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Original paper

Factors affecting pre-denning activity in Asian black bears

Seungyun Baek[1,*], Tadashi Iwasaki[1], Koji Yamazaki[2], Tomoko Naganuma[3], Akino Inagaki[1], Kahoko Tochigi[1], Maximilian L. Allen[4], Chinatsu Kozakai[5] and Shinsuke Koike[3,6]

[1] *Graduate School of Agricultural Science, Tokyo University of Agriculture and Technology, Fuchu, Tokyo 183-8509, Japan*
[2] *Department of Forest Science, Faculty of Regional Environmental Science, Tokyo University of Agriculture, Setagaya, Tokyo 156-8502, Japan*
[3] *Institute of Global Innovation Research, Tokyo University of Agriculture and Technology, Fuchu, Tokyo 183-8509, Japan*
[4] *Illinois Natural History Survey, University of Illinois, 1816 S. Oak Street, Champaign, IL 61820, U.S.A.*
[5] *Central Region Agricultural Research Center, National Agriculture and Food Research Organization (NARO), Tsukuba, Ibaraki, Japan*
[6] *Institute of Agricultural Science, Tokyo University of Agriculture and Technology, Fuchu, Tokyo 183-8509, Japan*

Abstract. Hibernation (denning) is an important aspect of the life history of Asian black bears (*Ursus thibetanus*), and denning chronology can be influenced by biotic and abiotic factors. We investigated activity patterns during the pre-denning period of Asian black bears using statistical process control in combination with activity sensors to quantitatively identify a marked reduction in activity from 2006 to 2017 in the Ashio–Nikko Mountains, Japan. Pre-denning activities were detected in 29 of 35 cases (83%), with an average duration of 2.7 ± 1.7 days, which is one to three days shorter than the duration for brown bears (*U. arctos*). The effect of bear's age, sex, and the abundance of hard mast on the duration of pre-denning were not significant.

Key words: activity change, denning chronology, den entry, hibernation, *Ursus thibetanus*.

There are three hibernating bear species that spend several months in their dens during winter and are native to the northern hemisphere: American black bear (*Ursus americanus*), Asian black bear (*U. thibetanus*), and brown bear (*U. arctos*). By hibernating, these bears cope with extreme environmental conditions, i.e., low food availability and low temperature; in addition, females give birth and raise their cubs while in the dens (Alt 1982; Friebe et al. 2001; Harlow et al. 2002).

Denning chronology, defined by temporal changes in behavior before and during denning, is influenced by biotic and abiotic factors, such as sex, age, reproductive status, food availability, and meteorologic factors (Craighead and Craighead 1972; Schoen et al. 1987; Friebe et al. 2001; Manchi and Swenson 2005; Baldwin and Bender 2010; González-Bernardo et al. 2020). Although extensive studies of denning chronology have examined the timing or duration of denning (Friebe et al. 2001; Manchi and Swenson 2005; Baldwin and Bender 2010; Waller et al. 2012; Yamamoto et al. 2016), the pre-denning period remains poorly understood. The pre-denning period is defined as the time between the end of hyperphagia, the period during which bears intensively search for food and store fat before hibernation, and den entry (González-Bernardo et al. 2020). During this period, bears display ecological characteristics including reduction of daily movement distance, den selection and construction, gradual reduction of activity, and staying close to the den (Craighead and Craighead 1972; Judd et al. 1986; Friebe et al. 2001; Manchi and Swenson 2005; Sahlén et al. 2015). A few studies have quantitatively examined these ecological characteristics in brown bears. Manchi and Swenson (2005) described that the mean daily movement distance of brown bears declined as the time of denning approached, especially during the last two weeks before denning. Sahlén et al. (2015) documented that the duration of staying close to the den until den entry in brown bears varied according to age, sex, and reproductive status. In addition, they identified a marked reduction of activity in the pre-denning

*To whom correspondence should be addressed. E-mail: altaica09@gmail.com

period (pre-denning activity) using acceleration measurement sensors within the Global Positioning System (GPS) collars and statistical process control. However, the factors that influence the pre-denning activities were not investigated, and the pre-denning activities of Asian black bears have not been examined. Using the methodology described in Sahlén et al. (2015) for brown bears, it is possible to quantitatively identify the pre-denning activities of Asian black bears and the factors which influence their pre-denning activities.

