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**Changes in body condition and behavior
of Hokkaido brown bears in relation to
seasonal and annual variations in diet**

(食性の季節変化および年次変動が
ヒグマの栄養状態と行動様式に与える影響の解明)

By

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PREFACE

Brown bears (*Ursus arctos*) are opportunistic omnivores that can change their diet in response to spatial and seasonal variation in food resources (Bojarska and Selva 2012; Kavčič et al. 2015). However, bears often rely on seasonally restricted, highly nutritious foods such as soft mast (*e.g.*, *Vaccinium* sp. berries, a source of carbohydrate; Hertel et al. 2018) and hard mast (*e.g.*, *Quercus* sp. acorns, a source of lipid; Naves et al. 2006), as well as seasonally available meats such as salmonid fish (a source of protein and lipid) that migrate upriver during the spawning season (Deacy et al. 2016). The challenge is that mast production and upstream salmon abundance vary by year, and the resulting annual fluctuation in dietary content affects body condition, survival, and reproductive success as well as movement and habitat selection of brown bears (Blanchard 1987; Stenseth et al. 2016; Welch et al. 1997; Zedrosser et al. 2006).

In Japan, brown bears inhabit only Hokkaido, the northernmost island of the country. The Shiretoko Peninsula (43°50′–44°20′ N, 144°45′–145°20′ E), located in eastern Hokkaido, has one of the highest densities of brown bear populations worldwide (Hokkaido Government 2017). The Shiretoko Peninsula contains high-quality brown bear habitat with a wide variety of food resources ranging from the coastal (*e.g.*, pink salmon, *Oncorhynchus gorbuscha*) to the alpine regions (*e.g.*, Japanese stone pine, *Pinus pumila*; Ohdachi and Aoi 1987). However, it remains unknown whether food habits vary by year and how such variation affects the body condition and behavior of bears.

This study aimed to clarify seasonal and annual variation in the consumption of high-nutrition foods among Shiretoko brown bears, and how those variations affect bear body condition and behavior. In **Chapter 1**, a noninvasive method that uses photographs was developed to assess the body condition of free-ranging brown bears. The precision of photograph-based measurements was examined using photographs of an identifiable bear in the Rusha area. In addition, the accuracy of the photograph-based measurement method was validated by using actual measurements of 7 captured individuals. In **Chapter 2**, to assess seasonal and annual fluctuation in adult female body condition in relation to diet and reproductive status, a 7-year longitudinal study was conducted in the Rusha area that included scat sampling and direct observation of bears. Using the method developed in **Chapter 1**, body condition of 12 adult females was evaluated. In **Chapter 3**, GPS data obtained from seven adult female bears were used to clarify how females changed their behavior depending on reproductive status and diet. I tested hypothesis that females with offspring were restricted from obtaining food resources due to poor mobility of cubs.

CHAPTER 1. DEVELOPMENT OF A NONINVASIVE PHOTOGRAPH-BASED METHOD FOR THE EVALUATION OF BODY CONDITION IN FREE-RANGING BROWN BEARS

Body condition, defined as the energetic state in an individual, especially the relative size of energy reserves such as fat and protein (Gosler 1996; Peig and Green 2009; Schulte-Hostedde et al. 2001), is an important determinant of health in both terrestrial and marine mammals. This study developed a noninvasive method of evaluating the body condition of free-ranging brown bears based on morphometric measurements obtained from photographs. The goal of this study was to develop an accurate, photograph-based evaluation method that could be applied to bears in various postures.

First, 476 bears captured in the Shiretoko Peninsula during 1998–2017 were weighed and measured, and their body condition index (BCI) was calculated based on residuals from the regression of body mass against body length. BCI showed seasonal changes and was lower in spring and summer than in autumn. The torso height:body length ratio was strongly correlated with BCI, which suggests that it can be used as an indicator of body condition.

