Nutritional condition and dietary profile of Japanese black bear (Ursus thibetanus japonicus) killed in western Japan in autumn 2004

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Abstract. The nutritional conditions and dietary profiles of Japanese black bears that intruded into residential areas in Hiroshima, western Japan, in autumn 2004 were estimated. Nutritional conditions were evaluated using a morphometric index, the body-condition index (BCI) deduced for the American black bear, which has similar morphology and physiology to the Japanese black bear. The BCI had a wide range, from –3.0 to 3.5, indicating a wide range of nutritional conditions of the bears. There were no significant effects of age class, sex, or month of capture on the BCI. Dietary profiles were estimated by measuring the carbon and nitrogen stable isotope ratios (δ¹³C, δ¹⁵N) of bear hairs, which archive information on dietary changes during the growth of the hair. These values indicated wide-ranging diets that included C₃ plants, animal matter, and anthropogenic food, and identified marked individual differences in dietary profiles. Individuals with a high BCI tended to consume high-δ¹⁵N food such as animal matter and acorns. Because the proportion of individuals that acquired the high-δ¹⁵N food was small, the amount and distribution of such food items might have been restricted and subject to competition among bears in Hiroshima in autumn 2004.

Key words: body condition, diet, Japanese black bear, stable isotope analysis.

In some years, many Japanese black bears (Ursus thibetanus japonicus) intrude into residential areas in autumn (Japan Wildlife Research Center 2005; Oi 2005), increasing the incidence of human injuries caused by bear attacks. Thus, many bears are killed as a countermeasure to these intrusions. It is important to clarify the mechanism of this behavior by bears to prevent such human-bear accidents. Although low forest fruit production in autumn, when bears become hyperphagic in preparation for hibernation, is considered to be the putative cause of this behavior (Oka et al. 2004; Oi 2005), the actual food habits and nutritional conditions of bears during these intrusions are not known.

It is important to evaluate the nutritional condition of bears to interpret behavioral changes in relation to fluctuations in food availability within a given habitat (Hellgren et al. 1993; Stirling et al. 1999). However, there are no practical indices that precisely represent the nutritional condition of the Japanese black bear. Cattet et al. (2002) proposed the body-condition index (BCI), which correctly predicts the nutritional condition of the polar bear (Ursus maritimus), brown bear (Ursus arctos), and American black bear (Ursus americanus) based on residuals from the regression of total body mass (TBM) against straight-line body length (SLBL). The BCI has a close positive relationship with true body condition, measured as the standardized residual of the combined mass of fat and skeletal muscle against SLBL, in bears that were dissected to determine individual tissue masses. The BCI also has a close positive relationship with the standardized residual of fat mass against SLBL. Both fat and skeletal muscles represent a major source of stored energy (Atkinson et al. 1996). Thus, we evaluated the nutritional condition of bears using the BCI.

We estimated the dietary profile of bears by measuring the carbon and nitrogen stable isotope ratios (δ¹³C, δ¹⁵N) along growth sections of bear hairs (Michael et al. 2003; Mizukami et al. 2005). More long-term and less-biased dietary information can be obtained via stable isotope analysis of animal tissues than by direct observation, scat analysis, and stomach content analysis, which can only archive dietary information for <1 week (Robbins et al. 2003).
Nakashita (2006) provided two alternate types of food that had remarkably different stable isotope signatures to captive Japanese black bears and demonstrated that sections of bear hair preserve isotopic information about the individual’s food sources for a given time period when the section of the hair grows. The hair of Japanese black bears grows at a relatively constant rate during approximately June to October, and the hair that grew in the previous year is molted between July and September (Nakashita 2006). Thus, hairs sampled in October and November grew in the year sampled and may archive temporal fluctuations in the stable isotope ratios of the diet from early summer to autumn of the year sampled (Nakashita 2006).