In this study, we aimed to quantitatively study the pre-denning activities of Asian black bears. In particular, we sought to identify pre-denning activities in Asian black bears and the factors that influence pre-denning activities and compared the duration of pre-denning activities between Asian black bears and Scandinavian brown bears. Because a previous study described significant differences between these species in heart rate changes during the period from hyperphagia to den entry (Fuchs et al. 2019), we assumed that the duration of pre-denning activities would also differ between Asian black bears and brown bears. Moreover, we assumed that the familiarity of the den area would affect the duration of pre-denning activities. Because younger bears may be less familiar with their home ranges than older bears and females have a stronger fidelity to their home ranges than males (Penteriani and Melletti 2020), we expected that the duration of pre-denning activity would be shorter in older bears than in younger bears and that the decrease in the duration of pre-denning activity with increasing age would be greater in females than in males. Furthermore, we hypothesized that the duration of pre-denning activity would be shorter in good mast years than poor mast years, because home range size is negatively affected by hard mast availability (Kozakai et al. 2011; Koike et al. 2012).

Materials and methods

Study area

The study was conducted in the Ashio–Nikko Mountains in central Honshu Island, Japan (36.44°–36.80°N, 139.22–139.49°E). In 2006–2017, the annual range of temperature and precipitation was 6.8°C–8.0°C and 1886.0–2976.0 mm, respectively (Oku-Nikko meteorological weather station, 36.44°N, 139.30°E; 1292 m above sea level [asl]; Japan Meteorological Agency 2020). The elevation ranged between 400 and 2400 m asl, and the landscape was characterized by steep terrain. The vegetation was deciduous broad-leaved forest consisting of *Quercus crispula*, *Q. serrata*, *Acer* spp., and *Fagus crenata* up to 1600 m asl. Mixed forests of *Tsuga* spp. and *Betula* spp. occurred above 1600 m asl. *Larix kaempferi* plantations were common between 1000 and 1600 m asl. *Cryptomeria japonica* and *Chamaecyparis obtusa* plantations were dominant below 1000 m asl.

Hard mast productivity

In our study area, bears primarily eat *Q. crispula* as a food source in autumn (Koike et al. 2012; Nakajima et al. 2012, 2018). From 2006 to 2017, we estimated mast production by visual assessments of *Q. crispula* throughout the study area. In 2006–2007, mast production was estimated by the method described by Mizui (1991), in which the numbers of acorns within a 50 × 20 cm area located in the upper crown of six different top branches per tree are counted. In 2008–2017, mast production was estimated by the method described by Nakajima et al. (2015), in which the crown of a tree is scanned with binoculars and the number of acorns is counted for a fixed time interval three times per tree. Using these data, we determined that the poor hard mast years were 2006, 2010, 2012, 2014, and 2016 (Kozakai et al. 2011; Masaki et al. 2020).

Bear data collection

We captured bears with barrel traps between 2006 and 2017. The bears were immobilized with tiletamine hydrochloride and zolazepam hydrochloride (Virbac, Carros, France) at a dosage of 8 mg/kg estimated body weight. A premolar was extracted for age determination. The bears were equipped with microchips and GPS collars (GPS3300S and GPS4400S, Lotek, Newmarket, Ontario, Canada; VERTEX PLUS, Vectronic Aerospace, Berlin, Germany) then released at the trap sites. All capture and handling methods were performed in accordance with the Guidelines for the Procedure of Obtaining Mammal Specimens as Approved by the Mammal Society of Japan (http://www.mammalogy.jp/en/guideline.pdf).

