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Factors affecting body weight fluctuation in free-ranging Asian black bears

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Abstract: The Asian black bear (*Ursus thibetanus*) shows seasonal changes in body weight, activity level, and range use. However, there is little information available on these factors in individuals in the wild. We documented the body weights of free-ranging Asian black bears from spring to autumn, 2017 to 2019, in the Nikko-Ashio Mountains, Tochigi Prefecture, Japan, by using a newly noninvasive body weighing system (NIBWS) that we developed. We also fitted Asian black bears with global positioning system (GPS) collars with built-in activity sensors to evaluate the relationship between body weight, behavioral factor, and activity level. Bears visited the NIBWS 88 times in 2017, 176 times in 2018, and 321 times in 2019. We recorded the body weights of 4 bears in 2017, 15 bears in 2018, and 11 bears in 2019. Specifically, we consecutively recorded the body weight of an adult female from 2017 to 2019 and collected GPS location data from 2017 to 2018. The adult female was solitary in 2017, and she was accompanied by 2 cubs in 2018 and the yearlings of those cubs in 2019. Her body weight was lowest in 2018, likely because she had spent a large amount of her energy expenditure on nursing her cubs, compared with the year when she was solitary or nursing her yearlings. The GPS data showed that no significant relationship was found between body weight and any behavioral factors. Although her activity level decreased drastically in late August, her body weight did not decrease accordingly. In contrast, a subadult female that we tracked in 2019 increased her body weight during May to August, likely because she was solitary and required high intake of energy and nutrition for growth. Although our results provide only a snapshot, we established NIBWS and this is the first record of body weight changes over multiple years in free-ranging Asian black bears to our knowledge.

Key words: age class, behavioral factor, demographic group, energy budget, Japan, noninvasive body weighing system, nutritional condition, *Ursus thibetanus*

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The Asian black bear (*Ursus thibetanus*; hereafter, “ABB”) seasonally shifts its diet (Hashimoto 2002), home range, and elevation (Kozakai et al. 2011, Arimoto et al. 2014). The ABB feeds mainly on new leaves and flowers of trees, grasses, ants, and vertebrate

carcasses from spring to summer (Koike et al. 2016), when the bears’ nutritional condition is poorer than in other seasons (Furusaka et al. 2019). For example, the estimated energy intake of ABBs was 80–300 kcal/day from social insects (i.e., ants) during spring and summer (Yamazaki et al. 2012). In contrast, during the hyperphagia period in autumn when hard mast (i.e., fruits of forest shrubs and trees, in this region especially

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that produced by *Quercus* spp.) is available, ABBs' energy balance may become substantially positive (Furusaka et al. 2019) and their nutritional condition is better than in spring and summer (Hashimoto and Takatsuki 1997). The ABB uses the body fat reserves accumulated in autumn during winter hibernation and in the following spring to summer (Yamazaki et al. 2012). Energy expenditure is likely to exceed energy intake from June to August if the previous autumn's hard mast crop has been poor (Furusaka et al. 2019). Hence, ABBs likely have the chance to recover their nutritional condition basically during the hyperphagia period in autumn.

The activity level of some bear species shifts dramatically through the year (Schwartz et al. 2010, Kozakai et al. 2013, McLellan and McLellan 2015). In particular, the activity level of ABBs is greatly reduced in August, just before the hyperphagia period (Kozakai et al. 2013). The heart rate of ABBs had a lower level at mean 64 beats/minute (bpm) from July to mid-August, compared with that of mean 110 bpm in the beginning of October (Fuchs et al. 2019). In addition, activity level differs with sex, age class, and reproductive status (hereafter, "demographic group"; Kozakai et al. 2013). Nutritional condition also differs with demographic group in the American black bear (*U. americanus*; Schwartz et al. 2014), which is closely related to the Asian black bear (Peppin et al. 2008). However, the findings of previous studies provide only few discontinuous data, and little is known about the relationships between behavior and nutritional condition in ABBs of each demographic group. To explain these behavioral and physiological characteristics, it is also necessary to determine the fluctuation of nutritional condition through a year.

Previous studies have used seasonal changes in body weight or body fat mass as an index of nutritional condition for ABBs. In captive ABBs, body weight increases in spring, levels off in summer, and increases rapidly in autumn (Hashimoto and Yasutake 1999). Data from nuisance-killed ABBs indicate that kidney fat mass decreases from den emergence (Apr–Jun) to late summer (Jul–Sep), and increases to the maximum value just before denning (Oct–Nov) and in the denning period (Jan–Mar; Gifu Prefecture 1995). On the other hands, these studies on free-ranging ABBs have collected only intermittent data from nuisance-killed individuals (Gifu Prefecture 1995, Yamanaka et al. 2011), and no continuous data are available on the body fat mass or body weight of free-ranging ABBs. In addition,

capturing by traps for ecological studies provides an opportunity to record the body weights of free-ranging ABBs; however, such opportunities usually only occur up to few times per year.