Materials and methods

Bear samples

In autumn 2004, many bears intruded into residential areas in Hiroshima prefecture in the western part of Honshu, Japan (Fig. 1). The bear population in Hiroshima prefecture is part of the Western Chugoku population, which is isolated and consists of approximately 300–740 bears within a 7,000 km² area (Japan Wildlife Research Center 2006). The hunting of bears in this area has been prohibited since 1994 to conserve the population, but kills of nuisance bears have been permitted. One hundred and five nuisance bears were killed in 2004, whereas 10 to 30 bears were killed each year from 1994 to 2003. With the help of the Hiroshima prefecture government, we obtained samples and body measurements from 80% of the bears killed in October and November, when many bears intruded into residential areas. The number of bears killed in these 2 months accounted for 73% of the total number of bears killed in 2004 (Fig. 2). Fifty-six bears were analyzed, excluding five cubs because the cubs followed their mothers and their food might have depended on that of the mothers.

The age of each bear was determined by counting cementum annuli of sectioned roots of lower fourth premolars (Craighead et al. 1970), and bears were classified into age classes. The age class “young” was assigned to animals 1 to 3 years old, which are assumed to be reproductively immature (Komatsu et al. 1994; Katayama et al. 1996). The age class “adult” was assigned to animals ≥ 4 years old. The samples comprised 21 adult males, 25 adult females, 6 young males, and 4 young females.

Nutritional condition

We used the equation for the BCI of American black bear to calculate the BCI of Japanese black bear because these two species have similar body size, body shape, and physiology (Nowak 1999). The BCI for American black bear is calculated as follows:

$$BCI = \frac{(\ln TBM - 3.21 \times \ln SLBL + 11.64)}{(0.29 - 0.017 \times \ln SLBL)}$$

where TBM is the total body weight in kilograms, and SLBL is the straight-line body length in centimeters.

Dietary profile

Hairs for the stable isotope analysis were sampled from the frontal region of the head. Hairs with the hair root were cut from root to tip in sections of 5 mm. As the hair sections become shorter, more information on diachronic dietary change could be obtained, but efficiency in preparing samples will decrease. We obtained 50 samples composed of four sections, three samples of five sections, two samples of three sections, and one sample of seven sections. A hair section of 5 mm will preserve dietary information for about 0.7–1.3 months if the presupposition that the hair grows at constant rate during approximately June to October (Nakashita 2006) is correct. The corresponding sections of hairs were pooled for each bear and treated as a unit for analysis. The unit of hair sections was rinsed with 2:1 chloroform:methanol solution to remove lipids and air dried.

Approximately 300 μg of hair sections (5–10 hair
sections) from each unit was enclosed in a tin cup and combusted in an element analyzer (NC-2500, Thermo Electron Inc.) interfaced to a mass spectrometer (MAT-252, Thermo Electron Inc.). The results of measurements were expressed as follows:

$$\delta^{13}C \text{ or } \delta^{15}N = [(R_{\text{sample}}/R_{\text{standard}}) - 1] \times 10^3,$$

where R is $^{13}C/^{12}C$ or $^{15}N/^{14}N$. The $R_{\text{standard}}$ for $\delta^{13}C$ or $\delta^{15}N$ was the Pee Dee Belemnite standard or atmospheric nitrogen, respectively. The precision (standard deviation) of isotopic measurements was estimated by repeatedly measuring glycine standards and was 0.12‰ ($n = 60$) for $\delta^{13}C$ and 0.19‰ ($n = 63$) for $\delta^{15}N$.

The stable isotope ratio of the hair of Japanese black bears will give a higher value than the food that was consumed because of fractionation or diet-tissue enrichment. For $\delta^{13}C$, the fractionation value is presumed to be 2‰ based on feeding experiments using captive bears (Hilderbrand et al. 1996; Felicetti et al. 2003; Nakashita 2006). For $\delta^{15}N$, the fractionation value is presumed to be 3‰ when invertebrates are consumed, 4‰ when mammals are consumed, and 5‰ when plants are consumed, based on feeding experiment using captive bears (Hilderbrand et al. 1996; Felicetti et al. 2003; Robbins et al. 2005; Nakashita 2006). By adding 2 and 3–5‰ to the $\delta^{13}C$ and $\delta^{15}N$, respectively, of potential bear food, the $\delta^{13}C$ and $\delta^{15}N$ of the hair of the bear that consumed the food can be estimated.