The GPS collars contained an activity sensor that recorded dual-axis motion of the animal's head and neck: i.e., up–down (hereafter Y-act) and side–side (hereafter X-act) movements (± 7.5°). The data for each axis motion (i.e., Y-act and X-act) were stored every 5 min for a maximum of 255 counts. As the activity value, we used the mean of Y-acts and X-acts in 5 min intervals, which was determined by:

$$activity\ value = (Y\text{-}act + X\text{-}act)\ counts/5\ min$$

In accordance with the method of Kozakai et al. (2008), each bear's activity status every 5 min was defined as inactive (number of activity counts ≤ 13) or active (number of activity counts ≥ 14).

Timing of den entry and activity data

In accordance with the method of Kozakai et al. (2011), we defined the date of den entry using the location and activity values acquired from the GPS collars. Because the bears used tree hollows, tree root cavities, and rock caves as den sites (Koike and Hazumi 2008), the GPS collars usually ceased generating successful fixes when the bears entered their dens. Therefore, we considered a bear as denned on the first day that the GPS fix rate dropped to 0%, and when the moving mean of daily active statuses (number of activity counts ≥ 14) was < 10% for three days. Because the daily activity and GPS fix rates fluctuated during pre-denning periods (Yamazaki et al. 2008; Kozakai et al. 2011), we used either the GPS data or the activity sensor data to estimate the date of den entry in cases in which only one of these datasets was available.

To determine when movement and activity changed significantly, we used statistical process control methods commonly used for controlling industrial processes (Shewhart 1931; Sahlén et al. 2015). The first step in statistical process control is to identify the "in control," which here means the normal activity pattern of the bear during the term prior to den entry. In general, control borders are two to three standard deviations around the mean. If the activity data cross the control border, then it is considered "out of control." We considered that pre-denning activity began when the bear's activity levels dropped under the control border.

Statistical analysis

Like Scandinavian brown bears, Asian black bears gradually reduce their activity before hibernation and have a bimodal daily activity pattern, which led us to define the pre-denning activity period by the method of Sahlén et al. (2015). The bimodal activity pattern complicates the determination of pre-denning activities; therefore, we set a window of moving averages to 150 continuous activity data points and obtained the final curve using Locally Weighted Scatterplot Smoothing (Cleveland 1979). Because 0 counted activity values (range 0–510) accounted for about 30% of the total Asian black bear activity data, we used all of the activity data, unlike in the brown bear studies, where only the upper 90th percentile of activity data was used (Sahlén et al. 2015). We used 35 cases (bear-years) of activity data from 23 individuals (Table 1) to obtain the statistical process control. The control behavior period (normal behavior) for each individual started on August 20, when we observed bear activity in our study area turning from summer to autumn (Kozakai et al. 2013), to the day before den entry. Two bears were captured after August

Table 1. The duration of pre-denning activity (Unit: Days; where UD = Undetectable) for the 35 cases of hibernation we examined, along with demographic information for Asian black bears and hard mast condition (HM) from the Ashio–Nikko Mountains

Bear ID	Year	Sex	Age	HM	Duration of pre-denning activity
AM01	2006	M	2	Poor	5
AM02	2006	M	3	Poor	1
AM04	2006	M	4	Poor	2
AF12	2007	F	6	Good	1
AF13	2007	F	6	Good	2
AM01	2007	M	3	Good	3
AM02	2007	M	4	Good	2
AF07	2008	F	7	Good	2
AF09	2008	F	4	Good	1
AF16	2008	F	2	Good	5
AF24	2008	F	6	Good	2
AM11	2008	M	6	Good	6
AM15	2008	M	4	Good	2
AM21	2008	M	5	Good	3
AF07	2009	F	8	Good	1
AF16	2009	F	3	Good	2
AF18	2009	F	3	Good	8
AF19	2009	F	2	Good	1
AF23	2009	F	11	Good	2
FB70	2009	F	13	Good	UD
AM15	2009	M	5	Good	4
MB64	2009	M	13	Good	2
AF07	2010	F	9	Poor	2
AF18	2010	F	4	Poor	2
AM15	2010	M	6	Poor	5
AF09	2011	F	7	Good	UD
AF35	2013	F	4	Good	2
AF45	2014	F	6	Poor	2
AM69	2014	M	6	Poor	4
AM69	2015	M	7	Good	UD
AF45	2016	F	8	Poor	UD
AF35	2017	F	8	Good	UD
AF55	2017	F	7	Good	UD
AM86	2017	M	3	Good	1
AM88	2017	M	4	Good	2

20, and their periods began on the day after they were captured (on August 24 and 29). We used data from the normal behavior period for all 35 cases as observed responses in a linear mixed model. We used the method described by Sahlén et al. (2015) to create graphs of the pre-denning activity of the study bears using the ggplot2 packages (R Development Core Team 2020). We defined the point that dropped below the lower control limit as the start of pre-denning activity (Fig. 1).