In this study, we evaluated the fluctuation in nutritional condition and investigated the behavioral factors that affected nutritional condition of ABBs according to demographic group by using a new noninvasive body weighing system (NIBWS) that we developed and global positioning system (GPS) collars with built-in activity sensors.

Study area

The study area (36.63–36.73°N, 139.34–139.46°E) was located in the Ashio-Nikko Mountains, in Nikko National Park, Tochigi Prefecture, central Honshu, Japan. Elevation ranged between 670 m and 2,000 m above sea level. The area is heavily deforested; it experienced a forest fire in 1887 and is contaminated by pollution from a copper mine that operated from the 1880s to 1989. Since the 1950s, extensive tree-planting operations have been carried out by the Forestry Agency, but some areas remain grassy or denuded. The major tree species planted are Japanese black pine (*Pinus thunbergii*), larch (*Larix kaempferi*), locust tree (*Robinia pseudoacacia*), Japanese clethra (*Clethra barbinervis*), Japanese green alder (*Alnus firma*), and birch (*Betula* spp.). Some patches of old-growth native forest remain, such as Japanese oak (*Quercus crispula*), konara oak (*Q. serrata*), and maple (*Acer* spp.).

Methods

Recording body weight by using the NIBWS and genetic sampling

We set up the NIBWSs from 2017 to 2019 in the study area (~4 km²) to lure the ABBs, which included the individuals that we had captured and fitted with GPS collars from 2003 to 2020 in this study area (Table 1; Table S1, *Supplemental material*). To build the NIBWS, we fixed a timber (1,820 × 38 × 89 mm) between 2 trees at 150 cm above the ground by using wire. We affixed honey bait (~200 cm³; poured into a plastic bottle with some holes punched on the upper side) to the center of the timber to entice visiting ABBs to stand (Higashide et al. 2013), rendering their chest mark visible. On a tree about 3 m downslope from the bait, we mounted an infrared-activated remote camera

Table 1. Locations where the noninvasive body weighing system (NIBWS) was set up to obtain body weight measurements from free-ranging Asian black bears (*Ursus thibetanus*) between 2017 and 2019 in the Nikko-Ashio Mountains, Tochigi Prefecture, Japan. The settled area was defined as a minimum convex polygon of the settled point of NIBWSs.

Year	2017	2018	2019
No. of scale locations	6	10	8
Survey area (km ²)	0.8	3.9	1.2
Mean distance between the scale location (km)	0.7	1.3	1.3
Scale availability period	late Mar–early Dec	mid-May–early Dec	mid-May–early Dec
Average interval of checking NIBWS (days)	13	9	18

(hereafter, “chest camera”; Trophy Cam HD Aggressor-119776, Bushnell, Overland Park, Kansas, USA). Under the bait, we placed a dustproof, waterproof platform scale (530 × 390 × 128 mm; SE-150KBL, A&D Company, Ltd., Tokyo, Japan) into a hole the size and height of the platform scale, so that the top of the scale was level with the ground. In the bottom of the hole, we laid 4 foundation bricks (20 × 20 × 3 cm) to stabilize the platform. To disguise the metal top of the platform scale and make it more likely that bears would step on it, we glued a plywood sheet, 10 cm longer and wider than the scale pan, to the scale pan.

The platform scale had a digital readout that shows the weight. To record each bear’s body weight, we mounted another infrared-triggered remote camera with 3 models (“weight camera”; Trophy Cam HD Aggressor-119776, Bushnell; Ltl-6310, Ltl Acorn, Des Moines, Iowa, USA; PH730s Trail Camera, ENKEEO, Shenzhen, Guangdong, China) in front of the digital readout to photograph each bear’s weight. We adjusted the angle of the weight camera to activate when a bear stepped on the platform scale. We fixed the digital readout to the base of a tree beside the platform scale with wire (Figs. S1, S2, *Supplemental material*). We programmed the chest camera and the weight camera to enter video mode for 60 seconds per activating event, with a 5-second delay between activating events.

From 2018 to 2019, we also wrapped barbed wire around the timber to collect bear hair for genetic analysis. To collect hair samples, we applied a mixture of essential oil of hinoki cypress (*Chamaecyparis obtusa*) and beeswax (hereafter, “Hinoki wax”) as a lure to the top of the timber. When an ABB smells Hinoki wax, it will usually rub its body on the source of the scent similar to its trait of rubbing its body on conifers (Ogawa et al. 2020).

To record bear body weight, we watched the weight-camera video recording of each bear visit to the scale

in frame-by-frame mode. We recorded up to 60 body weight values for each visit, then calculated the mean value. However, we did not record body weight values when bears were in certain physical positions (such as when a bear only had one foot on the scale) unsuitable for recording an accurate body weight. If we obtained >2 sets of weight-camera data for a single bear within a day, we used the data with the greatest number of mean body weight values.