The $\delta^{13}C$ and $\delta^{15}N$ of potential bear food were obtained from Minagawa and Akazawa (1988), Minagawa (2001), Narita (2003), and Nakashita (2006; Table 1). Bears are omnivorous, and the diet generally consists of leaves and shoots in spring; succulent forbs, soft mast, and invertebrates in summer; and soft and hard mast in autumn (Hashimoto and Takatsuki 1997). They also hunt and scavenge vertebrates such as the serrow, wild boar, and sika deer. Some of the food consumed by bears has a distinctive stable isotope signature. Corn is just one of the C$_4$ plants planted in the region, and has a markedly higher $\delta^{13}C$ (–11.1 to –10.4‰) than do C$_3$ plants such as wild plants (–32.3 to –24.2‰), but has similar $\delta^{15}N$ (–1.1 to 4.2‰) to that of C$_3$ plants (–4.1 to 4.7‰). Human food waste, and cattle fodder that often contains C$_4$ plant materials, and materials of ocean origin also have higher $\delta^{13}C$ (–20.7 to –17.2‰) and higher $\delta^{15}N$ (6.3 to 11.2‰) than do C$_3$ plants. The tissues of wild creatures tend to have higher $\delta^{15}N$ (–1.4 to 7.9‰) than do C$_3$ plants, but similar $\delta^{13}C$ (–29.6 to –23.7‰) to C$_3$ plants.

Because the maximum $\delta^{13}C$ and $\delta^{15}N$ of natural foods are –23.7‰ (invertebrate) and 7.9‰ (vertebrate), respectively, hair sections with $\delta^{13}C > -21\%$ strongly imply that the bear consumed a substantial amount of anthropogenic food, and those with $\delta^{15}N > 12\%$ and $\delta^{13}C < -21\%$ strongly imply that the bear consumed a substantial amount of animal matter in the wild. However, these criteria are only sufficient to predict the consumption of the different food materials when consumed separately and not in combination. According to the proportion of each food material consumed, the $\delta^{13}C$ and $\delta^{15}N$ have values intermediate to those of the original value of each single food type. Thus, it is possible that a bear con-

![Fig. 2. Monthly change in nuisance kills in 2004 in Hiroshima.](image-url)
sumed anthropogenic food if δ^{13}C is <–21‰ and animal matter if δ^{15}N is <12‰.

Starvation and nutritional stress also affect the stable isotope signatures of animal tissues (Hobson et al. 1993; Voigt and Matt 2004). The δ^{15}N enrichment of animal tissues was observed when captive animals were supplied with a nutritionally poor diet (e.g., Japanese quail *Coturnix japonicus*, Hobson et al. 1993; nectar-feeding bats *Glossophaga soricina*, *Leptonycteris curasoae*, Voigt and Matt 2004) and when wild Ross’ Goose (*Chen rossii*) had been fasting because of nesting (Hobson et al. 1993). Protein synthesis using catabolized nitrogenous compounds derived from the animal’s own body is the putative mechanism of this elevation in δ^{15}N because an animal’s body is already enriched in ^{15}N relative to its diet. We examined the presence of an increase in δ^{15}N in the rootmost hair section compared to the other sections of bear hair as evidence of starvation or nutritional stress when the BCI of bears was <–0.5, which is indicative of relatively poor nutritional condition.

