails. A particularly tame population at a monastery allowed for easy observation, and an observer could approach the birds without affecting their behavior; the partridges were often

approached to a distance of 10 m without disturbance. Each night, the arrival time (the moment when the first individual arrived at a roost) and perching time (the time when individuals remained motionless and silent in a crouched position) were recorded and then standardized to minutes before (positive values) or after (negative values) the sunset. The roosts were revisited the subsequent morning 30 min before sunrise and the departure of the partridges was observed. The departure time (the moment when the first individual flew down to the ground from trees) was recorded in minutes before (negative values) or after (positive values) the sunrise. Data on sunrise and sunset times were downloaded from <http://www.time.ac.cn/serve/sunriseset/>.

Roosting times of birds are not influenced only by temperature; day length, cloud cover and precipitation can potentially affect daily roosting times. Therefore, these factors were also included

Table 1. Descriptive statistics of environmental variables of the evening (n = 78) and morning (n = 91) in Pamuling Mountain, Sichuan, China, 2006–2007.

Environmental variable	Evening		Morning	
	Mean±SE	Range	Mean±SE	Range
Day length (min)	791.7±3.0	737.0...846.0	798.3±3.0	686.0...848.0
Temperature (°C)	5.7±0.5	-8...+13	3.5±0.4	-9...+11
Cloud cover (fourth)	2.1±0.1	1...4	1.7±0.1	1...4
Precipitation (fourth)	1.4±0.1	1...4	1.5±0.1	1...4

in the study. Temperature was measured using a thermometer around the roost. Cloud cover and precipitation were visually estimated and recorded applying four categories where 1 = a clear day or little precipitation and 4 = full cloud cover or heavy rain/snow. These three variables (day length, cloud cover and precipitation) were recorded 30 min before and 10 min after sunrise (Table 1). Day length was calculated in minutes (time between sunrise and sunset; Janicke & Chakarov 2007).

The data were analyzed using generalized linear mixed models (GLMMs) which fit statistical models to data with correlations or non-constant variability, using PROC GLIMMIX in SAS version 9.1.3 (SAS institute 2005), with a normal error distribution and an identity link function. The dependent variable, roosting time, was analyzed with respect to the independent variables temperature, day length, cloud cover and precipitation, with pair or family group as the random effect. We began with a model with all factors and two-way interactions included, and continued with a backward elimination of non-significant interactions (Gorman et al. 2005, Chin et al. 2005). All tests were two-tailed and  $P < 0.05$  was interpreted as being statistically significant. Means are given as SE, unless otherwise stated.

### 3. Results

#### 3.1. Arrival

The partridges were cohesive pairs or family-based units that spent all of their time together (observations from 13 pairs or families; Table 2). During the day, they usually foraged in alpine oak forests, rhododendron shrubberies and alpine meadows. They returned to roost sites (fir forests) on average 54.7 3.0 min (range = from 9 to 56,  $n = 78$  observations) before sunset. On average 31.9 1.7 min (range = from -3 to 86,  $n = 78$  observations) before sunset the individuals began flying up to trees. Finally, on average 22.9 1.8 min (range = from -13 to 59,  $n = 78$  observations) before sunset, individuals had selected their perching branches and became silent (Fig.2).

Fig. 3 shows changes in variables observed in the evenings, along with the progress of the breed-

Table 2. Szechenyi Monal Partridges observed in the Pamuling Mountain, Sichuan, China, 2006–2007.

Pair or family No.	Members		
	Female	Male	Young birds
1	1	2	2
2	1	3	3
3	1	2	2
4	1	2	2
5	1	1	0
6	1	1	0
7	1	2	2
8	1	1	2
9	1	2	0
10	1	2	1
11	1	1	1
12	1	2	1
13	1	1	0

ing season. In general, temperatures went up from March to September, and day lengths first gradually increased (being the longest in July), followed by a decrease. Rainy and snowy evenings mostly occurred before May, while evening cloud cover varied more irregularly over time. The arrival and perching times did not significantly change during the breeding season.

The generalized linear mixed model of arrival and perching times is shown in Table 3. Results re-

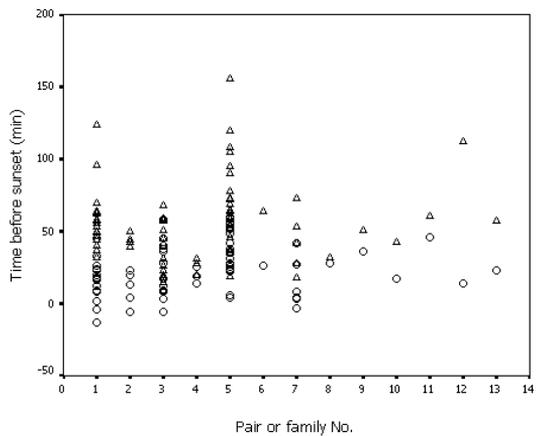


Fig. 2. Arrival (triangles) and perching (circles) times of 13 pairs or families of Szechenyi Monal Partridges in the Pamuling Mountain, Sichuan, China, during 2006–2007.

