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FFPRI Scientific Meeting Report 4

Biology of Bear Intrusions

-Proceedings of International Workshop on
“The Mechanism of the Intrusion of Bears into Residential Areas”-

November 21-22, 2008
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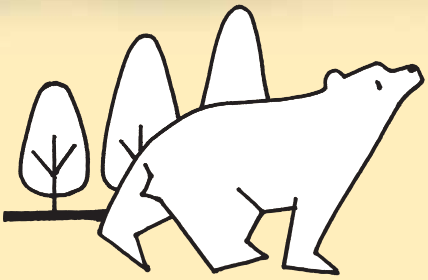

Forestry and Forest Products Research Institute

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Edited by Toru Oi, Naoki Ohnishi, Toru Koizumi, and Isamu Okochi

Forestry and Forest Products Research Institute

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Preface

The international workshop on “The Mechanism of the Intrusion of Bears into Residential Areas,” held in Kyoto, Japan, from November 22 to November 23 of 2008 has successfully drawn to a close.

This workshop was planned to promote research activities into bear biology and the dynamics underlying bear intrusion in Japan. Bears are at the top trophic level in the Japanese forest ecosystem and are regarded as symbols of healthy and fertile forests. However, in 2004 and 2006, Japan experienced mass intrusions by bears into residential areas, resulting in a number of human injuries and fatalities. Moreover, many bears were killed to prevent additional damage. Both the public and the government needed information on the dynamics underlying this phenomenon, and on methods for predicting such events in the future. Since 2004, our institute, in cooperation with Hokkaido University, Gifu University, Ibaraki Nature Museum, and the Wildlife Management Office (Ltd.) has been engaged in research projects focused on this issue. Other universities and prefectures have also begun to get involved in this research. It became time for us to summarize what we had achieved, and to consider the next step in our research. We arranged this meeting with this in mind.

Bear researchers have been relatively scarce in Japan. However, both established scholars, and especially young students, have recently come forward to study this species, despite the many challenges this topic presents to research. Many of the papers in these proceedings are indebted to the dedication of such young researchers, who will continue to contribute greatly to progress in the study of bear biology and conservation.

We hosted 81 participants at the workshop for experts and 128 participants at the public symposium. At this workshop, we have shared our scientific understanding of bear biology and the dynamics underlying bear intrusion. We can summarize the keys to future success in bear research as follows:

1) A comprehensive approach that includes physiology, genetics, behavior, and ecology;
2) Long-term research involving the monitoring of ecosystem dynamics;
3) Study of the human dimension with a view to educating humans and modifying their behaviors in order to avoid conflicts with bears, thus promoting conservation of the latter.

I should also emphasize one other achievement of this workshop: that it enabled the establishment of close friendships with outstanding foreign researchers. We invited speakers and participants from the United States, Taiwan, and Korea, and their advice and cooperation are essential for our future research.

At this point, we have a foundation from which our studies of bears can proceed. Working cooperatively, our institute will promote the further study of bears, particularly with regard to conservation and damage control.

Finally, I would like to express my appreciation and gratitude to the invited speakers: Prof. Michael Vaughan (Virginia Tech University), Dr. Diana Doan-Crider (Texas A & M University), Dr. Mei-Hsiu Hwang (Taiwan National Pingtung University of Science and Technology), Dr. Tsutomu Mano (Hokkaido Institute of Environmental Sciences), and Dr. Ken Ishida (the University of Tokyo), and to the chairpersons of the workshop session: Prof. Shingo Miura (Waseda University), Prof. Yin Wang (National Taiwan Normal University), Prof. Toshio Tsubota (Hokkaido University), and Dr. Koji Yamazaki (Ibaraki Nature Museum), as well as to all the participants in this workshop.

We are also indebted to the supporters of this workshop: the Japanese Ministry of the Environment, the Forestry Agency of Japan, the Kyoto prefectural government, the Asian Society of Wildlife Medicine and Conservation, the Japanese Society of Mammalogy, the Japanese Wildlife Conservation Society, and the Japanese Bear Network.

Dr. Kazuhiro Ishizuka
Vice president of the Forestry and Forest Products Research Institute
March 1, 2009

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Invited Paper

Biology of Bear Intrusions: 9-17 (2009)

The influence of food availability on American black bear (*Ursus americanus*) physiology, behavior and ecology

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Introduction

Historically, American black bears ranged throughout North America, but today they occupy only a fraction of their original range (Fig. 1). However, because they are distributed over such a wide geographic area, reproductive parameters and other vital rates vary across their range; bears in the southeastern part of their range appear to have the highest reproductive rates while those in the northwest have the lowest (Table 1). This apparent difference in reproductive performance may be food related (i.e., bears in the southeast feed primarily on hard mast while those in the northwest depend on soft mast; Vaughan 2002). Food availability in fall is particularly important as bears enter a hyperphagic phase and prepare for winter dormancy. For instance, Inman and Pelton (2002) determined that 59.3 percent of calories available to bears annually in Smoky Mountains National Park, Tennessee were available during mid September to mid December.

In examining the relationship between black bears and the food available to them, I reviewed many studies, but drew heavily from some of the more long-term studies (7-16 years, Jonkel and Cowan 1971; Rogers 1987; McLaughlin et al. 1994; McLaughlin 1998; Costello et al 2003). While short-term studies (2-3 years) can provide useful information, they fail to reveal the variability inherent in a long-lived species such as bears, which can lead to incorrect interpretation of data.

Pelton (1989) recognized early on from his many years of research that bears respond physiologically, behaviorally, and ecologically to food abundance. This paper addresses each of these areas, but is not an exhaustive review. Rather, it briefly outlines some of the ways bears respond physiologically, behaviorally, and ecologically to food availability and uses one or two examples to illustrate these responses.

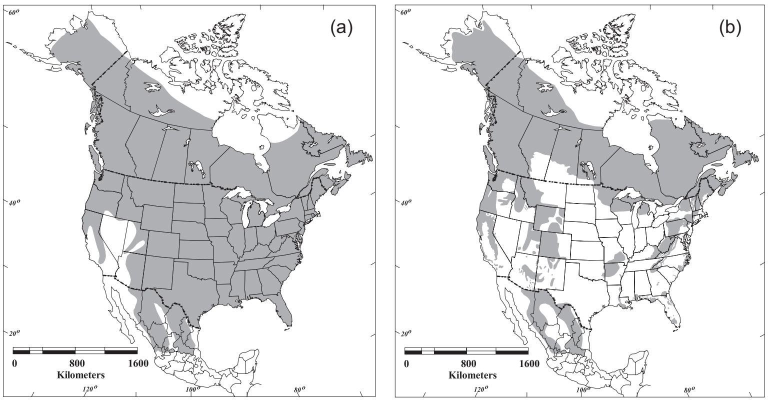


Fig. 1 Historic(a) and current(b) distribution of black bears in North America. Courtesy of Frank van Manen, University of Tennessee, Knoxville,TN

Table 1 Reproductive parameters of black bears in different regions of North America

Region	Primiparity	Interval	Litter Size	Yearling wt (kg)	Cub Sx (%)
Southeast	4.1 N=6 [1]	2.3 N=3	2.3 N=5	29.0 N=3	73 N=5
Northeast	4.6 N=5	2.1 N=4	2.6 N=5	19.8 N=5	65 N=5
Northwest	5.4 N=7	2.4 N=6	2.0 N=8	19.0 N=4	63 N=5
Southwest	4.5 N=3	2.3 N=3	1.9 N=3	24.7 N=3	57 N=2

[1] N = the number of studies used to derive a mean.

Physiology

Physiological variables that may be affected by food availability include, but are not limited to, blood chemistry, lactation, and physiological condition (reproduction, a physiological response, will be discussed in the Ecology section). Hellgren et al. (1993) examined blood values of 48 adult female bears in Minnesota in years when fall nutrition was good versus poor (Table 2). Red blood cell count, uric acid and thyroxin were higher in years of good nutrition, while mean corpuscular volume (MCV), urea nitrogen, and cortisol were higher in poor years. Red blood cell count and MCV, both indicators of hemoglobin level, suggest bears were in better nutritional condition in good years. Thyroxin, an indicator of metabolic rate, is positively related to energy intake, while urea nitrogen is positively related to protein intake. This suggests that in good years bears fed on high energy foods in fall while in poor food years high energy foods (hard mast, berries) were less available and bears fed on foods high in protein. Elevated cortisol levels in food scarce years suggest increased stress. Fanzmann and Swartz (1988) in Alaska also examined blood values of bears in good versus poor condition (Table 3), and suggested using hemoglobin for female bears and packed cell volume for male bears as the best indicators of nutritional condition when operating under field conditions since these values could be easily tested in a field lab.

Iverson et al. (2001) reported fatty acid values in the milk of black bears in Massachusetts relative to food availability. While they reported on more than 30 fatty acids, the two representative examples reported in table 4 illustrate that fat levels and perhaps the quality of milk produced by lactating females is reflected in the quality of their diet. However, no attempt was made to relate the quality of milk to growth and survival of cubs.

Schroeder (1987) determined physical condition ratios (PCR = body weight/total length) of bears in Redwood National Park and the San Bernardino Mountains of California and concluded that bears with a high PCR in areas where food was limited indicated their superior ability to compete for food, but in areas with abundant food, a high PCR reflected habitat quality or quantity. In both cases, adult bears always out competed younger bears.

In their long-term study of black bears in Montana, Jonkel and Cowan (1971) presented data that illustrated average weights of adult male and female bears fluctuated directly with huckleberry (*Vaccinium* spp) production; females appeared to be more severely affected by food shortage than males. Likewise, in a long-term study in Virginia, Vaughan (unpublished data) found that 1998 summer weights of adult male and female bears dipped to their lowest or near lowest levels in the 10-year study following a severe mast crop failure in 1997 (Table 5). Both studies illustrate the close tie between black bear nutritional condition and food available to them.

Table 2 Mean Body Mass and blood characteristics of 48 (189 samples) female black bears in Northern Minnesota 1970-1976, during good and poor years of mast and berry production

Character	Good years (N=74-89)	Poor years (N=24-93)
Body Mass (kg)	68.4	62.1
Red Blood Cells (10^6 /ml)	8.2	7.6
Uric Acid (mg/dl)	1.6	1.0
Thyroxine (ng/ml)	3.5	2.5
MCV (mM3)	63.3	66.6
Urea Nitrogen (mg/dl)	12.6	14.2
Cortisol (mg/dl)	6.7	7.6

Good years = 1970, 1971, 1973
Poor years = 1972, 1974, 1975, 1976
All comparisons significant at $p<0.05$
75-80% accuracy in classifying nutritional condition

Table 3 Condition-related blood values for black bears in Alaska 1977-85

Blood parameter	Sex	Good condition	Poor condition
Hemoglobin	Female	22.2 g/dL	17.0 g/dL
Packed cell volume	Male	47.5%	42.7%

Table 4 Fatty acid composition of black bear milk during winter dormancy relative to food abundance the previous fall

Measure	1994	1995	1996
Hard mast previous fall	Excellent	Good	Poor
% Acorns in diet	64-82	-	5
% Fat	19.8	19.6	18.0
18:2n-61	18.9	17.7	8.1
16:02	20.1	20.5	30.7

18:2n-61 and 16:0 are two of 30 fatty acids in bear milk measured by Hellgren et al. 1993. 18:2n-61 is indicative of a high fat diet and 16:02 is indicative of a high carbohydrate diet.

Table 5 Average summer weights (lbs) of adult male and female black bears on two study areas in the Appalachian Mountains of Virginia 1964-2002

	South		North	
Year	Female	Male	Female	Male
1994	N/A	N/A	120	193
1995	137	248	137	199
1996	135	191	126	222
1997 *	146	185	131	202
1998	133	170	122	177
1999	157	220	143	213
2000	135	165	127	209
2001	137	226	125	202
2002	145	189	124	203

* = A complete mast crop failure occurred in 1997
N/A= Not applicable (no data were collected on the southern study area in 1994)

Thus, from a physiological standpoint, food scarcity can result in blood values indicative of decreased health, poorer quality milk for cubs of females in nutritional stress, and decreased physical condition in general.

Behavior

Behaviors that may be influenced by food availability include daily and seasonal activity patterns, movements, nuisance activity, and social behavior.

There is some evidence that bears become more active and more nocturnal in fall as they go into a hyperphagic phase in preparation for denning. Garshelis and Pelton (1980) found that the daily activity patterns of black bears in Great Smoky Mountain National Park, Tennessee and North Carolina, varied seasonally. In spring, when food resources were limited, bears were mostly crepuscular, but they became diurnal and more active in summer as berries ripened. As hard mast (acorns) became available in fall bears increased their foraging activity and were much more nocturnal. Bridges et al. (2004) found a similar pattern for bears in Virginia (Fig. 2). In Sequoia National Park California, Ayres et al. (1986) reported that black bear activity patterns during June-August differed depending on the food source. Bears that fed on natural foods were most active during the day while bears that fed on human foods (trash, camper foods) were most active at night. While there are many more examples of shifts in daily and seasonal black bear activity patterns related to food availability, the patterns are relatively consistent throughout American black bear range.

Those who have studies black bear movements relative to food availability generally conclude that when food is limited movements increase, but when food is abundant movements are limited. In Idaho, Amstrup and Beecham (1976) described the movement and activity patterns of bears relative to plant phenology. They found significant correlations between phenological stages of plants used as bear foods and the amount of time bears were associated with those plants. For example, when huckleberries (*V. globulare*) were in the flowering stage bears were rarely found in association with the plants, but as the plants went through vegetative growth, fruit set, and fruit ripening, bears increased their association with the plants. In addition, they noted that plant development was delayed at higher elevations and bears were attuned to the delay and moved to higher elevations as food plants ripened. They also found an inverse relationship between daily movements and food availability.

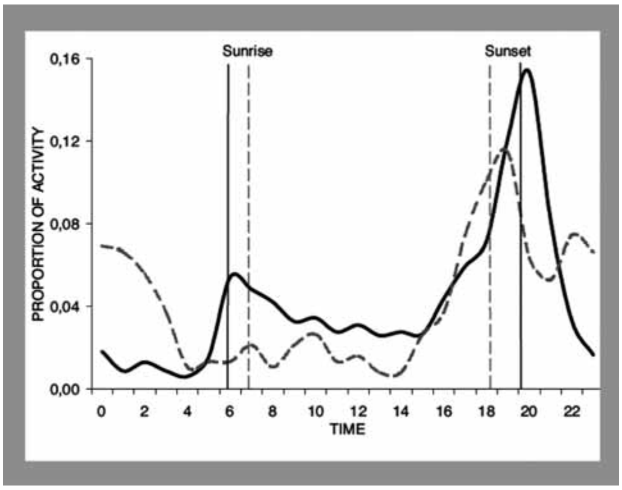


Fig.2 Daily activity patterns of black bears in the Appalachian Mountains of Virginia. From Bridges et al.(2004)

It is commonly accepted that black bears will shift ranges seasonally to take full advantage of food supplies, particularly in years of food scarcity. For instance, Beeman (1975) found that in years when mast crops were poor, 75% of marked black bears in Great Smoky Mountains National Park, Tennessee shifted from summer/spring ranges to fall ranges, but in years when mast crops were good only 25% shifted ranges. Lynn Rogers, in his classic long-term (1969-85) study of bears in Minnesota (Rogers 1987), also found that food abundance affected bear movements. In years when food was scarce, 50% of marked bears (N = 100) moved more than 7 km outside their normal fall range, but in years when food was abundant only 38% (N = 37) moved. The longest movements (90-201 km) occurred in food scarce years. Rogers (1987) suggested that cubs that move with their mothers may remember areas with abundant food and go back to those areas in years of food scarcity.

Much of our knowledge of social behavior in black bears comes not necessarily from studies designed to study behavior, but as incidental information from studies focused on other aspects of bear ecology. In general, it appears that when food is scarce bears search for areas of concentrated food, increasing home range size and home range overlap, which likely brings bears in close contact with each other. This may lead to social interactions not normally observed in this solitary animal. Jonkel and Cowan (1971) noted that bears in Montana fed within 100 m of each other when food was scarce and concentrated, but did not comment on social interactions. However, Herrero (1983) found that bears feeding at dumps in Alberta, Canada, formed hierarchal systems and social aggregations. Social interactions were characterized by tolerance, avoidance, and spacing. When agonistic interactions occurred, adult females with cubs dominated all other sex and age classes, and adult males dominated subadult males and females. In Minnesota female bears avoided dumps visited by male bears (Rogers 1987), and in Tennessee female bears avoided areas of high acorn concentration utilized by males (Beeman 1975). Thus, it appears bears either tolerate or avoid each other to reduce aggression when they are forced out of their normal solitary existence during times of food shortage.

Many states and provinces report an increase in black bear nuisance activity and kill permits issued in years when natural food is limited. For example, in 1985 when food was scarce in northern Minnesota and southern Ontario, Canada 90 bears were killed in Deluth, Minnesota and 70 bears were killed in Thunder Bay, Ontario because of increased nuisance activity (Rogers 1987). In a normal year, few or no nuisance bears were killed. However, food shortage is not the only explanation for an increase in nuisance activity. Other potential explanations include an increase in the bear population, increase in the number of dispersing 2-year olds, and an increase in the reporting rate. In Virginia, for instance, nuisance activity was high in three years(1988, 1990, 1997) when mast production was poor, but was not high in 1992 when the mast crop was poor (Fig. 3). On the other hand, in 1995 and 1998 when mast production was good nuisance activity was high. Thus, data on nuisance activity must be interpreted with caution and can not always be linked to food availability.

In summary, bear behavioral responses to food scarcity may include increased movements, increased activity, increase in home range size and overlap, increased social tolerance, and it may lead to an increase in problem bears.

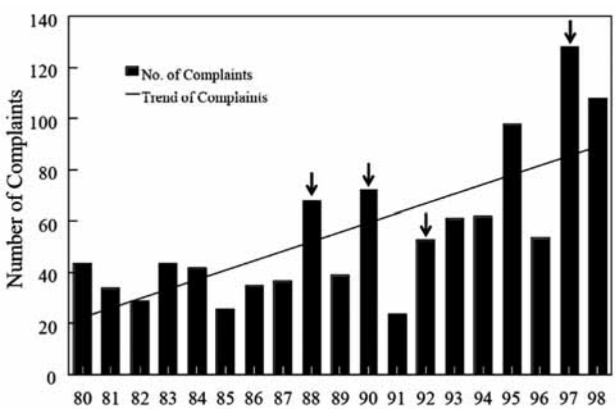


Fig.3 Nuisance black bear complaints in Virginia (1980-1998). Arrows indicate years of poor mast production. Courtesy Virginia Department of Game and Inland Fisheries

Ecology

Almost every aspect of a bear's life is affected by the amount of food available to it. Some of the more obvious aspects of bear ecology likely influenced by food availability include home range and habitat use, denning chronology, survival, non-sport mortality, harvest, reproduction and reproductive synchrony.

Home range and habitat use

Black bear home ranges normally vary in size with age and sex of the bear, i.e., male bears tend to have larger home ranges than female bears, and adult bears tend to have larger home ranges than subadult bears. But, regardless of age or sex, there is some evidence that home range size increases when food is limited. In coastal North Carolina, Jones and Pelton (2003) reported home range size for black bears in two parts of a large study area (Table 6a). One area (Big Pocosin) was characterized as mostly pine plantation with low food availability and the other (Gum Swamp) as lowland hardwood with abundant food. Home range size in the former was more than double home range size in the latter. Similarly, in Shenandoah National Park, Virginia Kasbohm et al. (1998) reported home range size for bears in areas affected by a gypsy moth (*Lymantria dispar*) infestation and

Table 6 Relationship between food abundance and home range size for bears in Coastal North Carolina (a) and the Blue Ridge Mountains of Virginia (b)

a.

Area	Food availability	95% MCP (km2)	N
Big Pocosin	Scarce	11.0	5
Gum Swamp	Abundant	5.3	8

b.

		95% MCP (km2)	
Female Status	**Season**	**Defoliated**	**Non-defoliated**
Solitary	Fall	29.7	14.9
With Cubs	Fall	19.0	10.9
Solitary	Annual	40.7	26.7
With Cubs	Annual	34.2	14.6

Table 7 Relationship between food abundance and home range size for black bears in Cold Lake, Alberta, Canada

Parameter	1975	1976
Number of Blueberries per m2	468	85
Dry Weight of Blueberries (gm/ m2)	10.4	1.8
Female Home Range Size (km2)	15	23
Area Occupied (km2)	19	39
Adult Female Fall Weight (kg)	121	89

Cold Lake, Alberta, Canada (Pelchat and Ruff 1986) areas not infected (gypsy moths defoliate oak trees resulting in the loss of mast crop). Home range sizes of bears in defoliated areas (i.e., food limited) were nearly double those of bears where food was more abundant (Table 6b). While these two examples were from the southeastern part of American black bear range where hard mast is the primary fall food, there are similar examples in the northwestern part of black bear range where bears depend on soft mast. In Alberta, Canada for instance, Pelchat and Ruff (1986) reported fall home range size for bears that fed mostly on blueberries (Table 7). Home range size and area occupied by bears when blueberry production was low (1976) was nearly double the size when blueberry production was high (1975). In all of the examples above home range overlap increased with food scarcity.

Habitat use also is affected by food availability. As an example, Schooley et al. (1994) determined use versus availability of beech mast for bears in Maine. In years when beechnuts were plentiful use exceeded availability, but in years that beech nut failed to produce, availability exceeded use (Table 8). In British Columbia, Canada, Davis et al. (2006) examined the influence of phenology on site selection by bears and concluded that site selection involved a complex set of decisions about food availability and human disturbance. Site selection was strongly linked to resources that provided food, but decisions were made not based on percent cover of food producing plants, but on the phonological development of the plants. The probability of use of a particular site within a habitat increased with food availability and decreased with human development. Thus, overall, food scarcity appears to result in an increase in black bear home range size, an increase in home range overlap, and shifts in habitat use patterns, which allow bears to take full advantage of existing food supplies.

Table 8 Relationship between food abundance and use of beech forest habitat

Female Black Bear Habitat Use			
Year	**% Use**	**% Available**	**Beechnut mast**
1986	76.5+	62.6	Abundant
1987	36.1-	62.6	Scarce
1988	71.7	61.2	Abundant

Schoolley et al 1994
% Available = percentage of bear habitat consisting of beech forest
% Use = percentage of time bears spent in beech forest habitat.

Denning

Dates of den entrance also appear to be influenced by food availability, but there are competing ideas. These ideas include: 1) In good mast years bears reach a physiological denning state faster and den early; 2) In good mast years bears stay out longer to take advantage of food resources; 3) In poor mast years bears take longer to reach denning weight and den late; and 4) Bears den when it requires more energy to gather food than the food provides (negative energy balance). Johnson and Pelton (1980) reported that bears in Tennessee denned in early December when mast crops were poor, but denned in late December when mast crops were good (Table 9). Researchers in Idaho, Montana, and Minnesota, reported similar results (Reynolds and Beecham 1980, Jonkel and Cowan 1971, Rogers 1987). In Maine, black bears that depended on beechnut mast, which produced a mast crop every other year, denned late when mast crops were good and early when mast crops were poor (Table 10; Schooley et al. 1994). This pattern had been going on for at least 11 years. Based on the timing of den entrance and food availability they concluded that bears den when they reach a negative energy balance.

Survival

The survival of all age classes of black bears is affected by food availability. Rogers (1987) measured survival of bear cubs in Minnesota during 1970-1980. Highest survival (88%; N=40) occurred when food was abundant in the year of conception and year of birth, and lowest (59%; N=37) when food was scarce in year of conception and year of birth.

Table 9 Influence of mast availability on den entrance of black bears in Smokey Mountains, Tennessee

Years	**Mast availability**	**$\bar{x}$ Den date**
1972-74	Poor	Early December
1976-78	Good	Late December
1978-79	Poor	Early December

Johnson and Pelton 1980

Table 10 Influence of mast availability on den entrance dates of female black bears in Maine

Reproductive Class	**N**	**1986**	**N**	**1987**	**N**	**1988**
Pregnant	8	Nov 2	1	Oct 22	20	Nov 7
Yearling	7	Nov 7	-	-	5	Nov 12
Solitary	6	Nov 17	13	Oct 10	6	Nov 16
Adult/ COY	1	Nov 1	5	Oct 10	-	-

Food abundant 1986 and 1988
Food scarce 1987
Concluded bears den when they reach a negative energy balance.

Survival was intermediate (78%; N= 68 and 69%; N=36) when food supply was good in year of conception and poor in year of birth, and poor in year of conception, but good in year of birth, respectively. Rogers (1987) also reported yearling survival in his long-term study and found that survival was directly related to yearling weight in March. Yearlings weighing less than 10 kg in March had poor survival and yearlings weighing greater than 13 kg had high survival (Table 11).

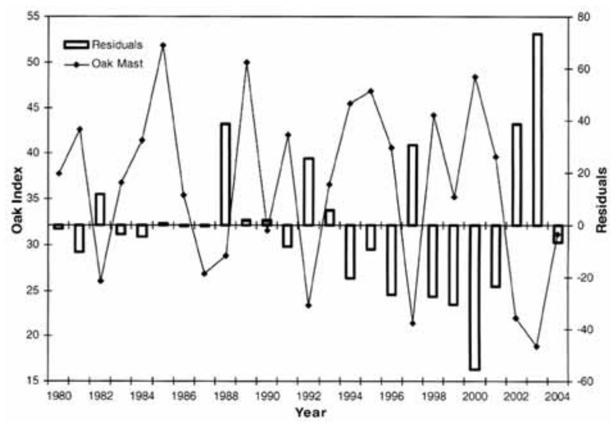
Throughout most of American black bear range bears are hunted, and in those areas hunting is the main source of mortality. However, other sources of mortality include road kills, illegal kills and damage permit kills. Ryan et al. (2007) examined non-sport mortality of bears in West Virginia and found a strong inverse relationship between non-sport mortality and oak mast abundance (Fig 4). The primary source of non-sport mortality was road kills, which likely reflected increased movements by bears looking for scarce food resources. Kills resulting from nuisance behavior plus illegal kills also likely reflected movement of bears into urban and residential areas in search of food.

Table 11 Relationship between March weights and survival of yearling black bears in Minnesota

Weight in March of 2nd Year	Number surviving	
	Telemetry[1]	**Recapture[2]**
< 10 kg	0 of 6	1 of 19
10 – 13 kg	7 of 9	9 of 18
> 13 kg	15 of 15	22 of 31

[1] Telemetry refers to survival determined from radio collared bears (e.g., 0 of 6 radio collared bears weighing less than 10 kg survived).

[2] Recapture refers to survival determined from recapture (e.g., only 1 of 19 bears weighing less than 10 kg was recaptured).



Residuals = the difference between predicted mortalities and actual mortalities. Predicted mortalities were derived by plotting actual mortalities (dependent variable) against year (independent variable) in a linear regression.

Fig.4 Non-sport mortality of black bears relative to oak mast abundance in West Virginia. From Ryan et al. (2007)

Noyce and Garshelis (1997) reported a significant relationship between harvest mortality of bears in Minnesota and hazel nut and oak production. They found that as food availability decreased harvest increased, and mean age of females in the harvest increased. The latter apparently was related to females congregating where food was concentrated making them more susceptible to the gun. McDonald et al. (1994) also found that harvest of bears in Massachusetts was influenced by food availability. He reported that in a year of excellent mast conditions only one percent of harvested bears were killed near agricultural fields, but the following year when mast conditions were poor, 40 percent of harvested bears were killed near agricultural fields, indicating that bears may turn to human related foods when natural foods are scarce.

