Japanese Journal of Veterinary Research 66(2): 71–81, 2018

JJVR

REGULAR PAPER Regional Study

Evaluation of body condition using body mass and chest girth in brown bears of Hokkaido, Japan (*Ursus arctos yesoensis*)

Jun Moriwaki[1)], Ryosuke Omori[2)], Michito Shimozuru[1)], Hifumi Tsuruga[3)], Tsutomu Mano[3)] and Toshio Tsubota[1,*)]

[1)] Laboratory of Wildlife Biology and Medicine, Graduate School of Veterinary Medicine, Hokkaido University, Sapporo 060–0818, Japan

[2)] Division of Bioinformatics, Research Center for Zoonosis Control, Hokkaido University, Sapporo 001–0020, Japan

[3)] Hokkaido Research Organization, Sapporo 060–0819, Japan

Received for publication, November 29, 2017; accepted, December 22, 2017

Abstract

Chest girth and body mass of 3,576 brown bears (*Ursus arctos yesoensis*) harvested for conflict management in Hokkaido, Japan during 1991–2012 were used to establish methods to assess body condition and to compare the body condition of bears by sex, month, year, and reproductive status. The body mass was estimated based on the chest girth in cases with no measurements of the bear body mass. Using the measured and estimated body mass, a growth curve by age was demonstrated to ascertain the mean asymptotical body mass (245 kg for males, 114 kg for females) and ages at 95% asymptotic body mass (14.2 years for males, 7.1 years for females). The body condition value of bears was evaluated as body mass difference (kg) between the individual body mass and the standard body mass as estimated from the growth curve. Body condition value changed seasonally with a low in summer and the highest in the autumnal hyperphagic period. Female body condition value was higher than the males during September. Fluctuation in annual body condition value was found for females; however, there was no difference between solitary adult females and females with offspring (cubs, yearlings, or offspring of unknown age). No significant fluctuation was found for males. Our body condition evaluation method using chest girth and body mass of brown bears is useful to elucidate different trends across sex, year, and season.

Key Words: body condition, body mass, brown bear, chest girth, *Ursus arctos yesoensis*

Introduction

The Hokkaido brown bear (*Ursus arctos yesoensis*) is the largest terrestrial mammal in Hokkaido, Japan. Although actual trends of some local populations remain uncertain, the population would be growing in general, and human–bear conflicts involving crop damage and bear intrusion into urban areas are increasingly frequent[21)]. Recently, the Hokkaido government has implemented a conservation and management plan for brown bears and has strived to mitigate

*Corresponding author: Toshio Tsubota, Laboratory of Wildlife Biology and Medicine, Graduate School of Veterinary Medicine, Hokkaido University, Sapporo 060–0818, Japan
Phone: +81–11–7065104. Fax: +81–11–7065569. E-mail: tsubota@vetmed.hokudai.ac.jp
doi: 10.14943/jjvr.66.2.71

human–bear conflict and to secure local population survival. For appropriate conservation and management of brown bear populations, scientific information related to their ecology, behavior, physiology, diseases, and human–bear relations is needed. Understanding the relationship between body condition and reproduction is important because body condition during the pre-hibernation period has been identified as a key factor affecting reproductive success in female bears[28]. Methods of accurate body condition assessment of bears are needed.

Several methods have been used to evaluate body condition in bears: kidney fat index (KFI)[15,19,22,42], bone marrow fat[15,19,22,42], fatty acid composition and lipid accumulation[18], blood chemistry[16], and bioelectrical impedance analysis (BIA)[10,17,27]. However, some methods presented above can be adopted only for dead animals. Others require special equipment and techniques. Alternatively, body mass measurements are often applied to ascertain the body condition of bears. These measurements facilitate the use of both dead and live animals, but the influence of sex and aging on the body mass must be considered. Further, such measurements should consider growth because bears continue to increase in body mass after sexual maturity: until eight years of age for males and until six years of age for females[11]. Kingsley *et al.* (1983)[23] reported that body mass changes varied by sex, growth level, and season. Therefore, using body mass as an indicator of body condition in bears requires a method that considers sex and growth effects.

Bartareau *et al.* (2012)[4] used growth curves to estimate the standard mass of brown bears and evaluated the body condition as the difference between standard and measured mass. This method is useful for body condition assessment if body mass data is available. However, body mass measurements are sometimes difficult to obtain in the field.

Hokkaido brown bears, can grow to 400 kg (males) or 150 kg (females)[36]. In Hokkaido, hunters are required to measure or estimate the body mass of the harvested bears[20], and in many cases those data are not based on a measurement but on an estimate related to the animal's appearance. Alternatively, other information related to physical measurements, including body length, withers height, chest girth, is more readily available for harvested bears in Hokkaido[20]. Evaluation of body condition is possible without measured body mass data if body mass can be predicted from other morphometric data. Maeda and Ohdachi (1994)[25] found a growth and developmental relationship between chest girth and body mass in Hokkaido brown bears, similar to bears in North America and Sweden[11,38]. Similar relations have been reported for other mammals[1,8,34]. The present study was conducted to develop a method of body condition evaluation using chest girth and body mass by considering sex and growth effects (age) for the brown bear population in Hokkaido, Japan, and to examine body condition by sex, month, year, and reproductive status.