To analyze the association of each factor with the duration of pre-denning activity, we used general linear mixed models (GLMMs) using the lme4 package (lme4 library, R Development Core Team 2020). To account for the repeated sampling of individuals, we included each individual as a random variable in the GLMM models. We determined the top candidate models using the model. dredge package (MuMIn library, R Development Core Team 2020). We used age, sex, and mast production (poor or good) as variables in GLMM to determine which variables influenced the duration of pre-denning activity. We compared models using Akaike's information criterion (AIC) values, considering the top models to be those with ΔAIC < 2 and the model with the lowest AIC value as the optimal model (Burnham and Anderson 2002). We performed all analyses with R version 3.6.3 (R Development Core Team 2020).

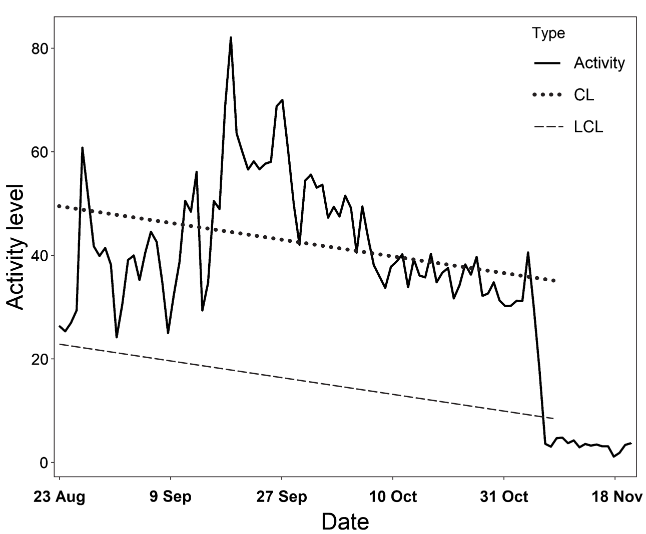

Fig. 1. An example of the fluctuation in activity level (black line) of an individual Asian black bear from the Ashio–Nikko mountains in Japan in 2010. The dotted line shows the bear-specific linear model of control limit (CL; normal activity), and the dashed line shows the lower control limit (LCL; pre-denning activity). We defined the start of pre-denning activity as the first day (November 6 in this example) in which the activity level dropped below LCL.

Results

We were able to statistically identify pre-denning activities for 29 of 35 observations (82.9%; Table 1). The duration of pre-denning activity was 2.7 ± 1.7 days (mean ± standard deviation [*SD*], median 2, range 1–8 days) before den entry (Table 1). The duration of pre-denning activity did not differ between the sexes (male 3.0 ± 1.5 days, $n = 14$ cases; female 2.3 ± 1.8 days, $n = 15$ cases; Mann–Whitney *U* test, $Z = 1.61$, $P = 0.11$). There was a tendency for the duration of pre-denning activity to decrease with increasing age in females (Fig. 2), but this was not a significant trend. We found three top models (Table 2), with the optimal model being the null model ($w = 0.37$), followed by age ($w = 0.20$) and sex ($w = 0.15$).