Statistical analysis

We examined the effects of sex (male, female), age class (young, adult), and month when the bear was captured (October and November) on the BCI using three-way ANOVA. In advance of the ANOVA, the BCI + 5 was square-root transformed to normalize the distribution. The differences in stable isotope ratios among BCI classes were examined using the Mann-Whitney U test or Kruskal-Wallis test (two-tailed, significance level of 0.05). BCI was divided into three classes: high BCI, individuals ranked in the highest one-fourth in BCI; low BCI, individuals ranked in the lowest one-fourth in BCI; and intermediate BCI, the remaining individuals. All statistical analyses were performed using SYSTAT 10 statistics software (SPSS Science Marketing Department, SPSS Inc., Chicago, IL).

Results

**Body-condition index**

We summarized the TBM and HBL of each age class (Table 2). The BCI ranged from –3.0 to 3.5 (mean ± SD; 0.64 ± 1.2; Fig. 3). There were no significant effects of age class, sex, or month of capture, and there were no significant interactions among any combination of these factors except for Sex × Age-class × Month (Table 3). The average BCI of the young (0.25 ± 1.4) was lower than that of the adults (0.72 ± 1.1), although they did not differ significantly (*U* = 262.5, *P* = 0.487).

**Stable isotope ratios**

The δ^{13}C of hair sections ranged from –24.1 to –19.3‰ (mean ± SD‰; –22.0 ± 0.7‰; Fig. 4), indicating that the bears consumed both natural and anthropogenic foods. The δ^{13}C of 13 hair sections of eight bears (14%) was >–21‰, implying the consumption of anthropogenic food.

The δ^{15}N of hair sections ranged from 1.4 to 6.5‰ (4.0 ± 0.9‰; Fig. 5). Thus, it is unclear whether the bears consumed animal matter because these values overlapped those expected for the consumption of only C_{3} plant matter (0.9 to 9.7‰).

The difference between the maximum and minimum stable isotope ratios within a series of hair sections from a single bear was 0.1 to 3.3‰ for δ^{13}C and 0.2 to 2.9‰.
Most (86%) of the observed differences between the maximum and minimum $\delta^{13}C$ within hair sections of a single bear and 30% of the same values for $\delta^{15}N$ were greater than the measurement error ($P < 0.05$; $0.47\%$ for $\delta^{13}C$, $0.74\%$ for $\delta^{15}N$, estimated as $2 \times 1.96 \times SD$ of measured values for standard glycine). This indicates substantial changes in the stable isotope ratio of the hair while the hair was growing. The patterns of temporal change in the stable isotope ratio in series of hairs varied, indicating individual differences in dietary profile. For example, of eight bears that might have consumed anthropogenic food, one had an anthropogenic food signature in the tip of hair sections, three had it in the root side of hair sections (Fig. 6), three had it in the middle hair sections, and one had it in all sections. Of 48 bears that had no anthropogenic food signature, 12 bears had a change in $\delta^{15}N$ from high (>4‰, the midpoint of the observed $\delta^{15}N$ range) to low from the hair tip to the hair root.

### Table 2. The total body mass (TBM) and the straight-line body length (SLBL) of each sex-age class of bear

<table>
<thead>
<tr>
<th>Source</th>
<th>Adult male</th>
<th>Adult female</th>
<th>Young male</th>
<th>Young female</th>
</tr>
</thead>
<tbody>
<tr>
<td>TBM (kg)</td>
<td>72.3 ± 19.8</td>
<td>58.7 ± 15.7</td>
<td>39.0 ± 10.2</td>
<td>38.0 ± 13.3</td>
</tr>
<tr>
<td>SLBL (cm)</td>
<td>137.3 ± 10.7</td>
<td>124.0 ± 8.6</td>
<td>112.0 ± 10.1</td>
<td>118.5 ± 13.3</td>
</tr>
</tbody>
</table>

Values indicate the mean ± standard deviation and range.