Materials and Methods

Morphometric measurements including body length, chest girth, and body mass were obtained from Hokkaido brown bears harvested from the population for conflict management for the 22 years from August 1991 through December 2012 ($n = 3{,}576$; 2,347 males and 1,229 females). Body length (cm) was measured from the nose tip to the anus. Chest girth (cm) was measured as the axillary girth just caudal to the scapula. Body mass (kg) was determined by suspending bears from a spring scale or placing them on an electronic load scale. Data on the presence of offspring, number of accompanying offspring, and estimated age of offspring of harvested bears was also collected from local government personnel and hunters. Offspring of harvested females were documented as present, not present, or unknown. In addition, offspring were categorized as cubs-of-the-year (COY), yearling, two years old, three years old, or of unknown age. The ages of all bears were ascertained by counting the cementum annuli of teeth[43]. The birth date for all COY was set as 1 February. Offspring age in days was calculated in days postpartum by subtracting this date from the date of mortality.

Body mass estimation based on chest girth: To estimate the body mass based on chest girth (male, 1,705; female, 913), body mass-chest girth regression (male, 602; female, 305) (logarithm transformed) was fitted to a generalized linear model separately to data for males and females following Kolenosky *et al.* (1989)[25] (i.e., we fitted models with variables of log scale of measured body mass as the explanatory variable and log chest girth as the response variable). We assumed that the log of body mass followed a gamma distribution.

Fitting age–body mass to the growth functions: To determine the age at which most sampled bears reach the greatest body mass, and to ascertain the standard mass based on age, we separately fitted the age and body mass for both sexes to four growth equation models: 1) von Bertalanffy (1938)[41], 2) logistic, 3) Gompertz (1825)[12], and 4) Richards (1959)[33].

$$A(t) = A_\infty \cdot [1 - e^{-K(t-T)}]^3, \quad (1)$$

$$A(t) = A_\infty \cdot [1 + e^{-K(t-T)}]^{-1}, \quad (2)$$

$$A(t) = A_\infty \cdot e^{-e^{-K(t-1)}}, \quad (3)$$

$$A(t) = A_\infty \cdot [1 + be^{-Kt}]^{-(1/m)}, \quad (4)$$

In those equations, the following variables are used: $A(t)$ is body mass (kg) at age t; A_∞ is the asymptotic body mass for the harvested bears; K is a relative growth rate parameter or maturing index (years^{-1}); T is the hypothetical age at zero body mass assuming the equation is fitted for all ages (years); I is the age at the inflection point when the maximum growth is theoretically achieved (years); b is an integration constant for a time-scale parameter; and m is a shape parameter indicating the position of the inflection point, which varies with the range of $-1 < m < \infty$[3].

Measured or estimated body mass was fitted to the four model functions. Then, the model with the smallest Akaike's information criterion (AIC) was selected as the best model. Some errors of age estimation[13] and measurements[9] were likely. Therefore, outliers were excluded from the box plot analysis (age vs. body mass data)[40]. Considering body mass growth, age categories were separated into respective ages until 8 years old for males and until 6 years old for females[11]. Thereby, ≥9-year-old groups for males and ≥7-year-old groups for females were included in the same group.

Evaluation of body condition: Body condition value was calculated from the body mass with age using:

$$\textit{body condition} = W_{ia} - W_i, \quad (5)$$

where W_i represents the standard mass (kg) of the harvested bears at age i, as estimated from a growth function. W_{ia} denotes the body mass (measured or estimated from chest girth) of a bear harvested at age i. For evaluation of the credibility of BC, it was correlated with other indices including BCI for the body condition of bears[7].

$$BCI = \frac{\ln BM - 3.21 \times \ln BL + 11.64}{0.29 - 0.017 \times \ln BL} \quad (6)$$

In addition, $hBCI$ was used to estimate the body condition index following Cattet *et al.* (2002)[7]:

$$hBCI = \frac{BM - a \times BL^b}{c} \quad (7)$$

where BM is body mass (kg); BL is body length (cm). Parameters a, b, and c are unknown and were calculated using BM with BL.

Statistical analysis: To evaluate the major factors affecting the body condition, we applied a Mann–Whitney U-test for paired analysis and multiple analysis of variance (MANOVA) for body condition value by sex, year, capture month, and age. If a significant difference was found, multiple comparison was performed using Peritz's method. Additionally, adult female body condition value was compared by offspring age. Age classes were separated into groups of 0–5, 6–10, 11–15, and ≥16. Statistical analyses including Peritz's method were conducted using R ver. 3.1.1 with significance inferred for $P < 0.05$[2,32]. In addition, Fisheries stock assessment (FSA)[29], FSAdata[30], and nlstools[5] were used to fit the von Bertalanffy, Gompertz, Richard, and logistic growth curves.

Results

Of the 3,576 bears, measurements of both body mass (body length) and chest girth were available for 602 males and 305 females; for 1,705 males and 913 females only chest girth was measured (Table 1). Among bears with these measurements, body mass was 3–520 kg for males ($n = 642$) and 8–204 kg for females ($n = 316$), body length was 45–260 cm ($n = 2{,}347$) and 50–280 cm ($n = 1{,}229$), and chest girth was 23–250 cm ($n = 2{,}307$) and 28–240 cm ($n = 1{,}218$). Ages were estimated for 0–3 year (young) bears for 1,266 males and 529 females, ≥4 year (adult) were 1,081 and 700 with maximum ages of 30 and 27 years, respectively. The 225 of 706 females (including 6 three years old females) sighted with offspring included 93 with COY, 78 with yearlings, 8 with two years old, 3 with three years old, and 43 with offspring of unknown age. The remaining 481 were solitary females without sightings of offspring. Body condition index *hBCI* was calculated as $hBCI = (BM - 0.000348 \times BL^{2.54}) / 38.0$.