We visited NIBWS at 13-day intervals in 2017, 9-day intervals in 2018, and 18-day intervals in 2019 (Table 1) to recalibrate platform scale, pour honey bait, change battery, and collect video data and hair samples.

Individual identification

Chest mark. The chest marks of ABBs are distinct and unique to each individual and are therefore useful for identification (Higashide et al. 2012). We identified individuals by using the chest marks that were video-recorded. At first, we clipped from the video data a scene that recorded a chest mark as a static image. Using the clipped static image, we distinguished the chest mark visually via some characteristic shape (Fig. S3a,b, *Supplemental material*). At last, we identified individuals with these chest mark pictures, which were obtained from the current study or captured ABBs from within this study area (Fig. S3c, *Supplemental material*).

Genetic analysis. We collected the hair samples from the barbed wire into paper envelopes by using heat-sterilized tweezers. To prevent contamination, samples for each barb or hair cluster were put in separate envelopes (Kitamura and Ohnishi 2011). Hair samples were stored at room temperature with silica gel packets, which were exchanged at a month interval, until DNA extraction. We extracted genomic DNA from the roots of hair samples by using a DNeasy Blood and Tissue kit (Qiagen, Inc., Germantown, Montgomery, Maryland, USA). We determined the genotype at 14 microsatellite

DNA loci (G1A, G1D, G10B, G10J, G10L, G10P, G10X, MSUT-1, MSUT-2, MSUT-6, MSUT-7, UarMU05, UarMU23, UarMU50 [Paetkau et al. 1995, 1998; Taberlet et al. 1997; Kitahara et al. 2000]) by polymerase chain reaction (PCR) according to Takayama et al. (2023). To identify individuals, we used the CERVUS software version 3.0.7 (Kalinowski et al. 2007) to calculate the probability of identity (PID; Waits et al. 2001). However, we placed the NIBWSs in small areas (0.8 km² in 2017; 3.9 km² in 2018; 1.2 km² in 2019) and visiting individuals could be close kin-relations with each other because of matrilineal site fidelity (Kozakai et al. 2017); therefore, we also calculated the probability of sib identity (PID-SIB), which is customized for use among siblings (Kitamura and Ohnishi 2011). However, we only utilized PID-SIB to identify individuals more precisely than PID and did not mention siblings among individuals that visited NIBWS. We used genotype data from the hair samples collected in this study, as well as from the 110 blood samples collected from individuals captured in this study area (see next section).

Calculating activity level and travel distance

We captured ABBs from 2003 to 2020 by using a handmade barrel trap (58 × 180 × 61 cm) baited with a bucket of honey. The barrel trap's door closes when a bear enters the trap and pulls the bait wired with a trigger. We set a very high frequency (VHF) transmitter to monitor the door closure. We immobilized captured ABBs by injection of a mixture of tiletamine hydrochloride and zolazepam hydrochloride (Virbac, Carros, France; 8 mg/kg estimated body weight), measured bear body weight and body size, collected blood samples for DNA analysis, and removed a first premolar for age determination. We fitted some ABBs with GPS collars (GPS3300S and GPS4400S [Lotek Wireless Inc., Ontario, Canada]; GPS Plus or Vertex Iridium [Vectronic Aerospace GmbH, Berlin, Germany]) with an activity sensor. For the Vectronic collars, the GPS location data could be retrieved via the iridium satellite, but the activity sensor data were downloadable only after the collars had been retrieved. All collars had a radioactivated collar-release device. We released all ABBs at the capture site. All experimental procedures followed the guidelines for animal research established by the Mammal Society of Japan (<https://www.mammalogy.jp/en/guideline.pdf>).

Within the group of bears for which we recorded continuous body weight by NIBWS, we obtained the

GPS location and activity sensor data from the retrieved GPS collar only of a single adult female (AF55). We classified the location data of AF55 as “traveling” or “stationary” by using a switching state-space model (SSSM; Arimoto et al. 2014). In addition, we classified “stationary” locations as “foraging” or “resting” on the basis of the activity sensor data. The collars with built-in activity sensors recorded horizontal and vertical motion at 5-minute intervals. Previous studies defined the threshold values of the total number of horizontal and vertical movements per 5 minutes (hereafter, “activity value”) for “active” or “inactive” for the Lotek (i.e., Kozakai et al. 2008). However, no threshold values had been defined for the GPS Plus Iridium collars. We therefore defined the threshold values for active and inactive states for the GPS Plus Iridium collars in accordance with the method of Arimoto et al. (2014), by using activity sensor data ($n = 104,206$). We assumed that inactive state continues to a certain time. If the probability of adjacent activity value ($a - 1$ or $a + 1$) = 0 was $>50\%$, we defined the activity value (a) as “inactive.” As the result, we defined activity values ≤ 13 as inactive, and activity values ≥ 14 as active for the Vectronic GPS Plus typecollars. We defined “stationary” locations in which bears were in an active state as “foraging locations” and “stationary” locations in which bears were in an inactive state as “resting locations.” We calculated the total hours of each day used for traveling, foraging, and resting. The fixed interval for GPS locations was 2 hours, so the duration of activity status (hereinafter, activity time) was determined in blocks of 2 hours. We used the software WinBUGS (Lunn et al. 2000) for Markov chain Monte Carlo analysis of SSSM and the Program R packages “R2WinBUGS” and “MASS.” Also, use of the SSSM allowed us to smooth errors and defects in the location data (Arimoto et al. 2014). We calculated daily travel distance by using the R package “adehabitatLT” on the basis of the smoothed location data. All R packages were implemented in Program R version 3.6.1 (R Core Team 2019).

