Stable isotope analysis of historical bone specimens of brown bears suggests that human activities have caused a long-term dietary shift in brown bears in Hokkaido Islands, Japan

Summary

Brown bears are opportunistic omnivores that flexibly change their feeding habits depending on the availability of dietary resources. We measured carbon, nitrogen and sulfur stable isotope ratios of bone collagen of brown bears in the Hokkaido Islands of Japan, and presented a historical record of major alterations in their feeding habits. Hokkaido brown bears used to feed on animal matter such as salmon and deer, whereas modern bears depend on plant matter like herbs and fruits. These dietary shifts probably occurred in the last approximately 100–200 years, which coincides with the beginning of modernisation in this region.

This study was published in *Scientific Reports* on 17 March 2015.

1. Introduction

Brown bears (*Ursus arctos*) are the largest terrestrial mammals in Japan, and are widely distributed throughout the northern hemisphere (Fig. 1). They are recognized as opportunistic omnivores that flexibly change their feeding habits depending on the availability of dietary resources. Brown bears generally eat various diets such as new vegetation, berries, nuts, invertebrates, mammals, crops, anthropogenic waste and salmon. Especially in North America, where many ungulates and salmon species are distributed, brown bears strongly depend on animal materials.

The Hokkaido Islands of Japan are on the southern limit of the distribution area of brown bears in the Far East. Although both ungulates (Sika deer) and salmon are found in Hokkaido, studies show that animal consumption (especially of salmon) by brown bears in this area is minimal, and that they mainly feed on plant matter such as herbs (e.g. Giant butterbur and apiaceae) and fruits (e.g. wild vine and kiwi berry). Even on the Shiretoko peninsula, which is a world natural heritage site and should be the best place for bears to eat salmon in Hokkaido, consumption of salmon by bears is significantly lower than in North America.

Why do brown bears in Hokkaido depend mostly on plant matter despite the abundance of deer and salmon resources? There are two possibilities regarding this issue: brown bears in Hokkaido originally depended on plant matter, or they changed their feeding habits for some reason.

To answer the question, “why do brown bears in Hokkaido tend to be herbivorous?”, we reconstructed the historical dietary shift of brown bears in the eastern and western regions of Hokkaido using carbon, nitrogen and sulfur stable isotope analysis. Stable isotope analysis can estimate the dietary composition of dead animals

if their bone samples are available.

2. Study methods and results

The potential diet items of Hokkaido brown bears were sampled from multiple points in the eastern and western areas. Bone fragments were sampled from local museums, Hokkaido University Botanical Gardens and Hokkaido Institute of Environmental Science. These samples were pretreated for stable isotope analysis, and the carbon, nitrogen and sulfur stable isotope ratios measured using a MASS spectrometer at the University of California and Research Institute for Humanity and Nature. Then, brown bear bones from each region were divided into three time bins: period 1 (pre-development phase; before 1890 for western areas and 1920 for eastern areas), period 2 (early phase of development; 1931–1942), and period 3 (post-development phase; after 1996). We compared the feeding habits of brown bears among each time bin. In addition, time-series plots for nitrogen stable isotope indicated the amount of assimilated animal protein, and determined the change-points of bear feeding habits.

Results of dietary comparisons among the three time bins showed that brown bears changed their feeding habits from a carnivorous diet to a herbivorous diet as time progressed (Fig. 2). In the eastern areas, period 1 bears mainly depended on terrestrial animals (64%) and salmon (19%), and the contribution of plant matter was relatively low (12% for C_3 herbs and 1% for C_3 fruits). By contrast, bears in periods 2 and 3 showed a high dependence on C_3 herbs (35% for period 2 and 54% for period 3) and C_3 fruits (30% for period 2 and 17% for period 3). Contributions of terrestrial animals to the bear's diet were relatively higher in period 2 (27%), but a low proportion in period 3 (8%). The consumptions of salmon (5% and 8%) and corn (5% and 9%) were relatively low for periods 2 and 3, respectively.