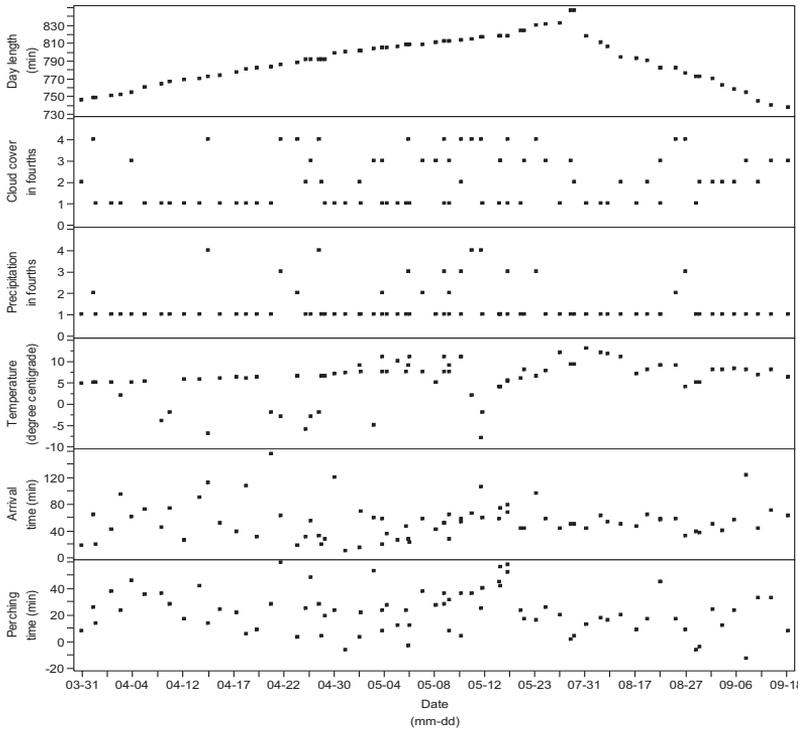


Fig. 3. Changes in variables observed in the evenings ( $n = 78$ ), along with the progress of the breeding season, in the Pamuling Mountain, Sichuan, China, during 2006–2007. Arrival and perching times were recorded in minutes prior to (positive values) or after (negative values) the sunset.

vealed that only temperature was negatively correlated with perching times ( $-1.29 \ 0.47$ ), while other factors and two-way interactions had no significant impact on arrival or perching times, indicating that the partridges perched earlier in cold evenings.

### 3.2. Departure

Ninety-one morning departures from 11 pairs or families were observed (Fig.4). Arousal was usually initiated by a loud call from one or two indi-

viduals, followed by calls from many others. While still calling actively, individuals rapidly began to fly down to the ground from trees. Departure time was on average  $7.3 \ 0.1$  min (range = from  $-13$  to  $32$ ,  $n = 91$ ) after sunrise.

Figure 5 shows changes in variables measured in the mornings, along with the progress of the breeding season. From March to October, temperatures increased and then decreased, peaking in August, and day lengths gradually increased from May to June, followed by a decrease. Rainy and snowy mornings rarely occurred after mid-May, and cloud cover varied irregularly over time. De-

Table 3. Effects of environmental factors on arrival ( $n = 78$ ) and perching ( $n = 78$ ). Temperature, precipitation, day length and cloud cover were considered as explanatory variables with pair or family number as the subject defined for a random effects model. The interactions not presented here were non-significant.

Source of variance	Arrival			Perching		
	df	F	P	df	F	P
Temperature	1,57	3.03	0.087	1,57	7.50	0.008
Day length	1,57	0.02	0.898	1,57	1.08	0.304
Cloud cover	3,57	1.38	0.259	3,57	1.17	0.328
Precipitation	3,57	0.24	0.868	3,57	0.65	0.585

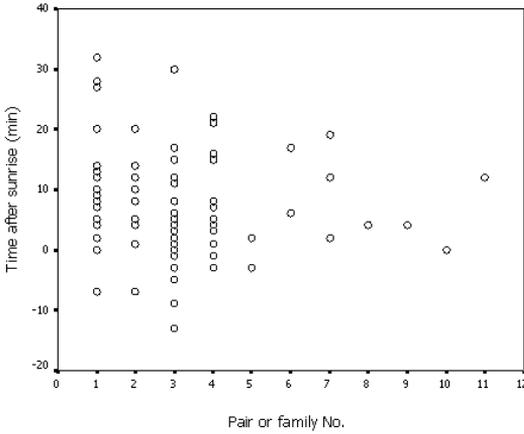


Fig. 4. Departure times of 11 pairs or families of Szechenyi Monal Partridges in the Pamuling Mountain, Sichuan, China, during 2006–2007.