Statistical analysis

For individuals with body weight data from multiple years, we compared differences between years for each individual by using the Tukey–Kramer honestly significant difference test (Tukey's honestly significant difference [HSD] test).

To determine the fluctuation pattern of activity value, we used a generalized additive model (GAM) and the

Table 2. Characteristics of free-ranging Asian black bears (*Ursus thibetanus*) for which body weight measurements were obtained between 2017 and 2019 by the noninvasive body weighing system (NIBWS) in the Nikko-Ashio Mountains, Tochigi Prefecture, Japan. We defined bears 2–4 years old as independent from their mother and bears >5 years old as adults.

Bear ID	Sex	Age in 2019	Age class	Body weight recorded	Demographic group			GPS location and activity data
					2017	2018	2019	
AF55	Female	9	Adult	2017, 2018, 2019	Solitary	With cubs	With yearlings	2017, 2018
AF46	Female	13	Adult	2019	Solitary	Solitary	Solitary	Null
AF82	Female	3	Subadult	2019	Solitary	Solitary	Solitary	Null

R package “mgcv.” As a response variable, we fitted activity value. As fixed terms, we fitted a smooth term for the date on which the activity value was recorded. The period of smooth terms (Date) was 6 June to 30 September, to facilitate comparison across all years.

We applied a linear regression model (LM) to clarify the effects of traveling time, foraging time, resting time, and traveling distance (“behavioral factors”) on fluctuations in body weight. We fitted body weight as a response variable and behavioral factors as explanatory variables. We assumed that body weight was influenced by the integrated value of behavioral factors before the recording of body weight. We summed the values of each separate behavioral factors in the intervals of 2 days, 4 days, 6 days, 8 days, and 10 days before body weight measurement. We constructed LMs by using these integrated values as the explanatory variable (behavioral factor). We selected the best LMs in each individual per year by selecting for the minimum Akaike information criterion (AIC_c). We evaluated the effects of activity values and behavioral factors on body weight only for AF55 because AF55 was the only individual for which we obtained a combination of GPS and activity data sets. We were able to perform these analyses only for 2017 and 2018 because we could not retrieve activity sensor data for AF55 in 2019. These analyses were performed in Program R version 4.0.5 (R Core Team 2021).

However, most bears’ body weights were recorded only once or a few times per year (Table S2, *Supplemental material*), and we were able to obtain continuous body weight records through multiple years for only one adult female (AF55). We obtained 9 body weight measurements (N_b) for AF55 in 2017, 7 in 2018, and 7 in 2019. In 2019, we were able to obtain continuous body weight measurements for another adult female (AF46, $N_b = 6$) and a subadult female (AF82, $N_b = 8$; Table 2). Although we obtained some other bears’ continuous body weight measurement

within a year (Tables S2, S3, *Supplemental material*), we focused on the above 3 female ABBs because the N_b of these individuals were more sufficient and recorded over a longer period. We recorded body weights of these 3 individuals between late May and September.

Results

Recording the body weight of bears by using the NIBWS

From 2003 to 2020, we had captured 110 individuals in this study area, and used all these chest mark photos and genetic samples to identify individuals that visited the NIBWS. The NIBWS was active for 252 days in 2017 (31 Mar to 8 Dec), 206 days in 2018 (17 May to 9 Dec), and 194 days in 2019 (21 May to 1 Dec). Bears visited the NIBWS 88 times in 2017, 176 times in 2018, and 321 times in 2019. Identification rate within these visits was 30% (26 times by chest mark) in 2017, 46% (81 times; 70 times by chest mark and 11 times by genetic analysis) in 2018, and 40% (127 times; 122 times by chest mark and 5 times by genetic analysis) in 2019. Eight identified individual bears visited the NIBWS in 2017, 23 visited in 2018, and 27 visited in 2019 (Table S1). Of these identifications, 2 bears visited multiple times (>5 times) in 2017, 8 visited multiple times in 2018, 9 visited multiple times in 2019, and 14 visited multiple times from 2017 to 2019 (Table S1). We recorded body weights of 4 individual bears in 2017, 15 bears in 2018, and 11 bears in 2019 (Tables S2, S3).