Reproduction

American black bears breed during the summer, have delayed implantation and a short gestation period, and den 4-7 months out of the year, thus all their nutritional needs must be met in 5-7 months. American black bears also have prolonged parental care (15-17 months), thus under normal conditions they produce young every other year. However, if they loose their young early (e.g., in the den or soon after leaving the den) they may breed in consecutive years. There is strong evidence that food availability influences reproductive success of black bears. In his classic, long-term study, Rogers (1987) found that 0 of 17 bears in Minnesota that weighed less than 67 kg on October 1 produced cubs, while 32 of 34 bears that weighed more than 80 kg on October 1 produced cubs. He also reported that only 33% of females were accompanied by cubs following food scarce years while 59% of females were accompanied by cubs following years of exceptional food abundance (Table 12). Likewise, in Massachusetts, Elowe and Dodge (1989) found in years when mast was abundant a higher proportion of potential mothers successfully produced young than in years when mast was scarce (Table 13). In Alaska, Schwartz and Franzmann (1991) reported vital statistics for two bear populations. Bears in a more food rich environment (1969 burn) were heavier, bred at an earlier age with less time between successive litters, and had higher cub survival than bears in a less rich food environment (1947 burn; Table 14). Costello et al.(2003) reported very similar reproductive results for bears in New Mexico (Table 15). Costello et

Table 12 Number of adult female black bears accompanied by cubs in years of varying food abundance in Minnesota

Mast condition	N	Number (%) accompanied by cubs
Scarce food	43	14 (33)
Moderately abundant	39	17 (44)
Exceptionally abundant	39	23 (59)

Table 13 Mast availability and proportion of potential black bear mothers that successfully reproduced in Massachusetts

		Reproduction following winter	
Year	Mast availability	Potential mothers	No. reproducing
1980	Very Abundant	5	5
1981	Very Scarce	8	2
1982	Good	7	6
1983	Good	7	7
1984	Very Abundant	5	4
1985	Scarce	6	2

Elowe and Dodge(1989)- Massachusetts

Table 14 Vital statistics for a bear population on the Kenai Peninsula, Alaska

	Year burned	
Vital statistics	1947	1969
Moose/ km2	0.3 – 1.3	3.3 – 3.7
Black bears/ 1000 km2	205	265
% Yearlings	14	23 *
Moose calves eaten/ bear	1.4	5.3
Age at 1st reproduction	5.8	4.6 *
Interval between litters	2.4	2.0*
Adult female wt (kg)	56	62 *
Yearling female wt in den (kg)	16	22 *
Cub survival	0.74	0.91 *

* indicates significant difference

Table 15 Proportion of adult female black bears in New Mexico that successfully reproduced under variable mast conditions

	Mast			
Reproductive opportunities	Good	Moderate	Poor	Failure
Failed (N= 18)	-	17%	22%	61%
Successful (N= 52)	8%	25%	54%	14%

Costello et al 2003- New Mexico

Table 16 Evidence of reproduction synchrony in black bears in New York

	Percent in harvest				
Age class	1964	1965	1966	1967	1968
1	41.5	5.9	37.0	10.9	30.7
2	4.0	35.4	5.4	31.2	8.1
3	17.2	9.4	21.6	6.3	17.7

Free and McCaffrey 1970 – New York

Percent in harvest refers to the percentage of a given age class in the harvest in a given year (e.g., in 1964 41.5 percent of harvested animals were in the 1 year age class, 4.0 percent were 2 year olds, and 17.2 percent were 3 years olds).

The reproductive index was a combination of 5 indices:

1. Proportion of females with cubs in the den.
2. Proportion of females with cubs in summer.
3. Recruitment index.
4. Proportion of 2-year olds in the harvest.
5. Proportion of 2-year olds among all bears captured in summer.

Mast = Mean number of acorns/10 limbs/tree sampled

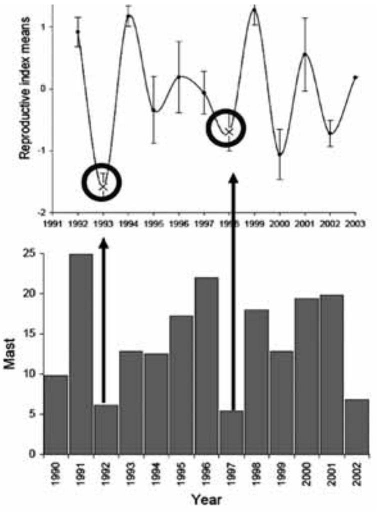


Fig. 5 Hard mast (acorns) production and reproductive synchrony in black bears in Virginia. Courtesy Virginia Department of Game and Inland Fisheries

al. (2003) also reported significant relationships between their indices to acorn and juniper berry production and cub survival, percent of females with yearlings, and both cubs and yearlings per female per year. Costello et al. (2003) concluded in their long-term study that acorn production had the greatest influence on natality and recruitment (i.e., mast failures = 60% decrease in natality and 70% decrease in recruitment). They further concluded that there is a minimum threshold below which reproduction is negatively affected and that it takes a complete mast crop failure to reach that threshold.

Another aspect of reproduction is reproductive synchrony. As noted earlier, adult female black bears normally reproduce in alternate years with 40-60 percent of the adult female population reproducing in any given year. Under synchronous reproduction adult females reproduce every other year, but 80-100 percent may produce one year and 0-20 percent produce in the alternate year. Synchronous reproduction can be brought about by a reproductive failure resulting from a complete mast crop failure. Under this scenario those females that would normally reproduce either fail to breed or loose their young in utero or post partum due to insufficient nutritional condition. Having lost their young early they then breed in consecutive years along with those females scheduled to breed bringing the population into reproductive synchrony. One of the earliest reported examples of black bears in reproductive synchrony was in New York (Free and McCaffrey 1972). They noted a high percentage of 1- and 3- year olds in the harvest in even numbered years and high numbers of 2-year old bears in the harvest in odd numbered years (Table16), but failed to assign a cause for this case of synchronous reproduction. In Maine, McLaughlin et al. (1994, 1998) demonstrated how black bears in 1 of his 3 study areas (Spectacle Pond), where bears depended on the alternate year production of beechnut mast, are in a perpetual state of reproductive synchrony. Bridges (2005) also demonstrated how black bears in Virginia were

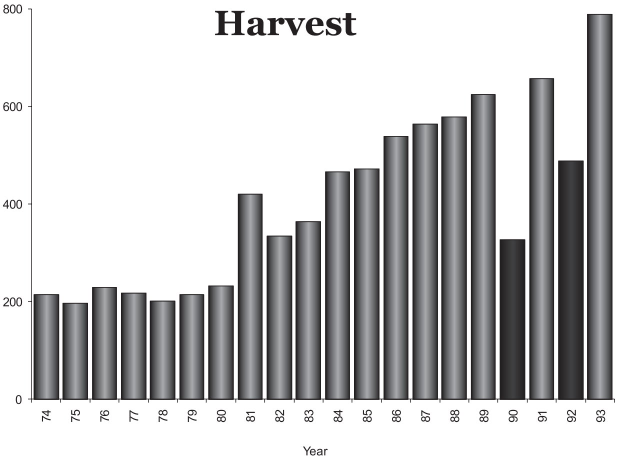


Fig. 6 Black bear harvest in Virginia 1974-1993.Courtesy Andrew Bridges, Virginia Tech University (Currently Institute for Wildlife Studies, Arcata, CA)

brought into reproductive synchrony in 1993 and 1998 by mast crop failures in 1992 and 1997 (Fig. 5).

The consequence of reproductive synchrony is a birth pulse resulting from a high proportion of females breeding in a single year (see Miller 1994, Figure 2 representing the percent of open females). The resulting production of a high number of cubs in a given year invariably leads to high numbers of 2-year olds dispersing four years and possibly six years after the mast crop failure that brought the population into reproductive synchrony. This influx of cubs may be seen in high harvest rates in alternate years (e.g., Free and McCaffery 1972; also see Virginia harvest data Figure 6) and high rates of nuisance activity and road killed bears in alternate years. It takes a near complete mast crop failure to bring a population into reproductive synchrony and reproductive synchrony can quickly go back to a normal reproductive cycle when mast crops are more dependable (Bridges 2005).

In summary, when food is limited black bears may respond reproductively with an increase in breeding age, an increase in breeding interval length, a decrease in cub survival, and an increase in total litter loss, thus a decrease in successful reproductive attempts. Total litter loss can lead to synchronous reproduction, which in turn can result in a birth pulse. A birth pulse may result in increased bear activity (e.g., problem bears) in alternate years starting four years after a complete mast crop failure.

It is obvious from the examples presented in this review that almost every aspect of a bear's life is affected by food availability. In some cases the effects on the bear population lead to increased human/bear interactions (e.g., bears searching for food in areas inhabited by humans, young bears dispersing into places occupied by humans). These interactions can have negative affects (e.g., injuries to humans and their property), but by keeping track of bear populations and their food supply managers can predict when conditions are right for possible invasions of bears into areas occupied by people. Using a well thought out educational program managers can prepare local human populations for possible invasions and instruct them on how to deal with the problem.

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Biology of Bear Intrusions: 18-21 (2009)

Predicting American black bear conflict and movements based on food production in a semi-arid environment in Mexico

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Introduction

Understanding the driving mechanisms behind how animals use and move throughout their landscapes is an important component for bear management. This is especially important in desert environments where climate can cause dramatic fluctuations in water availability, vegetation growth, and animal survival. Black bears (*Ursus americanus*) commonly occupy desert ecosystems in northern Mexico, and populations are expanding (Doan-Crider 2003). Because bear habitat can often be semi-biogeographically isolated, understanding what influences movements to and from those areas is important for the long-term genetic stability of metapopulations. In addition, because bears have such large home ranges and also depend on obtaining sufficient energy reserves to survive winter months, their movements across landscapes often quickly respond to changes within the environment, particularly that of food production. Often, as bears leave their natal areas and go in search for food during times of scarcity, conflicts with human-related food sources increase, resulting in high bear mortality rates. For bear managers trying to ensure the long-term survival of this species in Mexico, tools that are useful in forecasting movements and patterns in potential areas and times of conflict are needed.

Background

Prior to the 1950's, the American black bear ranged throughout the northern Mexican states of Sonora, Chihauhua, Coahuila, Nuevo Leon, Tamaulipas, Durango, Zacatecas, San Luis Potosi, Aguas Calientes, and Nayarit (Fig. 1). Recent additional reports from field biologists also include the states of Sinaloa, and Jalisco, but have not been documented in the literature (Doan-Crider, personal observation). The use of poisons and over-hunting resulted in the probable extinction of the Mexican grizzly bear (*Ursus arctos horribilis*), and the black bear was close behind with dangerously low numbers by the 1950's (Leopold 1959). Since that time, efforts to protect the bear resulted in a ban on bear hunting in the early 1950's, and was also classified as "endangered" by the Mexican government in 1986 (SEMARNAP 1999). Changes in public attitudes and an unprecedented effort by Mexican landowners to establish conservation cooperatives since that

Fig. 1 Mexican states where black bears are currently reported

time have resulted in the recovery of this species in many areas of its historic range. Some areas have rebounded so successfully that they now serve as reproductive reservoirs for adjacent Mexican mountain ranges and the neighboring American state of Texas (Onorato et al. 2007). In addition, a study conducted in the Serranias del Burro, Coahuila, between 1998-2001 indicated very high densities of black bears at 0.84 bears/km^2 (Doan-Crider 2003). Other Mexican states, such as Tamaulipas, Nuevo Leon, and Sonora, have noted increases in bear observations, although those populations have not been quantitatively studied. Increases in livestock predation have been reported by cattlemen's unions (Doan-Crider, personal observation), and efforts to minimize conflict have been made through public education. However, trained personnel are lacking to meet the demand of conflicts and provide the necessary extension to landowners. In 1999, the distribution of the black bear in Mexico was documented in a special report published by the International Union for the Conservation of Nature (Servheen et al. 1999). However, a new distribution map was regenerated by biologists at the First Mexican Black Bear Workshop in Saltillo, Coahuila, Mexico, in 2005, and results indicated that the bear population had been dramatically underestimated, and/or was expanding rapidly. Observations included in this map involved only females with cubs, indicating resident populations in areas where re-establishment was not expected.

Causes of conflict

During the past 20 years, declines in the cattle ranching industry along with shifts in landownership patterns have resulted in an increase in hunting operations on private lands. Deer feeding is a common occurrence, which landowners feel will help augment deer condition and antler growth. Unfortunately, deer feeders have become a source of non-natural food for bears, and are likely to blame for an increase in human-bear conflicts as bears become conditioned over time (Doan-Crider personal observation). In addition, because preventative education has not been implemented in rural areas, encounters with bears around human dwellings have become problematic because people are not aware that garbage, domestic livestock, and other attractants may augment bear-related conflicts.

Some conflicts have been documented in urban areas, such as Monterrey, Nuevo Leon, which is Mexico's third largest city with an urban population of approximately 5 million people. The city is surrounded by the Sierra Madre Oriental, which contains excellent bear habitat, and includes several national parks and protected areas. However, most of the area contains private landholdings, which also include deer hunting operations. Over the past 10 years, some bear sightings have been reported as housing developments spread into forested areas, and as mountain ranges become isolated by urban growth and highways. Most previous reports have been isolated, and pertain to individuals feeding bears or allowing bears to drink water out of swimming pools. However, during a severe spring and summer drought in 2008, over 40 conflicts were reported within the city perimeter, involving bears near schools, housing developments, around swimming pools, and in people's yards. Predation on small-stock (pigs) was also reported. Managers responded by hazing bears away from urban zones, and most bears responded favorably by returning to natural habitats. Five bears were relocated, and one bear died from dehydration after being roped by a construction worker. Media coverage was high, and public concern was great. The Mexican government took aggressive action to educate the public on managing attractants, and held a state-wide training course to education civil authorities on bear conflicts. The drought was relieved in the months of July-August, and bear reports diminished although there was some indication that a few human-conditioned bears may have remained in urban areas due to feeding from the public.

Management challenges

Recently, the Mexican government has opened dialogue with landowners to discuss the possibility removing the ban on hunting for areas that have documented high densities of black bears. However, funding is not available to quantitatively monitor bear densities at the level necessary to observe any shifts in density or population growth. While private landowners are requesting limited numbers of hunting permits, landowners are not informed as to the cost and time necessary to adequately monitor these populations.

The recent expansion of this species into its historic range and the management challenges that have accompanied its rapid growth emphasize the need to understand some of the driving mechanisms for bear population dynamics and their movements. This is especially important in desert ecosystems, where food production and the dependent animal populations can be highly variable.

Black bear landscape use in a desert ecosystem

Black bears in Mexico are known to inhabit a wide variety of habitats, from low-lying deserts to high mountain forests. Populations have even been documented in the lowest regions of the Chihuahuan desert (McKinney and Pittman 2000), although the carrying capacity is much lower. However, little is known about how, when, or why black bears use different landscapes within their home ranges, and about the tightly connected relationship with food production.

Northern Mexico contains a diverse range of vegetation and bear foods within habitats and elevation ranges (Rzedowski 1983). Bears diets can comprise up to 97% vegetative matter (Hellgren 1993), thus they can readily adapt to the diverse food selection available to them in desert ecosystems. In addition, because desert ecosystems are adapted to frequent water shortages, succulents such as prickly pear (*Opuntia* spp.), Yucca (*Yucca* spp.), and sotol (*Dasylirion* spp.) are common, and are consumed by bears (Hellgren 1993). However, because bears require high energy foods that will help them accumulate enough fat to endure winter months, they must focus on foods that provide as much energy as possible. Succulents alone are likely unable to replace the value of high caloric foods such as acorns (*Quercus* spp.), and madrone berries (*Arbutus* spp.), wild grapes (*Vitis* spp.), and black cherry (*Prunus* spp.), and while bears may be able to survive periods of scarcity, reproduction and survival rates are likely negatively affected (Doan-Crider 2003).

The influence of drought on food production

Drought may also have some influence on occupancy and expansion of the bear population, as bears in search of food may disperse into neighboring mountain ranges. Drought in northern Mexico is often patchy in nature; the production of bear foods can also be patchy (Doan-Crider 2003) and bears will often travel to areas where food is available (Rogers 1976). As bears travel between mountain ranges, they are likely to encounter human occupied areas, and potential for conflict can increase. In addition, bears will likely resort to non-natural food sources if they are readily available, including livestock (Doan-Crider in review). Because of economic constraints in Mexico, we are challenged with finding satisfactory methods to predict bear activity and movements, and to monitor populations. In addition, in a desert environment where food production is variable, dramatic fluctuations in bear activity, movements, and population growth can be observed.

The influence of food production on bears - a predictive model

Our objective was to develop a predictive model to better understand how the production of food influenced bear movements and reproductive rates. In the Serranias del Burro, Coahuila, Mexico, we evaluated black bear habitat use based on available digestible energy during 1998-2001. Because bear foods in Mexico are highly diverse, we used digestible energy (DE) as a single currency, which could then be conveyed as a single "caloric" map, which was constructed using a GIS based vegetation map. First, we identified seasonal key foods through fecal analysis. Those food items were then analyzed to determine calories/gram by conducting through total dietary assay. We measured food production of key foods through permanent plots that were randomly selected throughout the study area; plots were evaluated based on phenology of key foods (i.e. grapes and other berries in summer, acorns in early fall). The production of those food items were interpolated based on their species composition and percent canopy within the area's 7 vegetation associations using ArcMap and ERDAS. Individual maps were constructed for each food item, with interpolations based on food production data retrieved from sampling plots. Finally, seasonal maps were constructed for both 1999 and 2000, combining the DE values for all foods that were available during that season.

Simultaneously, we wanted to evaluate the amount of DE available to reproducing female black bears, and determine whether reproduction varied with DE. During 1999 and 2000, we captured, radio-collared, and measured the home ranges of 7 reproducing adult female black bears. The average DE within female black bear home ranges were compared to DE of their seasonal use for 1999 and 2000. Adult females used areas that contained 27% more digestible energy than areas not used within their overall home ranges during fall 1999, and 20% more than areas not used during fall 2000. In addition, females that did not produce cubs had lower DE within their home ranges. However, because our sample size was small, power was weak (Doan-Crider 2003).

During times of drought and low DE, we also noted increases in adult female and cub mortality (Doan-Crider

2003). Anecdotal observations indicated that high numbers of bears were concentrating in areas of high DE, thus exposing females and cubs to higher risks of encounters with adult males. Patterns of food production across a landscape may influence effective density of bears within food patches, thus exposing adult females and cubs to high risk of mortality from other bears. Density dependence of bears may be directly affected by food availability through altered social dynamics, particularly in a desert environment where vegetation fluctuates with weather patterns.

Recommendations

We felt that the model could have been strengthened in several areas for the measurement of food production: 1) other variables such as elevation, slope, and rainfall should be incorporated to better understand the influencing factors upon food production; 2) increased sample sizes for food plots; and 3) longer study periods to observe changes in DE over time. For bear movements, reproduction, and social interactions, we recommend: 1) higher sample sizes; 2) monitoring and documenting bear movements as related to food production; 3) estimations of bear numbers within food patches; and 4) monitoring of bear mortality and their causes.

While this food production model is likely not strong enough to support estimates of carrying capacity, it may serve as a useful tool to allow managers to predict bear movements and activities based on seasonal and yearly variations within the landscape. In addition, it might perhaps provide information needed to predict population growth and expansion trends, and contribute to the long-term persistence of the species.

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Acorns, oak trees, and black bears in Taiwan

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Acorns present a high-nutrition food for many wildlife species, including omnivorous bears throughout their geographical ranges. The objective was designed to estimate the activity and movement patterns of so-called Formosan black bears (*Ursus thibetanus formosanus*), and to monitor the phenology and acorn production of the locally dominant ring-cupped oaks (*Cyclobalanopsis glauca*) in the interior of the Yushan National Park, the largest park in Taiwan. The acorns started to fall off and be consumed by wildlife since October until February. Among the fallen acorns collected by 200 seed traps, 70% of them occurred in November and December, and 85% were consumed by various arboreal animals. Bear claw marks were found among half of the oak trees sampled (n = 507), indicating extensive use of acorns by black bears. The relative abundance index of large mammals, including bears and their potential prey, by camera-tapping coincided with the peak of acorn availability. The more acorns trees produced, the more frequently black bears used the trees.

Fall acorn production varied yearly and had a large impact on bear activities and movements. Bears were mainly active during daylight hours in spring and summer, and also during fall when acorns were scarce. Extensive nocturnal activity occurred in fall when acorns were abundant. Nocturnal activity in fall (54 ± 27%) was significantly greater than both in summer (32 ± 29%) and spring (28 ±18%, $P < 0.001$). In a mast acorn season, bears maintained a high activity level both during the daytime ($\bar{x}$= 62 ± 26%) and at night ($\bar{x}$= 70 ± 17%; $t = 1.52$, $P = 0.13$). In a poor acorn season, by contrast, bears were more active during the day than at night (83 ± 13% vs. 44 ± 15%; $t = 7.42$, $P < 0.001$). The mean diel activity level of bears in mast acorn seasons was higher than that in poor acorn seasons (66 ± 8% vs. 59 ± 12%; $t = 2.11$, $P = 0.04$), indicating that bears seemed to spend more time feeding when acorn was more plentiful.

During 1998-2001, 14 bears were radio-tracked and their annual home range sizes were 24-117 km^2. The focal study site in fall, Daphan, produced a relative abundance of acorns, attracting a dense congregation of bears. However, females and subadult males were socially excluded from this area, so they had to travel elsewhere. All radio-tracked bears that occupied Daphan in fall left this oak-dominated forest by December-January. Centers of fall ranges for 6 males in Daphan were separated from their ranges in the following spring by 6.5-15.4 km ($\bar{x}$= 11.3 ± 5.8 km). Bears tended to use lower elevations in spring than in summer and fall, corresponding with seasonal changes in food availability. Half of the radio-tracked bears once traveled beyond the park boundaries where they were more vulnerable to illegal hunting.We suggest suggesting that more protection is particularly needed for the locally endangered species along the edges of the park or during poor acorn years.

Biology of Bear Intrusions: 23-27 (2009)

Causes and prevention of brown bear related conflict in the human habitat in Hokkaido

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Introduction

As is the case with Asiatic black bears (*Ursus thibetanus*) in Honshu, Japan, brown bear (*Ursus arctos*)/human conflicts in and around human settlements in Hokkaido is a serious issue. Bear intrusions into human settlements raise fears in local people even if there are no human injuries or property damages. Regrettably, efforts to prevent damage to local communities are minimal and bears observed around human settlements are usually considered potentially dangerous by local and to be killed if possible (Mano 2006). As symbolized by the mass intrusions and subsequent kills of black bears in Honshu in 2004 and 2006 (Japan Bear Network 2007, Natural Environmental Bureau of Ministry of The Environment 2007, Urgent Research Group for the Bear Appearance problem in Toyama 2005), a large number of brown bear kills in Hokkaido will raise concerns about bear population maintenance.

In trying to explain why bears appear in and around human settlements and cause problems, various reasons have been pointed out, such as food shortage resulting from bear habitat destruction, mast failure, increasing bear population and so forth. Explaining bear intrusions is an old problem in Japan and the answers are not simple because of the many potential factors involved.

In this paper, I investigate seasonal brown bear kill statistics in Hokkaido to distinguish between environmental factors such as mast production and other factors such as bear behavior. This analysis may be useful in explaining the recent black bear intrusions in Honshu. In addition, I present a concept of future management of Hokkaido's brown bears based on the findings of this analysis.

Brown bear habitat in Hokkaido

Hokkaido is the northernmost island of Japan. Forest occupies about 70% of the 78,000km^2 island area all of which is potential brown bear habitat. Even though it has been more than 130 years since modern development began, brown bears still occur in more than 60% of the island (Hokkaido Institute of Environmental Sciences 2004). Agriculture is the major industry of Hokkaido, which is in the cold temperate or subarctic zone; a unique feature of brown bear habitat in Hokkaido is that the forested mountain range is usually surrounded by crop fields or residential areas. This implies occurrence of bears in and around human habitat as well as frequent crop damage by bears.

Brown bear caused damage and bear kills

Although the exact brown bear population size in Hokkaido is unknown, estimates range from about 2, 000 to 4,000 (Haga 1967; Inukai et al. 1985; Hokkaido Institute of Environmental Sciences 2000).

During 1955 - 2005, bear caused livestock damages and human injuries in Hokkaido were at high levels until the 1960s and 1970s, respectively. After that, both declined, especially livestock damages, which have remained at a very low level (Fig. 1).

The Hokkaido government introduced a "prophylactic spring bear kill" as a part of controll kill in 1966 hoping to reduce the bear population and bear caused damages (Hokkaido Government 1969). The spring bear kill lasted for 24 years until it was abolished in 1990. The number of bears killed as problem bears (control kills) declined during

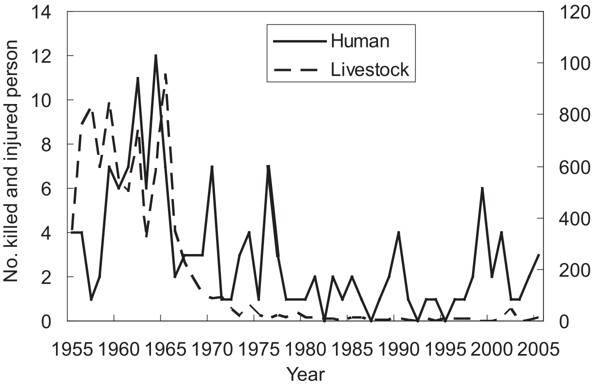

Fig.1 Brown bear-caused human casualties and livestock damage in Hokkaido during 1955 - 2005

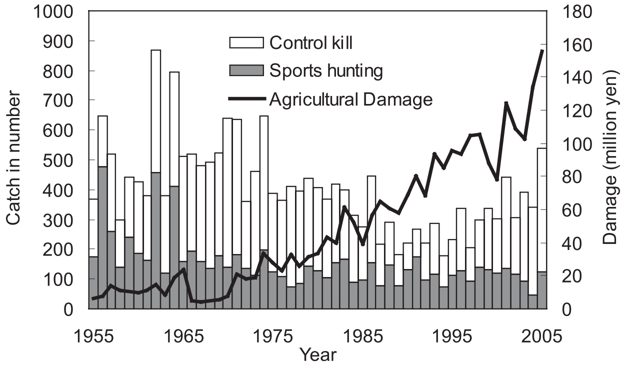

Fig.2 Brown bear-caused crop damage and brown bear harvest and control kills in Hokkaido during 1955 - 2005

Table 1 Seasonal diets of brown bears in Hokkaido

Month	Seasonal classification	Major diet of brown bears in Hokkaido
Jan.-May	Spring	herbaceous plants, acorn, sika deer (Eastern part)
Jun.-Jul.	Early summer	herbaceous plant, insects, succulent fruit, sika deer (Eastern part)
Aug.-Sep.	Late summer	herbaceous plant, insekts, succulent fruits, agricultural crops, sika deer (Eastern part)
Oct.-Dec.	Autumn	acorn, succlent fruits, agricultural crops, sika deer (Eastern part)

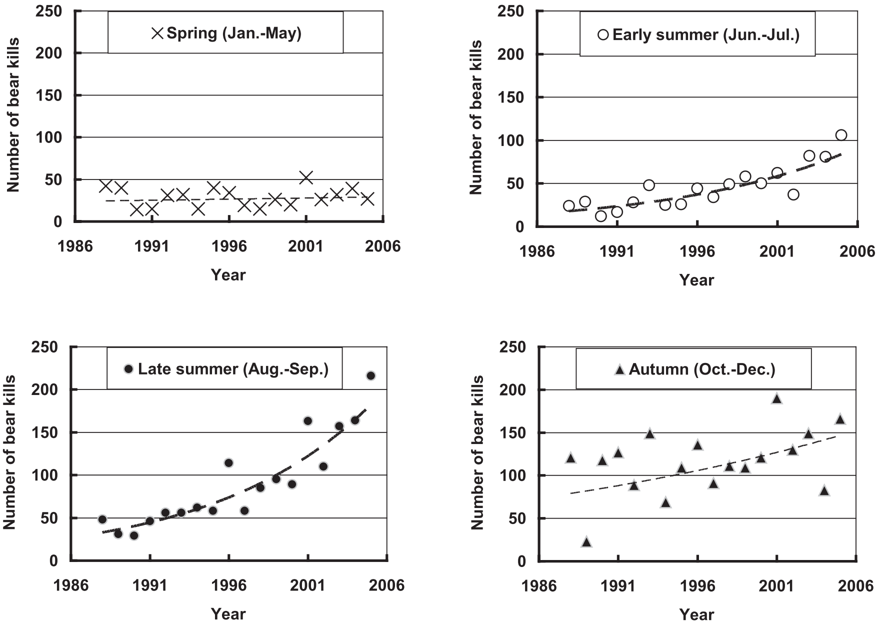

Fig.3 Seasonal brown bear control kills in Hokkaido during 1988 - 2005

the period when the bear hunt was carried out. However, the number of problem bears killed increased again after the spring bear hunt was abolished. At the same time, the total amount of bear caused crop damages consistently increased (Fig. 2). During the period1988 to 2005, after the spring bear hunt was abolished, the number of bears killed increased at a 6.7% annual rate, associated with consistently increasing crop damages by bears from the 1990s.

Brown bear food habit in Hokkaido

Consideration of seasonal changes of bear diet and food supply is necessary to interpret bear activities and/or behavior. According to Sato et al. (2005), using data collected during the 1990s, typical seasonal food items of brown bears in Hokkaido are as follows (Table 1): spring (January to May), is characterized by succulent herbs and acorns of the previous year. Social insects such as ants plus berries and succulent herbs are typical items in early summer (June and July). Characteristic items in late summer (August and September), when most crop damage occurs, includes agricultural crops such as corn, sugar beets, rice, melons, and apples. Lastly, acorns and berries are the major diet during autumn (October to December). Bears preyed on sika deer (*Cervus nippon*) throughout the year in the eastern part of Hokkaido from the 1990s (Sato et al. 2005).