Table 4. Effects of environmental factors on departure time. Temperature, precipitation, day length and cloud cover were considered as explanatory variables with pair or family number as the subject defined for a random effects model. The interactions not presented here were non-significant.

Source of variance	Departure		
	df	F	P
Temperature	1,72	4.08	0.045
Day length	1,72	2.11	0.151
Cloud cover	3,72	0.25	0.857
Precipitation	3,72	0.80	0.501

parture times fluctuated slightly during this period.

The generalized linear mixed model showed that only temperature was negatively correlated with departure times (−0.89 0.43), while other factors and two-way interactions had no significant effects on departure times, indicating that partridges departed later on cold than on warm mornings (Table 4).

### 4. Discussion

Temperature was associated with roosting times in the Szechenyi Monal Partridge. All other things being equal, the partridges tended to perch earlier and depart later the lower the temperature. As with birds in general, partridges may decrease their general level of activity during cold days. The temperature dependence indicates that, before perching, the Szechenyi Monal Partridge first gathers

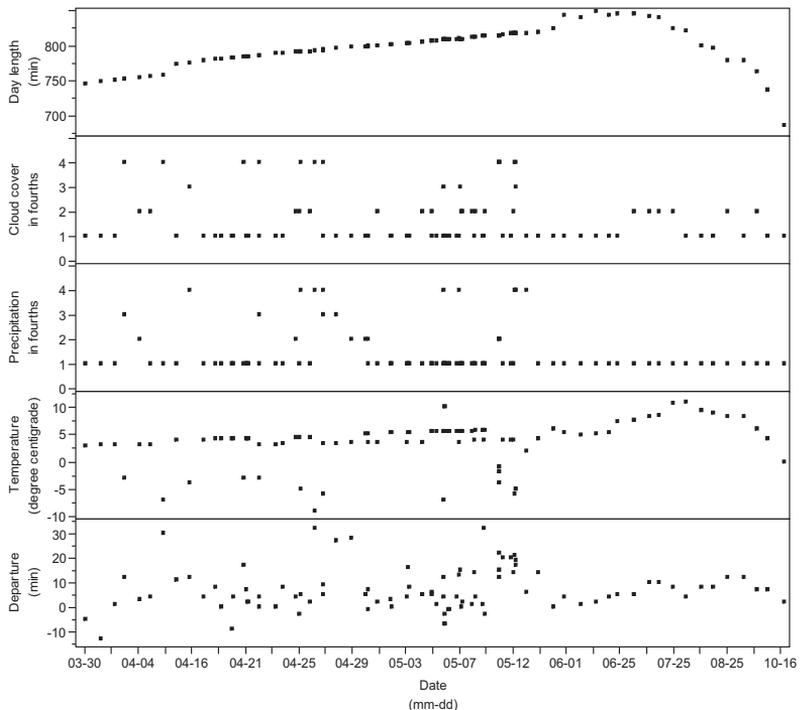


Fig. 5. Changes in variables observed in the study mornings (n = 91) along with the progress of the breeding season, in the Pamuling Mountain, Sichuan, China, during 2006–2007. Departure times were recorded in minutes prior to (negative values) or after (positive values) the sunrise.

the minimum energy resources necessary for overnight survival, and saves energy by remaining inactive rather than gaining more energy by actively foraging. The fact that the partridges roosted at some sheltered sites and adopted a huddled roosting behavior (Y. Xu, unpubl. data) supports this interpretation. Note, however, that the temperatures within the study period were not exceptionally low, not even in the highest study elevations.

At lower temperatures, the partridges did not arrive at roost sites earlier, which may be related to food availability. The partridges may not be able to gather the minimum energy resources required for overnight survival if they arrive too early at the roost sites when it is colder. Indeed food availability at roost sites was poorer than at foraging sites. The effects of low temperature were also much less pronounced on departure times than on perching times: temperature had a partial coefficient of  $-0.89$  for departure times versus  $-1.29$  for perching times.