The body weight of AF55 was similar in 2017 and 2019, ranging from about 43 kg to about 49 kg in both years; but it was significantly lower in 2018 than in 2017 and 2019, ranging from about 36 kg to about 40 kg (Fig. 1; Tukey’s HSD test; $P < 0.001$). This female was solitary in 2017, caring for 2 cubs in 2018, and caring for 2 yearlings in 2019, as confirmed both by direct observations and the NIBWS remote camera

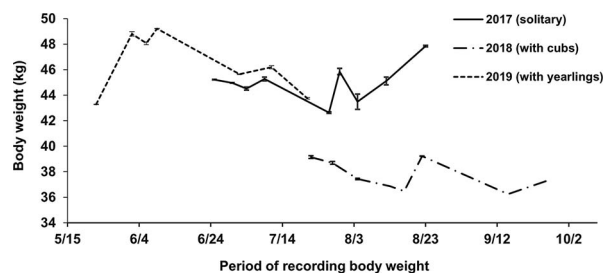


Fig. 1. Body weight of the adult female Asian black bear (*Ursus thibetanus*; AF55) recorded in the Nikko-Ashio Mountains, Tochigi Prefecture, Japan, between late May and September (x-axis = month/day) in 2017, 2018, and 2019. Error bars indicate standard error.

data. Therefore, we could compare fluctuations in the body weight of this female with her demographic group during each year. However, the date ranges for 2018 (mid-Jul to late Sep) and 2019 (mid-May to mid-Jul) did not overlap, and there was only about 50% overlap between 2017 (late Jun to late Aug) and 2018 (mid-Jul to late Sep). We also confirmed the same tendency in the study area, although these data were collected in a period previous to the current study—that body weight of 2 adult females with cubs (FB70 = 47 kg; AF23 = 42 kg) or with yearlings (FB70 = 41 kg) was lower than their body weight during the year that each was solitary (FB70 = 62 kg; AF23 = 57 kg; Table 3). However, adult female FB74 differed in having lower body weight during a solitary year (FB74 = 39 kg) than during the year with cub (FB74 = 53 kg; Table 3).

Activity level and body weight

The daily activity level (mean daily activity value) of AF55 exhibited nonlinear change over the time (Fig. 2; 2017 and 2018; $P < 0.001$). In both years, daily activity level was lowest in late August and was markedly higher

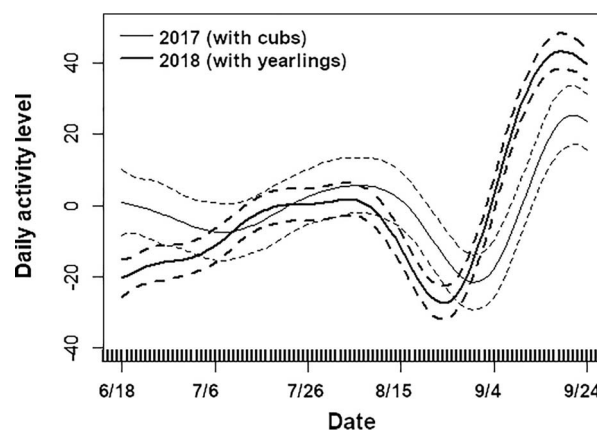


Fig. 2. Daily activity level estimated by the generalized additive model in the adult female Asian black bear (*Ursus thibetanus*; AF55) in the Nikko-Ashio Mountains, Tochigi Prefecture, Japan. Y-axis indicates difference value based on zero (indicating mean activity level). Activity data were obtained by using a global positioning system (GPS) collar with a built-in activity sensor attached to AF55. The dotted lines show 95% confidence intervals for each year. Recording was limited to the period when we also recorded body weight for AF55 in 2017 and 2018 (mid-Jun to late Sep; x-axis = month/day).

in September than in the summer (Jun to Aug), and the daily activity level in September was significantly higher in 2018 than in 2017. However, the mid-June activity level was lower in 2018 than in 2017 (Fig. 2). Fluctuations in the daily activity level were not fully synchronized with those in body weight because body weight slightly increased even in late August when the daily activity level decreased (Figs. 1, 2).

Effects of behavioral factors on body weight

Both in 2017 (solitary) and in 2018 (with cubs), behavioral factors did not have a significant influence

Table 3. Differences of body weight by demographic group of each individual adult female Asian black bear (*Ursus thibetanus*) in the Nikko-Ashio Mountains, Tochigi Prefecture, Japan. Body weight values of the 3 females were recorded at the barrel-trap site where they captured. These data were collected during a period previous to the current study.