Trend of seasonal bear kills

The trend in bear kills varied seasonally (Fig. 3). Kills in spring and autumn showed little variation while there seemed to be an increasing trend in early and late summer. The early and late summer bear kills rose at an annual rate of 11±4% and 11±3% (x±95%CI), respectively. By contrast, there were no significant trends in the spring and autumn kills.

A case study of the Oshima Peninsula region

Why did the early and late summer control kills increase and what was the reason for different bear kill trends among seasons? I consider a case study of the bear population in the Oshima Peninsula region to answer these questions. Oshima Peninsula is located in southwestern Hokkaido. The 8,000km^2 area is about 10% of the island, and brown bear range is about 5,600km^2. The brown bear population in the peninsula is estimated as several hundred, but with low accuracy (Hokkaido Institute of Environmental Sciences 2000), and considered to be isolated from those in northeastern Hokkaido (Kaji 1982).

An independent investigation was carried out in the Oshima Peninsula during the 1990s and 2000s to obtain a population density index. The index was based on the number of bear scats found by forest workers per unit effort (Hokkaido Institute of Environmental Sciences 2000). Beech (*Fagus crenata*) nut and oak acorn production has been also monitored in this region since the 1990s (Yasaka *et al*. 2001).

Mano (unpublished data) found no significant difference in the bear density index between the two periods. Because no changes occurred in bear range Mano reasoned the bear population size remained essentially unchanged during the monitoring period. However, the number of total bear kills increased at a rate of 5.8% annually since the 1990s. Among the seasonal kills, early and late summer kills increased significantly while spring and autumn kills showed no trends. Above all, the rate for late summer of 16±4 (x±95%CI) % was the highest value.

Autumn is the season during which bears feed on beech nuts and oak (*Quecus spp.*) acorns. Kon et al. (2005), using multiple regression, found that fewer bears were killed in the years of good mast yield and more bears were killed in years of mast failure. This suggests that the autumn brown bear kills are influenced by mast production. Therefore, it is possible to say the abundance of brown bear kills is partly explained by the production of bear food in autumn.

In contrast, late summer is the season most damage occurred and bear kills in this season showed a consistent increasing trend. However, it is hard to explain the kills' increasing annual rate of 16% by brown bear population growth alone. Late summer (August and September) is regarded as a transition time in the diet of brown bears in Hokkaido. Bear diets change from the succulent herbs and social insects in summer to acorns and fruit in autumn (Ohdachi and Aoi 1987, Sato et al. 2005). It is the season in which bears depend mostly on agricultural crops. Needless to say, the learning ability of bears is very high (Stirling and Derocher 1990) and learning at an early age apparently influences the subsequent feeding habits of individuals (Mazur and Seher 2008).

Since there is very little effort to prevent crop damage, most bears adjacent to agricultural fields have a chance to learn the taste of crop. Thus, the increasing number of bears learning the taste of crops likely explains the increased use of agricultural crops at this time of year and thus the high number of control kills in late summer.

Brown bear population management in the future

As I noted in the previous section, it has been suggested that the proportion of problem bears, which have learned the taste of crops, is increasing throughout the brown bear population. This makes it necessary to reduce the number of problem bears to reduce bear related conflicts in Hokkaido.

Table 2 shows criteria for using a "phase" approach for classifying problem bears (Tsuruga and Mano 2008). Two axes, one representing whether bears cause crop and livestock damage, and the other representing bear behavior toward humans are used to place bears in a phase 0, 1, 2, or 3 category. It is crucial to determine the phase of problem bears with objective criteria before control actions are taken, and to evaluate the consequence of management activities, including control kills, supposedly targeting and controlling problem bears.

We have monitored the number of phase specific problem bears in the Oshima Peninsula region since 2001 (Tsuruga and Mano 2008). Every report of brown bear problems by people was recorded on a prescribed form and evaluated. We estimated the number of individuals that caused problems and, using the criteria in Table 2, assigned them to a phase category.

Fortunately, almost no phase 3 bears, those which offensively attack and injure or kill people, have occurred. Phase 0 bears, which should not be problematic, were very

Table 2 Criteria for categorizing problem brown bears by "phase"

Behavior toward crop or livestock	Behavior toward humans		
	Avoidance	Non- avoidance	Offensive
Not damaging	Phase 0	Phase 1	Phase 3
Damaging	Phase 2	Phase 2	Phase 3

few; most individuals were phase 1 or 2. In spite of no human injuries and/or property damage, phase 1 bears can be problematic because they do not avoid people or do not mind exposing themselves to people. We identified 100 to 200 phase 1 bears year after year. Many phase 1 bears tend to be young subadult individuals having little experience with people. We hope to convert these bears to the phase 0 using proper management measures. However they can become phase 2 bears if they learn to eat crops due to too little effort in damage prevention. Regrettably, so far these bears are killed if noticed by people.

Another concern is the high number (> 100) of phase 2 bears damaging agricultural crops or livestock each year. Given that the brown bear population in the Oshima Peninsula region is estimated to be several hundred, phase 2 bears could be a fair portion of the total population.

We have verified the efficiency of some problem prevention measures for brown bears in Hokkaido such as electric fences and bush mowing around crop fields (Hokkaido Institute of Environmental Sciences 2004). It was suggested that an increase in the number of problem bears feeding and depending on agricultural crops because of no damage prevention efforts would lead to a vicious circle of increasing agricultural damage and controlled bears. Thus, how to spread and increase the use of preventative measures to stop the vicious circle is an essential issue.

Population control plus reducing the number of problem individuals is essential for brown bear conservation in Hokkaido. Bear control actions should use the “phase” approach to evaluate individual bears. Both total population numbers and problem individuals must be monitored. We can achieve accountability for brown bear conservation in Hokkaido when balancing competing goals for conflict reduction by decreasing problem individuals and maintaining the population above a certain level.

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Biology of Bear Intrusions: 28-31 (2009)

History and the future of Japanese black bear - human coexistence

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Introduction

In the early 21st century, we may see a shift of bear-human interactions in Japan, for which we will need to develop new ideas to maintain good relationships between the two species in the future. In Honshu and Shikoku Island of Japanese Archipelago, Japanese black bears (*Ursus thibetanus japoincus*) mainly inhabit deciduous cool temperate forests. Because of their covert behavior, bears are seldom seen in the forest. Even so, they often inhabit areas close to the villages and towns, and sometimes invade agricultural fields, orchards, and come around and even into the houses.

In the recent 60-year hunting statistics for Japan, the numbers of removed (hunted or culled) black bears have been between 1,000 to 3,000 per year (Fig. 1).

In 2006, almost 4,000 bears were removed, which is an exceptionally large number. Most animals were culled in residential areas for the protection of human life or agricultural products (Fig. 1). Numbers of removed bears were also high in 2004 in the Toyama, Ishikawa and Fukui prefectures. A high number of black bear observations were reported within townships during that time (Japan Wildlife Research Center 2005). It is possible that these extreme fluctuations in bear removals may be related to fluctuations in mast crops of beech (*Fagus crenata*) and acorns (*Quercus spp.*), which are important food resources for reproduction of the black bear in most of its range (Ishida 1995, Hashimoto et al. 2003, Masaki et al. 2009). However, the increase in bear removals during 2004 and 2006 may not have been attributed solely to the fluctuation of forest food production.

It is suggested by a demographic mathematical model simulation developed by Horino and Mirua (2000) that mortality of adult bears may be a significant factor contributing to the probability of population extinction (Horino & Miura 2000). Several local populations in Shikoku (western Honshu), and in the "Shimokita" peninsula (northern-most area in Honshu), are considered to be threatened (Fig. 2). Consequently, these populations must be managed with caution. The development of co-existence programs between black bears and human beings will ensure the long-term survival of the species, and will help preserve Japan's natural history.

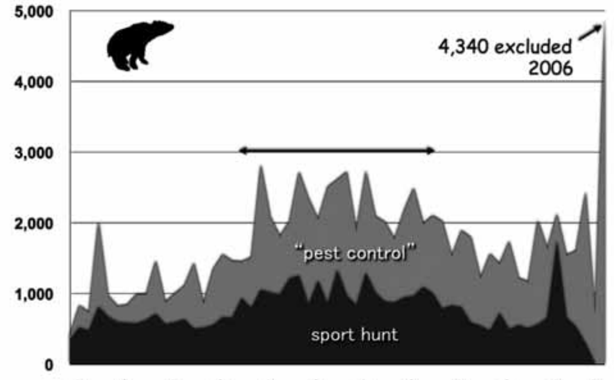

Fig. 1 Number of excluded (removed / killed) black bears in Honshu and Shikoku Islands in each fiscal year. The numbers in sport hunt in 2005/2006 fiscal years have not yet reported (referring to Japan Wildlife Research Center 2005). The double head arrow indicates the period of rapid economic growth and highly intensive artificial forest plantation '("Kakudaizorin" in Japanese) with a large number of hunters.

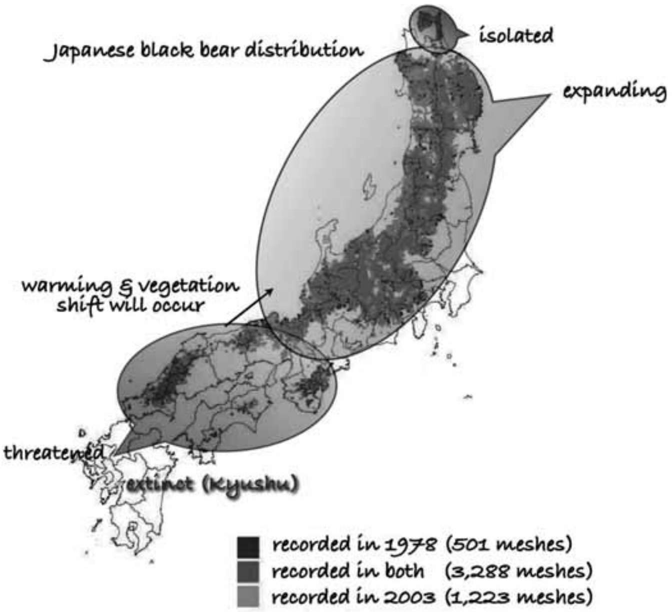

Fig. 2 Distribution of Japanese black bear in 1978 and 2002, with indication of its population conditions. (National Natural Environment Census, the Ministry of the Environment (C) Biodiversity Center, MOE)

Ecology and geography

Black bears and human beings share the same biological features: similar body size, hunting behavior diet, etc., and thus can be considered as ecological competitors. Both black bears and human beings depend on and compete for temperate forest resources in Japan.

Rudis and Tansey (1995) found that the American black bears (*Ursus americanus*) avoid human residential areas, and subsequently become evicted from their preferred forest habitats in the southern states of the United States. It is reasonable to expect the same relationship between Japanese black bears and humans, where human density is much higher, including in and around mountainous areas.

Historically, bears and humans have shared land and have been occupying different habitat in Japan for over 30,000 years. Japan is very mountainous, and the forested areas cover about 2/3 of the country. Terrain is steep and rugged, which has somewhat limited human impacts on bear populations. However, boundaries between the shared habitats of each species have recently shifted.

History

Within 1 million years ago, mammals varying from small shrews to large mammoths reached the Japanese archipelago, which later likely became extinct because of climate change and hunting by humans (Kawamura 2007).

Based on stone tool fossils (Obata 2007), it appears that Japanese ancestors reached the Japanese archipelago approximately 40,000 years ago. Around that time, the earth was cooler, and the Japanese archipelago was connected to the continent at the northern and southern ends of Japan. Fossils of black bear bones have been discovered from Kagoshima (southern most Kyushu Island) to Aomori (northern most Honshu Island) in the substrate of the Jomon era (~8,000 yr. B.C.; Nishinakagawa *et al.* 1993). Based on this evidence, it appears that bears have been present in Japan for as long as humans.

Kito (2000) describes the population and distribution of human beings as having changed simultaneously with climate and the production of cool temperate forests (Tsuji 2007). Because human populations have increased over 10,000,000 and have expanded their range over the entire temperate region, we can assume that human agricultural activity during the recent 500 years (Kito 2000, Fig. 3) has excluded the bear.

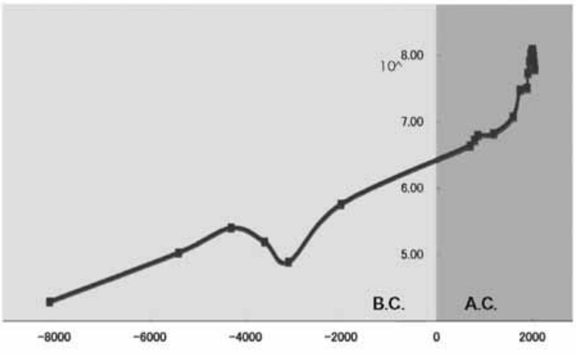

Fig. 3 Japanese human population estimation from the literatures (A.C.8000 - , demographic census 18-2005, and expectation - 2050). Referring Kito (2000) for the past and the demographic statistic analysis by Ministry of Health, Labour and Welfare for the future of 2050

The Japanese industrial revolution that was introduced through western countries during the 19th century, along with the new *Meiji* government policies, have caused human populations to increase and grow exponentially. During this time, hunting and the use of guns became more common as well. Consequently, human impacts on wildlife, including bears, had increased because of urbanization and hunting. The wolf was extirpated from Japan in the early 20th century.

After World War II, forest management changed significantly in Japan. Now, more than half of forested areas are covered by homogenous monocultures of conifers, which are used for timber production. This has created an environment of low biodiversity, and habitat quality for bears is low. Human populations have continued to increase exponentially until reaching more than 120 million in 2004. Wildlife was heavily hunted with high performance guns during this rapid economic development era (indicated by a two -headed arrow in Fig .1). Numbers of registered gun hunters were higher than 400,000 from 1968 to 1980, but have decreased to less than 200,000 now. The black bear population became extinct on Kyushu Island, and became threatened in Shikoku and western Honshu during the 1980s.

Currently, there are no precise estimates of the black bear population in Japan. However, the history of humans may be indicative of a probable rapid decrease in 20th century. It is likely that numbers were lowest during the 1970s and 1980s (Fig.1).

During the 1980s, Japan's use of wood for fuel and houses diminished, and was replaced by oil, less expensive imported woods and building materials. Since then, Japanese forest resources have somewhat recovered. While forested areas have not increased much, forest volume has increased (Table 1). During this period, the distribution area of Japanese black bear has also increased (Fig. 2).

Future

By the end of the 21st century, the Japanese human population is expected to decrease by about 20 or 30 percent (Fig. 1). Black bear expansion is likely if human populations continue to decrease and land use changes.

Currently, human populations have already started declining, and human activity in mountain villages is diminishing (Okuda 2006). The trend of population shifts to urban areas and the decrease in the nation-wide population will continue for the next several decades (Okuda 2006).

The forest structure is also changing from a coniferous monoculture toward a temperate natural broad leaf forest, and forest biomass is increasing rapidly (Table 1). Because of these changes, there has been an unexpected increase in conflicts between bears and humans, which was notable in 2004 and 2006. This is likely due to the changing boundaries between areas inhabited by bears and humans, bringing bears into closer contact with human populated areas.

The Japanese black bear population in western Honshu and Shikoku, where warm temperate evergreen forest is dominant, is isolated and continues to be threatened (Oi and Yamazaki 2007). Global warming proceeds and warmer areas will shift to the northeast (Fig. 2). This environmental change may be a factor in the human-bear conflicts of 2004 and 2006.

In order to predict future interactions between humans and bears in the next 50 years, it is profitable for us to review the history for the last 10,000 years. With this information, we should be able to develop an optimal conservation strategy to improve coexistence between bears and humans.

Some of the most important factors are decreases in the human population; shifts in human landscape use toward less mountainous and urban areas; and global warming. These factors can also be applied to the situation with the brown bear in Hokkaido (Mano 2006, 2009).

Carrying capacity of black bears in Japan is hard to estimate. However, the population of humans before the advent of agriculture is worth considering. In addition, statistics regarding forest resources and home range sizes of breeding female black bears are available, and can possibly help calculate broad estimates (Table 2). The large population can be maintained in the northeastern area in Honshu. In western areas, however, careful planning and monitoring will be necessary to conserve the bear population and also to control their intrusion into human habitat.

Safety for humans should be highly prioritized at forest edges. In mountainous areas, however, priority should be given to bear protection, where humans will be held responsible for their own security. Humans should be educated about preventing encounters with bears, or minimizing injury by wearing a leather jacket and helmet, carrying counter assault, and being aware of the bears.

Conclusion

To achieve the optimum coexistence, the development of a new strategy to ensure and measure human security in all areas, but most importantly in areas of high human density. We can perhaps predict human use and activity, and prepare zoning laws that would fulfill conservation strategy objectives. As land use shifts and humans leave mountainous areas, wildlife will continue to inhabit the foothills and other low human density areas. I recommend that we construct a buffer zone to keep wildlife out of the low-lying areas. However, we also need education programs for people still inhabiting mountainous aeas to ensure safety. To improve our system and adapt to environmental changes in the future is part of our natural heritage, and is not impractical in its implementation.

Acknowledgement I am greatly appreciative that Dr. Toru Oi and the staff of the Forest and Forest Products Research Institute invited me to the symposium as one of the speakers. I would also like to thank the staff of the University Forest in Chichibu at the University of Tokyo for their assistance with my bear research career.

Table 1 Japanese forest resources (Forest Census by Forestry Agency)

	x1000 ha		x1000 sq.m.			
Year	Planted area	Natural area	Plant vol. coni.	Plant vol. bl	Nat. vol. coni.	Nat. vol. bl
2002	10,361	13,349	230,3485	34,555	490,923	1209,937
1995	10,398	13,382	186,4030	27,963	464,125	1143,891
1990	10,327	13,526	157,8863	18,981	444,656	1093,458
1986	10,219	13,666	134,1460	19,261	444,072	1055,951
1981	9,895	13,994	105,4113	12,773	440,609	987,834

* plant volumes are for artificial conifers (coni), artificial broad-leaf (bl), natural conifers, and natural broad-leaf.forests.

Table 2 Forest area in the 26 prefectures, where the black bear was culled in 2006, of all 48 (except Hokkaido of the brown bear) in Japan (Forestry Agency Statistics, "March 31, 2002"), and roughly estimated density* of breeding female black bears at each forest type.

Forest type	Area sq. km.	♀bear density
natural broad-leaf	60,200	1 / 10 sq.km.
planted broad-leaf	1,021	1 / 10 sq.km.
planted coniferous	52,879	1 / 30 sq.km.
natural coniferous	12,500	0

*, referring Ishida (2001), Yamazaki (unpublished), Yamazaki et al. (2009), Nishi (pers. com.), WMO (2001)

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Voluntary Paper

Biology of Bear Intrusions: 35-39 (2009)

Status of the 2006 drastic rise of Asiatic black bear (*Ursus thibetanus*) intrusions into residential areas in Nagano Prefecture

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Introduction

In Japan, the Asiatic black bear (*Ursus thibetanus*) occurs in 3 main islands (Honshu, Shikoku and Kyushu). The main distribution area of bears is cool-temperate deciduous forests in central to eastern Honshu, while some local populations on eastern and western parts of Chugoku District (western Honshu), Kii Peninsula and Shikoku are isolated and Kyushu populations are presumably extinct (Ministry of the Environment 2002; Abe et al. 2005). Nagano Prefecture (13,585 km^2 in extent, 170-3,190 m above sea level) is landlocked and located in mountainous areas of central Honshu, and bears are widely distributed throughout the prefecture, except urban areas in basins (Nagano Prefecture 1995, 2002; Biodiversity Center of Japan 2004).

In 2006, an extraordinary number of bears intruded into residential areas (including human habitations and agricultural lands) in Honshu, and 4,340 bears were culled as a pest. Since 1950's, this is a record number of annual culled bears, followed by that of 2,204 culled bears in 2004 (Yoneda 2007). In Nagano Prefecture, 558 bears were culled in 2006, and this is also a record number in the prefecture, followed by that of 276 culled bears in 1970 (Fig. 1). Why did so many bears intrude into residential areas in the year 2006?

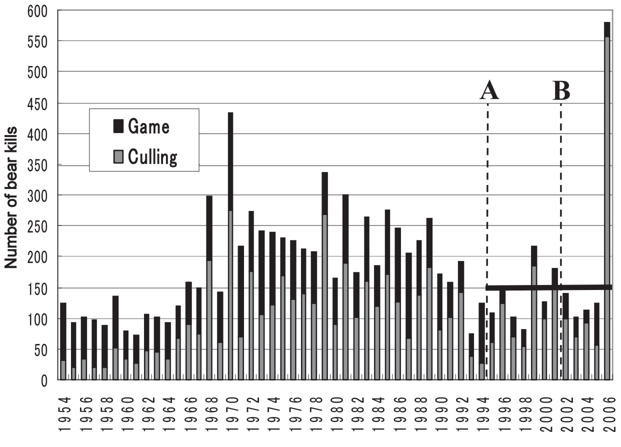

Fig. 1 Fluctuation of numbers of annual bear kills in Nagano Prefecture. A and B indicate starts of "Asiatic black bear management plan" and "Specific wildlife conservation and management plan (Asiatic black bear)" of Nagano Prefecture, respectively. Horizontal thick line between 1995 and 2006 is upper limit of 150 annual bear kills. (Drawn from data of Forestry Department, Nagano Prefecture)

In this paper, I will describe the bear management plans of the Nagano Prefecture first, and then review an outline and causes of the drastic rise of bear intrusions into residential areas in Nagano Prefecture.

Bear management plans in Nagano Prefecture

In Nagano Prefecture, the annual cost of bear damage to forestry and agriculture such as planted trees, orchards, corns, apiaries and other properties averaged over 68 million yen between 1979 and 1999 (Huygens and Hayashi 2001), and was around 100 million yen in the last decade (Nagano Prefecture 2007a), although it was over 200 million yen in 2006 (Nagano Prefecture, unpublished data). The annual number of persons attacked by a bear was 0 to 3 between 1973 and 1993. However, it tended to increase after 1994, and was 7 to 9 after 2002, and then it was 18 in 2006 (Nagano Prefecture 2007a). In 2004, one person was killed for the first time in the prefecture and 2 in 2006.

In order to correspond to the bear issues, the Nagano Prefectural Government drew up a bear management plan in 1995 (Nagano Prefecture 1995). The government promoted the plan to "Specified Wildlife Conservation and Management Plan" as the revision in 2002, according to the Specific Wildlife Conservation and Management Planning System which was newly established within the framework of the Wildlife Protection and Hunting Law in 1999 (Nagano Prefecture 2002). Furthermore, the Specific Wildlife Conservation and Management Plan was revised as a second edition in 2007. The basic contents were the same in the 3 plans. Aims of the plans were conservation of the present stable bear population, avoidance of bear attacks on humans and decrease of bear damage to forestry and agriculture, and the goal was coexistence of humans and bears, practically segregation of habitations between humans and bears.

For the management of bear populations, the population size in the prefecture was estimated to be about 1,300 bears in 1995 and 1,300 to 2,500 bears in 2002. In the former 2 plans, at most 150 bear kills (culling and game) per year were tolerated to conserve this population size, although Huygens and Hayashi (2001) criticize the upper limit value based on the low reliability of population size estimations and the voluntary system of limit of bear kills without penalties for failing. The limit was almost kept till 2005, although it was somewhat exceeded in 1999 and 2001. However, it was extremely exceeded in 2006 (Fig. 1). In the latest plan in 2007, population size was estimated to be about 1,300 to 3,100 bears after subtracting 558 bear kills in 2006, although the differences of estimated population sizes among the 3 plans did not actually indicate fluctuation of population sizes because of the different methods and the low reliability of population size estimations (Kishimoto and Sato 2008). In the latest plan, the upper limit of annual bear kills was not fixed, and was supposed to be decided every year.

Outline of bear intrusions into residential areas in 2006

The Nagano Prefectural Government collected numbers of witness cases of bear appearance signs such as bear itself, foot prints, scratching marks, bear damage to crops etc. via municipal governments in 2005 and 2006. The total number of witness cases in the prefecture was 4,554 in 2006 which was 4.4 times the number of that in 2005. Out of the total number in 2006, that in forests was 1,187 which was 2.6 times of that in 2005, and that in residential areas was 3,367 which was 5.6 times of that in 2005.

Annual numbers of cases of bear attacks on humans were 7 to 9 between 2002 and 2005, but that was 16 in 2006 in which 18 persons were attacked. Almost all cases of bear attacks occurred in forests between 2002 and 2005, but 9 (56%) of 16 cases occurred in agricultural lands and human habituations in 2006 (Fig. 2).

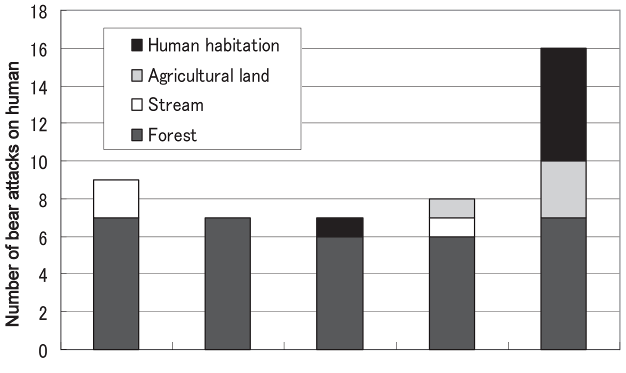

Fig. 2 Places of bear attacks on humans in Nagano Prefecture (Nagano Prefecture 2007b)

These data indicate that drastically many bears intruded into residential areas in 2006. In fact, Nagano Prefecture (2007b) reported exceptional examples of bear intrusions into residential areas in 2006. Some examples were as follows. (1) In Iiyama City, a bear attacked an old woman at a yard of her house 300m away from the nearest forest edge. Her house was surrounded by agricultural lands where bears were frequently sighted over 200m away from forest edges in 2006, while bears had appeared in at most adjacent areas to forest edges till 2006. (2) A bear which was sighted at a river-side in Matsukawa Village flight over 3km through open areas such as agricultural lands. (3) In Ikeda Town, foot prints of bears were found on a side-walk in an urban area. (4) In Komagane City, bears were sighted several times in a residential area between middle July and early August.

Causes of the drastic rise of bear intrusions in 2006

The drastic rise of bear intrusions into residential areas in 2006 was presumed to occur with a combination of two causes. One was expansion of bear habitats in rural areas with changes of coppice woodlands. This was a potential cause taking a long-term process over half a century. The other was a serious food shortage in mountain areas as a primary bear habitat. This was an immediate cause in 2006.

Expansion of bear habitats with changes of coppice woodlands

In Japan, coppice woodlands in rural areas were periodically (e.g. an interval of 10-20 years, Takeuchi 1999) cut for fuel and construction materials in the past to become a buffer zone between bear habitats and human residential areas. However, coppice woodlands have become useless and have not been cut in the present days, because resources such as petroleum and woods are usually imported in Japan now. Consequently, coppice woodlands have grown up to become habitats of bears.

I will show the case of a rural area in Nagano City as an example that coppice woodlands changed into bear habitats (Nagano Nature Conservation Research Institute 2004). The area between Iizuna Heights (about 1,000m above sea level) and the main urban area of Nagano City (about 300m above sea level) is a so-called rural area with a mosaic of coppice woodlands, agricultural lands and human habituations. Bear distribution gradually expanded in the rural area between 1995 and 2001 (Nagano City 2003), and lately bears appeared at adjacent areas to the main urban area (Nagano

City, unpublished data). According to a questionnaire survey, coppice woodlands of the rural area were periodically cut to be open until the middle 1950's (Nagano Nature Conservation Research Institute 2003). However, lately, the coppice woodlands have changed into bear habitats. Furthermore, corn fields and orchards which are scattered in the woodlands attract bears. It was confirmed that a female bear hibernated and gave birth less than 1 km away from the urban area (Kishimoto et al. 2002). This suggested that some bears already grew up in the rural area and possibly become familiar to residential areas as a result.

Serious food shortage for bears in 2006

While expansion of bear habitats with changes of coppice woodlands was suggested to be a background of the drastic rise of bear intrusions into residential areas in 2006, the immediate cause was presumed to be serious food shortage for bears in mountain areas in the year. Annually bears most frequently intruded into residential areas and were culled in middle or late August (Fig. 3), probably because crops such as corns and fruits which attracted bears grew ripe in this season. Furthermore, foods for bears were presumed to be limited in mountain areas in summer, while foods are abundant with sprouts of various plants in spring and with acorns in autumn. However, in 2006, numbers of culled bears conspicuously increased in early August, and two peaks for numbers of culled bears were shown in late August and in late October (Fig. 3). This suggested that serious food shortage occurred in the summer and the autumn of 2006.