Based on positive correlation between both logarithmically transformed measured body mass (*BM*) and chest girth (*CG*), the brown bear body mass was calculated as $BM = \exp^{(-5.61 \pm 0.17) + (2.23 \pm 0.04) \times \ln(CG)}$ for males and $BM = \exp^{(-4.52 \pm 0.25) + (1.98 \pm 0.06) \times \ln(CG)}$ for females (mean ± SE) (Fig. 1).

Table 1. Numbers of brown bears classified by measurements including chest girth and body mass in Hokkaido, Japan during 1991–2012 ($n = 3{,}576$)

Sex	Chest Girth	Body Mass +	Body Mass −	Total
Male ($n = 2{,}347$)	+	602	1,705	2,307
	−	40	0	40
Female ($n = 1{,}229$)	+	305	913	1,218
	−	11	0	11

+, present; −, not present

Growth curve models that were fitted to measured and estimated body mass revealed no large differences in AIC values (Table 2). A von Bertalanffy equation was selected as the best fit and standard mass was estimated as $BM = (245 \pm 5) \times [1 - \exp^{(-0.24 \pm 0.01) \times \{age + (2.79 \pm 0.23)\}}]^3$ for males and $BM = (114 \pm 2) \times [1 - \exp^{(-0.4 \pm 0.04) \times \{age + (1.61 \pm 0.26)\}}]^3$ for females (mean ± SE) (Fig. 2). The ages at which bears reached 95% of asymptotic body mass were 14.2 years for males and 7.1 years for females.

Body condition value was calculated as the deviation from the standard mass using a von Bertalanffy equation and ranged from −169 to 188 kg for males and −65 to 88 kg for females. *BCI* values ranged from −9.2 to 12.7 and *hBCI* were −9.2 to 7.3 for males and females, respectively. Correlated natural logarithmically transformed *BC* (with 200 added to produce positive values) was found to be positively related with another index (*BCI* and *hBCI*). Correlation coefficient was greater for *hBCI* (males, 0.456; females, 0.509) than for *BCI* (males, 0.292; females, 0.399) (Fig. 3).

Results demonstrate that the body condition value of bears was more dependent on the capture month and age class ($P < 0.001$ and $P = 0.043$) than by year and sex ($P = 0.058$ and 0.905). Additionally, monthly variation during March–December was −193 to 194 kg for males and −77 to 96 kg for females, with respective mean widths of 33 kg and 26 kg. For females,

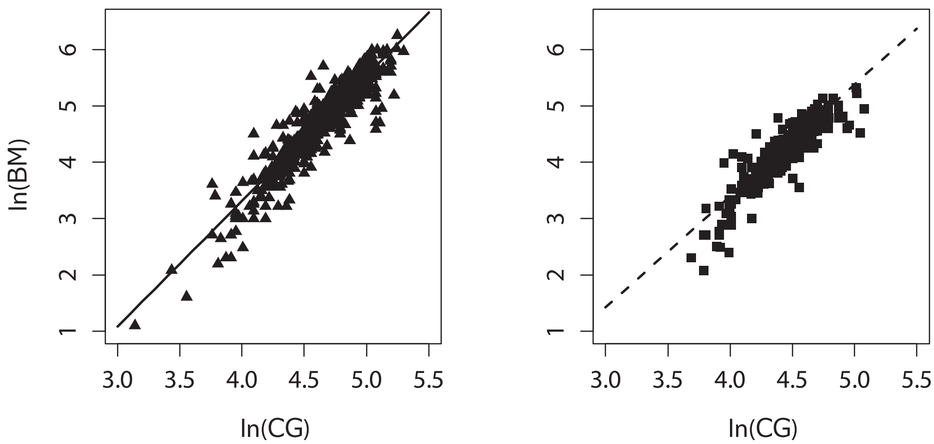

Fig. 1. Correlation between chest girth (*CG*) and body mass (*BM*) of brown bears, sampled from mortality in Hokkaido, Japan 1991–2012. Dashed and dotted lines respectively represent the prediction of the mean: ▲, male ($n = 602$); ■, female ($n = 305$). Estimates were $BM = \exp^{(-5.61 \pm 0.17) + (2.23 \pm 0.04) \times \ln(CG)}$ for males, $BM = \exp^{(-4.52 \pm 0.25) + (1.98 \pm 0.06) \times \ln(CG)}$ for females (mean ± SE).