### Table 3. The results of ANOVA for the effects of sex, age class, month of capture, and their interactions on the body-condition index (BCI) of bears

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of squares</th>
<th>df</th>
<th>Mean Squares</th>
<th>F-ratio</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td>0.164</td>
<td>1</td>
<td>0.164</td>
<td>0.126</td>
<td>0.724</td>
</tr>
<tr>
<td>Age-class</td>
<td>4.073</td>
<td>1</td>
<td>4.073</td>
<td>3.128</td>
<td>0.083</td>
</tr>
<tr>
<td>Month</td>
<td>0.135</td>
<td>1</td>
<td>0.135</td>
<td>0.104</td>
<td>0.749</td>
</tr>
<tr>
<td>Sex × Age class</td>
<td>3.085</td>
<td>1</td>
<td>3.085</td>
<td>2.369</td>
<td>0.130</td>
</tr>
<tr>
<td>Sex × Month</td>
<td>4.291</td>
<td>1</td>
<td>4.291</td>
<td>3.295</td>
<td>0.076</td>
</tr>
<tr>
<td>Age class × Month</td>
<td>0.384</td>
<td>1</td>
<td>0.384</td>
<td>0.295</td>
<td>0.590</td>
</tr>
<tr>
<td>Sex × Age-class × Month</td>
<td>5.937</td>
<td>1</td>
<td>5.937</td>
<td>4.559</td>
<td>0.038</td>
</tr>
<tr>
<td>Error</td>
<td>62.499</td>
<td>48</td>
<td>1.302</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
root (Fig. 7), and two bears had a change in $\delta^{15}N$ in the reverse direction. Eight bears had consistently high $\delta^{15}N$ (Fig. 8), whereas 17 bears had consistently low $\delta^{15}N$ (<4‰; Fig. 9). Nine bears showed other patterns of fluctuation in $\delta^{15}N$.

We looked for an increase in $\delta^{15}N$ in the rootmost section, which likely grew just before the bear was captured, by comparing it to the $\delta^{15}N$ of other sections, as evidence of serious starvation or nutritional stress when the BCI of the bear was <−0.5 (eight bears). An increase in $\delta^{15}N$ was observed in only two individuals, but the maximum increases were only 0.6 and 0.3‰, which were smaller than the measurement error.

The relationship between BCI and the stable isotope ratio

The BCI was not influenced by age class, sex, or month of capture. Consequently, all of the data were pooled. The means and standard deviations of $\delta^{15}N$ of all hair segments from a single bear in the high, intermediate, and low BCI classes were 4.1 ± 0.6‰ ($n = 14$), 3.9 ± 0.7‰ ($n = 28$), and 3.6 ± 0.7‰ ($n = 14$), respectively, and did not differ significantly among BCI classes (Kruskal-Wallis test, $H = 4.18$, $P = 0.124$). The means and standard deviations of $\delta^{13}C$ of all hair segments from a single bear in the high, intermediate, and low BCI classes were −22.1 ± 0.6‰ ($n = 14$), −22.1 ± 0.6‰ ($n =
Fig. 6. The typical diachronic change in the stable isotope ratio, which might reflect anthropogenic food consumption.

Fig. 7. The typical diachronic change in the stable isotope ratio showing high to low change in $\delta^{15}$N with constantly low $\delta^{13}$C.

Fig. 8. The typical diachronic change in the stable isotope ratio showing consistently high $\delta^{15}$N and low $\delta^{13}$C.