In the western areas, bears in period 1 mainly depended on terrestrial animals (56%) and C_3 plants (41%), and the consumption of salmon (3%) was low. Bears from periods 2 and 3 showed substantially higher consumption of C_3 plants (84% for period 2 and 85% for period 3) relative to that of period 1, and the consumption of terrestrial animals and salmon was low (7% and 1% for period 2 and 5% and 0% for period 3, respectively).

The temporal changes in the nitrogen stable isotope values suggest that the decline of the trophic level of brown bears began in 1800–1900 in both the western and eastern areas (Fig. 3). This period correlates with the beginning of the Meiji period (1868) and intensive development of the Hokkaido islands.

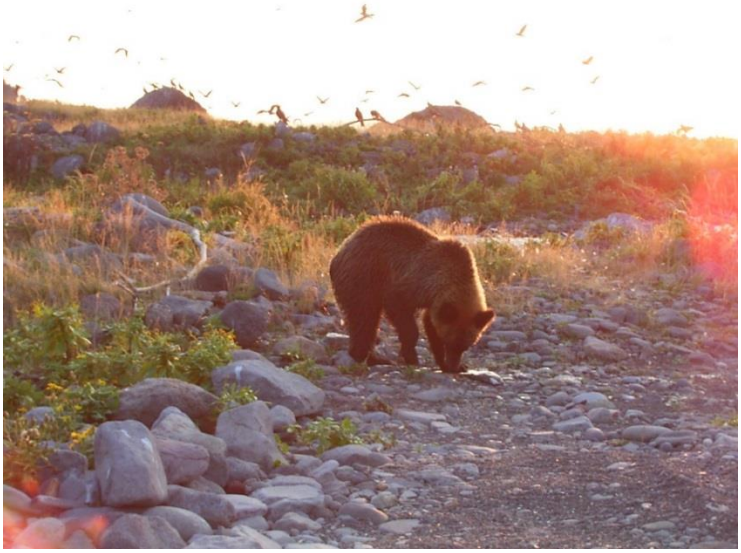

Figure 1: A brown bear eating salmon at Shiretoko peninsula (photo by Takahiro Nometsu; Shiretoko Nature Foundation).