In the summer of 2006, items of food shortage were not clear, although wasps (Vespidae) , which were a food item of Asiatic black bears in summer (Hashimoto and Takatsuki 1997), were confirmed to be scarce in 2006 by questionnaire samples of beekeepers, blight control labors and forestry labors (Nagano Prefecture 2007b). In the autumn of 2006, items of food shortage were certainly acorns of oak trees (*Quercus crispula and Q. serrata*) and beechnuts (*Fagus crenata*), which were main food items in autumn (Hashimoto and Takatsuki 1997), although distribution of beech forests were limited in small areas of northern Nagano. The prefectural government has researched ripe rates of acorns, beechnuts and chestnuts (*Castanea crenata*) for prediction of bear damage since 2002, and confirmed serious failure of crops of acorns and beechnuts in 2006, while chestnuts were abundant (Nagano Prefecture 2007b). In 2006, the number of culled bears decreased once in early October (Fig. 3), probably because bears went back to mountain areas to eat acorns, seeds of beech and chestnuts. But they intruded into residential areas again because of shortage of these food items.

In autumn, Asiatic black bears often leave a field sign on the tree, so-called "bear nest" which is an eating site of acorns, beech nuts, chestnuts and so on. The prefectural government researched numbers of bear nests along 63 study routes (2-10 km in extent) all around the prefecture in 2005, and 36 of the 63 study routs in 2006 (Nagano Prefecture 2007b). In spite of smaller number of study routs, conspicuously more number of bear nests was found in 2006 than in 2005 (Fig.4). Presumably, bears usually wait acorns etc.to drop after growing ripe and then ate them, but they could not wait drops of acorns etc. because of food shortage in the summer of 2006, consequently made many bear nests. The most number of bear nests was found in chestnut trees in 2006, probably because chestnuts were abundant. In the year when crops of oak and/or beech fail, bears depend on chestnuts for foods in autumn (Mizoguchi et al. 1996; Hashimoto 2002). These results also suggested serious food shortage in the summer and the autumn of 2006.

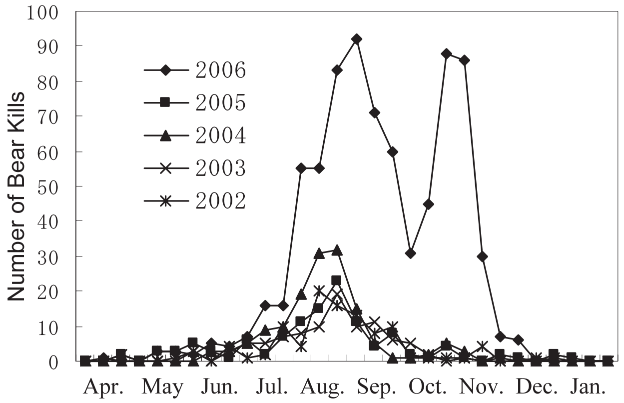

Fig. 3 Seasonal fluctuation of numbers of culled bears in Nagano Prefecture (Nagano Prefecture 2007b)

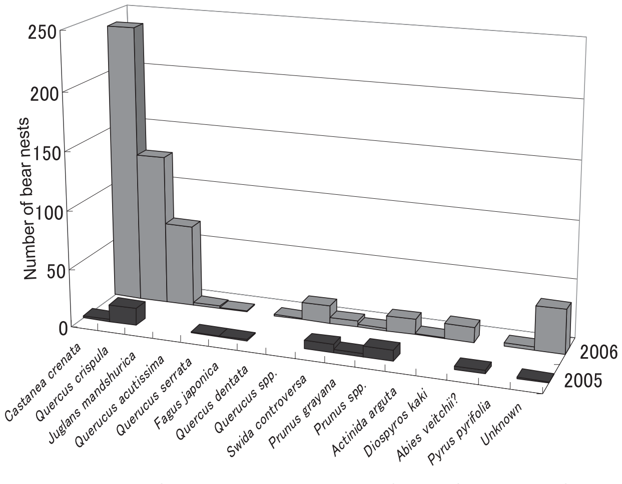

Fig. 4 Numbers of bear nests in Nagano Prefecture (Nagano Prefecture 2007b)

According to the Nagano Prefecture's bear management plans, ages of culled bears were estimated by a method of cementum annuli counts of teeth, usually first premolars. Fig. 5 shows the age structures of 168 bears and 367 bears culled in 2001-2005 and in 2006, respectively. Out of a total of the 535 bears, 99.7% of 340 bears in which reasons of culling were known were culled because of nuisance behavior around residential areas, such as damages to crops, orchards, apiaries or fish farms and intrusions into human habituations. Therefore, the age structures indicate the trend of ages of invasive bears into residential areas.

Predominantly 2- to 5-year-old bears were culled in 2001-2005, while conspicuously more bears over 6 years of age were culled in 2006 than in 2001-2005 (Fig. 5). This suggested that young bears tended to intrude into residential areas, and older bears tended to stay in mountain areas in the ordinary years 2001-2005 without serious food shortage. On the other hand, not only young bears but older bears may have roamed to seek foods and intruded into residential areas in the drastic year 2006. This also supports serious food shortage in mountain areas in 2006.

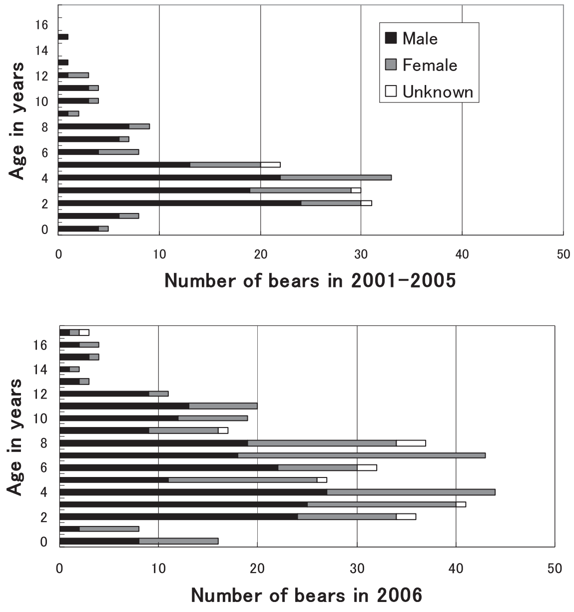

Fig. 5 Age structure of culled bears in Nagano Prefecture

Issues of bear management plans for drastic bear intrusions

The drastic rise of bear intrusions into residential areas in 2006 was the first experience for Nagano Prefecture. The Specific Wildlife Conservation and Management Plan for bears of Nagano Prefecture didn't work well for this situation. The plan encouraged various methods such as electric fences, making open areas as a buffer zone between agricultural lands and forests, removing attractants of bears and aversive conditioning to prevent bear damages instead of culling. Especially electric fences are an effective material against bear damage to crops, apiaries and fish farms (Huygens and Hayashi 1999), and consequently defend attracting bears to residential areas. These methods have been gradually used through the prefecture, although public awareness with the methods may still not be enough. However, if these methods were adequately used widely through the prefecture, the drastic rise of bear intrusions into residential areas would not be avoided. The plan corresponds to bear issues in ordinary years, but not to those in drastic years with serious food shortage in mountain areas like the year 2006.

How can we prevent the drastic rise of bear intrusions into residential areas? In the brown bear (*Ursus arctos*), Minamiyama et al. (2006) suggested that the forest having many kinds of food trees is necessary to conserve population and reduce bear damage to crops, because the diet of bears included various items in the poor mast year of acorns as comparing with that over 95% of the diet were acorns in the rich mast year. However, it takes a very long period of time to make such forests with many kinds of food trees. We have now very difficult issues to solve for reconsideration of the bear management plan corresponding to bear intrusions into residential areas in the year of serious food shortage.

Acknowledgments I thank Forestry Department, Nagano Prefecture for providing information on the bear management plans of the prefecture.

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Biology of Bear Intrusions: 40-43 (2009)

Key findings on bear intrusions into residential areas in Nagano Prefecture from stable isotope analysis

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Introduction

Stable isotope analysis is widely used to study animal ecology. Since carbon and nitrogen isotopic compositions in animal tissues correlate with diet compositions (DeNiro and Epstein 1978, 1981; Minagawa and Wada 1984), studies on the distribution of these isotopes can furnish valuable information on animal diet and feeding behaviors. Carbon isotopes ($\delta^{13}C$) are typically used to determine the relative contribution of C_3 and C_4 plants consumed by herbivores (DeNiro and Epstein 1978), and nitrogen isotopes ($\delta^{15}N$) can be used to determine the trophic level of the animal within its ecosystem.

Isotope analysis in case of the Asiatic black bear in Japan is useful because natural bear food found in the mountains have isotopic values different from those of most anthropogenic food consumed by animals straying into residential areas (Nakashita 2006).

Here, we present the typical characteristics of the isotopic ratio according to reflecting the feeding history of bears that stray into residential areas in Nagano prefecture. We also report our findings regarding the characteristics of the isotopic ratio in the year 2006, which saw a large number of such intrusions.

Sample and Stable isotope analysis

Stable isotope analyses for food habits have been previously performed using various animal tissues such as hair (Schoeninger et al., 1998; Panaello and Fernández, 2002; Mizukami et al., 2005a,b), blood (Ben-David et al., 1997; Narita et al., 2006), bone collagen (Schoeninger and DeNiro, 1984; Cormie and Schwarcz, 1994), muscle (Yamamuro et al., 2004) and so on. In particular, hair is useful to analyze stable isotopes because collection, storage, and pretreatment for analysis of hair is easy and it retains information on the diet consumed during its growth period. Taking advantage of the fact that the hair of Asiatic black bear grows continuously during the active season, we can estimate the overall food habit during the active season. Moreover, since the hair continuously grows from late spring to autumn, we can estimate the feeding history of the bear by examining the hair along its length. Therefore, we collected hair samples from Asiatic black bears in Nagano prefecture.

Hair samples were rinsed with 2:1 chloroform-methanol solution to remove lipids, and air-dried. The samples were then analyzed in 2 ways. For whole hair analysis, whole hair samples were obtained from all the bears so that the results represented the average value for the entire length of the hair. For growth section analysis, hair samples were cut into 5mm-thick sections from the root to the tip. Corresponding sections of hair were gathered to obtain a sufficient amount sample for analysis and then analyzed separately.

The nitrogen and carbon isotopic compositions of the hair samples were determined by using a conventional method with elemental analyzer/isotope ratio mass spectrometry (EA/IRMS, Finnigan Delta V Advantage interfaced with FlashEA 1112 HT, Thermo Fisher Scientific). The δ notation defined in the following equation was used to represent the isotopic composition:

$\delta(‰) = (R_{sam} - R_{std}) / R_{std} \times 1000$,

where R_{sam} is the isotope ratio of the sample, and R_{std} is the isotope ratio of the international standard: Vienna Pee Dee Belemnite (V-PDB) for carbon (^{13}C) and air for nitrogen (^{15}N). We determined every sample twice. Since these data showed analytical errors in carbon and nitrogen isotopic compositions smaller than 0.2‰ and ±0.3‰ respectively, we adopted their mean values.

Distribution characteristics in the isotopic ratio reflecting the feeding history of the intruding bears

Before we discuss the characteristics of the isotopic ratio reflecting the feeding history of intruding bears in Nagano prefecture, we examine the feeding pattern in bears which live in mountainous regions. Figure 1(a) shows the typical distribution pattern of the isotopic ratio of a bear inhabiting the mountain area throughout the year. Data on the upper-side points are obtained from hair tips, corresponding to the growth in late spring, while data on the lower-side points are obtained from the hair bases, corresponding to the growth in the fall. The deviation in the δ^{13}C values is very small during the period of hair growth, while the deviation in the δ^{15}N values of the hair tip and base is relatively high. These findings suggest that this bear mainly fed on C_3 plants during the active season and that it may have consumed foods of animal origin in spring. Thus, for bears inhabiting mountainous regions, we can see some deviation in the δ^{15}N values. On the other hand, data for rural bears, especially the nuisance bears, showed large deviations and varying patterns from the root to tip.

Figure 1(b) shows the typical isotopic ratio pattern of a bear heavily depending on corn. This bear was killed in a corn-producing district in November 2004. The analysis of the hair tip, which grew in spring, indicates that the bear mainly consumed C_3 plants during that season. The analysis of the central part of the hair, which grew during the summer, indicates that the bear ate corn, the only C_4 plant in the area. However, the analysis of the hair base, which grew during the fall, clearly indicates that the bear reverted back to consuming C_3 plants. Thus, bears raiding corn fields would show higher levels of δ^{13}C in those sections of the hair that represent growth in summers.

Figure 1(c) shows the typical case of a bear feeding on garbage. This bear was killed near a hotel garbage disposal site in September 2001. Values for both δ^{13}C and δ^{15}N are low at the hair tip, but towards the hair root, both the values increase simultaneously. These values are close to the levels found in the hair of the Japanese people, which may be considered to be an index of the garbage. This suggests that this bear mainly consumed C_3 plants in spring, but later, shifted to garbage, after which it was killed. It may be inferred that the levels of both δ^{13}C and δ^{15}N are high among bears that depend heavily on garbage for food.

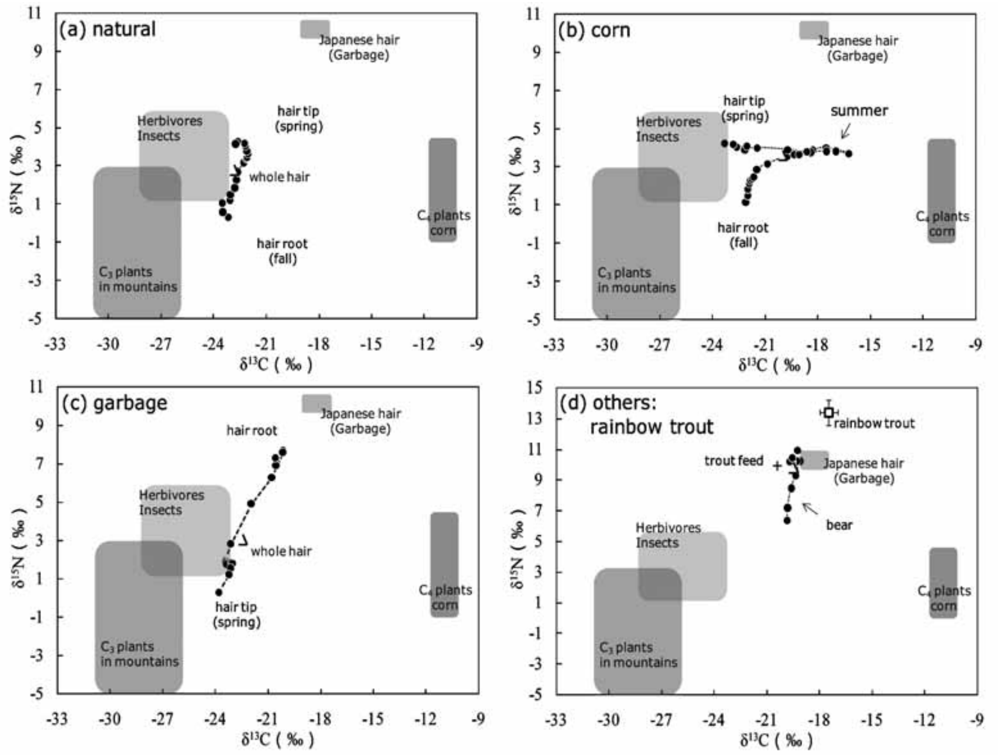

Fig. 1 Characteristics of the isotopic ratio reflecting the feeding history of the intruding bears. (a) Natural pattern: A bear inhabiting the mountain area throughout the year. This bear was captured in Omachi town in June 2002. (b) Corn pattern: The typical case of a bear depending heavily on corn. This bear was killed in Shinanomachi town in November 2004. (c) Garbage pattern: The typical case of a bear depending on garbage. This bear was killed in Karuizawa in September 2001. (d) Other pattern: A bear depending on rainbow trout at a fish farm in Miyadamura village captured in June 2005

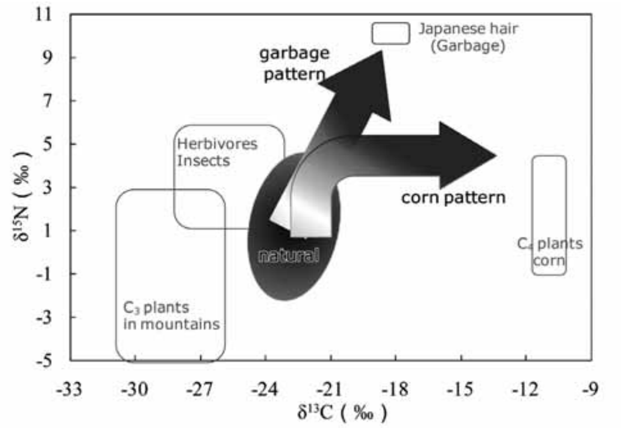

Fig. 2 Summary of the patterns of feeding history in bears

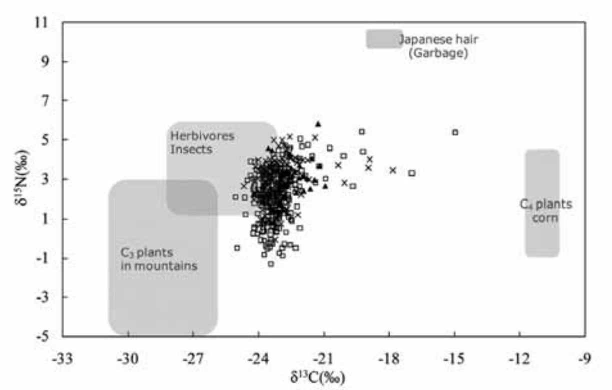

Fig. 3 The distribution of δ^{13}C and δ^{15}N for Asiatic black bears captured or killed in Nagano prefecture between 2005 and 2007. ▲ indicates bears captured or killed in 2005; □ in 2006; and × in 2007

Figure 1(d) presents the case of a bear that depended heavily on rainbow trout for food at a fish farm, until it was captured in June 2005. In this case, we also analyzed the isotopic composition of the rainbow trout meat as well as of the trout's feed. The δ^{13}C and δ^{15}N values for the rainbow trout meat at the farm were higher than those of the Japanese human hair. These values for the trout's feed were also high. Thus, the δ^{15}N and δ^{13}C values for the bear were high throughout the period of hair growth. Thus, bears that ate foods with unusual isotope ratios exhibited patterns quite different from regular bears inhabiting the mountains.

A summary of the patterns of feeding history based on the isotope analysis is shown in Figure 2. Bears inhabiting the mountains throughout the year, show a vertical shift on the δ^{13}C - δ^{15}N map. On the other hand, bears straying into residential areas demonstrate different patterns. However, there may be cases that do not fit these patterns necessarily. Some bears stray into residential areas, but eat natural foods or foods that have isotope ratios similar to mountain foods. The characteristics of isotope compositions in such cases would be similar to those of regular mountain bears.

Findings for the characteristics of the isotopic ratio in 2006

In 2006, a considerable number of Asiatic black bears strayed into residential areas in Honshu, the largest island of Japan. In Nagano Prefecture, 704 bears were captured. Of them, 558 were killed and 146 were released in the year 2006 (Kishimoto 2009). We determined the δ^{13}C and δ^{15}N values using hair samples of bears captured or killed between 2005 and 2007 in order to examine the difference between the year 2006 and other years. Values of both δ^{13}C and δ^{15}N for bears captured or killed in 2006 (n = 225; δ^{13}C：–25.0 to –15.0 (min–max) and δ^{15}N：−1.3 to + 5.4‰) had ranges larger than the values of bears captured or killed in 2005 (n = 42; δ^{13}C：−24.2 to –20.9 and δ^{15}N：+0.8 to +5.9 ‰) and 2007 (n = 121; δ^{13}C：–24.7 to –17.8 and δ^{15}N：–0.1 to +5.2‰); this may probably be due to a wider diversity of food consumed in 2006 (Figure 3). These findings imply that a wider variety of food was consumed by bears in the year 2006. It was noteworthy that δ^{15}N values for some bears were very low. We could not clearly identify the reason for this, but the following was considered as one of the possible reasons. We have collected δ^{15}N data from precipitation, plants, and Japanese macaques in the Northern Japan Alps from the submontane area to the alpine area since 2005 (Yoh et al. in preparation). The δ^{15}N values obtained from the alpine area were clearly lower than those from the submontane area in all the categories of precipitation, plants, and Japanese macaque. For example, the δ^{15}N values of the Japanese macaque obtained from the alpine area was –0.1 ± 0.3‰ (mean ± SD; n = 9), while those of from submontane area were +2.5 ± 0.8‰ (mean ± SD; n = 39). If bear has similar trend of these isotopic result, the bears which had very low δ^{15}N values would inhabit the deep mountain. This suggests that there is a possibility that even alpine bears ordinarily inhabiting only mountainous areas strayed into residential areas in the year 2006. With respect to the ages of the culled bears, it was found that, previously, mainly bears aged 2–5 years tended to be culled, but unusually, in the year 2006, bears aged 2–12 years were culled; this suggested that even comparatively old bears that inhabited only mountainous areas strayed into residential areas in the year 2006 (Kishimoto 2009). Similarly, a study of the feeding marks on trees demonstrated an usual tendency in the year 2006: the bear marks in 2006 were observed on a much wider range of tree species than in ordinary years; this trend may be attributed to acorn failure in the mountains in the year 2006 (Kishimoto 2009). Thus, the food shortage in the year 2006 could also be one of reasons for bear intrusions into residential areas in Nagano prefecture.

The results obtained by isotope analysis in combination with other data from killed bears, including their biological traits, and the status of acorn and beechnut production in the bear habitat can furnish valuable information on the behavior of bears; however, such information would be limited to obtain. By monitoring the abovementioned parameters, we can obtain ecological information for Asiatic black bears and may be able to identify the reasons for bear intrusions into residential areas; it is expected that such data will provide relevant information for the promotion of bear conservation and management programs.

Acknowledgements We would like to thank the municipal and prefectural officers in Nagano prefecture for their help in the collection of samples.

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Biology of Bear Intrusions: 44-47 (2009)

Nutritional condition and dietary profile of invasive bears in Hiroshima Prefecture, western Japan

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Introduction

Hiroshima Prefecture, the western home of the Asiatic black bear (*Ursus thibetanus*) in Japan (Fig. 1), experienced mass intrusions by bears into residential areas in 2004 and 2006 (Fig. 2). Although low forest-fruit production, especially of *Fagaceae* acorns and nuts in autumn when bears become hyperphagic in preparation for hibernation, is considered the putative cause of this behavior (Oka et al. 2004; Oi 2005, low fruit production hypothesis: LFP hypothesis), the actual food habits and nutritional conditions of bears during intrusions are unknown. We described monthly changes in the number of invasive bears captured as nuisance bears and their body condition, and examined the consumption of *Fagaceae* acorns and nuts using stable isotope analysis on hairs from invasive bears.

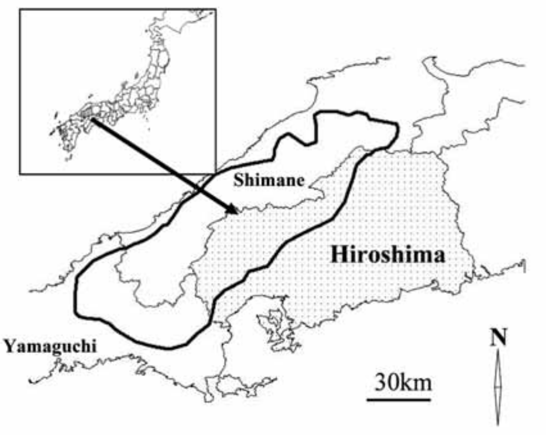

Fig. 1 Distribution of the Asiatic black bear in Japan, and the location of Hiroshima prefecture. The bold line delineates the distribution of the Western Chugoku bear population

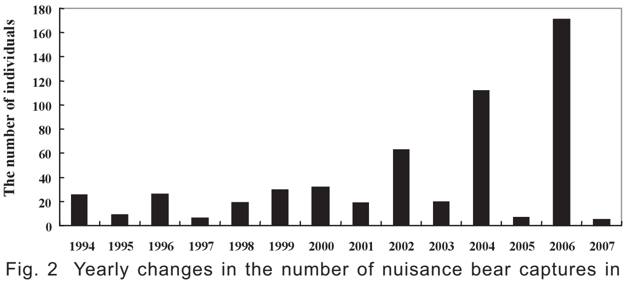

Fig. 2 Yearly changes in the number of nuisance bear captures in Hiroshima; this census provides an indicator of the number of intrusive bears

Materials and Methods

The bears in Hiroshima Prefecture are part of the Western Chugoku bear population, which is isolated and consists of approximately 300–740 bears within a 7,000-km^2 area (Japan Wildlife Research Center 2006). Because this population has been recognized as threatened, the hunting of bears has been banned since 1994, but the killing of nuisance bears is permitted.

The capture of nuisance bears requires special permission from the Prefecture Government, which requires reports detailing the sex, the estimated age, and the date and location of each capture. We tallied temporal changes in the number of monthly captures reported to the government in each year during the period from 2001 to 2007. We obtained 212 samples (80% of the bears captured, excluding cubs) and information on the place and date of each nuisance bear capture in Hiroshima Prefecture since 2001.

We evaluated the nutritional condition of invasive bears in October and November using a morphometric index proposed by Cattet et al. (2002). Cattet et al. (2002) proposed the body-condition index (BCI), which predicts the nutritional condition of a bear based on residuals from the regression of total body mass (TBM, in kg) against straight-line body length (SLBL, in cm) in the American black bear (*Ursus americanus*). We used the BCI equation developed for the American black bear to calculate BCI values of Asiatic black bears because these two species have similar body sizes, body shapes, and physiology (Nowak 1999):

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

We estimated the dietary profile of each bear by measuring carbon and nitrogen stable isotope ratios (δ^{13}C, δ^{15}N) using NC-2500 (Thermo Electron Inc.) and MAT-252 (Thermo Electron Inc.) along growth sections of bear hairs (Nakashita 2006; Oi and Furusawa 2008). Because old hairs molt from July to September, and new hairs grow at a constant ratio from June to October, hairs sampled in October and November had grown in the year sampled. Therefore, bear hairs provided an archive of temporal fluctuations in dietary stable isotope ratios from early summer to autumn in the year sampled (Nakashita 2006). Hairs were obtained from the frontal region of bear heads and cut from root to tip into 5 mm sections. As the hard mast foods are available from September, the root side sections, which were estimated to grow from the middle of September to the end of October, were used in the analysis. Corresponding hair sections were pooled for each bear and treated as a unit for analysis. Measurement results were expressed as follows:

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

where R is ^{13}C / ^{12}C or ^{15}N / ^{14}N. The precision (standard deviation) of isotopic measurements was estimated by repeatedly measuring glycine standards and was 0.18‰ (n = 163) for$\delta^{13}C$ and 0.19‰ (n = 164) for$\delta^{15}N$.

A bear's hairs have higher stable isotope ratios than the food the bear consumed because of fractionation or diet-tissue enrichment. By adding 2‰ and 3–5‰ to the $\delta^{13}C$ and $\delta^{15}N$ values, respectively, of potential bear foods, the $\delta^{13}C$ and $\delta^{15}N$ values expected in hairs from bears that consumed those foods can be estimated (Hilderbrand et al. 1996; Felicetti et al. 2003; Nakashita 2006). The $\delta^{13}C$ and $\delta^{15}N$ values of potential bear foods were obtained from previous studies (Minagawa and Akazawa 1988; Minagawa 2001; Narita 2003; Nakashita 2006). Because the maximum $\delta^{13}C$ value in natural bear foods is -23.7‰ (invertebrates), hair segments with $\delta^{13}C > -21‰$ strongly imply that the source bear consumed a substantial amount of anthropogenic food, such as human food waste, cattle fodder that often contains C_4 plants, and oceanic material. Because the 95% confidence intervals of the $\delta^{13}C$ and δ^{15} N values of hard mast foods, such as acorns (*Quercus crispula, Quercus serrata*), chestnuts (*Castanea crenata*), and beech nuts (*Fagus creanata*), are -31.1 to -24.7‰ and -1.3 to 2.0‰ (n = 5) (data are based on Nakashita (2006); Narita (2003)), respectively, hair segments with $\delta^{13}C$ values between -29 and -22.7‰ and δ^{15} N between 3.7 and 7‰ suggest that the source bear consumed a substantial amount of hard mast foods. We qualitatively evaluated the degree of hard mast food consumption by bears through visual comparison of a $\delta^{13}C$ - $\delta^{15}N$ graph between the actual range of stable isotope ratios of bear hairs and the range of stable isotope ratios predicted for bears that only consumed hard mast foods.