Bear ID	Sex	Date	Age	Demographic group	Body weight (kg)
FB70	Female	Jun 2004	8	With yearlings	41
		Jun 2005	9	Solitary	62
		Jun 2006	10	With cubs	47
FB74	Female	Jun 2006	10	With cub	53
		Aug 2007	11	Solitary	39
AF23	Female	Aug 2008	10	Solitary	57
		Jul 2009	11	With cub	42

Table 4. Best linear regression models for body weight of an adult female Asian black bear (*Ursus thibetanus*; AF55) in 2017 (solitary) and 2018 (with cubs) in the Nikko-Ashio Mountains, Tochigi Prefecture, Japan. “AIC_c” is Akaike information criterion corrected for small sample size. “SE” is the standard error.

Demographic group (recording yr)	Model		Intercept	Estimate	AIC _c	SE	r ²
	Behavior	Integrated days					
Adult female, solitary (2017)	Resting time (hr)	2	39.716	0.240	39.535	0.160	0.244
Adult female, with cub (2018)	Traveling time (hr)	8	40.849	-0.088	31.194	0.038	0.474

on body weight of AF55 (Table 4). In 2017, the traveling time of AF55 (solitary) was the shortest of the 3 daily activity times (Fig. 3a; average traveling time = 2.97 hr/day, average foraging time = 10.45 hr/day, average resting time = 10.58 hr/day). The explanatory variable of the best-fit model was the resting time integrated over 2 days, which had a positive effect on body weight (Table 4; Estimate = 0.244, SE = 0.160, AIC_c = 39.535). In 2018, the traveling time of AF55 (with cubs) was also shortest (Fig. 3b; average traveling time = 3.49 hr/day, average foraging time = 9.05 hr/day, average resting time = 11.46 hr/day). The explanatory variable of the best-fit model was the traveling time integrated over 8 days, which had a negative effect on body weight (Table 4; Estimate = -0.088, SE = 0.038, AIC_c = 31.194).

Differences in body weight fluctuations between adult and subadult bears

We plotted the fluctuation of body weight starting in late May (0%) for each individual. In contrast to the adult female bears (AF46 and AF55) whose body weights decreased from June to August, the body weight of the subadult female bear (AF82) increased by 20% from late May to August (Fig. 4).

Discussion

We applied the NIBWS and succeeded in measuring body weight of ABBs without capture for the first time. In 2017, our method involved identifying individuals solely based on chest markings using the NIBWS, yet the identification rate was deemed insufficient. Subsequently, in 2018 and 2019, we enhanced our identification process by incorporating hair samples for genetic analysis in addition to chest markings; these served as complementary methods. Consequently, genetic analysis of hair samples compensated for instances where identification based solely on chest markings failed, albeit to a limited extent. Thus, when utilizing the NIBWS, the combined approach of capturing chest

markings and collecting hair samples may be preferable for simultaneous identification.

To our knowledge, this is the first time anyone has determined patterns of body weight fluctuation in free-ranging ABBs of different demographic groups. The body weight of the adult female (AF55) was lower in 2018 (when she was caring for 2 cubs), than in 2017 (when she was solitary), or in 2019 (when she was caring for 2 yearlings). This pattern indicated that the adult female bear had higher energy expenditure or reduced food intake when she was with cubs compared with in her other demographic groups. Generally, mammals expend a large amount of energy on raising offspring (Zera and Harshman 2001), which causes poor nutritional condition due to lactation, and influences cementum annuli width of the first premolar tooth (Tochigi et al. 2018). When searching for food, females with cubs can be limited in terms of movement distances (Shirane et al. 2021). Hence, AF55 may also have been limited in time available to spend foraging when she was with a cub and required to nurse it intensively. In addition, AF55 may have provided a larger amount of milk for cubs than for the yearlings because of the difference in demand from neonates of each age. However, this pattern was not necessarily confirmed in the study area in other females (see Table 3). The body weight of FB70 with cubs and with yearlings was lower than that when she was solitary, which indicated that FB70 might have had higher energy expenditure or reduced food intake not only with cubs but also with yearlings. On the other hand, the body weight of FB74 during solitary year was lower than during the year with cub, which indicated that FB74 might have had higher energy expenditure or reduced food intake when she was solitary compared with when she was with cub. Hence, we have no clear explanation about this phenomenon. An additional investigation to increase the sample size of body weights for each demographic group is needed because the number of female body weight samples was too small to clarify these tendencies.