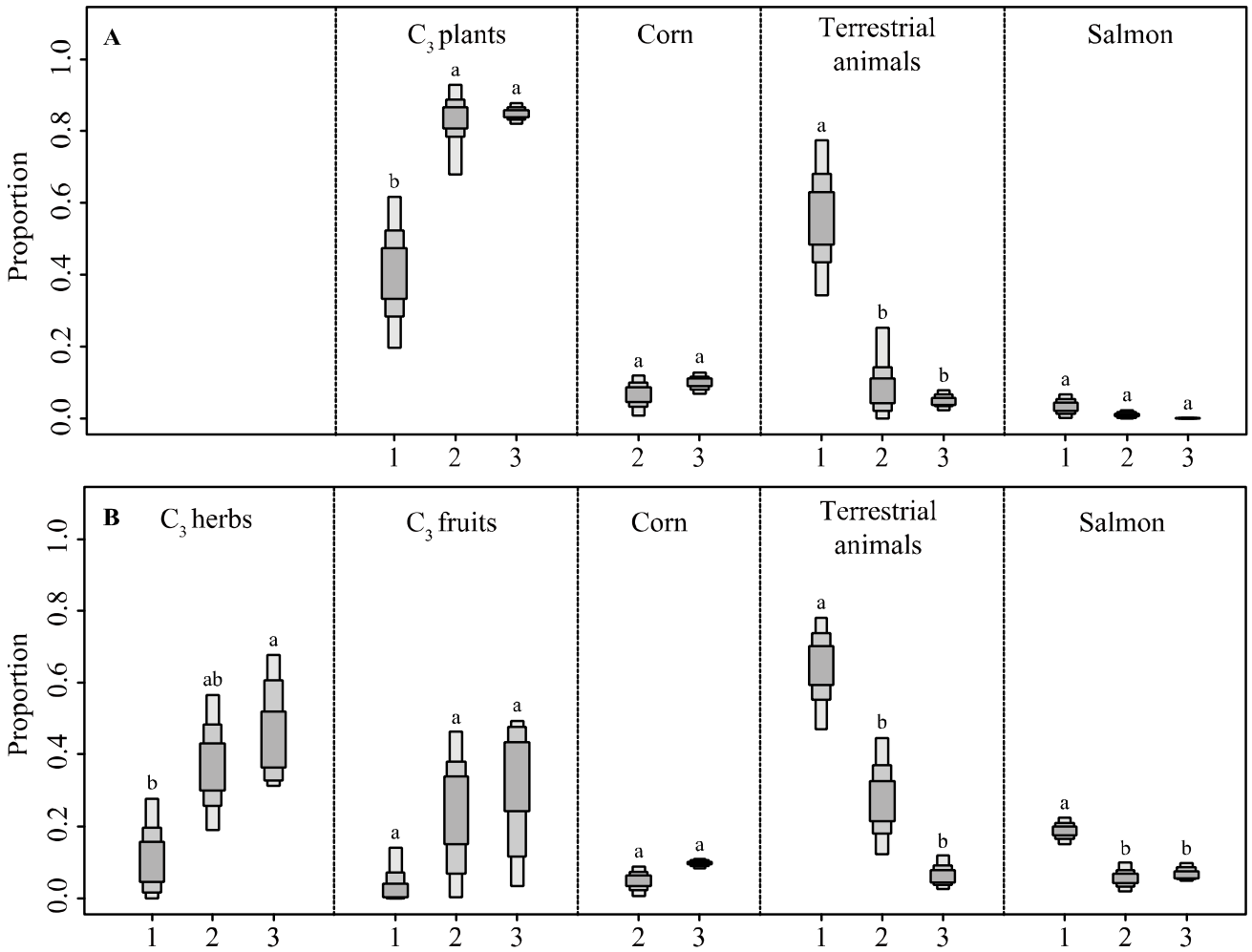

Figure 2: Historical variation of dietary components of Hokkaido brown bears. Box plots illustrate high and low 95%,

75% and 50% high density ranges of proportions of each prey item. Numbers under the horizontal axis refer to each time bin (Period 1-3). Different letters indicate significance based on the overlap of 95% high density ranges.