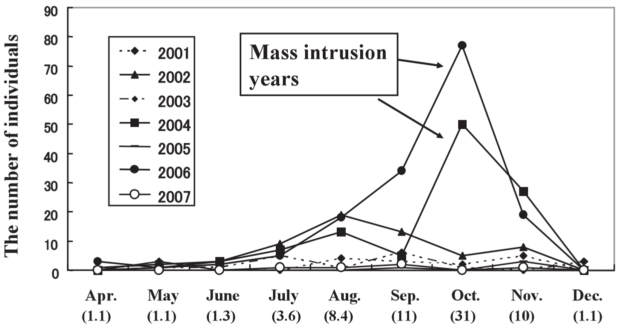

Fig. 3 Monthly changes in the number of nuisance bear captures from 2001 to 2007 in Hiroshima. Numbers in parenthesis are standard deviations of the number of individuals killed during the month. Massive bear intrusions occurred in 2004 and 2006

Results

The capture of nuisance bears occurred from April through December (Fig. 3). The monthly pattern in the number of captured bears differed between mass intrusion years (2004 and 2006) and all other years (Fig. 3). The standard deviations of the number of nuisance bears captured in each month were 1.1 in April, 1.1 in May, 1.3 in June, 3.6 in July, 8.4 in August, 11 in September, 31 in October, 10 in November, and 1.1 in December (n = 7). This indicates that the number of nuisance captures is most variable in October, followed by September and November. These months coincide with the pre-hibernation period of bears.

The BCI ranged from -4.0 to 4.5 (mean ± SD; 0.64 ± 1.2, n = 140) in mass intrusion years and from -4.5 to 3.0 (0.21 ± 1.4, n = 20) in all other years (Fig. 4). The BCI ranged widely both in mass intrusion and other years, and the values from the two temporal groups overlapped completely. However, BCI values in mass intrusion years appeared to be skewed slightly to lower values compared to the other years, but this was not statistically significant (Mann-Whitney *U* = 1102, P = 0.12).

The $\delta^{13}C$ values ranged from -24.1 to -19.3 ‰ (mean ±

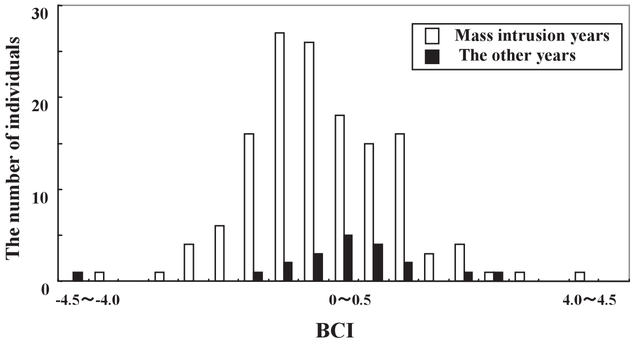

Fig. 4 Distribution of BCI values in October and November during years with massive bear intrusions (2004 and 2006) and during other years (2001?2003, 2005, 2006). Bear cubs are excluded

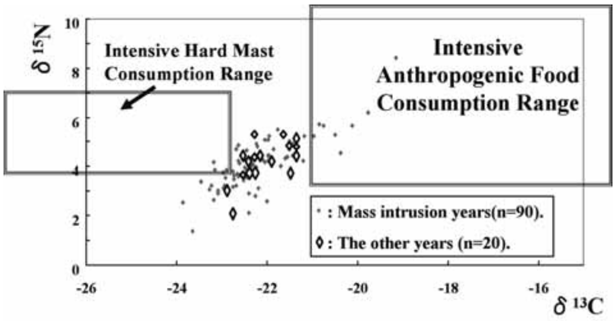

Fig. 5 Distribution of δ13C and δ15N values in root side sections of hairs from individual bears collected during years with massive bear intrusions and from all other years

SD; -22.0 ± 0.7‰, n = 90) in mass intrusion years and from -23.7 to -21.2 (-22.2 ± 0.63‰, n = 20) in all other years. The δ^{15}N values of hair sections ranged from 1.4 to 6.5‰ (4.0 ± 0.9‰, n = 90) in mass intrusion years and from 2.7 to 5.2‰ (4.2 ± 0.61‰, n = 20) in all other years. The stable isotope ranges overlapped completely between mass intrusion years and the other years (Fig. 5). Six percent of the bears captured in mass intrusion years had stable isotope values that overlapped with the range of values predicted for bears that consumed only hard mast foods; most bears had stable isotope values that differed considerably from the expected range for diets that included substantial hard mast consumption.

The δ^{13}C values from 9% of the invasive bears in mass intrusion years were >-21‰, suggesting those bears had consumed anthropogenic food. No bears had comparable δ^{13}C signatures during the other years.

Discussion

In 2004 and 2006 in Hirhoshima, an extraordinary number of bears invaded residential areas; these years represented the highest annual numbers of nuisance bear captures during the period between 1994 and 2007. The highest numbers of invasive bear captures in 2004 and 2006 occurred in September, October, and November, whereas comparably high capture numbers were not seen during those months in other years. This indicates that the mass intrusion of bears into residential areas happened in autumn, during the pre-hibernation period when bears become hyperphagic (Nelson et al., 1983). *Fagaceae* acorns and nuts can be major food sources for bears when they are available in autumn (Hashimoto and Takatsuki 1997), though their productivity fluctuates annually (Komiyama et al. 1991; Masaki et al. 2008). Although we do not have data regarding yearly crop productions of such hard mast foods in Hiroshima, the LFP hypothesis is indirectly supported by the coincidence between the season when mass intrusions occurred and the fruiting season of hard masts.

The BCI values of invasive bears were quite variable. However, the number of thin bears captured in 2004 and 2006 appeared to be higher than during other years. More samples from years with low numbers of nuisance captures are needed to test this hypothesis.

The stable isotope signatures of invasive bears, both in mass intrusion years and during other years, suggest that most of the invasive bears had not consumed substantial amounts of hard mast foods. The number of such bears was also higher in mass intrusion years than during other years. Mass intrusion years might be characterized by an increase in the number of bears that do not consume substantial quantities of hard mast foods. However, we do not know whether non-intrusive bears had consumed large amounts of hard mast foods. Thus, we cannot conclude that hard mast crop failures caused the massive bear intrusions from the results of the stable isotope analysis of bear diets. Investigation of the dietary profiles of non-invasive bears is required. Furthermore, the sample size of the stable isotope ratio analysis of hard mast foods was somewhat small to accurately predict the range of stable isotope values expected in bears that consumed substantial amounts of hard mast foods. Measurements of stable isotope ratios of hard mast foods from various sites within the bear habitats are needed. A quantitative evaluation (Minagawa 1992; Phillips and Koch 2002) of the proportion of hard mast consumption is also required.

Nine percent of the intrusive bears were assumed to have consumed substantial amounts of anthropogenic foods, such as food garbage, cattle fodder, and maize, during the mass intrusion years. These food sources need to be controlled using electronic-fencing, burial, or burning, to avoid the attraction of bears to human settlements, because such attraction induces conflicts between bears and humans.

Acknowledgements We thank the Hiroshima Prefecture Government, the Hiroshima Hunters Association, and the Hiroshima Environment and Health Association for their support in collecting samples and information. This research was supported by the "Pollution Control Research Fund" of the Ministry of the Environment, Japan.

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Biology of Bear Intrusions: 48-51 (2009)

Is there any relationship between the number of nuisance-killed Japanese black bears (*Ursus thibetanus japonicus*) and their nutritional condition?

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Introduction

The cause for the bear intrusion into human residential areas is considered to be multifactorial. Amount of food resources, social change in "satoyama" (a type of countryside in Japan consisting of agricultural and forestry land with residential area nearby) such as depopulation, aging and abandonment of crop lands, and decreasing hunter population are supposed to be key factors (Ministry of the Environment 2007). Among these factors, the amount of food resources is probably most important. In fact, Oka et al. (2004) found a positive correlation between the number of nuisance-killed Japanese black bears (*Ursus thibetanus japonicus*) and the beechnut (*Fagus crenata*) crop failure. This suggests that lacking in food resources is associated with massive intrusion. As lacking in food resources deteriorates the nutritional condition of bears, thus we expected some relationship between bears' nutritional condition and the extent of intrusion. We hypothesized that the nutritional condition is poor in the year of large number of nuisance kills. The objective of this study was to test this working hypothesis.

Materials and Methods

We used the bear samples killed as nuisances during 2005-2007 in Gifu and Fukushima prefectures. The age of the bears was determined by cementum annulus count, and grouped into the following classes: cub (0 yr), subadult (2-4 yr) and adult (5- yr). As no yearling (1 yr) was captured in this study, we did not include yearling class. For the evaluation of the nutritional condition, we measured the following body fat indices: kidney fat index (KFI), abdominal subcutaneous fat (ASF) and femur marrow fat (FMF). KFI was the ratio of the weight of perirenal fat to the weight of kidney itself. KFI was originally defined by Riney (1955) as a nutritional index for deer. We made a little modification to Riney's KFI in consideration for the anatomical differences between deer and bears. Briefly, only the fat that directly attached to the kidney was weighed in our KFI, while Riney's measures whole fat mass surrounding the kidney. To confirm the effectiveness of our KFI, we measured the both KFIs on 15 samples, and found a high correlation (R=0.873, p<0.01) (Yamanaka 2007). Hereafter, our modified KFI is simply denoted by KFI. ASF was the thickness of subcutaneous fat in epigastric area. Measuring method for subcutaneous fat has not been so firmly established as for KFI and FMF. In deer, Riney (1955) used "back fat index", which was the thickness of subcutaneous fat at lower back. In bears, no quantitative method has been established, and, as far as we know, only subjective, semi-quantitative scorings have been employed in a few researches (Hazumi et al. 1985; Costello et al. 2003). We introduced ASF for a more objective and quantitative evaluation. We chose epigastric area instead of lower back as the measuring position in consideration of the easiness in collecting samples. We took a palm-sized abdominal wall sample. After freezing it, we cut it perpendicular to the hair stream at two planes which were approximately 30 mm apart from each other. Then, the minimum thickness of subcutaneous fat on each section was measured. ASF was defined as the average of the two measurements. FMF was measured according to Neiland (1970). We took bone marrow from the middle one third of thigh bone, dried it at 60 degree Celsius. FMF was defined as the ratio of the dry weight to the wet weight of the marrow.

We analyzed those body fat indices statistically through two steps. Throughout the analysis we used analysis of variance (ANOVA) and *post hoc* multiple comparison by Tukey's honest significant differences method (Tukey's HSD) with the significance level of p<0.05. We employed an additive linear model, *i.e.*, assumed no interaction among explanatory variables, considering our limited sample size. The statistical software used was R (R Development Core Team 2007) with library package MASS (Venables and Ripley 2002).

Step 1 -- We examined the effects of age class, month of capture and sex on the body fat indices using the data set of 2006 in Gifu which had the largest sample size among the data sets with single year and single location. The sample sizes were n=49 for KFI, n=38 for ASF and n=47 for FMF.

Step 2 -- We pooled the data adequately according to the results of the first step (see Results) to produce the annual data set for each location and each index: The age class was limited to subadult and adult, *i.e.*, cub was excluded; Since the month of capture in which we could collect the data every year was limited from July to September, we used the data only from this period and pooled them regardless of month of capture; The data from both sexes were pooled for KFI and FMF, and the sex effect on ASF was taken into consideration by carrying out two-way ANOVA with year and sex as the explanatory variables. The annual data sets thus created were tested for statistical differences among years. The sample sizes of the annual data sets of Gifu Prefecture were n=30 for KFI, n=27 for ASF and n=30 for FMF. Those of Fukushima Prefecture were n=29 for KFI and n=20 for ASF. FMF was not obtained from Fukushima Prefecture.

Finally, the result of the statistical analysis was compared to the annual numbers of nuisance kills tallied by the authorities.

Results

Step 1 -- Age class had a significant effect on all the three indices. KFI and ASF of cub were significantly lower than those of subadult and adult. FMF of cub was significantly lower than that of all the other classes. Month of capture had a significant effect on KFI and ASF. KFIs in November and December were significantly higher than those in July and September; ASF in November (no ASF was obtained in December) was significantly higher than those in July to October. Sex had a significant effect on ASF. Male had a significantly higher ASF than female.

Step 2 -- ANOVA on the annually pooled data of the body fat indices detected significant differences ($p<0.05$) among years in all indices of Gifu Prefecture and KFI of Fukushima Prefecture. *Post hoc* multiple comparison revealed that these indices had significantly higher values in 2006 than in 2007 ($p<0.05$). In ASF of Fukushima Prefecture, no significant difference was detected.

According to the data tallied by the authorities, the number of nuisance-killed bears during July to September, *i.e.*, during the same period as we tested the annual differences in the body fat indices, was as follows: In Gifu, 11 bears in 2005, 79 in 2006 and 37 in 2007; in Fukushima, 40 in 2005, 331 in 2006 and 69 in 2007.

Discussion

The reason why cubs had lower body fat indices than the other age classes may be because they consume energy intake for their skeletal and muscular growth, and not for storing fat. The effect of month of capture on the body fat indices may reflect the seasonal change in types of food eaten by bears. From spring to summer, bears eat mainly grasses and berries. However, once hard mast becomes available in autumn, they shift to eating it (Hashimoto and Takatsuki 1997). Hard mast contains high calorie compared to other bear's food like grasses and berries (Elowe and Dodge 1989). Bears may enhance their nutritional condition in November and December by eating high-calorie hard mast. Sex effect on the body fat indices was seen only on ASF. We have not yet come up with any reasonable interpretation. Further study is needed on this effect.

The result of the second step of the statistical analysis showed that all the indices except for ASF of Fukushima Prefecture had significantly higher values in 2006 than in 2007. When considering the sample size of ASF of Fukushima Prefecture in 2007 (n=2), the power of the statistical test in this case may not be sufficient to detect a significant difference. Overall, it is concluded that the nutritional condition of nuisance-killed bears from July to September was significantly better in 2006 than in 2007. However, the number of nuisance kills, when comparing 2006 and 2007, was high in 2006 and low in 2007 in spite of significantly better nutritional condition in 2006. This means that our working hypothesis was denied, *i.e.*, the nutritional condition is not always poor in the year of large number of nuisance kills. The deterioration in nutritional condition is not a necessary condition for the intrusion of bears. We speculate that bears intrude into residential areas not because their nutritional condition has become worse, but simply because they feel hungry under the lack of food resources. The direct trigger for intrusion might be the hunger irrespective of the nutritional condition. When they are lacking in food resources, they feel hungry and may intrude into residential areas whatever their nutritional condition may be.

Then, some questions may arise: Given that nuisance-killed bears in July to September of 2006 felt hungry much more than those of 2007, the amount of food resources must have been scarce during July to September in 2006. Nonetheless, why did the bears have good nutritional condition in 2006? The key to the answer may be a time lag with which the amount of food affects the nutritional condition. As we experience in our daily life, the change in amount of food we eat alters gradually, not immediately, our nutritional condition such as weight and adiposity. The lack of food is supposed to affect the nutritional condition with a certain time lag. However, we do feel hungry before our weight or adiposity is lost substantially. The lack of food can induce the sensation of hunger much sooner than it deteriorates the nutritional condition. This allows us to suppose that the simultaneous occurrence of hunger and good nutritional condition is possible.

The next, related question would be how the bears in 2006 got their good nutritional condition. We speculate that the remnant hard mast was abundant in spring of 2006 and bears enhanced their condition by feeding on it. It is well-known that, after an abundant hard mast crop in autumn, the remnant mast is still available in spring and bears feed on it (Mizoguchi et al. 1996; Hashimoto and Takatsuki 1997; Tsubota et al. 1998; McDonald and Fuller 2005). And according to the beechnut crop report available on the website of Forestry and Forest Products Research Institute (http://www.ffpri.affrc.go.jp/labs/tanedas/tanedas-index.html), the crop was good in 2005 and failed in 2006. Although the crop report does not directly predict the amount of the remnant mast in the next spring and we do not have any data about it in those years, the situation allows us to imagine that bears may have had chance to feed on the remnant mast and store fat in spring of 2006, but not in 2007. In 2006, the enhancement of nutritional condition in spring may have compensated the deterioration in summer.

Some readers might point out a possible effect of human-related food on the nutritional condition of nuisance-killed bears. The nutritional condition of nuisance-killed bears might be altered by eating human-related food. This effect is an interesting topic by itself, and should be quantitatively evaluated in the future. Nonetheless, as far as we discuss the difference, not the absolute level, of the nutritional condition among years, we speculate that the effect may be small. Since the production of human-related food such as agricultural crops and trash does not so drastically fluctuate annually as that of wild food, the effect of human-related food seems to be relatively stable among years. Therefore, though it is a mere speculation, the effect may raise the baseline of the annual level of nutritional condition, but the difference among years probably will not be affected much.

Another question may be “Is the nutritional condition totally irrelevant to the intrusion?”, or “Does the nutritional condition have nothing to do with the intrusion?” We are thinking of a possibility that, in the long term, the nutritional condition has a certain effect on the intrusion. In general, the nutritional condition of an animal is considered to possibly affect its survival and reproduction. In Ursidae, Rogers (1976) observed that female American black bears (*Ursus americanus*) that did not gain sufficient weight before denning usually failed to produce cubs, and that cubs and yearlings with light weight suffered heavier mortality. She also reported the relationships between amount of food resources and several reproductive parameters. Some other researchers also have pointed out the relationship between amount of food resources and reproductive and survival parameters in American black bears (Eiler et al. 1989; Elowe and Dodge 1989; Costello et al. 2003), and in Japanese black bears (Hashimoto 2003). The theory in population dynamics, on the other hand, tells us that survival and reproduction rates determine the growth rate of a population. Therefore, the nutritional condition may change the population size. The change in the population size, in turn, may affect the extent of intrusion, because the increased population size is supposed to lead to increased incidents of intrusion if any other condition remains the same. To verify the above story, however, a long-term study is needed in the future.

Conclusion

Our working hypothesis, “The nutritional condition is poor in the year of large number of nuisance kills.” was rejected. The number of nuisance kills was high in 2006 and low in 2007 in spite of significantly better nutritional condition of nuisance-killed bears in 2006. The deterioration in nutritional condition was not a necessary factor for the intrusion of bears, *i.e.*, bears did not intrude into residential areas because their nutritional condition had become poor. We proposed a possibility that bears intrude simply because they feel hungry under the lack of food resources.

Acknowledgements We thank Dr. T. Mano of Hokkaido Institute of Environmental Sciences for his helpful advice on age determination by cementum annulus count. We also appreciate the generous cooperation of officials and hunters of Gifu and Fukushima prefectures in collecting samples. This study was supported by "Pollution Control Research Fund" to Forestry and Forest Products Research Institute from the Ministry of the Environment, Japan.

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Biology of Bear Intrusions: 52-55 (2009)

Physiological and endocrinological mechanism for body fat accumulation during the pre-hibernation period in the captive Japanese black bear, *Ursus thibetanus japonicus*

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Introduction

Bears in the northern hemisphere have an active phase from mid-April to November and denning phase from December to mid-April. During the denning period, bears hibernate with low body temperature, low respiratory rate, low heartbeat and low metabolism, and never eat, drink, defecate nor urinate (Nelson et al. 1973, Hellgren 1998). Regarding reproduction, bears exhibit mating season from June to August and give birth in late January or early February during the denning period (Tsubota et al. 1994). An entire gestation period is about 6-7 months, however an actual fetal growth period is only about 2 months because the delayed implantation period maintains 4-5 months during pregnancy (Tsubota et al. 2001). After parturition, female bears nurture their neonates during the denning period.

Bears need a lot of energy during hibernation, for their basal metabolism, fetal growth and nursing if they are pregnant. Hashimoto et al. (1999) examined changes in body weight of Japanese black bears, *Ursus thibetanus japonicus* from May to December and categorized 3 kinds of phases of body weight gain of this period. Especially in Phase 3, which is pre-hibernation phase from November to December, bears rapidly increase their body weight as the result of hyperphagia for hibernation preparation. This body weight gain is considered to be due to increase of body fat because respiratory quotient of hibernating bears is calculated to be about 0.7, that is the theoretical value when bears consume just fat as an energy source during hibernation (Nelson et al. 1973).

Japanese black bears eat mainly nuts and fruits during pre-hibernation period. For example, oak nut (*Cercus crispula*), one of the primary foods of bears in autumn contains 85% of carbohydrate in whole nutrition (Dr. T. Masaki, Forestry and Forest Products Research Institute, personal communication). That means bears obtain a lot of sugar from nuts and fruits to catabolize lipid during pre-hibernation period.

The purposes of the present study were to clarify an effective mechanism of bears to synthesize lipid from carbohydrate and to accumulate body fat, and to know what is a physiological signal that transmits information of body fat accumulation level to the reproductive organs. The present study was conducted in Ani-Mataginosato Bear Park, Kita-akita-shi, Akita Prefecture, Japan (40°N, 140.4°E), and captive Japanese black bears were used for all of the experiments. During the active season approximately from mid-April to November, bears were provided dried corn and water, whereas about 4.5 months during the winter, the bears hibernated in indoor rooms without feeding.

Measurement of body fat mass by bioelectrical impedance analysis

This chapter summarizes the studies about body fat mass measurement, which have been reported by Nakamura et al. (2008b). Body fat mass of five pregnant females was measured by bioelectrical impedance analysis using Quantum-X (RJL systems, U.S.A.). After chemical immobilization using a mixture (Zoletil, Virbac, France) of zolazepam HCl and tiletamine HCl and medetomidine HCl (Domitor, Meiji Seika Kaisha, Ltd, Japan), the bears were positioned recumbent on his left side and were attached 4 electrodes on 2 places of left fore and hind legs. After reading resistance by Quantum-X, fat ratio was calculated by the equations for the American black bear, published by Farley and Robbins (1994). Relative changes in body weight and body fat mass when the value in September is regarded as 100% are shown in Fig. 1. Both of body weight and body fat mass increased similarly from September to early November in pre-hibernation period. Although data are not shown in the figure, the body fat ratio reached the peak level in December (approximately 40%). The present study demonstrates that bioelectrical impedance analysis using Quantum-X may be available for measurement of body fat mass and fat ratio of Japanese black bears, and that there were seasonal changes in fat ratio of female bears with increase from September and highest in December.

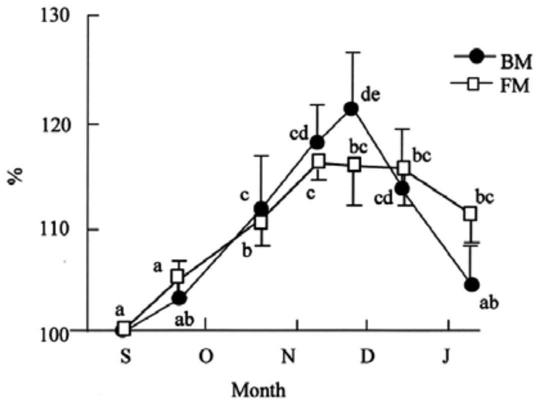

Fig. 1 Seasonal changes of body mass (BM) and fat mass (FM) in 5 captive Japanese black bears from 2005 to 2006. This graph shows relative changes of the values from the beginning of September as 100%. Vertical bars represent S.D. Different letters (a - e) indicate significant differences (P<0.05). (From Nakamura et al. 2008b)

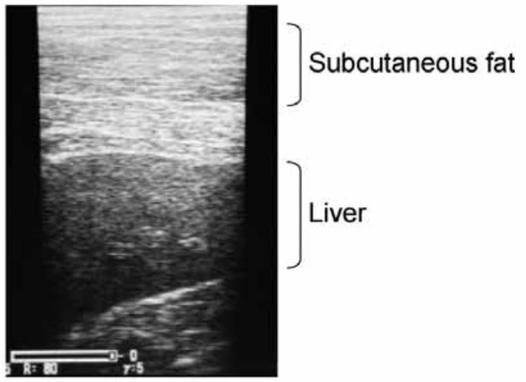

Fig. 2 Ultrasonographic image of the liver of a Japanese black bear in October. A liver area is shown as low echogenic image below the subcutaneous fat area

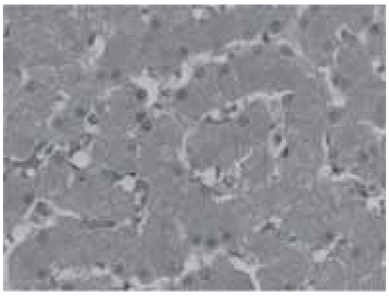

Fig. 3 A histopathological view of the liver from a Japanese black bear which was killed in November. No fatty liver (no vacuolation) was diagnosed

Ultrasonographic and histopathologic liver view

Recently, we obtained a preliminary data of ultrasonographic liver image and observed the liver histopathologically to know whether lipid would be biosynthesized from carbohydrate, and accumulated in the liver of Japanese black bears during pre-hibernation period (Figs. 2 and 3). In the ultrasonographic image of an abdominal area of a bear under anesthesia in October, a view of any fatty liver was not seen. Also in the histopathological view of the liver from a bear which was killed in November, when bears get hyperphagia for hibernation, no view of fatty liver (no vacuolation) was seen. It is speculated that bears may have an effective mechanism to synthesize lipid from carbohydrate and to accumulate body fat with no pathological sign such as fatty liver during pre-hibernation period.

Serum leptin profiles and expression of leptin mRNA in white adipose tissue (WAT)

This section summarizes the studies about dynamics and function of leptin, which have been reported by Tsubota et al. (2008) and Nakamura et al. (2008a). There are two primary function of leptin, one of the hormones secreted from adipose tissue. One is to transmit a signal of body fat accumulation to the central nervous system and control an appetite and energy expenditure; the other is to transmit the signal to the reproductive organs and control puberty, oocyte maturation and development of fetuses and to need for conception, implantation, pregnancy, development of mammary gland and lactation.

First, six female bears were used for studies on annual changes in body weight, serum progesterone concentrations which were measured by radioimmunoassay described by Palmer et al. (1998) with some modifications, and serum leptin concentrations which were measured by using a sandwich Enzyme-Linked Immunosorbent Assay (ELISA) developed for canine leptin measurement (canine-leptin-specific ELISA kit: Shibata et al. (2005), Morinaga Institute of Biological Science, Inc., Japan) according to the manufacturer's instructions. Annual changes in body weight, serum progesterone and leptin concentrations in 3 mated and 3 unmated female bears are shown in Fig. 4. Body weight exhibited a regular pattern with a gradual increase from June, a peak in late November and subsequent decrease until April in both mated and unmated bears. In 3 female bears which mated but produced no cubs, serum progesterone concentrations were low from May to July and began to increase in August. Subsequently a marked elevation was observed in mid or late November, as reported by Sato et al. (2001). One female bear in unmated bear group was able to interact with male bears through a fence during mating season and showed a marked elevation in its progesterone concentration in early December as similarly in mated bears. However, the other 2 bears which were completely separated from male bears showed no remarkable progesterone upsurge throughout the year except for a transient elevation in January. Both mated and unmated females showed the similar tendency in the annual changes in serum leptin concentrations, being stable at low levels from May to August or September, starting to increase from September or October, and reaching the peak in late November.

Second, five pregnant female bears were used for studies on changes in serum leptin concentrations and expression of leptin mRNA in WAT. Serum leptin concentrations were measured by canine-leptin-specific ELISA kit and leptin mRNA expression in WAT was semiquantified by one-step real-time RT-PCR using the leptin transcripts. Changes in serum lepin concentrations and expression of leptin mRNA in WAT in 5 pregnant female bears are shown in Fig. 5. Changes in serum leptin concentrations exhibited the similar tendency with a peak in November as reported by Tsubota et al. (2008). However, there was no significant difference in leptin mRNA expression among months although the expression tended to increase in late November and January.