Second, the precision of photograph-based measurements was examined using an identifiable bear in the Rusha area ($44^{\circ}11'–44^{\circ}12' \text{ N}$, $145^{\circ}10'–145^{\circ}12' \text{ E}$). This area is designated as a special wildlife protection area where public access is not allowed without permission. Bears in this area have become habituated to and thus ignore humans, which allows us to observe bears directly at close range (Shimozuru et al. 2020). A total of 220 lateral photographs of this bear were taken September 24–26, 2017, and classified according to bear posture. The torso height:body/torso length ratio was calculated with four measurement methods and compared among bear postures in the photographs. The results showed torso height:horizontal torso length (TH:HTL) to be the indicator that could be applied to photographs of the most diverse postures, and its coefficient of variation for measurements was $<5\%$. In addition, when analyzing photographs of this bear taken from June to October during 2016–2018, TH:HTL was significantly higher in autumn than in spring/summer, which indicates that this ratio reflects seasonal changes in body condition in wild bears.

Third, BCI was calculated from actual measurements of seven females captured in the Rusha area and TH:HTL from photographs of the same individuals. A significant positive relationship was found between TH:HTL and BCI, which suggests that the body condition of brown bears can be estimated with high accuracy based on photographs. This simple and accurate method is useful for monitoring bear body condition repeatedly over the years and contributes to further investigation of the relationships among body condition, food habits, and reproductive success.

CHAPTER 2. DINING FROM THE COAST TO THE SUMMIT: SALMON AND PINE NUTS DETERMINE THE SUMMER BODY CONDITION OF FEMALE BROWN BEARS ON THE SHIRETOKO PENINSULA

A variety of mammal species experience fluctuations in body condition as a result of varying energy intake and expenditure (Boswell et al. 1994; Fietz and Ganzhorn 1999; Parker et al. 2009). On the Shiretoko Peninsula, brown bears have seasonal access to high-lipid pine nuts and high-protein salmon. To assess seasonal and annual fluctuation in the body condition of adult female brown bears in relation to diet and reproductive status, a longitudinal study was conducted in the Rusha area during 2012–2018.

First, 2,079 bear scats were collected in the Rusha area from June to November. The point-frame analysis of scat contents revealed that pine nuts accounted for 39.8% of energy intake in August and salmon accounted for 46.1% in September. In addition, their consumption by bears varied annually. Based on the percentage of estimated dietary content in August, 2013 (47.4%), 2014 (47.5%), 2016 (47.3%), and 2018 (42.9%) were identified as years with high pine nut consumption. Similarly, 2013 (54.4%), 2016 (65.4%), and 2018 (72.2%) were identified as years with large consumption of salmon; all of these years also involved high consumption of pine nuts.

Second, 1,226 lateral photographs were taken when encountering 12 adult female bears (≥ 5 years old) that could be easily identified and were frequently observed in the Rusha area throughout the surveillance period. Using the method developed in Chapter 1, TH:HTL was calculated as an index of body condition. Generalized additive mixed models were used to identify nonlinear effects of month on body condition and the relationships among body condition, dietary content, and reproductive status. Results indicated that body condition continued to decline until late August and started to increase in September when salmon consumption increased. In addition, body condition began to recover earlier in years when consumption of both pine nuts and salmon was high. Furthermore, females with offspring had poorer body condition than solitary females, in particular in late August in years with light salmon consumption.

This study revealed that subalpine pine nuts and coastal salmon, which are foods unique to the Shiretoko Peninsula, determine the summer body condition of female brown bears. In addition, August is the harshest season for brown bears on the peninsula, in particular when bears cannot heavily consume salmon. Furthermore, females with dependent offspring exhibited a poorer body condition than solitary females. Although the results of this study suggest that brown bears frequently travel between the subalpine region and the coastline for foraging, further research is needed to clarify whether such movement is even possible for females with cubs and whether habitat selectivity differs depending on reproductive status.

CHAPTER 3. AN INVESTIGATION OF RESTRICTED MOUNTAIN CLIMBING AND SALMON FISHING AMONG FEMALE BROWN BEARS WITH DEPENDENT YOUNG IN HOKKAIDO, JAPAN

Animal movement is determined by energetic costs associated with acquiring resources. In addition to food availability, factors such as reproductive status, den site availability, or avoidance of conspecifics or predators can affect the movement of individuals (Nathan et al. 2008). Using Global Positioning System (GPS) location data during 2014–2020, I examined changes in female bear behavior according to reproductive status and summer diet. This study hypothesized that females with offspring were restricted from obtaining food resources due to the poor mobility of cubs. Seven adult female bears (≥ 5 years old) were immobilized and fitted with GPS transmitter collars to track their movement. These collars recorded bear locations at a fixed frequency of 2 h.