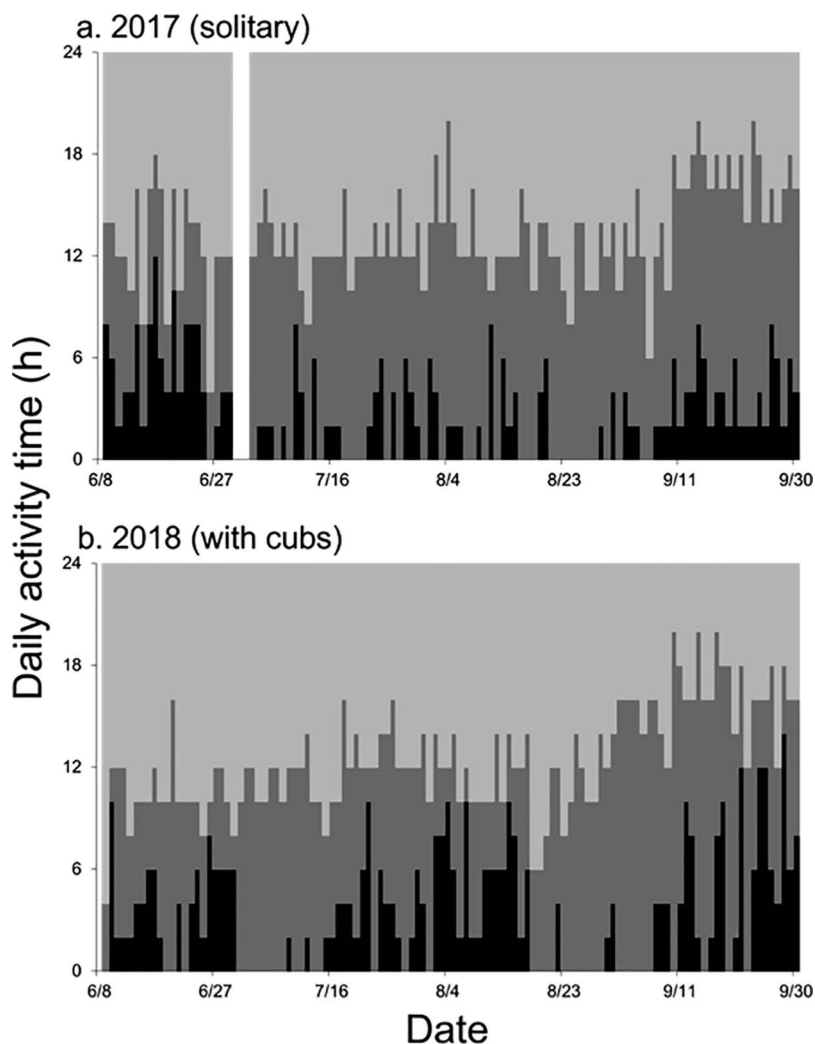


Fig. 3. Continuous changes in activity time per day for the adult female Asian black bear (*Ursus thibetanus*; AF55) in the Nikko-Ashio Mountains, Tochigi Prefecture, Japan. Light gray grid indicates a resting time and day, dark gray grid indicates a foraging time and day, and black grid indicates a traveling time and day. Activity times were calculated in hours (h) by using a state-space switching model and activity data obtained from a global positioning system (GPS) collar with a built-in activity sensor attached to AF55. Recording was limited to the period when we also recorded body weight for AF55 in 2017 and 2018 (mid-Jun to late Sep; x-axis = month/day). (a) 2017 (solitary) and (b) 2018 (with cub). A blank of (a) was caused by a failure of GPS location data.

The body weight of AF55 decreased at about the same rate from mid-June to late July in both 2017 (solitary) and 2019 (with yearlings), even though her demographic group differed between these two periods. It could be assumed that the energy balances were also similar for this female between the two periods (when the female was solitary vs. with yearlings). However, it is necessary to consider that we measured body weight of the adult female within a limited period (May–Sep),

which did not completely overlap during 2017 (solitary), 2018 (with cub), and 2019 (with yearling).

The decreased daily activity level we observed in August supported the findings of previous studies that indicated seasonal fluctuations of activity (Kozakai et al. 2013) and heart rate (Fuchs et al. 2019). However, we could not confirm that body weight clearly declined in August in accordance with the decrease in activity level. Body weight might have decreased slightly in

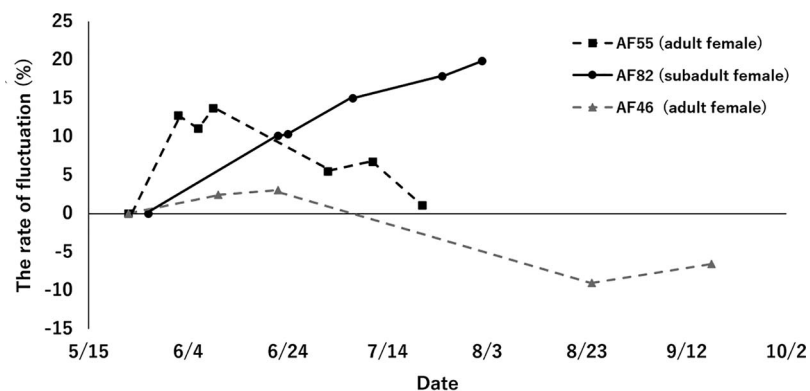


Fig. 4. The fluctuation rate of body weight for 3 free-ranging Asian black bears (ABB; *Ursus thibetanus*) in 2019 (x-axis = month/day) in the Nikko-Ashio Mountains, Tochigi Prefecture, Japan. Points indicate weight relative to the body weight in late May (0%) for each individual. Those 3 ABBs are all females. AF55 was caring for yearlings, other ABBs were solitary.