Fig. 9. The typical diachronic change in the stable isotope ratio showing consistently low $\delta^{15}$N and low $\delta^{13}$C.
28), and \(-22.2 \pm 0.7\% \) (\(n = 14\)), respectively, and did not differ significantly among BCI classes (Kruskal-Wallis test, \(H = 0.113, P = 0.945\)). The means and standard deviations of \(\delta^{15}C\) in the latter half of the hair segment series (two fourths of hair cut into four sections, one third of hair cut into three sections, two fifths of hair cut into five sections, and three sevenths of hair cut into seven sections) from a single bear, which might have grown in late summer and autumn, in the high, intermediate, and low BCI classes were \(4.0 \pm 0.9\% \) (\(n = 14\)), \(3.7 \pm 0.6\% \) (\(n = 28\)), and \(3.3 \pm 0.8\% \) (\(n = 14\)), respectively, and differed significantly among classes (Kruskal-Wallis test, \(H = 6.597, P = 0.037\)). The means and standard deviations of \(\delta^{13}C\) in the latter half of hair segment series from a single bear in the high, intermediate, and low BCI classes were \(-22.1 \pm 0.9\% \) (\(n = 14\)), \(-22.3 \pm 0.5\% \) (\(n = 28\)), and \(-22.2 \pm 0.9\% \) (\(n = 14\)), respectively, and did not differ significantly (Kruskal-Wallis test, \(H = 0.198, P = 0.91\)). Bears that had a high \(\delta^{15}N\) signature (>4‰) in the latter half of the hair segment series composed 21% of the bears examined.

Discussion

Body condition

The wide range of BCI indicates that bears that intruded into residential areas had a wide range of nutritional conditions. These individual differences in BCI were not the result of age class, sex, or month of capture. Hashimoto and Yasutake (1999) reported that the body weight of captive adult female bears increased rapidly during the period from November to December as a result of hyperphagia in preparation for hibernation. Some variation in BCI might be explicable by such seasonal changes in weight, although we did not find an effect of month of capture. The range of BCI in October (–1.2 to 3.8) was as wide as that in November (–0.9 to 3.5, with one outlier of –3.0; Fig. 3), which suggests that there were marked individual differences in nutritional condition in both October and November. The age class may affect the BCI because the small body size of young individuals causes inefficient expenditure of acquired energy and is a disadvantage in competition for food. The young age class had smaller average BCI than did the adult class, although not significantly so. It is possible that the small sample size of the young age class might have resulted in type II error. Further study based on larger samples is needed to clarify the influence of age class on the BCI.

The relationship between dietary profile and body condition

The wide range of \(\delta^{13}C\) and \(\delta^{15}N\) suggests marked individual differences in food acquisition, which might influence the BCI. Individuals with a high BCI tend to have high \(\delta^{13}C\) in the root side of hairs, implying that they depended on high-\(\delta^{13}C\) food items in late summer and autumn. This food might be animal matter, acorns, or both, in addition to anthropogenic food. Insects are candidates for the high-\(\delta^{15}N\) food items in the summer because they are abundant and are found in bear feces frequently in summer (Hashimoto and Takatsuki 1997). The high-\(\delta^{15}N\) food items available in autumn might include hard mast such as *Quercus* acorns. Hard mast tends to have higher \(\delta^{15}N\) than other C3 plant food items (Narita 2006), although the ranges of \(\delta^{13}C\) overlap (Table 1); the identification of acorn consumption via \(\delta^{15}N\) is difficult. The analysis of feces and stomach contents help to solve this question. Anthropogenic food such as human food waste, cattle fodder, and corn also provide nutrition to bears. Only 14% of the bears were suspected to have consumed anthropogenic food. Because the proportion of individuals that acquired anthropogenic food and high-\(\delta^{15}N\) food was restricted and small, the amount and distribution of such food items might have been restricted and subject to competition among bears in Hiroshima in autumn 2004. Future research should evaluate the actual abundance of such food items including hard mast.

Temporal fluctuations in \(\delta^{13}C\) and \(\delta^{15}N\) (typical examples are shown in Figs. 6 and 7) were observed in most bears, which might reflect seasonal changes in bear food availability (Hashimoto and Takatsuki 1997). Starvation can contribute to some \(\delta^{13}C\) enrichment (Hobson et al. 1993; Voigt and Matt 2004); however, the increase in \(\delta^{13}C\) in the series of hair segments observed in the two bears with a BCI < –0.5 was smaller than the expected measurement error. Thus, we conclude that there was no evidence of seriously poor nutrient conditions that culminated in autophagia.

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