First, hourly movement velocity was calculated by dividing the Euclidean distance between consecutive locations by the associated time lag. As a result, brown bears exhibited a circadian movement pattern, with peaks around dawn and dusk. Females with cubs moved more slowly than solitary females did during early and late summer. Vegetation also affected movement velocity, resulting in slow travel in the alpine region. Second, a resource selection function was used to model season-specific habitat selection. In years with high pine nut consumption, bears selected alpine shrub communities during late summer. One female with cubs also selected alpine regions in the same way that solitary females did. By contrast, during late summer in years with low pine nut consumption, bears tended to avoid alpine regions, regardless of their reproductive status. Third, the probability of bears visiting a salmon spawning site during each monitored hour was calculated by summing the number of visits to the spawning site and dividing the result by the total number of locations. The result showed that solitary females spent more time at the salmon spawning site in daytime than at night in autumn. Females with cubs were also more likely to visit the river during the day than at night or twilight. Although there were no significant differences, solitary females tended to visit rivers at higher probability than females with cubs.

This study determined that female brown bears on the Shiretoko Peninsula change their behavior depending on reproductive status and summer diet. Females with cubs were restricted in movement; however, the use of alpine regions and salmon spawning sites by mothers was not significantly different from that of solitary females. Although energy intake may be reduced due to behavioral restrictions, increased energy expenditure due to cub rearing is probably a greater factor leading to poor body condition of mothers revealed in Chapter 2. In addition, the RSF models showed that brown bears used different areas depending on food condition in summer. To clarify whether food shortages can lead to bear intrusion into residential area, it is necessary to further study regional differences in the feeding habits and behavioral responses of brown bears.

CONCLUSION AND MANAGEMENT IMPLICATION

This study clarified annual variations in the consumption of pine nuts and salmon in late summer and those effects on the body condition and behavior of adult female brown bears in the Shiretoko Peninsula, Hokkaido, Japan. August was the harshest season for brown bears, in particular when bears cannot heavily consume salmon. However, eating a large amount of both pine nuts and salmon enables rapid recovery of body condition of female brown bears. In addition, increased energy expenditure due to cub rearing was probably a great factor leading to poor body condition of females with dependent young. Furthermore, annual fluctuation in pine nuts affected habitat selection of bears in late summer, resulting in bears avoiding alpine regions in years with low pine nut consumption.

Our findings may help to clarify the causes of the human–bear conflicts. Human–bear conflicts, including agricultural crop depredation and intrusion into human residential areas, have become a serious problem in the Shiretoko Peninsula, which often result in the removal of bears as nuisances. Especially in 2012 and 2015, the number of bears killed for nuisance control was nearly twice the usual number, peaking in August. The present study revealed that the two years with increased human–bear conflict on the Shiretoko Peninsula (2012 and 2015) were consistent with the low consumption of both pine nuts and salmon, suggesting that summer energy shortages may lead to bear intrusion into residential areas. However, the results showed that bears exhibited poor summer body condition not only during 2012 and 2015, but also in other years, indicating that malnutrition is not the sole factor causing bears to intrude into human settlements. Therefore, it would be premature to state that food shortages alone cause human–bear conflicts in this brown bear population. The fact that this study was able to reveal variation in the diets and body conditions of brown bears in the Rusha area, far from residential areas, is advantageous for understanding the natural ecology of brown bears. In future studies, we hope to clarify the characteristics of bears that appear in human settlements by comparing the diets and body conditions of brown bears around residential areas with the results of this study.

The conservation and management of large mammals is a difficult task that requires not only scientific knowledge, but also social, political, and economic circumstances. The Shiretoko Peninsula, with its wildlife protection areas, farmlands, fishermen's settlements, residential areas, and also tourist spots, can be a good model area for thoroughly investigating the complex relationships between wildlife and humans. I hope that empirical research on the Shiretoko Peninsula will continue for a long time, and that it will clarify the effects of maternal learning, personality, and human habituation on the energy balance and behavior of brown bears. Such research should give us hints on how to build better relationships with wildlife.

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