Table 2. Parameters for growth curves of body mass fitted by sex in brown bears sampled from mortality data in Hokkaido, Japan 1991–2012

Sex	Model	A_∞ (kg)		K (years^{-1})		AIC
Male (n = 2,225)	von Bertalanffy	244.75	(±4.58)	0.24	(±0.01)	23638.04
	Richards	265.63	(±11.18)	0.14	(±0.03)	23628.94
	Gompertz	240.17	(±4.12)	0.28	(±0.01)	23646.34
	Logistic	231.81	(±3.36)	0.41	(±0.02)	23674.48
Female (n = 1,158)	von Bertalanffy	113.78	(±1.61)	0.47	(±0.04)	11004.72
	Richards	114.05	(±1.95)	0.45	(±0.09)	11006.66
	Gompertz	113.30	(±1.55)	0.52	(±0.04)	11005.13
	Logistic	112.30	(±1.44)	0.68	(±0.05)	11007.72

A_∞, asymptotic body mass; K, relative growth rate parameter; AIC, value for evaluating and comparing models and standard errors in blankets (±SE). Considering errors in age estimates and measuring error, outliers of measurements were excluded using a box plot.

body condition value showed little variation from March to September (between −10.0 ± 8.5 kg and −0.9 ± 1.7 kg). Body condition value in males was lower in August (−10.5 ± 2.3 kg) with an increase of 8.1 ± 4.5 kg in April (Fig. 4). Male body condition value declined more than female conditions during September (Mann–Whitney U test; $P = 0.018$). Nevertheless, significant body condition value recovery was found during October–December for males and females (Peritz's method; both $P < 0.05$): index increased from 5.6 ± 2.9 kg to 17.1 ± 3.3 kg for males and from 4.0 ± 2.1 kg to 16.4 ± 2.6 kg for females. The highest condition was in November.

For females, no differences were found between age classes or by reproductive status throughout the year: accompanied by COY 1.9 ± 3.1 kg, yearlings −0.1 ± 3.3 kg, offspring of unknown age 8.0 ± 5.4 kg, or solitary −0.7 ± 1.5 kg (Fig. 5; Peritz's method, $P > 0.05$).

No significant fluctuations were found in body condition value among male bears by year. However, the female condition was higher in 1992, 2000, 2003, and 2008 (24.1 ± 9.2 kg, 19.0 ± 6.8 kg, 8.9 ± 3.6 kg and 5.2 ± 3.7 kg), but lower in 1999, 2004, 2010, and 2012 (−5.0 ± 3.5 kg, −8.1 ± 3.7 kg, −4.3 ± 2.6 kg and −11.6 ± 2.5 kg). Results show significant differences between 1992 and 1999, 2000 and 2004, 2000 and 2010, 2000 and 2012, 2003 and 2012, and

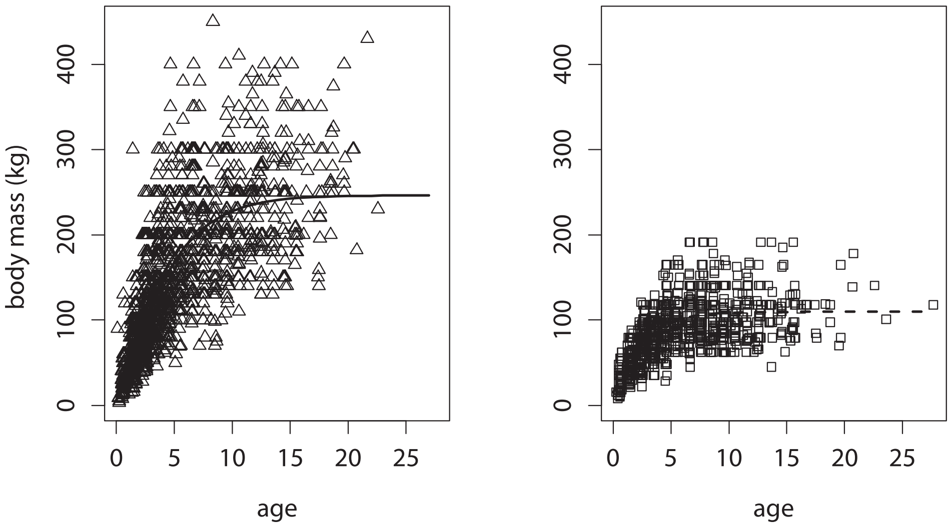

Fig. 2. Distribution of age – body mass (*BM*) for brown bears sampled from mortality in Hokkaido, Japan during 1991–2012. Filled symbols denote measured *BM*, not-filled symbols denote *BM* estimates from chest girth: ▲, male (n = 2,225); ■, female (n = 1,158). By fitting the von Bertalanffy growth curve estimates were $BM = 244.8 \times \{1 - \exp^{-0.24 \times (age + 2.79)}\}^3$ for males, $BM = 113.8 \times \{1 - \exp^{-0.47 \times (age + 1.61)}\}^3$ for females. Considering errors in age estimates and measuring error, outliers of measurements were excluded using a box plot.