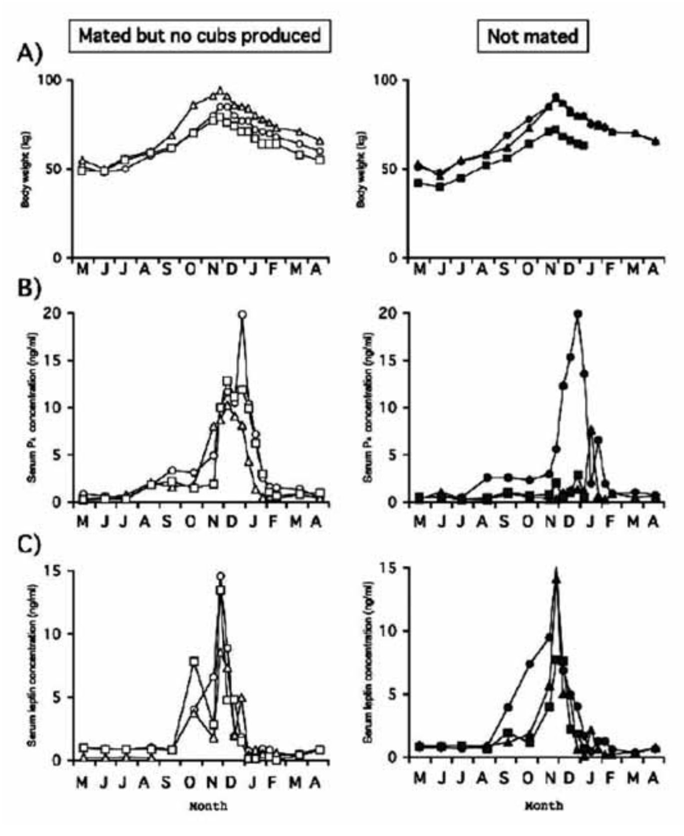

Fig. 4 Annual changes of the body weights (A), serum leptin concentrations (B) and serum P4 concentrations (C) of the captive female Japanese black bears. The left-side graphs are of the 3 mated bears, and the right-side is of the 3 unmated bears. The values of individual bears are shown in different lines in the figure. None of the mated female bears produced cubs. Among the unmated bears, one bear had contact with males through a fence, and the other 2 bears were segregated completely from males. (From Tsubota et al. 2008)

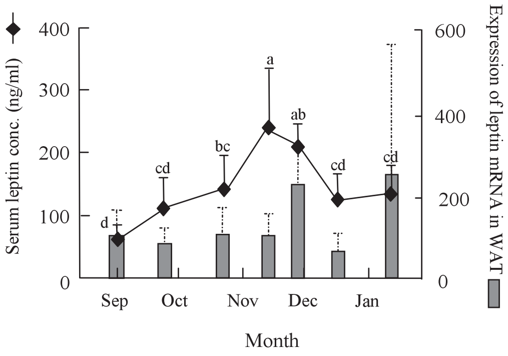

Fig. 5 Changes in serum leptin concentration and leptin mRNA expression in white adipose tissue of five captive pregnant Japanese black bears from 2005 to 2006. Vertical bars represent standard deviations (S.D.). Different letters (a - d) indicate significant differences (P<0.05). (Modified from Nakamura et al. 2008a)

The reason why the difference of fluctuation pattern between leptin mRNA expression in WAT and serum leptin concentration remains unknown but it is confirmed that leptin was synthesized in WAT and that peripheral levels of leptin indicated an elevation in pre-hibernation period.

These two studies propose a hypothesis that leptin may be a signal for accumulation level of body fat to judge nutritional condition for reproduction in bears. When bears accumulate sufficient body fat in pre-hibernation period, leptin will be released much and pregnancy will be maintained. But if bears cannot accumulate sufficient body fat, pregnancy would be disturbed, which might result into reproductive failure.

By examining accumulation level of body fat which may be affected by yearly crop fluctuation of forest food production in autumn, we can judge nutritional condition and predict reproductive success of bears in order to propose better management of bear populations for their conservation.

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Biology of Bear Intrusions: 56-59 (2009)

Is there a genetic difference between invasive and non-invasive bears?

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Introduction

In Japan, the Asian black bear *Ursus thibetanus* (G. Cuvier, 1823) is found mainly on Honshu (Fig. 1). Although the bears prefer broad-leaved forests (Hashimoto et al.. 2003), they sometimes invade human residential areas. When bears or signs of bears are observed, local governments occasionally cull them as pests. The number of bears killed fluctuates widely, in 2004 and 2006, large number of bears invaded residential areas, and more than 4,500 bears were killed on Honshu, even though their population is estimated to be only 10,000 to 15,000.

In normal years (i.e., when few bears are killed), most of the dead were males younger than 5 years of age. In mass intrusion years, both adult males and females invaded residential areas, despite the female-biased philopatric migratory behavior of bears. For the management of bear populations, it is important to determine whether the invasive behavior (with such an irregular movement pattern) has a genetic basis.

In the present study, we aimed to determine whether the invasive behavior of bears has a specific genetic component and to investigate changes in the genetic structure of bears during a mass intrusion year.

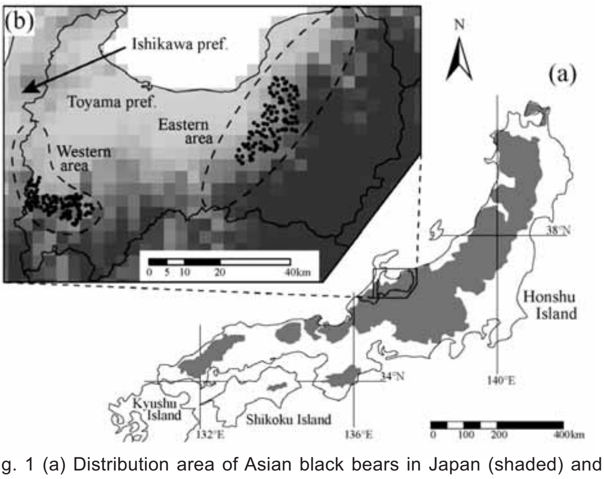

Fig. 1 (a) Distribution area of Asian black bears in Japan (shaded) and the prefectures studied (inland line). (b) Graded altitude map of the study area. Dots indicate the locations of hair traps. Tissue samples were collected in the area delimited by the broken lines, i.e., western and eastern areas

Materials and Methods

We collected tissue samples from 46 black bears from Toyama prefecture in Japan between 2004 and 2007 (Fig. 1). Nine bears were culled in 2004, and 32 in 2006. In 2005, samples from 5 bears hunted as game were collected. In addition, 2 tissue samples of bears culled in 2004 and 2006 were obtained from the eastern part of Ishikawa prefecture, close to the border with Toyama prefecture. We set hair traps in eastern and western Toyama prefecture in 2005 and 2006, and in 2006 and 2007, respectively. In each area, 100 hair traps were set, at a density of 1 trap km^{-2}, for 12 days in August of each year. Honey was used as trap bait on the first day and during the last 5 days; on the intervening days, the hair traps were set without bait.

Genomic DNA was extracted from tissues by using a MagExtractor (Toyobo) kit and from hairs by using a DNA Extractor FM kit (Wako). Hairs without roots were discarded before extraction. The genotypes at eight microsatellite DNA loci (G1A, G10B, G10M, G10X, MSUT-2, MSUT-6, UarMU05, and UarMU23) (Kitahara et al.. 2000; Paetkau et al. 1995; Taberlet et al. 1997) were determined for all individuals, by using the PCR technique. In all tissue samples and a portion of the hair samples, we sequenced a highly variable region of the mtDNA control region and its 5′-flanking region (ca. 700 bp), as described by Ohnishi et al. (in press). These same samples were also used for sex determination by genotyping the amelogenin gene, using primers SE47 and SE48 (Yamamoto et al. 2002).

Treatment of hair samples generally followed the method of Paetkau (2003). We checked genotypes in all samples that were successfully amplified. At this stage, identities of individual bears were unknown. Samples were searched for pairs of identical genotypes. Such pairs were recognized as samples from a single bear. When sample genotypes could not be paired with any other, the samples were omitted from further analysis. For cases in which hair samples of a bear were found at more than one trap, the activity center (Hayne 1949) was treated as the capture point.

The probabilities of identity (P_{ID} and P_{IDsib}) (Paetkau and Strobeck 1994; Waits et al. 2001) were calculated using GENECAP 1.2.1 software (Wilberg and Dreher 2004). Parentage was analyzed using CERVUS 3.0.3 software (Kalinowski et al. 2007). Relatedness (*r*) among individuals was estimated following the method of Queller and Goodnight (1989) using KINSHIPS 1.2 software (Goodnight 1996).

Results and Discussion

In total, 609 hair samples were collected from the hair traps. We successfully genotyped more than seven loci in 106 of these samples, and these 106 samples were included in the analyses. Using eight microsatellite loci, the two probabilities of identity (P_{ID} and P_{IDsib}) were 5.50×10^{-9} and 6.56×10^{-4}, respectively; these values were adequate to allow identification of all individuals in the study area.

The number of samples collected in 2005 and 2006 were sufficient for analysis. The culled bears were considered as invasive bears, and the samples from the hair-traps were considered as control bears. Owing to the small number of invasive bears in 2005, the hair-trap samples and five tissue samples obtained from game hunters were treated as controls.

Twelve mitochondrial haplotypes were detected in the samples, and most of the haplotypes were restricted to bears from either eastern or western areas (Fig. 2). A few haplotypes were observed in both areas, but these bears were not always invasive, although all were males. The haplotype frequencies did not differ significantly between invasive and control bears in either area (Exact test, $p > 0.05$) in 2006 or across sampling years (Fig. 2).

An estimation of parentage identified 10 kin groups, each containing more than two individuals (Fig. 3). The capture points of all individuals in four kin groups were within the eastern area, and the capture points of all individuals in another kin group were restricted to the western area. Among individuals of the remaining five kin groups, the capture points occurred in both eastern and western areas. Nine of the 10 kin groups comprised both invasive and control bears, and no kin group consisted solely of invasive bears. Furthermore, there were no differences in haplotype frequencies between invasive and control samples. Thus, we conclude that no specific genetic component in any kin group was associated with mass intrusion.

The relationship between relatedness (*r*) and geographic

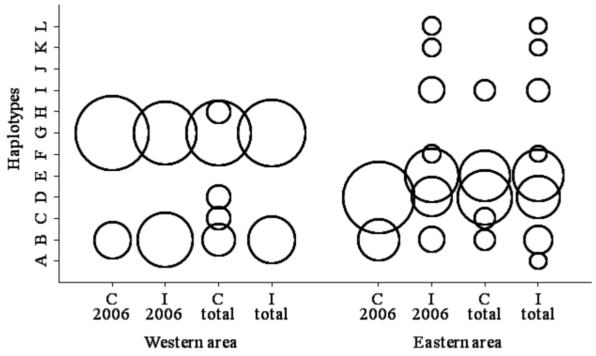

Fig. 2 Haplotype frequencies in the western and eastern areas. C2006 and I2006 indicate control and invasive bear samples, respectively, collected during a mass intrusion year (2006). C-total and I-total indicate control and invasive bear samples, respectively, across all sampling years

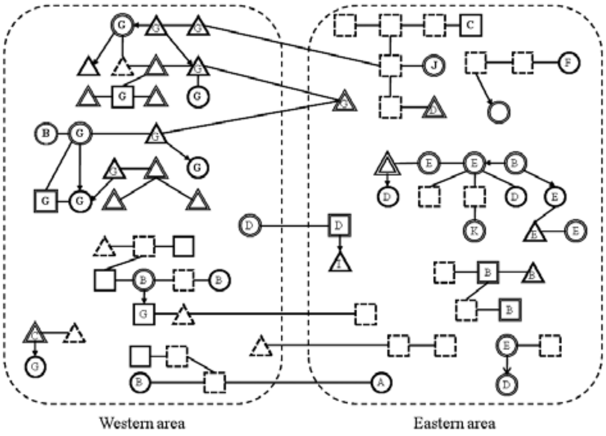

Fig. 3 Family trees for kin groups with more than two bears. Circles, squares, and triangles indicate invasive bears, control samples in mass intrusion years (2004 and 2006), and bears in normal years (2005 and 2007), respectively. Double, single, and dotted lines indicate male bears, female bears, and bears of unknown sex, respectively. Arrows indicate parent-offspring relationships; different letter indicates different haplotype

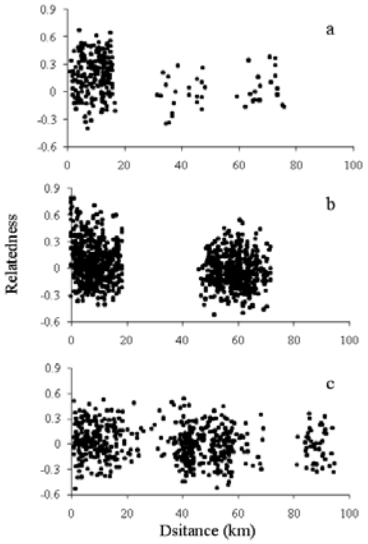

Fig. 4 The relationship between relatedness and geographic distance in (a) bears in a normal year (2005, *N* = 23; Mantel's randomization test, $p < 0.001$), (b) control samples in a mass intrusion year (2006, *N* = 44; $p < 0.001$), and (c) invasive bears in a mass intrusion year (2006, *N* = 33; $p > 0.05$)

distance among individuals is shown in Fig. 4. Relatedness was negatively correlated with the distance in 2005 and control samples in 2006 (Mantel test, $p < 0.001$; Fig. 1a). The same negative correlation was found for controls in 2006 ($p < 0.001$; Fig. 1b); however, there was no negative correlation for invasive bears in 2006 ($p > 0.05$; Fig. 1c), and this observation (lack of negative correlation) held when male and female invasives were analysed separately (data not shown).These results suggest that culled bears had moved greater distances than control bears and that when mass intrusion occurred, invasive bears of both sexes ranged over large areas, causing genetic mixing within the population.

When area-unique haplotypes were discovered in another geographic area (western or eastern), the samples were always from males only. Black bear area-unique haplotypes have been reported in previous studies (Ishibashi and Saitoh 2004; Ohnishi et al. in press). Moreover, male-biased dispersal (which spreads unique haplotypes into other areas) occurs in bear populations of western Japan (Ishibashi and Saitoh 2004). Thus, males move away from their natal areas due to natal dispersal and/or invasion behavior, and importantly, females do not, even when they participate in mass intrusions.

We still do not know how genetic structure changes after mass incursions of bears. In the present analyses, we used bears captured in 2005 and hair samples collected in 2006 as controls, and bears culled in 2006 as invasive bear samples. Although a mass intrusion also occurred in 2004, we were unable to collect an adequate sample size for analysis. Nevertheless, the genetic structure in 2004 would have likely been similar to that in 2006. Thus, when the genetic structure is disrupted by a mass intrusion, it becomes restructured by the next year. One possible reason for the restructuring is the long-distance seasonal movement of the bears. Mass intrusions occur in autumn, followed by movement to overwintering dens later in the same season; with the return of spring, the bears move again. These movement processes would result in the restoration of the genetic structure before the next mating season, such that an irregular genetic structure caused by mass intrusion would not affect the genetic structure of the population in the next generation. Therefore, the disruption of the genetic structure caused by an intrusion is a transient event, with no lasting consequences for the bears.

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Biology of Bear Intrusions: 60-63 (2009)

Behavioral study of free-ranging Japanese black bears I - Does food abundance affect the habitat use of bears? -

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Introduction

In 1969, VHF radio collar was deployed for the first time on a Japanese black bear (*Ursus thibetanus*) japonicus in the Kyoto University Forest of Ashu, Kyoto. Then, in the early 1980s, bear tracking studies using VHF radio telemetry system were carried out in Taihei Mts., Akita Prefecture, Hakusan Mts., Ishikawa Prefecture, Nikko Mts., Tochigi Prefecture, and the Southern Japanese Alps, Shizuoka prefecture. From those previous studies, we were able to learn the home range size, daily activity rhythm, seasonal movement, and habitat use of the bears. However, we still do not know the reason behind the occasional mass appearance of the bears around human settlements.

Mass appearance of bears around human settlements in recent years has become a serious problem in Japan. Recently, cases of mass appearance occurred in 2004 and 2006 on Honshu Island. In 2004, 109 people were injured by bears (including 2 deaths), and 2,021 bears were killed. Again in 2006, 145 people were injured by bears (including 3 deaths), and 4,340 bears were killed.

These extraordinary mass appearances of bears in residential area happened in autumn, and were suspected to be caused by forest crop failure in autumn, when bears became hyperphagic in preparation for hibernation. In American black bears (*Ursus americans*) , bears travel long distances when food resources were deficient in an area, (e.g. Garshelis and Pelton 1981; Rogers 1977); male bears leave their original range and possibly re-establish in other areas, while adult females double the size of their home range when droughts take place (Doan-Crider unpubl. data); bears travel farther and become more attracted to human-related food resources when acorn crops fail (Noyce and Garshelis 1997). We have been investigated the relationship between bear behavior, and abundance and distribution of food resources to clarify the actual mechanism behind mass appearance of Japanese black bears in and around human settlements during autumn. In this report, we describe the sizes and altitude of home ranges of bears in two different crop abundance years, and discuss the influence of the crop abundance on the home range use of bears.

Study Area and Methods

Our study area was located in the Nikko-Ashio Mountains (in Tochigi and Gunma Prefectures), primarily within the Nikko National Park with elevation ranges from 800 to 2500 m. In the Ashio area, the vegetation was destroyed by a forest fire in 1887 and by sulfur dioxide pollution from a copper mine from the 1880s to 1950s. However, extensive tree-planting was carried out later, with continuing vegetation recovery. Thus, the area is an open habitat and is characterized by grasses with patches of planted forests such as ryobu (*Clethra barbinervis*), yashabushi (*Alnus firma*), larch (*Larix kaempferi*), locust tree (*Robinia pseudoacacia*), and Japanese black pine (*Pinus thunbergii*).The Nikko area is dominated by Japanese beech (*Fagus crenata*) and mizunara oak (*Quercus crispula*), although larch plantations are also scattered across the area.

We captured bears using hand-made barrel traps baited with honey, rainbow trout (*Oncorhynchus mykiss*), and sika deer (*Cervus nippon*). We set traps at 3–4 sites each year and checked them each morning and evening. We immobilized trapped bears with tiletamine hydrochloride and zolazepam hydrochloride (Virbac, Carros, France). After obtaining body measurements and extracting a premolar, we placed a microchip, ear tags, and a GPS collar on each bear and released them at the trap site.

We used GPS3300S and GPS4400S (Lotek Wireless Inc., Newmarket, Ontario, Canada), setting fix intervals from 5 minutes to 2 hours. All collars contained an activity sensor and had a radio activated drop-off. The collar unit and battery pack weighed 550-800 g.

In order to estimate the availability of food resources in autumn, we carried out a hard mast production survey using the Masaki and Abe (2008) method on mizunara oak and Japanese beech at 37 points covering the entire study area. The production status of each point was classified as “very good” ($\geq$ 20 masts/1000 m^2 at the branch tip (50 cm in length and 20 cm in width)), “good” ($\geq$ 5), “moderate” ($\geq$ 1), and “poor” (< 1).

In this paper, we essentially defined the summer when the bear stays in the Ashio area and the autumn when the bear migrates from the Ashio area to the surrounding areas until the pre-hibernation period (a week before the den entry), thus the end of the summer and the beginning of the autumn differed by individual. However in 2007, no bear migrates from the summer range. Therefore, we defined the summer as period from June 1^{st} to August $31^{st,}$ and the autumn from September 1^{st} to the pre-hibernation period.

In 2007, we tracked a total of 13 bears fitted with GPS telemetry collars, of which nine were captured in 2007 and four that had been previously captured in 2006. We then conducted range analysis using the data set of a male (AM04) and a female (FB70) in 2006 and 2007. We also conducted altitude analysis using the data set of 2 females (bear ID: FB70, FB74) and 4 males (AM01, AM02, AM04, MB67) obtained in 2006 as well as that of 5 females (AF09, AF09, AF12, AF13, FB70) and 3 males (AM01, AM04, MB67) obtained in 2007.

Results

In 2007, mizunara oak acorn production in the area was relatively good (Fig.1) and more abundant than in 2006 when production was poor, while beech nuts failed to crop. During autumn 2007, most of the bears remained in the Ashio area where fruiting mizunara oak trees were abundant (Fig.2). The bears were more active in autumn than in summer and exhibited marked shifts in their home ranges in 2006 (Fig.2). And the home range size of the bears that could be tracked both in 2006 and 2007 were larger in 2006 (95%MCP: 166km2 for the male (AM04), and 23km^2 for the female (FB70)) than in 2007 (44km^2 for the male, and 5km2 for the female). In the autumn of 2006, the most of the bears except two males, AM01 and AM02, migrated to lower altitudes compared to the summer, in contrast, in the autumn of 2007, the most of the bears except a male, AM01, migrated to higher altitudes compared to the summer (Fig.3, 4, Table 1).

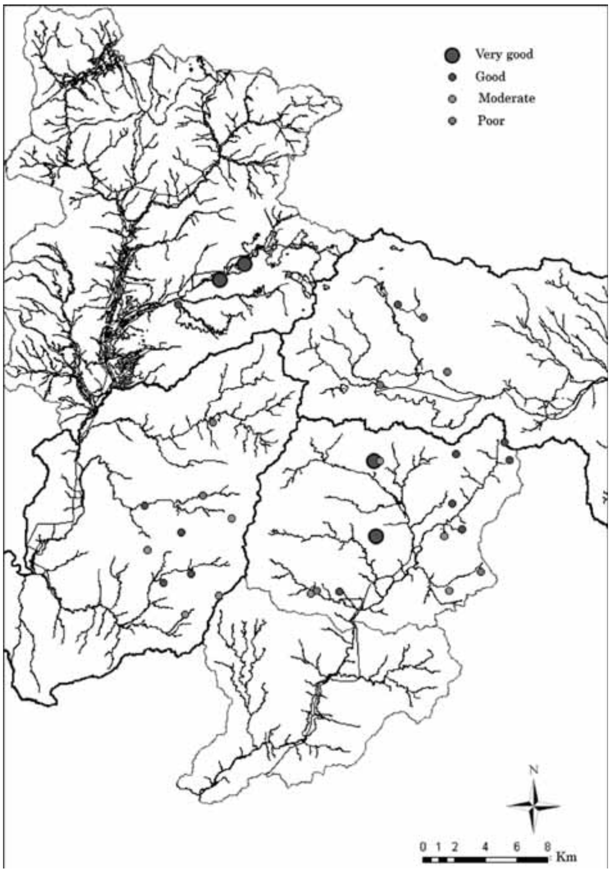

Fig.1 Hard mast production status of mizunara oak in 2007 in Nikko·Ashio Mts., central Japan

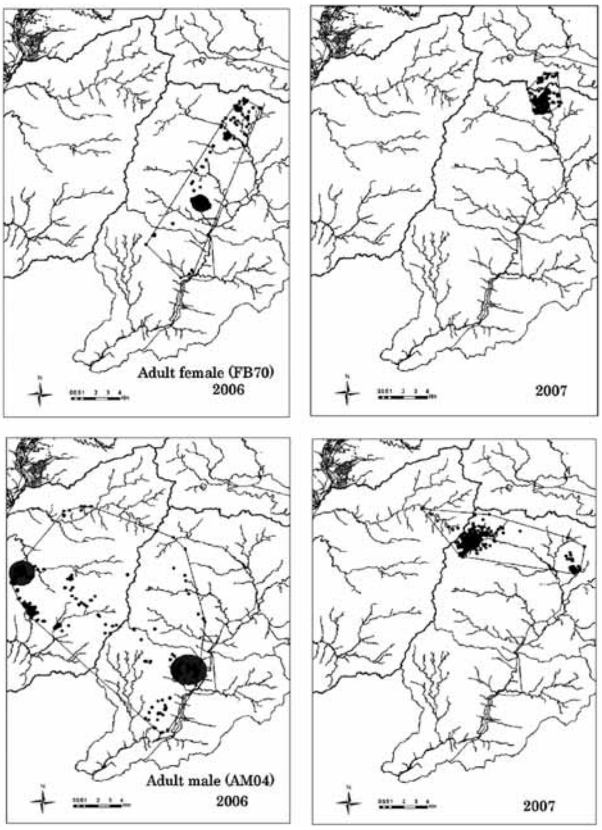

Fig.2 Range use difference between autumn 2006 and autumn 2007 for an adult male and adult female in Nikko·Ashio Mts., central Japan. The dots indicate the GPS fix points, and the black circles indicate 50%Adaptive Kernel Home Range

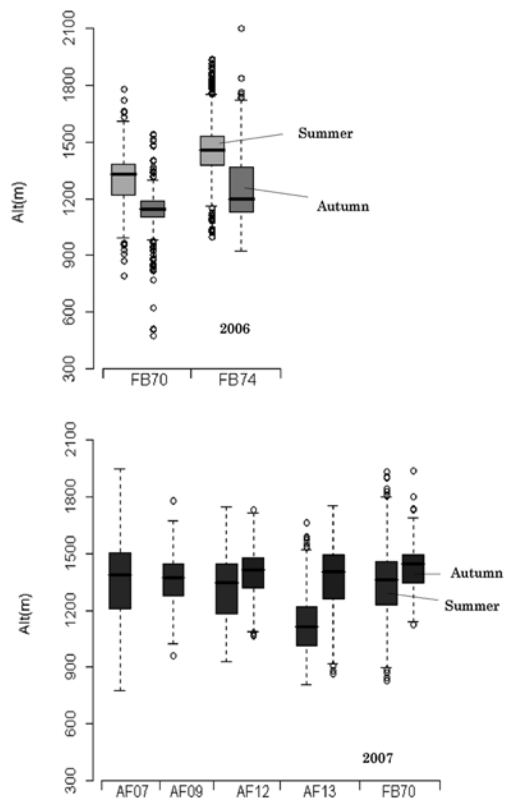

Fig.3 Seasonal utilized altitude differences between 2006 and 2007 for females in the Nikko·Ashio Mts., central Japan.
The boxes indicate the median, 25%, and 75% quartiles, while the whiskers indicate the smallest and largest values. The open circles indicate outliers

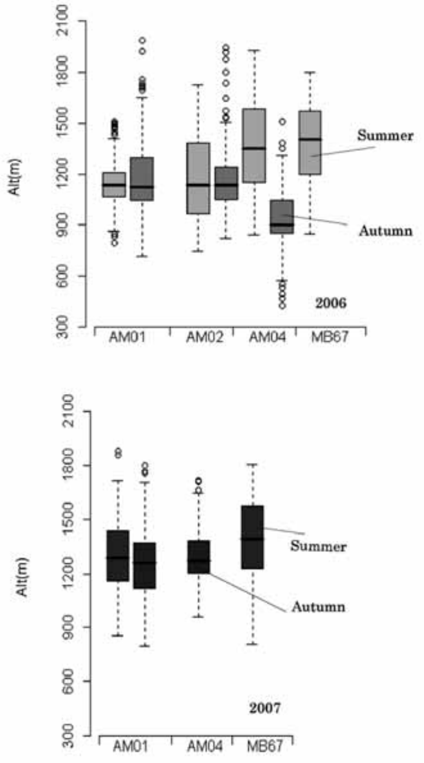

Fig.4 Seasonal utilized altitude differences between 2006 and 2007 for males in the Nikko·Ashio Mts., central Japan.
The boxes indicate the median, 25%, and 75% quartiles, while the whiskers indicate the smallest and largest values. The open circles indicate outliers

Table 1 Utlized altitude of the bears in the two different crop abundance years, 2006 and 2007, in the Nikko-Ashio Mts., central Japan.

				Utlized alt.			
Year	Sex	Bear ID	Season	Mean	SD	n	P^1
2006	Male	AM01	Summer	1135.8	113.8	861	0.2798
			Autumn	1177.3	188.0	665	
		AM02	Summer	1165.3	242.6	1152	0.8936
			Autumn	1170.4	255.4	442	
		AM04	Summer	1396.6	392.3	812	0.0000
			Autumn	937.3	150.4	313	
	Female	FB70	Summer	1301.8	123.5	1698	0.0000
			Autumn	1135.7	119.5	647	
		FB74	Summer	1474.7	159.1	1148	0.0000
			Autumn	1262.3	191.0	807	
2007	Male	AM01	Summer	1289.8	178.8	455	0.0002
			Autumn	1244.7	169.6	488	
	Female	AF12	Summer	1324.9	158.7	643	0.0000
			Autumn	1401.9	121.0	765	
		AF13	Summer	1132.9	159.3	703	0.0000
			Autumn	1362.4	184.9	667	
		FB70	Summer	1349.9	194.6	692	0.0000
			Autumn	1422.4	111.7	478	

1 Mann–Whitney U–test

Discussion

In the autumn of 2006, there was a mast failure, and the bears traveled an extensive range. However, in contrast, due to the high production of acorns at higher altitudes during autumn 2007, bears migrated to higher altitudes compared to autumn 2006, when the acorn crop failed in most of the areas studied including those at higher elevations. These phenomena suggest that the bears were able to adapt to their food conditions and traveled long distances in search of food resources in 2006. However, there is limited land space for bears in the Nikko-Ashio Mountains. Similar is true of other bear habitats in Japan, and this may be the reason why many conflicts between bears and humans occurred in 2006. In fact, 93 bears were nuisance-killed in the Tochigi Prefecture in 2006, this figure being about 3 times that of an average year.

Thus, mast failures could be one of the significant reasons for these conflicts, but it does not explain the whole situation. However, from a long-term viewpoint, we believe these frequent bear appearances can be explained by two other factors. First, the zone between mountain and town areas, a traditional agricultural area called satoyama (Washitani 2001) which originally divided major bear habitats from human activity, has lost its function as a buffer zone because of declined activity in these areas. Secondly, as a result of a decline in hunting in satoyamas, there is a new generation of bears that do not fear people. In addition, due to Japan being geographical small while sustaining a large population, bear habitats and human settlements are very close to each other or partially overlap.