Discussion

We quantitatively identified a marked change in activity levels (pre-denning activities) in Asian black bears, for the first time. Pre-denning activities were detected with the use of statistical process control in 83% of cases. The duration of pre-denning activities ranged from one to eight days, with a mean of 2.7 days. This is one to three days shorter than for Scandinavian brown bears, and the maximum observation period differed by more than eight days (Sahlén et al. 2015). Fuchs et al. (2019) described differences in the heart rate of Asian black bears in Japan compared with brown bears in Scandinavia. The heart rates of Asian black bears decreased in late summer, increased drastically in autumn, and decreased drastically until den entry. The authors suggested that the characteristics of the changing heart rate of bears were potentially influenced by their responses to food availability. Brown bears in Scandinavia stably consume ants, forbs, ungulates, and berries in the summer and autumn and intensively consume berries in the autumn (Persson et al. 2001; Hertel et al. 2019). However, the food availability of Asian black bears in Japan drastically decreases in the late summer and drastically increases with the ripening of acorns in the autumn (Kozakai et al. 2013; Furusaka et al. 2019). Because bears need to store enough fat for hibernation (Folk et al. 1972), Asian black bears have to spend more time in foraging in the autumn, which may cause an increase in activity for a short time. Furthermore, the difference between Asian black bears and brown bears in the duration of the decline in activity may be due to differences in the main autumn food items. In the autumn, brown bears

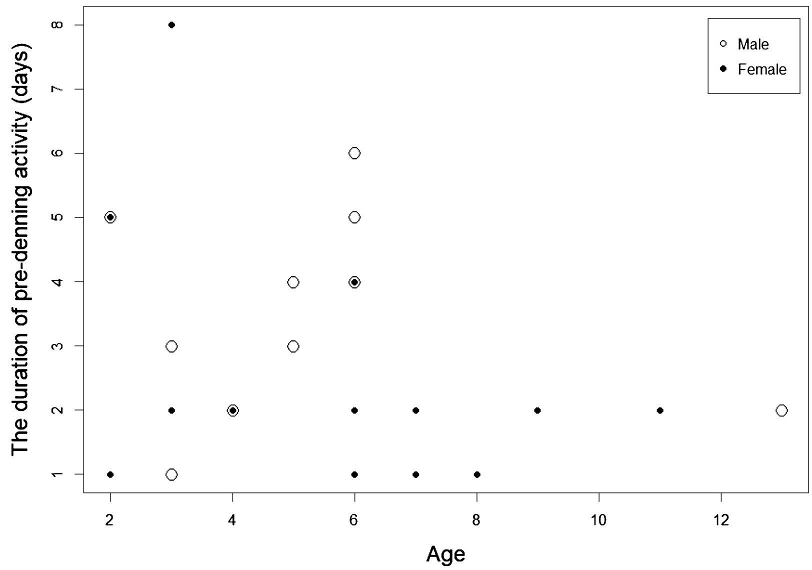

Fig. 2. Age-specific duration of pre-denning activity by sex.

Table 2. Model selection table showing Akaike's information criterion tests for affecting the period of pre-denning activity of Asian black bears from the Ashio–Nikko Mountains

Model intercept	Variables			*df*	logLik	AICc	ΔAICc	*w*
	Age	Mast	Sex					
0.99				2	–53.49	111.40	0	0.37
1.27	–0.05			3	–52.87	112.70	1.25	0.20
0.90			+	3	–53.13	113.20	1.77	0.15

Blank cells show that the variable is not included in the candidate model.

eat berries and Asian black bears eat acorns as their staple foods. Berries generally decompose after they fall and cannot be eaten, resulting in a gradual decline in food availability. Acorns, on the other hand, remain on the forest floor without decomposing after falling (Koike 2009). Therefore, brown bears may decrease their activity in response to the decrease in food availability, but Asian black bears may maintain a high level of activity and then rapidly decrease their activity just before den entry because they can eat acorns until just before hibernation.

We did not find any significant relationship between the duration of pre-denning activities and factors that were suspected to be influential, i.e., age, sex, and the abundance of hard mast. Previous studies suggested that denning chronology differs according to sex and reproductive status, i.e., single or with cubs, and when single, pregnant or not (Judd et al. 1986; Manchi and Swenson 2005; Waller et al. 2012). Unfortunately, the reproductive status of most of the females in this study was unknown, which likely limited our analysis. Further studies could clarify these issues by using larger sample sizes in which the reproductive status of female bears was known and identifying any differences in the pre-denning period due to reproductive status or other factors.

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