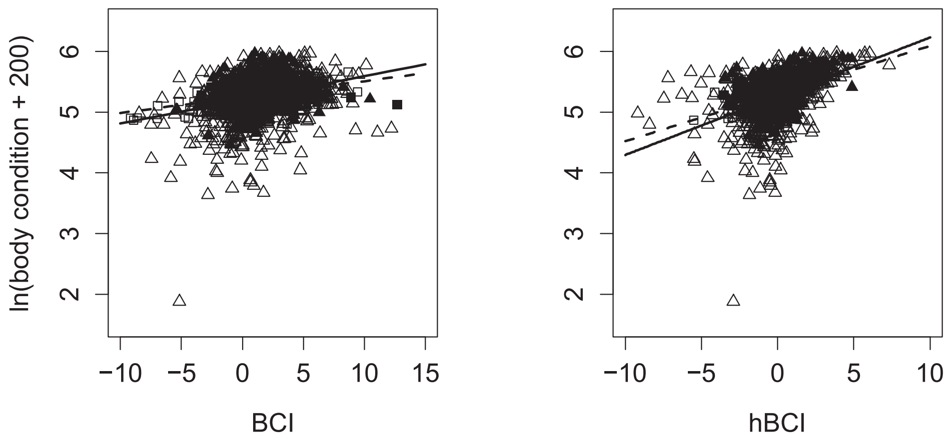

Fig. 3. Correlation between body condition and body condition index (*BCI*) or *hBCI* of brown bears, sampled from mortality in Hokkaido, Japan 1991–2012. For convenience, 200 was added to the body condition to produce numbers positive and then transferred to natural logarithms. Filled symbols denote the measured body mass (*BM*), not-filled symbols denote *BM* estimates from chest girth: ▲, male (n = 2,223, excluding 2 of unknown body length); ■, female (n = 1,158). Correlation coefficients for *BCI* are 0.292 for males; 0.399 for females. Those for *hBCI* are 0.456 for males and 0.509 for females. Considering errors in age estimates and measuring error, outliers of measurements were excluded using a box plot.

2008 and 2012 (Fig. 6; Peritz's method, compared among groups 1991–2003 or 2000–2012 as the total number of comparisons was limited, $P < 0.05$).

Discussion

In this study, we demonstrated an estimation of body condition obtained from differences between the standard growth curve based on body mass and weighed or estimated individual body mass at mortality. To obtain better body condition estimates, it was important to obtain

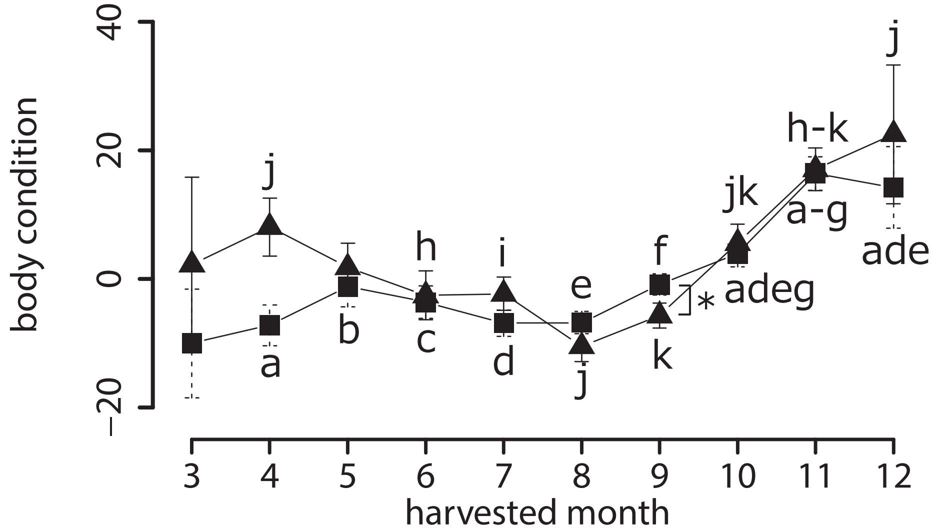

Fig. 4. Body condition of brown bears by month, sampled from mortality in Hokkaido, Japan 1991–2012: ▲, male (n = 2,221); ■, female (n = 1,152). Upper and under bars from each symbol denote the standard error (±SE). Individuals euthanized during January–February were excluded because of scarcity for analysis (n = 10; 4 males and 6 females). [a–j]: Significant differences are labeled with the same letters (including a, April vs. October, November and December for female; d, July vs. October, November and December for female; e, August vs. October, November and December for female; j, August vs. April, October, November and December for male; k, September vs. October and November for male, by multiple comparison (Peritz's method, $P < 0.05$). Significant sex difference was found for September (Mann–Whitney U test; *: $P = 0.018$). Considering errors in age estimates and measuring error, outliers of measurements were excluded using a box plot.

accurate body mass estimates. However, instead of body mass measurements, as reported for captive[25)] and wild bears[11,38)], body mass was calculated from chest girth to the power of x from wild bears. This estimation allowed us to evaluate the body condition based on chest girth without body mass data.

The growth patterns among the four growth equations used in this study were similar. The growth pattern of body mass included sex differences: female bear mass was less than half the male bear mass. Moreover, according to the age at which they reached 95% of their asymptotic mass, both males and females continued to grow after sexual maturity (females, 3–4 year; males, 9–12 year)[39)]. Females attained the body mass growth plateau earlier than males. Overall, these different growth patterns of body mass across sexes and over time must be considered for body condition evaluation.