This phenomenon is also known for the Black-billed Magpie (Reebs 1986). As an explanation we suggest that roosting times are associated with the hunger level of individuals. The partridges were evidently hungry in the mornings after a long night, and their increased motivation to forage might have made them less reluctant to leave the roost trees in cold or rainy/snowy mornings. These interpretations suggest that the amplitude of temperature effects on roosting times may depend on food availability and/or hunger level. Clearly, the effects of temperature on general activity of birds could be predicted if food items are available in such abundances that birds easily fulfill their energy requirements.

Body temperature of a bird individual might become lower if the individual is drenched with rain and snow, and therefore may spend longer time at a roost. In the present study, precipitation was included in the analysis to see whether rain or snow played a role similar to that of temperature. However, precipitation and associated interactions did not significantly correlate with roosting times. We suggest that the conditions at foraging habitats were good so that the partridges could forage in some sites with better shelter, such as a well-developed tree canopy.

Day length and cloud cover were predicted to have stronger effects on roosting times than other

environmental factors, because birds utilize longer days to a larger extent, and their daily activity budgets are regulated by light intensity (Janicke & Chakarov 2007). For diurnal species, one would have expected a reduced activity on long and cloudy days, or an increased activity on short and clear days (e.g., Martin & Haugen 1960, Schreiber 1967, Daan & Aschoff 1975, Brodie 1980, Reebs 1986, Doucette & Reebs 1994, Janicke & Chakarov 2007, Karlsson 2007). Surprisingly, the roosting times of Szechenyi Monal Partridges were not affected by day length or cloud cover, i.e., the partridges did not decrease their activity on long and cloudy days or increase it on short and clear days.

The reason for this is unclear, but it may be attributed to territory requirements. The partridges actively defended their breeding territories during the early and middle post-hatching period from May to August. They were also reluctant to leave their foraging sites and apparently attempted to spend as much time on them as possible. This behavior probably resulted in the lack of change in activity time. During incubation (from March to April) males protect their mates near nests (range  $<100$  m), and pairs or families tend to form flocks in late post-hatching period (from September to October) (authors pers. obs.). During these two periods, the partridges might not defend their foraging sites so actively or spend so much time on them. We suggest this to be the mechanism why they did not increase their activity times.

In conclusion, Szechenyi Monal Partridges were shown to decrease their general level of activity to minimize heat loss in low temperatures, but the amplitude of these temperature effects may depend on food availability or the hunger level of individuals. Such information can effectively guide the species monitoring. Future studies on the focal species should be done using even larger sample sizes and reduced data variance. In the present study, sample clustering and randomization of data were attempted to circumvent this issue by means of generalized linear mixed models. More attention should also be paid to additional environmental variables, such as wind speed and food availability. Moreover, because in winter weather conditions are more adverse and the partridges may maintain communal roosting, the species winter ecology may provide valuable insights on individual survival and on factors affecting it.

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### Lämpötilan ja muiden ympäristötekijöiden vaikutus metsälumipyynn *Tetraophasis szechenyii* lepäilyaikoihin pesimäkaudella

Alhaisissa lämpötiloissa linnut voivat vähentää aktiivisuuttaan lämmönhukan minimoidakseen, tai lisätä aktiivisuuttaan lämmöntuoton toivossa. Tässä tutkimuksessa näitä aspekteja tarkasteltiin metsälumipyynn, tutkimalla pesimäaikaista lepokjaksojen kestoa. Yksilöt saapuivat lepopaikoilleen  $54.7 \pm 3.0$  min ennen auringonlaskua ( $n = 78$ ), istuskelivat oksistossa  $22.9 \pm 1.8$  min ennen auringonnousua ( $n = 78$ ), ja lähtivät lepopaikastaan  $7.3 \pm 0.1$  min auringonnousun jälkeen ( $n = 91$ ). Yleistetty lineaarinen malli, jossa oli muuttujina lämpötila ja useita muita parametrejä (kuten päivänpituus, pilvipeite ja sademäärä), osoitti – oletettaessa muiden tekijöiden vaikutus hallituksi – että pyyt aloittivat istuskelun aiemmin ja jättivät lepopaikansa myöhemmin kylminä päivinä.

Tulos viittaa siihen, että metsälumipyöyt vähentävät aktiivisuuttaan lämmönhukan minimoidakseen alhaisissa lämpötiloissa. Pyyt eivät kuitenkaan saapuneet lepopaikkaansa aikaisin kylminä päivinä, ja alhaisen lämpötilan vaikutus lepopaikasta lähtöön oli vähäisempi kuin istuskeluun: lämpötilan vaikutuskerroin oli  $-0,89$  lepopaikasta lähtöajalle ja  $-1,29$  istuskeluajalle. Siten lämpötilan vaikutuksen suuruus näyttää riippuvan ravinnon saatavuudesta tai lintuysilöiden nälkäisyydestä.

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