July and August (see Fig. 1). That difference may indicate that the adult female minimized energy expenditure even though there was great variation in activity level. The adult female seemed to decrease motion as long as possible during resting times to reduce energy expenditure because food resources were not sufficient to recover nutritional condition during spring to summer in this study area (Yamazaki et al. 2012). However, that trend could not be solely explained by activity levels. Energy balances are determined based on daily changes in body fat (Barboza et al. 2009) and are calculated as energy intake minus energy expenditure (Furusaka et al. 2019). However, the current study did not estimate energy intake because we were unable to collect samples related to individual feeding habits.

For the adult female (AF55), no significant relationship was found between body weight and any behavioral factors in 2017 (solitary) and 2018 (with cubs). As mentioned earlier, relying solely on behavioral factors is insufficient to explain changes in body weight because body weight fluctuations are influenced by both energy expenditure and energy intake. In addition, AF55 may have expended energy in ways that would be very hard to measure by SSSM and activity sensor value. Andersen and Aars (2008) reported that females with cubs are more alert to disturbances, and respond more strongly to them, than do adult males or solitary individuals. Thus, the foraging location of AF55 in 2018 (with cubs) was likely the site not only of foraging, but also of nursing and alerting behaviors. Similarly, the resting location of AF55 in 2018 (with cubs) also seemed to include the nursing of cubs. A future

study is necessary to monitor feeding categories and quantities, while simultaneously measuring body weight through direct investigation or biologging devices at the individual level.

We also observed variations in body weight that may differ between subadults and adults, as the body weight of a subadult female (AF82) increased from spring to summer. Protein is essential for subadult bears and is required for building body mass and sustaining health (Tsubota 1998), but subadult bears cannot match adult bears in intraspecific competition over food resources (Costello et al. 2016). Therefore, we suppose that subadult bears may spend more time searching for food than adults do in order to obtain the vital nutrients and energy they require, even during seasons when food availability is limited. The subadult female we observed might succeed in obtaining food and increasing her body weight, even under those conditions.

We hypothesized that bears of different demographic groups would have different energy-spending and energy-obtaining strategies. However, we were able to obtain continuous body weight and GPS location data over multiple years for only one adult female bear, and even for this bear we were not able to record her body weight in autumn. In future studies, it will be necessary to improve the NIBWS for free-ranging bears and to select study sites where more bears are expected to visit more often. As we hypothesized, definition of behavior classes differed with bear demographic group, but mechanical classification of behavior had limitations. For example, we were unable to capture alerting or nursing behaviors, which may have consumed significant

resources. Hence, as mentioned above, future studies should also evaluate whether activity data match the actual behavior patterns of ABBs by combined use of direct observation and biologing devices.

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Supplemental material

Table S1. Number of visits to the noninvasive body weighing system (NIBWS) by bears during 2017–2019 in the Nikko-Ashio Mountains, Tochigi Prefecture, Japan. ID “AN” indicated bears lacking verified sex, age, and age classes because they had not been captured.

Table S2. Number of body weights (BW) recorded in each bear by the noninvasive body weighing system (NIBWS) during 2017–2019 in the Nikko-Ashio Mountains, Tochigi Prefecture, Japan. ID “AN” indicated bears lacking verified sex, age, and age classes because they had not been captured.

Table S3. Body weight value recorded in each bear by the noninvasive body weighing system (NIBWS) during 2017–2019 in the Nikko-Ashio Mountains, Tochigi Prefecture, Japan. Upper row is the date body weight was recorded. Lower row is the body weight value in kilograms. We defined bears 2–4 years old as independent from their mother and bears >5 years old as adults. ID “AN” indicated bears lacking verified sex, age, and age classes because they had not been captured.

Fig. S1. The noninvasive body weighing system (NIBWS) used in the Nikko-Ashio Mountains, Tochigi

Prefecture, Japan. The dotted arrow indicates the camera angle.

Fig. S2. Arrangement of the noninvasive body weighing system (NIBWS) located in the Nikko-Ashio Mountains, Tochigi Prefecture, Japan. The upper image was taken from the perspective of the remote camera used to photograph the Asian black bears' chest marks. The lower image was taken from the perspective of the remote camera used to photograph the body weight (left side of white outline) shown on the digital readout of the platform scale (center of white outline). The remote camera for

body weight was mounted to capture both the digital readout and the platform scale.

Fig. S3. An example of how a chest mark could be photographed clearly and used to identify Asian black bear individuals at a noninvasive body weighing system (NIBWS) located in Nikko-Ashio Mountains, Tochigi Prefecture, Japan. This bear (a) and (b) was photographed on the same occasion at the NIBWS in 2017. This individual bear had been captured previously in a barrel trap in 2017 (c). Arrows and circles indicate the individual features used to identify this individual.