Estimation of the body condition requires evaluation of the extent of body mass changes from a single standard mass. However, the *BCI*

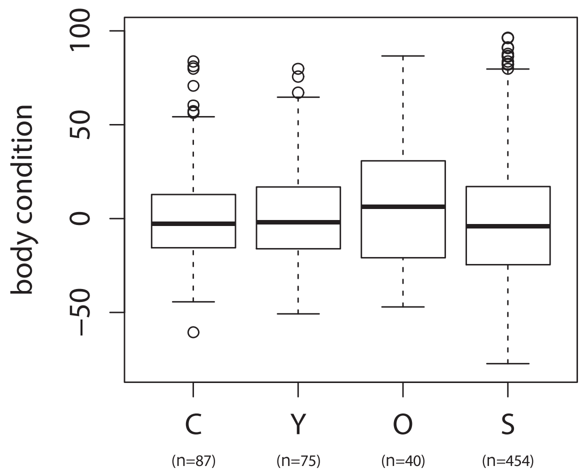

Fig. 5. Body condition of female brown bears by reproductive status, sampled from mortality in Hokkaido, Japan 1991–2012. Upper and lower bars from each box denote the standard error (±SE): C, accompanied by cubs of the year; Y, yearlings; O, offspring of unknown age; S, solitary immediately before mortality. Values in parentheses denote sample numbers. Females accompanied by 2- or 3-year-old offspring (n = 11) were excluded from comparisons of body conditions because sample numbers were limiting. No significant difference was found among reproductive status. Considering errors in age estimates and measuring error, outliers of measurements were excluded using a box plot.

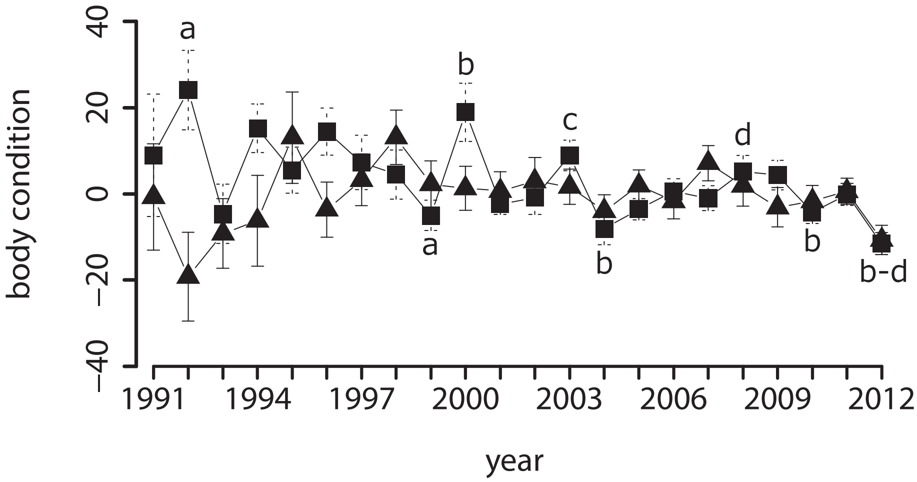

Fig. 6. Body condition of brown bears by year, sampled from mortality in Hokkaido, Japan 1991–2012: ▲, male (n = 2,221); ■, female (n = 1,152). Individuals euthanized during January–February were excluded because of scarcity for analysis (n = 10; 4 males and 6 females). Upper and lower bars from each symbol denote the standard error (±SE). [a–c]: Significant differences are labeled with the same letters (including a, 1992 vs. 1999; b, 2000 vs. 2004, 2010 and 2012 for female; c, 2003 vs. 2012 for female; d, 2008 vs. 2012 for female, by multiple comparison (Peritz's method, compared among groups 1991–2003 or 2000–2012 as the total number of comparisons was limited, $P < 0.05$). Considering errors in age estimates and measuring error, outliers of measurements were excluded using a box plot.

equation did not fit data from bears in Japan, including black bears (*Ursus thibetanus japonicus*) and brown bears, because as reported for Japanese black bears (*Ursus thibetanus japonicus*)[31], this study revealed that *BCI* has only weak correlation with the body condition value and that the fit was low for Hokkaido brown bears. Therefore, no equation incorporating *BCI* is available for body condition analysis. We assessed *hBCI* based on an equation of Cattet *et al.* (2002)[7]. Results show that *hBCI* fit body condition value of brown bears, except for some bears with low value. Growth varies with differences in energy requirements including physical activity levels, as determined by sex and aging. Moreover, fat deposition and utilization also differ by sex and age in bears[22,42].

An important limitation of this study must include regional differences in the body conditions because this study used a small sample size in every region. Therefore, we compared the body conditions of bears comprehensively throughout the whole area of Hokkaido, Japan. For females, variation in the annual condition was found, although the condition of males did not vary by year. For females, the body condition value was >5 kg in 1992, 2000, 2003, and 2008, but <−4 kg in 1999, 2004, 2005, and 2012. The female body condition value might reflect the amount of food in autumn including acorns of the Japanese oak (*Quercus crispula*) and berries such as *Actinidia* spp. and *Vitis coignetiae*[37]. In autumn, bears eat mainly acorns during years of abundance, but in years of low production of acorn, bears shift to berries and crops[37]. Fat accumulated during autumn is not only used for fasting during hibernation, but also for the negative energy balance during spring–summer[15]. Body condition is dependent on resource abundance in autumn of the prior year. A rapid decline in body condition occurs during fasting from extended hibernation and while sustaining a negative energy balance from extended summer food scarcity.

This study indicated that body condition changed seasonally. Body mass would include fatness and body size as a body frame. This frame size can be determined by age but not by season; also grows during young. Therefore, fatness (body condition value) changed seasonally.