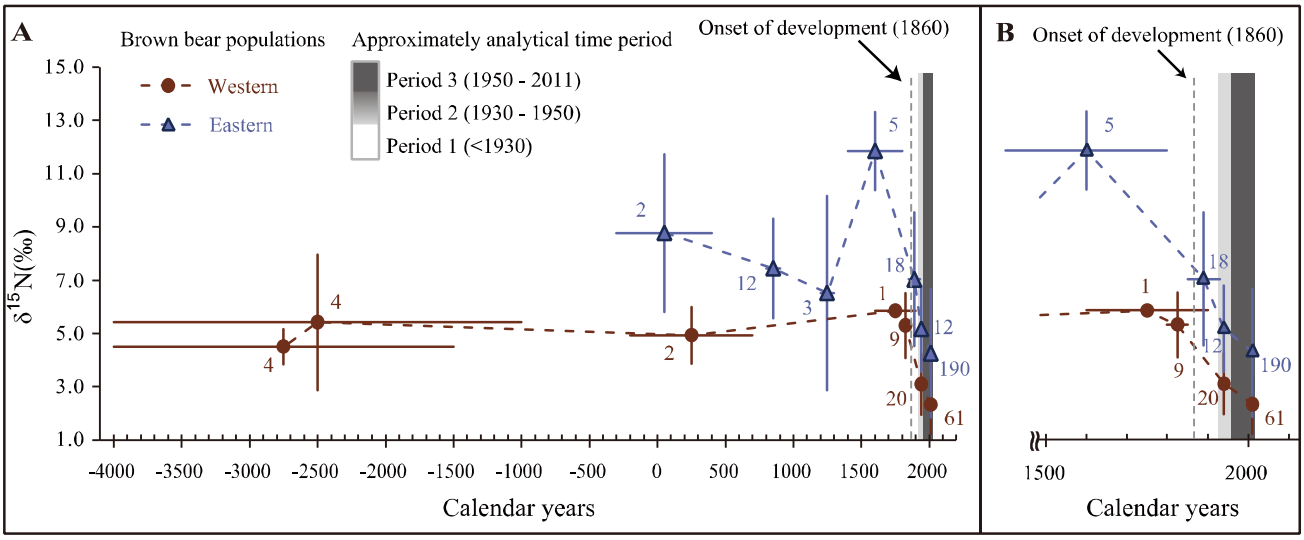

Figure 3: Temporal shifts of $\delta^{15}N$ values of bone collagen for two Hokkaido brown bear populations. (A) represents a $\delta^{15}N$ shift within the whole period, and (B) is an expanded plot after 1500. The decline of the $\delta^{15}N$ values of brown bears began in 1800–1900 in both the western and eastern areas.

3. Pervasive effects

Our results suggest that food availability for Hokkaido brown bears has shifted in the last 100–200 years, which coincides with the beginning of modernisation in this region. Therefore, human activities have contributed to the changing trophic level of brown bears in the Hokkaido islands. This includes a major decline in the marine-terrestrial linkage in the eastern region, and a loss of indirect interactions between bears and wolves, which potentially enhanced deer predation by brown bears. Furthermore, our findings imply that brown bear remains can be an ecological indicator reflecting alteration in their food webs. We hope that our achievement contributes to the progression of conservation biology and stable isotope ecology.

4. Future projects

We showed major alterations in the feeding habits of Hokkaido brown bears, however, up to this point, the specific factors that resulted in the dietary shifts are unknown. Although human activities are most likely the cause, there are many anthropogenic factors. To apply our findings to the conservation of brown bears and ecosystems of the Hokkaido Islands, we have to identify a specific cause that altered the feeding ecology of brown bears. An important issue is how the change of food availability for brown bears affected the ecosystems of Hokkaido Islands. For example, bear-salmon interaction is an important driver of nutrition transfer from marine to terrestrial ecosystems. What factors limit salmon predation by brown bears? How does it affect the

ecosystem and how we can restore the bear-salmon relationship? We will continue our investigation to answer these questions.

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Title：Major decline in marine and terrestrial animal consumption by brown bears (*Ursus arctos*)

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Article information：Scientific Reports 5: 9263 (DOI: 10.1038/srep09203)

<Glossary>

Stable isotope

Isotopes are elements that have the same atomic number but different mass numbers because they have a different number of neutrons. Some isotopes, called radioisotopes, are unstable and dissipate excess energy by spontaneously emitting radiation, while others have never been observed to undergo radioactive decay and are described as stable isotopes. Stable isotopes are ^{12}C and ^{13}C for carbon, ^{14}N and ^{15}N for nitrogen and ^{32}S and ^{34}S (principally) for sulfur. Stable isotope ratios of carbon, nitrogen and sulfur show unique isotope fractionation within food webs, and therefore we can use the stable isotope ratios as an indicator to understand interrelationship between organisms.

Carbon stable isotope ratio ($\delta^{13}C$)

Carbon stable isotopes possess distinctly different isotope ratios between C_3 plants (all woody plants and many herbs) and C_4 plants (herbs such as corn and minor grains) due to fractionation during photosynthetic carbon fixation. $\delta^{13}C$ values were used as an indicator of the consumption of agricultural crops because corn is the only C_4 plant eaten by Hokkaido brown bears.

Nitrogen stable isotope ratio ($\delta^{15}N$)

The stable nitrogen isotope ratios increase along with the food chain. Generally, animals have higher trophic level than plants. Therefore, nitrogen stable isotope ratios of organisms reflect the contributions of animal matter to the consumer's diet.

Sulfur stable isotope ratio ($\delta^{34}S$)

Sulfur stable isotope is minimally enriched along with trophic level, but it differs significantly between animal species from terrestrial and marine ecosystems. Sulfur stable isotope ratios of brown bears can be used as an indicator of salmon consumption.

Food web

A food web consists of all the "prey-predator interactions" in a single ecosystem.