Historically, conflicts between people and bears in these shared zones (satoyama) have been continuously present. People traditionally have prevented the invasion of bears into these areas using guns and traps in an effort to maintain the land around their village for firewood collection, charcoal production, and agricultural cultivation. In this way, satoyamas have functioned as a buffer zone, separating towns from mountain areas. Currently, satoyamas are experiencing a rapidly decreasing and aging human population. Tending of the satoyamas has been neglected, and thus food resources for bears in these areas have increased in comparison to food resources available in managed forests.

The local people no longer harvest fruits from trees planted near houses, and this attracts bears as well as other wildlife including wild boars and Japanese monkeys. For example, many persimmon trees had been planted around houses in satoyamas. The fruits were enjoyed by many people as a precious sweet tasting food and as a survival food during famine. However, the lifestyle of people has changed. In modern days, sweets can be easily found at stores, and the persimmons are left unharvested due to a declining and aging population. These persimmons attract wildlife such as black bears and monkeys and have become a major cause of human-wildlife conflicts.

Satoyamas have become a place that provides bears with good food resources that are easy to obtain. Since 1992, the quota on black bear sport hunting in Japan has been voluntarily reduced by the Japan Hunting Association. At the same time, the nuisance control killing of bears, which had been carried out briskly, has also declined in response to the rise of negative public opinion. These two methods of removing bears from the population should be evaluated, in addition to careful monitoring of any changes in the number of bears killed as part of a scientific management plan.

Shortages of food resources in the mountains, the changing structure of satoyamas, and lack of a scientific management system could all be primary factors in the appearance of bears near human settlements in recent years. If this hypothesis is correct, similar conflicts will continue to occur in the future.

Due to what seems to be a rapid expansion of bear distribution on some parts of Honshu Isl. (Japan Wildlife Research Center 2004), there is an urgent need to formulate better management plans.

Acknowledgement We would like to thank S. Haneo and H. Yokota for field assistance, Gunma District Forest Office - Omama branch and Nikko District Forest Office of the Forestry Agency for permission to enter and set traps in the National Forest, and Tochigi Prefectural Imaichi Forest Management Office for giving us permission to capture bears. This study was supported by "Pollution Control Research Fund" to Forestry and Forest Products Research Institute from the Ministry of the Environment, Japan.

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Biology of Bear Intrusions: 64-66 (2009)

Behavioral study of free-ranging Japanese black bears II: How do bears manage in a food shortage year?

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Introduction

Japanese black bears (*Ursus thibetanus japonicus*) intruded into residential areas in 2004 and 2006. Oka et al. (2004) reported an increased number of nuisance bear kills in some regions of Tohoku, Japan, during years with poor beechnut (*Fagus crenata*) crops. Hard mast, which includes beechnuts, was argued to be the staple food of bears in autumn, and therefore greatly influenced the invasive behavior of bears (Oi 2005). However, few studies have examined the relationship between hard mast production and bear behavior (but see Hwang and Garshelis 2007).

The purpose of this study was to determine the behavioral characteristics of Japanese black bears associated with food shortages in autumn by comparing bear behavior in two autumn seasons with different production levels of hard mast.

Study area

The Ashio-Nikko Mountains form the boundary between Tochigi and Gunma Prefectures in central Japan. Elevation ranges from 500 to 2500 m. Natural forests below 1600 m are dominated by deciduous broad-leaved species (*Quercus crispula, F. crenata, Acer* spp.), and forests at higher elevations are mixed forests (*Tsuga* spp. and *Betula* spp.). *Cryptomeria japonica, Chamaecyparis obtusa* (below 1000 m), and *Larix kaempferi* plantations (1000-1600 m) are also present. In the summer habitat of most of the study bears (Ashio area), the vegetation was destroyed by a vast forest fire in 1887 and subsequently by sulfur dioxide pollution from a copper mine from the 1880s to the 1950s. However, extensive tree-planting operations have been implemented since then, and the vegetation has been recovering. Grasses and patches of planted tree species, such as *Clethra barbinervis, Alnus firma, L. kaempferi, Robinia pseudoacacia*, and *Pinus thunbergii*, characterize the area.

Quercus crispula is a major hard-mast-producing tree within the study area. In 2007, *Q. crispula* acorn production was moderate, but more abundant than in 2006 (Yamazaki et al. 2009).

Methods

Home-range size, daily activity rhythm, time budget, and hibernation period were the parameters measured to assess bear behavior. Locations and activity data were obtained for 18 Japanese black bears (4 females and 4 males in 2006, and 5 females and 5 males in 2007) that were fitted with GPS and activity-sensor collars (Lotek Wireless Inc., Canada; model GPS3300S and GPS4400S) during the summer and autumn seasons.

Home-range sizes were calculated using the 95% minimum convex polygon method. Bear activity rhythms and time budgets were estimated by the activity sensors, which recorded vertical and horizontal movements of the collars attached to the necks of the bears every 5 minutes. The activity value was determined from the total number of both axes counts. Preliminary tests of the sensors using captive Japanese black bears certified that the activity value recorded by the sensor was a good indicator of active and inactive behavior patterns of bears (Kozakai et al. 2008). Thus, the active or inactive state of each bear was assigned to each 5-minute record from the activity sensor. The daily time budgets were estimated from the proportion of active time per day. For the hibernation period, we estimated the day of den entry according to the following definitions: (1) the daily active time budget was at less than 10%, and (2) the GPS fix rate dropped to 0%.

Results

Activity rhythms in Fig. 1 show that bears were mostly diurnal in both seasons and years. During the summer, activity peaks occurred at dusk, while during the autumn, activity peaks occurred at dawn and dusk. Nighttime activity levels were also higher in the autumn. These tendencies were similar in 2006 and 2007. The median daily active time length ranged from 5.8 to 13.5 hours in the summer, and from 12.0 to 15.7 hours in the autumn. Most bears (4of 5 in 2006 and 5 of 6 in 2007) showed more active time per day

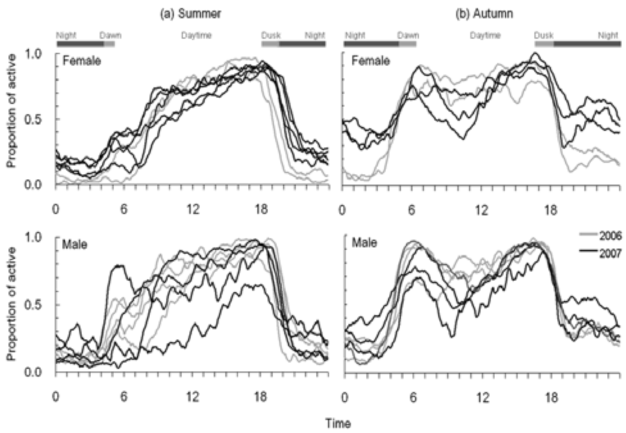

Fig. 1 Daily activity rhythms of Japanese black bears in the Ashio Mountains, central Japan, in 2006-2007. Each line indicates an individual bear

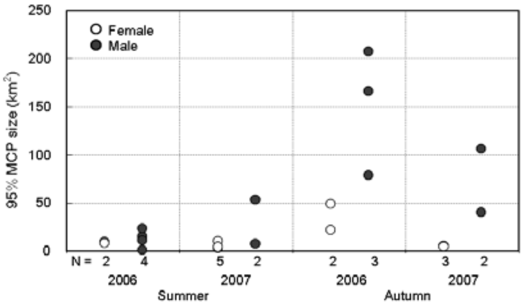

Fig. 2. Home-range sizes of Japanese black bears in the Ashio Mountains, central Japan, in 2006-2007. Numbers indicate bear sample size

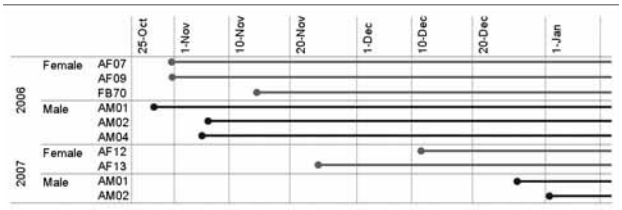

Fig. 3 Estimated day of den entry of Japanese black bears in the Ashio Mountains, central Japan, in 2006-2007. Circles indicate estimated day of den entry, and lines indicate hibernation period

in the autumn compared to the summer ($P < 0.05$, Mann-Whitney U-test), which might be related to the increase in activity at dawn and at night during autumn. We tracked 4 bears (1 female and 3 males) during both autumns. The proportion of daily active time for the 4 bears did not differ between years ($P > 0.05$, Mann-Whitney U-test).

The home-range sizes of the bears are shown in Fig. 2. The maximum home-range size in autumn was 49 times (2006) and 3 times (2007) larger than the maximum summer home-range size. The estimated day of den entry (Fig. 3) was earlier in 2006 (between late October and mid-November) than in 2007 (between late November and early January). For example, two males (ID: AM01, AM02) entered hibernation about 2 months earlier in 2006 compared to 2007.

Discussion

In the autumn, study bears exhibited similar daily activity rhythms (Fig. 1) and time budgets during both years examined, although the sample sizes were small. The bears used hard mast stands in both years (Nemoto et al. unpublished), and used different habitats according to different crop distributions. Asiatic black bears in Taiwan also demonstrate similar activity rhythms during the autumn (oak) season. That is, these bears have diurnal and prolonged active phases in the autumn compared to the spring and the summer (Hwang and Garshelis 2007). These autumn activity patterns may be common among bears feeding on hard mast crops. However, the home-range size and den entry parameters differed between years (Figs. 2, 3). In the autumn of 2006, the bears moved throughout a wider area (Fig. 2) and hibernated earlier than in 2007 (Fig. 3). These broader movements suggest that bears may have been foraging for food that was scarcer in 2006 than in 2007. In addition, earlier den entry may be the result of the behavioral tendency of bears to cut foraging costs when energy intake is poor.

In conclusion, when food supplies were scare, Japanese black bears foraged for scarcely distributed foods over a larger area and entered hibernation earlier. Further research on the feeding behavior of bears is necessary to clarify the mechanisms of bear intrusions.

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Biology of Bear Intrusions: 67-71 (2009)

Influence of fruiting phenology on fruit feeding behavior of Asiatic black bear, central Japan

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Introduction

The Asiatic black bear (*Ursus thibetanus*) is one of the largest mammals inhabiting the islands of Honshu and Shikoku in Japan. Previous studies of their food habits from fecal droppings have shown that they feed more on plant matter, especially fruits, than on animals (e.g., Hashimoto and Takatsuki 1997). Studies have also shown that the availability of the primary food items varies between seasons and regions (e.g., Hashimoto and Takatsuki 1997). Qualitative analyses have shown that, in spring, bears ate herbs, young leaves and buds of trees, and if available, nuts that fell in the autumn of the previous year. In summer, bears eat tree leaves, herbs, berries, colony-forming insects such as bees and ants. In autumn, hard masts of beech and oak are the staple food in central Japan (Hashimoto and Takatsuki 1997). The increase of fruit species in the diet of bear according to the increase of the number of tree species which bore fruit in autumn indicates that their diet is likely to be affected by forest plant phenology (Koike unpubl. data). And, it is important to remember that, in general, because fruit production and the fruiting period varies between years (e.g., Shibata et al. 2002), the diets of frugivores will also change from one year to the next (e.g., Mattson et al. 1991). Several studies have suggested that dry fruit such as nuts and acorns production greatly affects bear feeding habits in autumn and spring in Japan (e.g., Mizogich et al. 1996; Hashimoto et al. 2003; Sato and Endo 2006), and consequently the crop failure of the hard mast have a marked effect on the number of nuisance-bear kills (Oka et al. 2004).

We investigated the influence of the variation in fruit phenology and production on feeding behavior of bears by examining maturing process of fruits and signs of bear feeding on the trees..

Materials and Methods

The study area is located in the Misaka Mountains north of Mt. Fuji in Yamanashi Prefecture of central Japan. The topography of the area is characterized by steep slopes and narrow valleys, from 330 to 1792 m above sea level in elevation.

Fruits availability and bear feeding in a forest tree community

Since direct observation of bears is difficult in Japan, signs of foraging by bears gave the basis of the information to clarify the feeding behavior of the animals. Collecting sufficient quantities of fecal samples was difficult due to the steep slopes and the frequent rain which extinguish the feces rapidly. In this study, we used fecal samples and signs of foraging such as the presence of a “bear shelves”. Bear shelves are piles of broken branches at the top of trees and are formed by bears to reach fruits. We also checked claw marks left on the trunks to identify food items and determine the feeding period.

The 13-km survey route was set through both mountain ridges and valleys in the secondary deciduous forest. We used the route to collect fecal samples and observe bear shelves and claw marks. These surveys were usually conducted at intervals of 10 days from May 2000 to November 2001, excluding the period between December and April when the bears hibernate (Koike and Hazumi 2008). To clarify forest structure and the phenology of ripe fruits, we established 27 plotus of 20 × 20 m along the survey route. In each plot, we tagged all woody plants of both the tree-layer and the shrub-layer, and monitored their fruiting phenology.

Fruiting phenology of Prunus jamasakura and utilization by bears

We assessed the relationship between the phenology of fruit maturation of *P. jamasakura* and the feeding period of bears in the field. *P. jamasakura* is one of the common tree species in the deciduous forests of central Japan (Oba 1989). Its seeds are frequently found in bear feces (Koike et al. 2008). And, *P. jamasakura* is one of the very few woody species bearing fleshy fruits during June–July on the Pacific Ocean-side of Japan, and the bears feed on the fruits exclusively. The phenological characteristics recorded were fruit color, remaining fruit number, fruit size, and sugar concentration. To clarify the phenology of *P. jamasakura* fruits, we monitored the flowering date of *P. jamasakura* and its fruit phenology afterwards. We monitored 102 *Prunus* trees in the study area every day until they no longer bore fruit to determine when the bears fed on the fruit. Two criteria, claw marks left on the tree trunks and the presence of a "bear shelf" were used to judge which fruits had been eaten.

Results

Fruit availability and bear feeding in a forest tree community

113 species of woody plants were recorded in the study plots. A total of 34 plant species were identified as "foods for bears" based on 160 fecal samples, 135 bear shelves and claw marks. Figure 1 shows the presence of ripe fruit and signs of feeding by bears from May 2000 to November 2001. We observed ripe fruits from June until November in both years. In September and October, the number of fruit-bearing species was high. Triangle represents case in which both feces and signs of foraging were observed, square refers to case in which only feces samples were obtained, and the dark shaded area shows where ripe fruits were observed for each species. The periods when signs of feeding were observed similar between years.

Bears consumed all types of fleshy fruits, and dry fruits, principally nuts and acorns. From the findings, fleshy fruits seem to be an important food resource for bears because the production of fleshy fruits appeared to be more stable than dry fruits. Each fleshy fruit species was available only for short time period, however they ripened by turns, thus some of the species were always available throughout the study period. On the contrast, each of dry fruits were available for longer period, however, the consumption by bears differed from year to year. In autumn, the annual variation in nut and acorn production might have had a marked effect on the diets of bears. For example, the fruiting and usage of *Juglans ailanthfolia* was observed in the study area in 2000, but not in 2001. Similarly, the available and utilized period of *Q. crispula and Q. serrata* in 2001 was longer than in 2000. These results suggest that the consumption of dry-fruit species by bears might be influenced by variable nature of dry food production.

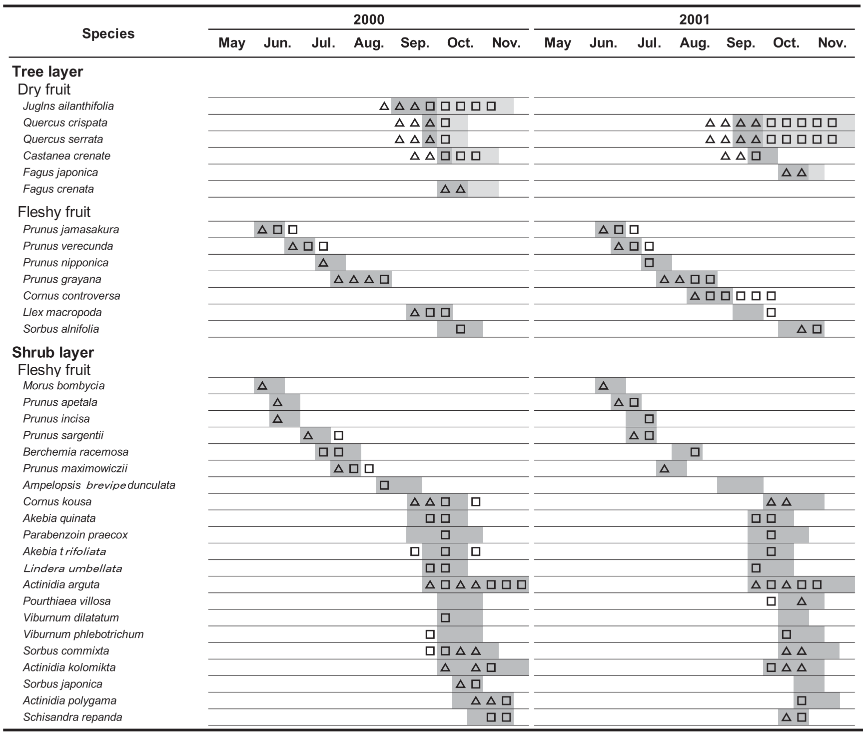

Fig. 1 Phenology of ripe fruit eaten by bears and signs of feeding by bears from May 2000 to November 2001. Feeding behavior was assessed using foraging signs such as claw marks left on the trunks, the presence of "bear shelves", and collecting fecal samples. No surveys were conducted between December and April

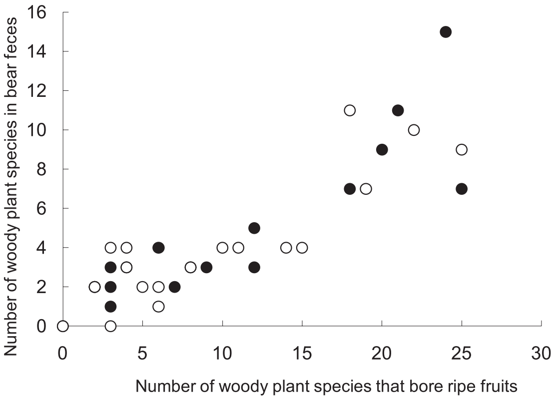

Fig. 2 The relationship between the number of plant species that bore ripe fruit except shrub layer plant species ripening with dry fruit species and the number of fruit species found in bears feces. The feces were collected from April 2000 to November 2001 except from December to March. 2000; r^2=0.81, 2001; r^2=0.80, P<0.01. 2000 (●) and 2001 (○)

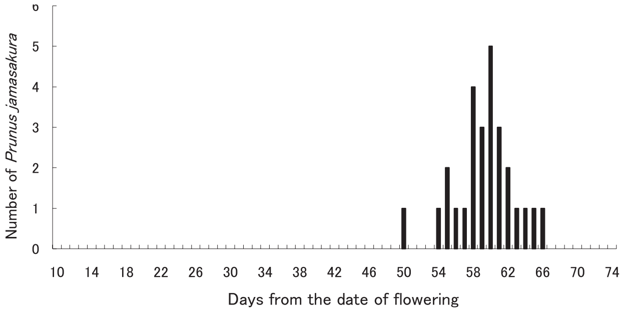

Fig. 3 Frequency of bear signs on *Prunus jamasakura* . Signs included claw marks on the trunk and stems and bear shelves in the trees

Excluding the shrub-layer species that produced dry fruit whose fruits were not consumed by bears, there was a positive correlation between the number of plant species that bore ripe fruit and the number of plant species of which seeds were found in the fecal samples in both years (for 2000; r^2=0.81, P<0.01, for 2001; r^2=0.80, P<0.01. Fig. 2).

Feeding and fruiting phenology of Prunus jamasakura

P. jamasakura in the study area flowered in early April, and the date of flowering was delayed as alititude increased. In addition, there was a change in the proportions of fruits of different colors and the duration that fruit were available (Fig. 3). All fruit were recorded as being green until 38 days after flowering, before changing to red-green, red, and then black. Fruit matured at 50 days after flowering, and fruits fell at approximately 70 days of after flowering.

Figure 3 shows when bears fed on fruit after flowering. We observed 27 claw marks on 24 trees in the study area. Evidence of the fruit feeding on the fruits was observed from 50 to 66 days after flowering. The fact that 17 signs (63%) were recorded from day 58 to day 62 after flowering indicates intensive utilization of fruit during this period. Figure 4 shows the condition of the fruit at the time they were consumed by bears. Mean fruit size did not differ among fruits of different colors and when the size of fruit reached was the largest 55 days after flowering. Sugar concentration differed among fruit in differently colors, and the concentration increased as the fruit matured. Bears fed on fruit from day 50 to day 66 after flowering, when most of the fruits were attached to the tree branches, with large size, and high sugar concentration. Bears only fed on mature fruits and obtained high-quality nutrients.

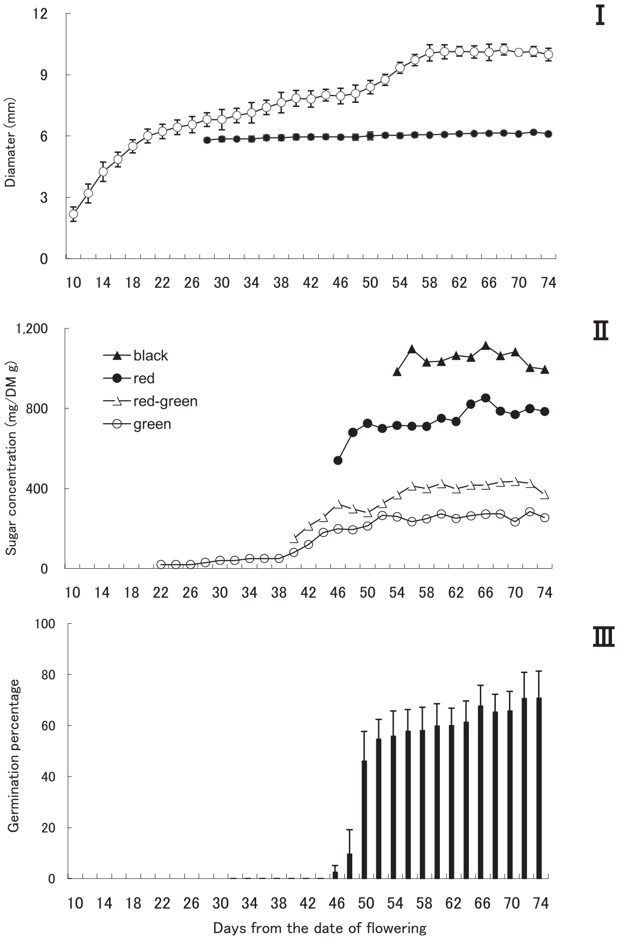

Fig. 4 Fruit phenology of *Prunus jamasakura.* (I) Changes in fruit diameter (mm; mean ± SD of all colors) and seed diameter (mm; mean ± SD of all colors) after the date of flowering. (II) Changes in sugar concentration (mg/g DM) of fruit of each color after the date of flowering. *n* = 15. (III) Rate of seed germination (mean ± SD of all colors) after the date of flowering. In A and C, *n* = 30 from days 10 to 74. Each survey sampled from each tree

Observations of bear signs showed that bears ate *P. jamasakura* fruit over 28 days, from 5 June to 2 July, then moved to higher altitudes as time passed. Figure 5 shows the relationship between the date when bears marked trees and the altitude of the marked trees. We observed that bears fed on *P. jamasakura* fruits mostly from 58 to 62 days after flowering by using wide range of altitudes to follow the peak of fruit maturation.

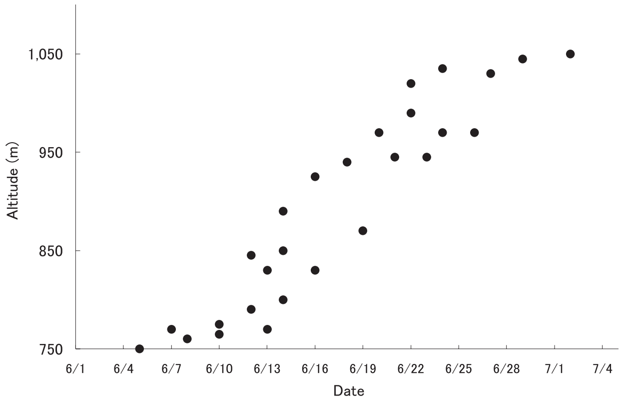

Fig. 5 Relationship between the date when bears marked trees and the altitude of the marked trees. n = 102

Discussion

The reason why bears moved to eat fruits late in the fruiting season might be that bears selected and fed on *P. jamasakura* fruits when they were most nutritious and that the date of fruit maturing was later at higher altitudes. This has been observed in previous studies of American black bears and brown bears, which select foods that are easy to digest (e.g., Mealey 1980, Herrero 1985). By feeding only on ripe fleshy fruits while moving around the mountain, it is likely that the bears would have obtained high levels of nutrients. Previous studies (e.g., Davis et al. 2006) and the results in this study show that bears could alter their diets in response to food resource availability in the forest.

Bears ate fruits from a large number of species in the cool-temperate deciduous forest (Koike and Masaki 2008). Their consumption patterns appeared to be based on the phenology of fruit ripening and on yearly fluctuations in fruit production. The annual and seasonal variability in the fruits used by the bears suggests that they use fruits opportunistically. The findings suggest that bears select their habitat based on the distribution and phenology of food-producing plants. Maintenance of a diverse mixture of tree and shrub species in deciduous forests that will reduce the influence of annual fluctuations in fruit abundance would be an important component of bear management to minimize human–bear conflict, and to better manage bear populations. Further long-term investigations of the quantitative and nutritional aspects of fruit production in each species and their phenological changes and annual fluctuations should be conducted to improve our understanding on frugivory in bears.

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Biology of Bear Intrusions: 72-75 (2009)

Altitudinal changes in the fruiting phenology of a deciduous oak in relation to the feeding behavior of Asiatic black bears

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Introduction

The intrusion of Asiatic black bears (*Ursus thibetanus*) into human-populated areas has become a major wildlife issue in Japan. In 2004 and 2006, numerous bears appeared in populated areas, causing an increase in the number of human-bear accidents and culled bears. Several ideas have been advanced to explain the intrusions: over the long term, the decline of the hunter population has made bears less aware of humans, abandonment of rural mountains (*satoyama*) provides good habitat for bears near human areas, and unharvested crops and fruit and vegetable waste attract bears to human areas (Oi and Yamazaki 2006). However, these reasons do not explain the yearly fluctuation in human-bear conflicts. Shorter term triggers for the intrusions have also been advanced: lack of food resources due to annual variations in food resource availability and fluctuations in bear populations (Oi and Yamazaki 2006).

In fact, hard mast abundance and human-bear conflicts are correlated (Taniguchi and Osaki 2003; Oka et al. 2004). Hard mast is the main autumn food for bears (e.g., Hashimoto and Takatsuki 1997), and bears have been reported to change the kind of hard mast they use according to abundance (Mizoguchi et al. 1996; Hashimoto et al. 2003). In the northern Japan Alps, bears descend from their summer habitat, where green vegetation is available, to autumn habitat, where hard mast is available (Izumiyama and Shiraishi 2004). However, how hard mast directly affects bear foraging behavior is not known. In terms of summer food resources, Koike et al. (2008) reported that *Prunus jamasakura* fruit matures later at higher altitudes, and bears forage later at higher altitudes. A similar phenomenon can be expected with autumn food, in that changes of hard mast fruiting phenology may affect bear feeding behavior. In this study, we hypothesized that hard mast fruiting occurs earlier at higher altitudes, as leaves fall earlier, and later at lower altitudes. We expect that in a poor crop year, bears will move in tandem with fruiting phenology (from higher to lower altitude) to use crops more efficiently, whereas in a good crop year many foods will be available at all altitudes, so bears will not need to move in relation to fruiting phenology. To test our hypothesis, we investigated two questions: 1) How does acorn fruiting phenology change with altitude, and 2) When and at what altitude do bears feed on the acorns?

Materials and Methods

The study was conducted in the Ashio Mountains in Japan, which cross Tochigi and Gunma Prefectures, in 2007. We established two study sites each at altitudes of 900, 1200, and 1400 m (six sites in total). At each site, we surveyed the fruiting phenology of *Quercus crispula* acorns and acorn foraging by bears. As the expanse of the study area is well within the size of the home range of a single bear, it could be used by one individual. However, home ranges can overlap. Thus, multiple bears appeared to be using the study sites (Yamazaki 2008). Among the hard mast found in the study area, we chose *Q. crispula* acorns as a study material for several reasons. First, they are the main autumn food of bears in many places in Japan (Hashimoto and Takatsuki 1997). Second, they have a short masting cycle (Taniguchi and Osaki 2003). Third, patches of good crop occur within in an area even in a bad mast year (Mizoguchi et al. 1996; Tanigchi and Osaki 2003). Last, *Q. crispula* is distributed over a broad elevational range (Masaki personal communication). Thus, we expected *Q. crispula* to be an important autumn resource for bears and to critically influence their foraging behavior.