Moreover, condition change of bears occurred in two periods: lean mass increase (i.e. during spring–summer) and fat mass increase (i.e. during autumn) as reported by Belant *et al.* (2006)[6]. Our body condition evaluation method might cover these timings as slight increases were noted for females during spring–summer, whereas fat mass increased for both males and females during autumn with hyperphagia, as noted in earlier studies[14,28]. Further, as Belant *et al.* (2006)[6] reported, females maintained body condition during spring–summer. However, the male body condition declined in summer. A possible reason might be the increase of activity during April–July of the mating season[21]. Annual home range size of adult males is 10–500 km^2, and is ten times larger than that of females[21]. During the mating season, adult males increase their movement[21]. Their body condition might thereby decline. For brown bears in Hokkaido, body condition variation is inferred to indicate both differences of sex and season.

In North America, the body condition of females declined when they were accompanied by their offspring, including COY and yearlings[17]. However, our study found no significant differences in condition among females with COY, yearlings and offspring of unknown age and solitary. Additionally, no significant body condition variation was found for females among age groups. These results suggest that female bears give birth only when their condition is above a threshold[35]. Moreover, it is noteworthy that the reproductive status depends on whether offspring were observed at the time of mortality. Some females that gave birth might be regarded as solitary because of infanticide or starvation[26]. Consequently, classification of females as solitary may not reflect their actual reproductive history. More detailed research might be necessary to clarify female condition changes with reproductive status. Evidence of pregnancy and parturition using corpora lutea in the ovary and placental scars in the uterus may provide additional insights.

We established a body condition evaluation method using chest girth and body mass and evaluated the body condition of brown bears in Hokkaido, Japan by sex, year, month and reproductive status. Body condition differed according to sex, month, and year (for females), but not by reproductive status and age class of females. Proper conservation and management necessitates the use of important biological information from more detailed research from annual examinations of regional evaluations of body condition by sex, month, and age class.

Acknowledgments

We thank the hunters and officials of Hokkaido as well as Shiretoko Nature Foundation for supplying bear data and measurements, and thank A. E. Derocher and K. R. Taylor for helpful inspiration, advice, and review. We also thank T. Takada, A. Satake, H. Uno, K. Takai, M. Nagano, and K. Sakamoto for fruitful comments related to our research. We also appreciate the efforts of the Associate Editors and the reviewers, who kindly offered suggestions related to our manuscript. This study was conducted in part by the Program for Leading Graduate Schools "Fostering Global Leaders in Veterinary Science for Contributing to One Health" grant no. (F01), MEXT, Japan.

References

1) Afolayan RA, Adeyinka IA, Lakpini CAM. The estimation of live weight from body measurements in Yankasa sheep. Czech J Anim Sci 51, 343–348, 2006
2) Aoki S. R niyoru toukei shori. http://aoki2.si.gunma-u.ac.jp/R/index.html/. Accessed 22 May 2015.
3) Bartareau TM, Cluff HD, Larter, NC. Body length and mass growth of the brown bear (*Ursus arctos*) in northern Canada: model selection based on information theory and ontogeny of sexual size dimorphism. Can J

Zool 89, 1128–1135, 2011

4) Bartareau, TM, Larter, NC, Cluff, HD, Leone EH. Body condition and growth dynamics of American black bears in northern Canada. Ursus 23, 12–20, 2012
5) Baty F, Ritz C, Charles S, Brutsche, M, Flandrois J, Delignette-Muller M. A toolbox for nonlinear regression in R: The package nlstools. J Stat Softw 66, 1–21, 2015
6) Belant JL, Kielland K, Follmann EH, Adams LG. Interspecific resource partitioning in sympatric Ursids. Ecol Appl 16, 2333–2343, 2006
7) Cattet MRL, Caulkett NA, Obbard ME, Stenhouse GB. A body–condition index for Ursids. Can J Zool 80, 1156–1161, 2002
8) Cook RC, Cook JG, Vales DJ, Johnson BK, Mccorouodale SM, Shipley LA, Riggs RA, Irwin LL, Murphie SL, Murphie BL, Schoenecker KA, Geyer F, Hall PB, Spencer RD, Immell DA, Jackson DH, Tiller BL, Miller PJ, Schmitz L. Regional and seasonal patterns of nutritional condition and reproduction in elk. Wildl Monogr 184, 1–44, 2013
9) Eason TH, Smith BH, Pelton MR. Researcher variation in collection of morphometrics on black bears. Wildl Soc Bull 24, 485–489, 1996
10) Farley SD, Robbins CT. Development of two methods to estimate body composition of bears. Can J Zool 72, 220–226, 1994
11) Glenn LP. Morphometric characteristics of brown bears on the central Alaska Peninsula. Int Conf Bear Res and Manage 4, 313–319, 1980
12) Gompertz B. On the nature of the function expressive of the law of human mortality, and a new mode of determining the value of live contingencies. Philos Trans R Soc Lond 115, 513–583, 1825
13) Harshyne WA, Diefenbach DR, Alt DR, Matson GM. Analysis of error from cementum-annuli age estimates of known-age Pennsylvania black bears. J Wildl Manage 62, 1281–1291, 1998
14) Hashimoto Y, Yasutake A. Seasonal changes in body weight of female Asiatic black bears under captivity. Mammal Study 24, 1–6, 1999
15) Hazumi T, Maruyama N, Mizuno A, Torii H, Maita K. Nutrient examination of Japanese black bear. In: A report on the change of forest and large mammal ecology, Environmental Agency ed. Tokyo. pp. 80–84, 1985.
16) Hellgren EC, Rogers LL, Seal US. Serum chemistry and hematology of black bears: physiological indices of habitat quality or seasonal patterns? J Mammal 74, 304–314, 1993
17) Hilderbrand GV, Schwartz CC, Robbins CT, Hanley TA. Effect of hibernation and reproductive status on body mass and condition of coastal brown bears. J Wildl Manage 64, 178–183, 2000
18) Hissa R, Hohtola E, Tuomala-Saramäki T, Laine T, Kallio H. Seasonal changes in fatty acids and leptin contents in the plasma of the European brown bear (*Ursus arctos arctos*). Ann Zool Fennici 35, 215–224, 1998
19) Hokkaido Government. Report of a biological survey on sika deer and brown bear in Hokkaido. Hokkaido Nat. Preserv. Div, Sapporo, 1992.
20) Hokkaido Government. A textbook for bear shooting and trapping. 2006. http://www.pref.hokkaido.lg.jp/ks/skn/higuma/mokuzi.htm.
21) Hokkaido Government. Conservation and management of brown bear in Hokkaido. 2017. http://www.pref.hokkaido.lg.jp/ks/skn/higuma/higuma.htm. Accessed 17 December 2017.
22) Hokkaido Institute of Environmental Sciences. Report of brown bear and sika deer ecological survey II; wildlife distribution and abundance research report; brown bears (1991–1995). Hokkaido Institute of Environmental Sciences, Sapporo. 1996.
23) Kingsley MCS, Nagy JA, Russell RH. Patterns of weight gain and loss for grizzly bears in northern Canada. Int Conf Bear Res and Manage 5, 174–178, 1983
24) Kolenosky GB, Lunn NJ, Greenwood CJ, Abraham KF. Estimating the weight of polar bears from body measurements. J Wildl Manage 53, 188–190, 1989
25) Maeda N, Ohdachi S. Growth and body measurements of Hokkaido brown bear in captivity. Proc. of the Second East Bear Conf. pp. 68–76, 1994.
26) Moriwaki J, Shimozuru M, Tsuruga H, Mano T, Tsubota T. Estimation of reproductive parameters and their annual variation in brown bears of Hokkaido, Japan. Ursus 27, 99–109, 2017
27) Nakamura S, Okano T, Yoshida Y, Matsumoto A, Murase Y, Kato H, Komatsu T, Asano M, Suzuki M, Sugiyama M, Tsubota T. Use of bioelectrical impedance analysis to measure the fat mass of the Japanese black

bear (*Ursus thibetanus japonicas*). Jpn J Zoo Wildl Med 13, 15–20, 2008

28) Nelson RA, Folk GE, Pfeiffer EW, Craighead JJ, Jonkel CJ, Steiger, DL. Behavior, biochemistry, and hibernation in black, grizzly, and polar bears. Int Conf Bear Res and Manage 5, 284–290, 1983
29) Ogle DH. FSA: Fisheries stock analysis. R package version 0.8.3. 2015a
30) Ogle DH. FSAdata: Fisheries stock analysis, datasets. R package version 0.3.2. 2015b
31) Oi T, Furusawa H. Nutritional condition and dietary profile of Japanese black bear (*Ursus thibetanus japonicus*) killed in western Japan in autumn 2004. Mammal Study 33, 163–171, 2008
32) R Core Team. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. 2014.
33) Richards FJ. A flexible growth function for empirical use. J Exp Bot 10, 290–301, 1959
34) Riney T. Evaluating condition of free-ranging red deer (*Cervus elaphus*), with special reference to New Zealand. N Z J Sci and Technol 36, 429–463, 1955
35) Samson C, Huot J. Reproductive biology of female black bears in relation to body mass in early winter. J Mammal 76, 68–77, 1995
36) Sato Y. *Ursus arctos* Linnaeus, 1758. In: The Wild Mammals of Japan, First ed. Ohdachi SD, Ishibashi Y, Iwasa MA, Saitoh T. eds. Shoukadoh, Kyoto. pp. 232–234, 2009.
37) Sato Y, Endo M. Relationship between crop use by brown bears and *Quercus crispula* acorn production in Furano, central Hokkaido, Japan. Mammal Study 31, 93–104, 2006
38) Swenson JE, Kasworm WF, Stewart ST, Simmons CA, Aune K. Interpopulation applicability of equations to predict live weight in black bears. Int Conf Bear Res and Manage 7, 359–362, 1987
39) Tsubota T, Kanagawa H, Aoi T, Mano T. Sexual maturity of the Hokkaido brown bear. Asiatic Bear Conf 1, 1–9, 1990
40) Tukey JW. Box-and-whisker plots. In: Exploratory data analysis. Tukey JW. ed. Addison-Wesley, USA. pp. 39–43, 1977.
41) von Bertalanffy, L. A quantitative theory of organic growth (Inquiries on growth laws II.). Hum Biol 10, 181–213, 1938
42) Yamanaka A, Asano M, Suzuki M, Mizoguchi T, Oi T, Shimozuru M, Tsubota T. Evaluation of stored body fat in nuisance–killed Japanese black bears (*Ursus thibetanus japonicus*). Zool Sci 28, 105–111, 2011
43) Yoneda M. Age determination and age structure of the Ezo brown bear. J Mamm Soc Jpn 7, 1–8, 1976.