Fruiting phenology

We measured three aspects of fruiting phenology: mass, chemical content, and number of acorns in the tree canopy. From these, we estimated the temporal change in the available energy (AE) of acorns in tree canopies. For each altitude, we sampled acorns biweekly from the tops of five to six individual trees, from flowering to acorn fall, to measure mass and chemical content. The dry weight of ten acorns per tree was measured in each survey and averaged for each altitude to yield an index of acorn mass.

For chemical content, we measured crude protein, crude fat, and total sugar to estimate the AE (AE = crude protein% × 23.7kJ + crude fat% × 39.5kJ + total sugar% × 15.6kJ). AE is a positive attractant to bears, whereas tannin content, which we also measured, is a negative factor. Acorns were freeze dried and milled for analyses. Crude protein was estimated as 6.25 × nitrogen. Nitrogen was measured by NC-analyzer (Series Ⅱ CHNS/O Analyzer 2400; Perkin Elmer Inc.) using acetanilide as a calibration standard. Crude fat was measured by extraction in diethyl ether for 8 h in a Soxhlet apparatus. Total sugar was measured as a sum of water soluble sugar content (WSC) and starch. WSC and starch was extracted with hot water extraction and perchloric acid extraction, respectively, and determined by the phenol-sulfuric acid method (Dubois et al. 1956). Absorbance was measured at 485nm in a microplate reader (Sunrise Rainbow RC; Tecan trading AG), using D-glucose as a calibration standard. Starch was estimated as glucose equivalent × 0.9. Tannin was measured by the index of tannin astringency (i.e. the ability of precipitating proteins) using the radial diffusion method (Hagerman 1987). Tannic acid was used for calibration standard.

The fall of acorns from trees was directly observed or estimated via seed traps (three traps per tree) for six individuals at each altitude to estimate the number of acorns in the tree canopy, biweekly.

Acorn foraging by bears

We investigated acorn foraging by bears by walking an approximately 1-km route and looking for feeding signs at more than 50 trees per route at each site, every week from 13 August to 14 November. The feeding signs observed were branches broken by bears (bear shelves), claw marks on tree trunks, and broken pericarps on the ground.

Results

Fruiting phenology

Fig. 1 shows the phenology of acorn mass growth. Acorn weight increased rapidly after early September at all altitudes. Dry weight continued to increase until reaching a maximum size when the acorns fell. Thus, the timing of maximum acorn size was influenced by the falling period, not altitude, and the maximum size of acorns did not differ by altitude (p>0.05, Kruskal-Wallis test).

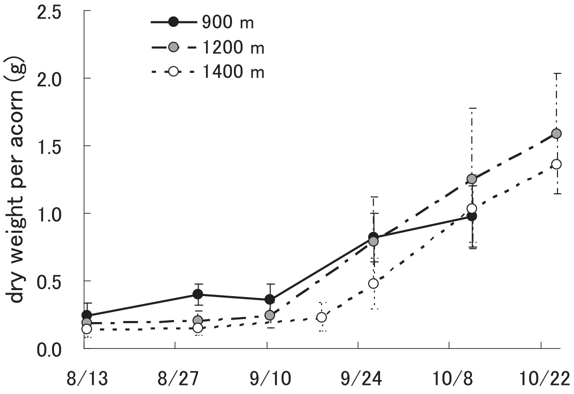

Fig. 1 Temporal change in the dry weight of *Q. crispula* acorns in the Ashio Mountains. Ten acorns per tree from five trees at 900 m and six trees at each of 1200 and 1400 m were weighed and averaged

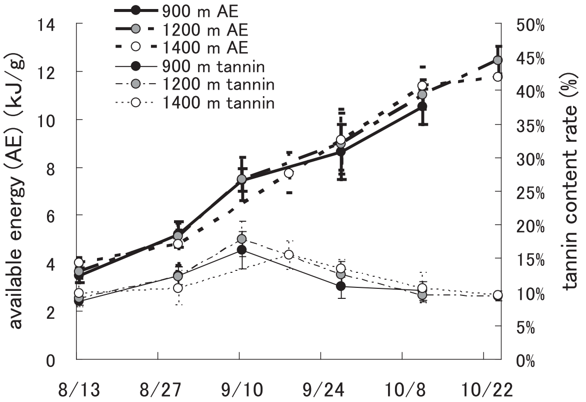

Fig. 2 Temporal change in the available energy (AE) and tannin content per dry weight of *Q. crispula* acorns in the Ashio Mountains. The AE and tannin content of acorns from the same trees as in Fig. 1. were measured

Fig. 2 shows the phenology of acorn chemical content. AE continued to increase, whereas tannin content initially increased, and then decreased after early September at all altitudes. Thus, AE and tannin content reached maximum and minimum values, respectively, just when the acorns fell and were influenced by the falling period, not altitude. The maximum AE value and minimum tannin content did not differ by altitude (p>0.05, Kruskal-Wallis test).

Fig. 3 shows the proportion of the remaining number of acorns on trees, using the number of acorns on 10 September as 100%. The falling process did not differ among altitudes. The median date of falling off (i.e., the date when the remaining proportion was 50%) was not significantly different among altitudes (Fig. 4; p>0.05, Kruskal-Wallis test). However, the median date of individuals varied significantly among altitudes; the coefficient of variance was

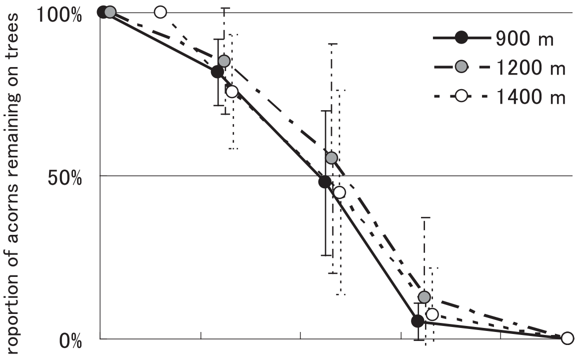

Fig. 3 Temporal change in the proportion of remaining *Q. crispula* acorns in the tree canopy in the Ashio Mountains. The number of acorns on each tree on 10 September represented 100% and was used to calculate the proportion of remaining acorns. Six trees were sampled at 900, 1200 and 1400 m

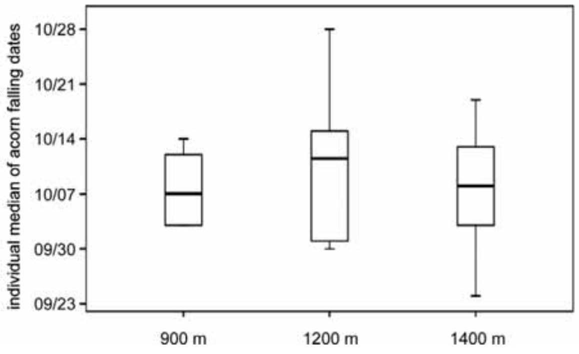

Fig. 4 Comparison of the individual median of acorn falling dates (shown by the horizontal line at 50% in Fig. 3) at 900, 1200, and 1400 m altitude in the Ashio Mountains. The boxes represent the median, 25th percentile, and 75th percentile, and the lines indicate the maximum and minimum values at each altitude

greater at higher altitudes (0.17 at 900 m, 0.33 at 1200 m, and 0.29 at 1400 m).

Based on these data, we estimated the temporal change in the AE of acorns on trees by multiplying the number of acorns on trees, dry weight per acorn, and AE per dry weight for each period (Fig. 5). The AE of acorns on trees peaked in late September at 900 m, and in early October at 1200 and 1400 m. AE also decreased earlier at 900 m, and energy was available for longer periods at higher altitudes.

Acorn foraging by bears

Fig. 6 shows the number of trees with feeding signs and when they were observed. Trees with claw marks only were separated from those with other feeding signs, as claw marks alone cannot indicate whether the bears ate the acorns. Foraging was observed from 27 September at both 1200 and 1400 m, but no feeding signs were observed at 900 m. Acorn foraging was also observed after 27 September in other areas of the Ashio Mountains (personal observation).

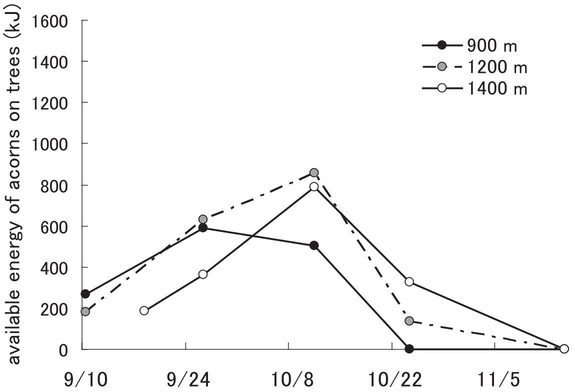

Fig. 5 Temporal change in the available energy (AE) of acorns in the tree canopy of the Ashio Mountains. Acorn AE in the tree canopy was estimated, with the number of acorns on 10 September representing 100% at all altitudes

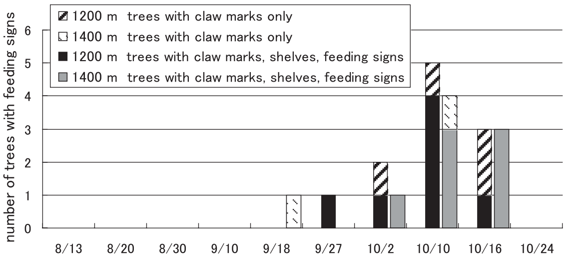

Fig. 6 Temporal change in the number of *Q. crispula* trees with bear feeding signs in the Ashio Mountains

Discussion

We found no difference in the timing of acorn maturation or falling period among altitudes. However, the individual variance in the falling process (indicated by the median date variance) was greater at higher altitudes, resulting in a higher and longer AE period of the trees. Since size and nutrition value increase until the falling-off period, an area with individuals with later falling periods produces more energy. Thus, as the sites at 1,200 and 1,400 m had more varied falling periods, resulting in individuals with later falling periods, these sites had a later and larger energy peak.

The study year (2007) was a good crop year for *Q. crispula* acorns, which were available at all altitudes at approximately the same time, but bears foraged on acorns only at higher altitudes. Other hard mast in the same season (*Q. serrata, Castanea crenata,* and *Fagus* species) did not produce well in 2007 (Masaki, unpublished data), so their influence on bear behavior was assumed to be negligible. We propose two reasons to explain why the bears foraged only at higher altitudes. First, since acorns were available longer at higher altitudes, bears may have selected locations at these altitudes. Second, bear selection of food resources could be random, and locations with longer availability simply had a greater chance of being used.

At 900 m, we observed feeding signs on *Cornus controversa* in the season before acorn foraging began (late August). The availability of food resources before the acorn crop could influence the timing of acorn use. Thus, investigations considering variable food resources are needed. Also, this is long-term research, as fruit production varies annually within and among species (Shibata et al. 2002). Researching the fruiting phenology and abundance of various fruits will contribute to understanding the foraging behavior of bears and will be important in clarifying the mechanism of bear intrusion.

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Biology of Bear Intrusions: 76-81 (2009)

Annual and regional variation in seed production of beech trees (*Fagus crenata*)

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Introduction

Fagus crenata Blume is a dominant tree species in cool temperate forests of Japan and has a strong masting habit (e.g., Shibata et al. 2002; Hoshizaki and Hulme 2002). This species often constitutes most of the biomass in a Japanese cool temperate forest (Nakashizuka 1984); therefore, its masting has considerable effects on the population dynamics of mammals that feed on *F. crenata* seeds including Asiatic black bears (*Ursus thibetanus*) (Koike and Masaki 2008). In addition, recent frequent invasions of Asiatic black bears into residential areas appear to be linked with annual fluctuations in the seed production of *F. crenata* in cool temperate forests of northern Japan (Oka 2006; Oka et al. 2004). Therefore, understanding and predicting mast seeding in *F. crenata* in terms of climatic cues is crucial to control intrusion of bears into urban regions.

Previous studies have suggested various weather conditions as cues for masting, including higher temperature (e.g., McKone et al. 1998; Seløas 2000; Schauber et al. 2002), lower temperature (e.g., Piovesan and Adams 2001; Sakai 2002; Seløas et al. 2002; Kon et al. 2005; Kon and Noda 2007) or drought (e.g., Piovesan and Adams 2001, 2005). Thus, there are various climatic cues depending on plant species and area (Kelly 1994; Kelly et al. 2000).

Also for *F. crenata*, there is a debate on the climatic cues of mast seeding. Kon et al. (2005) and Kon and Noda (2007) suggested that a lower average minimum temperature than usual in April–May could result in flower bud initiation, thereby causing mast seeding in the subsequent year. In contrast, Suzuki et al. (2005) suggested that higher temperatures or drought in summer could cause mast seeding in the subsequent year. Based on these studies, we expect that there might be a geographical or regional variation in terms of climatic cues for mast seeding among *F. crenata* populations.

This study analyzes 18-year data of *F. crenata* fruiting in 163 stands covering the northern part of Japan (ca. 200 km × 500 km), which were monitored visually. Our aims are to clarify how seed production of *F. crenata* is spatially synchronized and how it fluctuates annually, and to relate these spatial and annual variation to climatic data obtained from local weather stations by the Automated Meteorological Data Acquisition System (AMeDAS). Based on these analyses, we will assess the possibility of using weather conditions to predict the masting of *F. crenata*.

Methods

Assessment of seed production

This study was conducted in the Tohoku district, which is the northeastern part of Honshu Island, Japan. The production of seeds in the *F. crenata* forests in this district was visually assessed in autumn of every year from 1989 to 2006 in the 158 stands of this species within the forests managed by Forester Offices of the Tohoku Regional Forest Office of the Forest Agency of Japan. The distance between neighboring stands was 8.0 ± 6.0 km (mean ± SD).

Visual assessments were carried out by the Forester Office staff. They determined the proportion and condition of fruiting trees based on the appearance of these trees in a stand. Seed production was classified into 4 ranks: non-seeding (NN) in which seed production was not observed in any *F. crenata* trees, poor seeding (PR) in which seed production was partly observed on the crown of a few trees, modest seeding (MD) in which seed production was observed in the upper part of the crown in more than half of the trees, and mast seeding (MS) in which seed production was observed in the entire crown of most trees.

These categories corresponded well with the seedfall density observed beneath the crowns of fruiting *F. crenata* trees: 411.9 ± 221.8 seeds m^{-2} for MS, 70.0 ± 73.3 for MD, 37.6 ± 58.3 for PR, and 0.3 ± 0.7 for NN (Suzuki et al. 2005). These data were published on the website of the Forestry and Forest Products Research Institute (TANEDAS, http://www.ffpri.affrc.go.jp/labs/tanedas/, in Japanese) and more details of the methods are available in Suzuki et al. (2005) and Masaki et al. (2008).

The boundary values between the categories were calculated as the midpoint of logarithmic mean seedfall densities (3.5, 51.3 and 169.8 seeds m^{-2} in the ascending order). Hereafter, these values will be used to transform seeding categories to seedfall densities and inversely, to categorize the seeding degree.

The data obtained during 1990–2006 from Hokkaido Island, which is located north of Honshu Island, were also included in the analyses. These data included 5 stands located 32–81 km apart from each other, all of which were on the Oshima Peninsula, which is the northern limit of *F. crenata* distribution. The data were published in Yasaka et al. (2003) and on the website (in Japanese) of the Hokkaido Forestry Research Institute. These data were transformed into the same seeding categories used in the Tohoku district. Thus, 163 stands in total were used for the analyses.

Data analysis

To evaluate temporal synchronization of seed production between a pair of stands, time-series analysis was conducted for the pair after replacing the codes (MS, MD, PR, and NN) with corresponding seedfall densities. Cross-correlations with lag 0 (cc_0) were calculated between all pairs of the stands, compiled as a 163×163 matrix, and used for cluster analysis (a group average method) to identify groups of stands with temporally synchronized seeding. The threshold used to distinguish different groups was cc_0=0.48, which was significant at the 5% level.

Weather conditions during the study period were analyzed using the data obtained at the meteorological stations near each of the stands (< 20 km). In this study, the weather during the growing season (April–September) was analyzed because flower buds were thought to be formed during this period (Mikami and Kitakami 1983). At each station, the daily mean values of mean, highest, and lowest temperature were calculated for the 19-year period (1988–2006), and the values of daily anomaly (i.e., deviations from daily mean values) for mean, highest, and lowest temperature were calculated.

To determine critical weather conditions that will cause masting in subsequent years, a tree model was constructed (cf. Crawley 2002). Prior to the analysis using the tree model, we preliminarily examined the weather conditions that were likely to cause mast seeding in subsequent years. A pulsed climatic cue is known to be useful for predicting the occurrence of masting (e.g., Rees et al. 2002). Therefore, based on the suggestions in previous studies (Terazawa et al. 2004; Kon et al. 2005; Suzuki et al. 2005; Kon and Noda 2007), we carefully examined temporal changes in temperature like positive (negative) pulses during summer (spring) for the years preceding mast seeding. Thereafter, the pulse of a weather variable was quantified by summing the continuously positive (or negative) anomalies of daily means. For the index of summer drought (cf. Suzuki et al. 2005), the number of days when daily precipitation was continuously less than 2 mm was used.

In addition to these weather variables, seedfall density was also included as an index of crop size because crop size in one year often negatively correlates with crop size in the subsequent year (Isagi et al. 1997; Masaka 2001; Kon et al. 2005).

A response variable for this model is a seedfall density in each year averaged for each of the groups identified by the cluster analysis stated above. Each of the explanatory variables (weather conditions and seedfall densities) was also averaged for each group.

In the present study, all possible combinations of the variables were tested as explanatory variables of the model. Using AIC (residual deviance + 2 × the number of terminal nodes), the model that most accurately predicted the seedfall density of the subsequent year was selected. To evaluate how the selected model reproduced the observed pattern of masting, the model was verified by comparing the observed and expected seedfall densities. Language R (R Development Core Team 2006) was used for all the abovementioned calculations.

Results

Annual variation in seed production

The cluster analysis revealed 11 groups within which the temporal variation in seedfall density was significantly synchronized among the stands. These groups were merged into 5 parent groups at the higher level of the dendrogram (A–E). Hereafter, each group is numbered with the name of its parent group (A1–2, B1–2, C1–2, D1–2, E1–3). In the dendrogram, 2 stands were not categorized into any of the 5 parent groups, and these stands were not included in the subsequent analyses. Groups A2, C1, C2, and E3 contained ≤ 5 stands, and from the viewpoint of statistical accuracy, these groups were also excluded from the subsequent analyses. Thus, the remaining 7 groups were used for the following analyses. Examples of the annual variation in masting of these groups in terms of seedfall density are shown in Fig. 1.

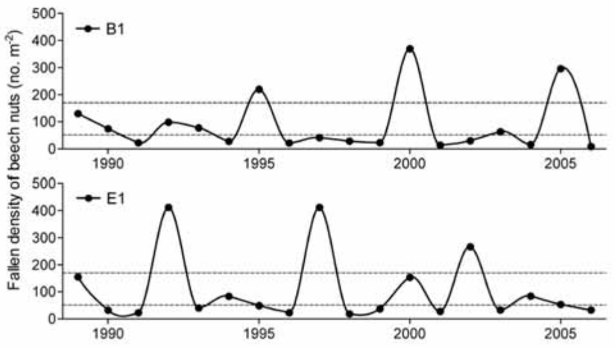

Fig. 1 Annual variation in the mean seedfall density (seeds m^{-2}) for stands belonging to some of the groups identified by the time-series analysis and the cluster analysis. Horizontal bars in each figure represent the thresholds between mast seeding, modest seeding and poor seeding (169.8 and 51.3 seeds m^{-2})

Spatial variation in seed production

Each group exhibited a characteristic distributional pattern (Fig. 2). Stands of B1 and B2 were distributed throughout the Tohoku district, except for the southern region and the Oshima Peninsula of Hokkaido Island. Stands of D1 were found mostly in the southern region of the Tohoku district, while those of D2 were located in the middle part of the district. Stands of E1 were distributed both in the Oshima Peninsula and in the northwestern region of the Tohoku district, while those of E2 were found only in the latter area.

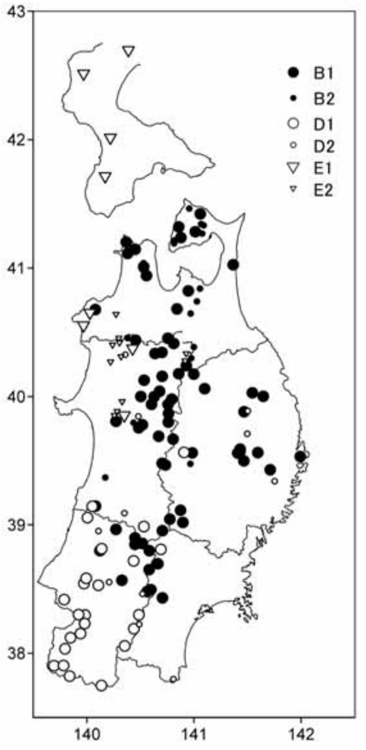

Fig. 2 Distribution of stands for the major groups. Lines on Honshu Island represent prefectural boundaries

Climatic variation

As shown in Fig. 1, group B1 showed mast seeding in 1990 and 2000. With regard to masting in 2000, for example, the weather conditions in 1999 (the year before 2000) for group B1 were characterized by continuously positive anomalies of daily mean temperature (35 days; Fig. 3) and drought (14 days; data not shown) during the period of July–August. Group E1 showed mast seeding in 1992, 1997, and 2002. With regard to masting in 1997, for example, the seasonal change in temperature in 1996 (the year before 1997) had typically continuously negative anomalies of daily mean temperature (23 days) in May (Fig. 3). These climatic traits were often clearly observed for other years and groups preceding the masting year.

Based on these preliminary observations, pulses of temperature were defined as the sum of continuously positive anomalies of daily mean temperature in summer (July–August) (*MTSM*, °C·days) and the sum of continuously negative anomalies of daily mean temperature in spring (April–May) (*MTSP*, °C·days).

As shown in Fig. 3, several pulses were observed during the focal periods. Those pulses with maximum absolute values were used. The same calculations were also conducted for the daily highest temperature (*HTSM* and HTSP; the index of daytime temperature) and for the daily lowest temperature (*LTSM* and *LTSP*; the index of nighttime temperature). In addition to these 6 weather variables, summer drought (*SMDR*) and seedfall density (*SFDN*) were included in tree models to predict seed production in the subsequent year. SFDN was log-transformed to meet the assumption of normality.

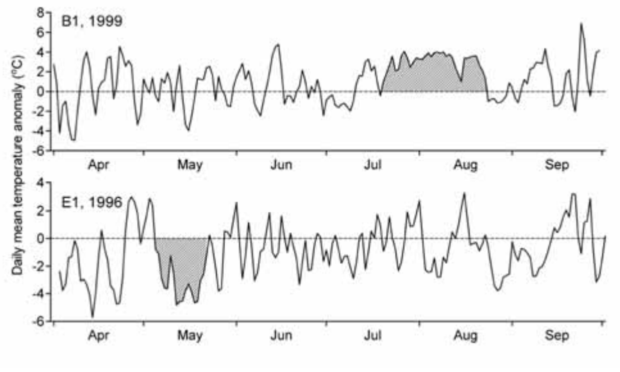

Fig. 3 Examples of seasonal change in the daily mean temperature in 1999 for group B1 (top) and in 1996 for group E1 (bottom). The temperature is shown by the daily anomaly. The shaded areas represent the pulses characterizing the years that might cause mast seeding in the subsequent years

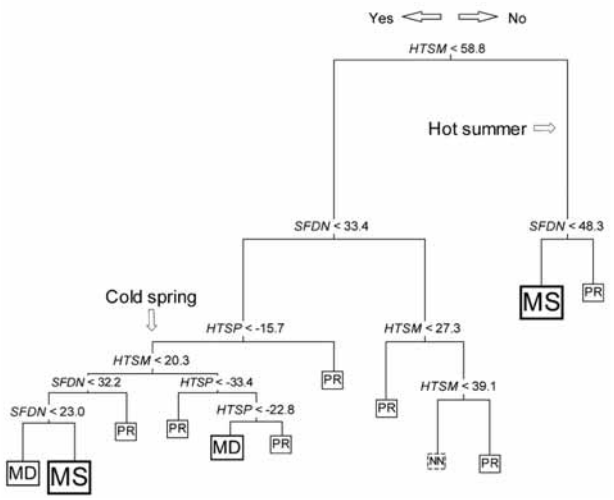

Fig. 4 The tree model that best explained the annual variation in the logarithm of seedfall density for the seven groups during 17 years. The terminal nodes are represented by boxes. Mast seeding, modest seeding, poor seeding, and non-seeding are denoted by MS, MD, PR, and NN, respectively. The abbreviations at the nodes are as follows: *HTSM*, sum of continuously positive anomalies of daily highest temperature during summer (°C・days); *HTSP*, sum of continuously negative anomalies of daily highest temperature in spring (°C・days); and *SFDN*, seedfall density (seeds m^{-2}). The seedfall densities at the terminal nodes are denoted also by the line width

The tree model

The model selected by referring to AIC values included 3 variables: *SFDN, HTSM* and *HTSP* (Fig. 4). By the verification, this model was proved to predict mast seeding with 64% accuracy and mast + modest seeding with 85% accuracy.

This result showed that the most critical variable determining the seedfall density was daytime temperature during summer (Fig. 4). Even when summer temperatures were not very high, lower temperatures during spring (*HTSP* <-15.7 °C·days) could result in mast or modest seeding.

HTSM tended to be causal for most of the mastings found in groups A1, B1 and B2. In contrast, *HTSP* was a prominent cue in groups E1 and E2. Groups D1 and D2 showed intermediate patterns between these extremes.

Discussion

An important result of this study was that mainly 2 types of climatic cues were found to cause mast seeding of *F. crenata* in the subsequent year: higher temperatures in summer (mostly for the Tohoku district), and lower temperatures in spring (mostly for the Oshima Peninsula and a part of the Tohoku district). This result well agrees with previous studies, which independently postulated that the summer high temperature (Suzuki et al. 2005) or spring low temperature (Kon et al. 2005; Kon and Noda 2007) was the causative factor. Masting of some populations of *F. crenata* (mostly E1 and E2) was controlled by lower temperatures in spring and that of other populations (mostly B1 and B2) was controlled by higher temperatures in summer.

The summer temperature was shown to be more decisive than the crop size. Seed production in a year is negatively correlated with that in the preceding year, and this effect can overwhelm the effects of climatic cues as the cause of masting in some plant species (e.g., Monks and Kelly 2006). However, with regard to *F. crenata*, climatic variation is more critical to controlling masting. As observed for nodes MSs in the tree model (Fig. 4), the crop size in a year affects the crop size in the subsequent year only when climatic conditions meet some requirements.

Previously, Mikami and Kitakami (1983) showed that initiation of flower buds of *F. crenata* had been completed by July in a stand of the Tohoku district. However, the present study suggested that higher temperatures during July–August were the most influential factor of mast seeding in the subsequent year. Higher temperatures after July might promote the subsequent development of the initiated flower buds. This idea needs to be tested in the future by physiological studies.

In the tree model, the anomaly of daytime temperature was selected for both spring and summer. However, a previous study on the Oshima Peninsula, in which branches of *F. crenata* were warmed experimentally at night during the spring, revealed that the daily lowest temperature (i.e., nighttime temperature) had decisive effects on floral initiation (Kon and Noda 2007). This discrepancy between the two studies might have resulted partly from the significantly positive correlation between daily higher and lower temperature (r=0.67, p<0.001, n=126). Furthermore, since only the nighttime temperature was controlled in the experiment of Kon and Noda (2007), the possibility that daytime temperature in spring might have been more critical cannot be ruled out. This also needs to be tested in the future by physiological studies on flower bud initiation of *F. crenata*.

In the present study, the tree model was not a complete tool for predicting seed production of *F. crenata*, in that it sometimes failed to predict mast seeding or misinterpreted the levels of seeding. Several probable errors can be listed in addition to using seedfall density, not flowering density. First, the data itself contained errors due to more or less subjective assessments. In the present study, to mitigate such errors, the stands of a temporally similar pattern of masting were grouped and averaged. This approach, however, might not be a perfect solution.

Second, masting of *F. crenata* itself is probably chaotic. Satake and Iwasa (2002a, b) predicted that spatial and temporal variation in seed production could occur without assuming environmental fluctuation or genetic variation among the populations. Even if the masting of *F. crenata* is controlled by deterministic rules, spatially synchronized seeding, with unpredictable annual fluctuation, can occur.

To make the prediction algorism more accurate, further study is essential. Even with the 18-year study, the data is still insufficient to statistically analyze temporally infrequent events of *F. crenata* masting. A longer-term study with additive data (e.g., flowering density in spring) would be of use.

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