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A model to predict the occurrence of Asiatic black bears at the municipal level using mast production data

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Abstract: This study analyzed how 3 Fagaceae species (*Fagus crenata, Quercus crispula,* and *Q. serrata*) affect the occurrence of Asiatic black bears (*Ursus thibetanus*) in and around residential areas from generalized linear mixed models based on monitoring data of bear occurrence and masting over 14 years (2005–2018) in municipalities in Hyogo Prefecture, Japan. The constructed models suggest that it is important to consider the effects of mast production by multiple dominant Fagaceae species, not only within a municipality but also in the surrounding area, to predict bear occurrence with practical accuracy at the municipal level. The accuracy of the predictive model increased as the number of Fagaceae species in the model increased. Models differed among municipalities in their accuracy to predict bear occurrence, which was related to the effect of *F. crenata* mast production, which was correlated with the proportion of *F. crenata* forests in each municipality. I suggest that the accuracy of prediction at the municipal level depended on the effect of *F. crenata* mast production because the spatial and temporal synchrony of *F. crenata* mast production was stronger than that of other species. To take preventive action to reduce conflict between humans and bears, it would be useful to construct a model to predict bear occurrence at the municipal level based on monitoring data of mast production in multiple Fagaceae species.

Key words: Asiatic black bear, bear occurrence, *Fagus crenata*, generalized linear mixed model, Japan, *Quercus crispula*, *Quercus serrata*, *Ursus thibetanus*

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In Japan, it is well-known that the numbers of Asiatic black bears (*Ursus thibetanus*) that occur in and around residential areas fluctuate widely from year to year (Kishimoto 2009, Yamazaki 2017, Fujiki 2018). Previous studies have suggested that this annual fluctuation is related to mast production in trees of the Fagaceae family (Taniguchi and Osaki 2003, Oka et al. 2004, Oka 2006, Mizutani et al. 2013, Fujiki 2018). Fagaceae trees are dominant in the broad-leaved forests in Japan, and their mast contains fat and carbohydrates at levels suitable for building copious amounts of body fat in bears (Matsuyama 1982, Hashimoto and Takatsuki 1997, Kirkpatrick and Pekins 2002). Bears need to accumulate sufficient fat to survive hibernation and reproduce successfully (Nelson et al. 1983, Hashimoto and Yasutake 1999). It is therefore inferred that mast from Fagaceae species is an important autumn food source for efficient accumulation of body fat in bears (Kozakai et al. 2011, Oi et al. 2012).

Bears tend to extend their home ranges in years of poor Fagaceae mast production (Arimoto et al. 2011, Kozakai et al. 2011, Yokoyama et al. 2011), which often brings them close to residential areas where orchards of Japanese persimmon (*Diospyros kaki*) and chestnut (*Castanea crenata*) are abundant (Arimoto et al. 2011, Oi et al. 2012). Increased bear occurrence in and around residential areas leads to an increased frequency of conflict between humans and bears (including human injury and agricultural field damage; Kishimoto 2009, Merkle et al. 2013, Can et al. 2014). The frequency of conflicts, however, can be reduced by taking preventive action by informing residents in advance of a potential increase in bear occurrence (Oka et al. 2004). Many prefectural governments have monitored Fagaceae mast production to predict mass occurrences of bears on a prefectural scale, which is from thousands to tens of thousands of square kilometers (Mizutani et al. 2013, Nakajima and Kodani 2013, Fujiki 2018).

Recently, Fujiki (2018) demonstrated that the frequency of bear occurrence in autumn in and around residential areas in a prefecture (approx. 7,800 km^2) can be

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predicted with a high degree of accuracy from statistical modeling of long-term monitoring data of mast production of multiple Fagaceae species that are dominant in an area and the frequency of bear occurrence. However, it is important to consider spatial variation in bear occurrence within prefectures in order to develop a more practical predictive model. In general, there are differences in the composition of forest types (Arimoto et al. 2011, Fujiki 2018) and annual fluctuation patterns in mast production in key Fagaceae species on a local scale within prefectures (Suzuki et al. 2005, Masaki et al. 2008, Vacchiano et al. 2017). Further, the annual frequency of bear occurrence also differs on a local scale within prefectures (Fujiki et al. 2011). Thus, to predict the frequency of bear occurrence on a local scale, it is necessary to develop a predictive model at the municipal level (i.e., in cities or towns, which are lower administrative units within prefectures; Fujiki 2018).

Previous studies have indicated that the home ranges of Asiatic black bears tend to extend from approximately 100 to 200 km^2 in years of poor mast production (Kozakai et al. 2011, Yokoyama et al. 2011). The land areas of prefectures are generally tens of times larger than the home range of a bear in a year of poor mast production; therefore, it is thought that most bears that occur in and around residential areas in a prefecture come from habitats within the prefectural area. In this case, it should be possible to predict the frequency of bear occurrence using mast production data for key Fagaceae species collected within the prefecture (Fujiki 2018). However, the land areas of municipalities are much smaller, ranging from approximately the size of a bear's home range to several times larger than a bear's home range in a poor mast year, so many bears that occur in and around residential areas in a municipality might come from habitats outside of the municipal area. In this case, it might be difficult to predict the frequency of bear occurrence within a municipality with high accuracy, unless the mast production of key Fagaceae species was monitored not only within, but also outside, the municipality.

Fujiki (2018) confirmed that the frequency of autumn bear occurrence in and around residential areas in Hyogo Prefecture, western Japan, can be predicted at the prefecture level with a high degree of accuracy by monitoring the mast production of 3 Fagaceae species: *Fagus crenata, Quercus crispula,* and *Q. serrata*. The present study investigated whether the frequency of bear occurrence in Hyogo Prefecture could be predicted at the municipal level, as well as at the prefectural level, by monitoring the mast production of these species. I investigated whether considering mast production in multiple species and in the area surrounding a municipality was effective when predicting bear occurrence at the municipal level. I also explored factors affecting the accuracy of predicting bear occurrence at the municipal level. Lastly, I discussed the direction of future research for developing a more practical and accurate predictive model of bear occurrence.

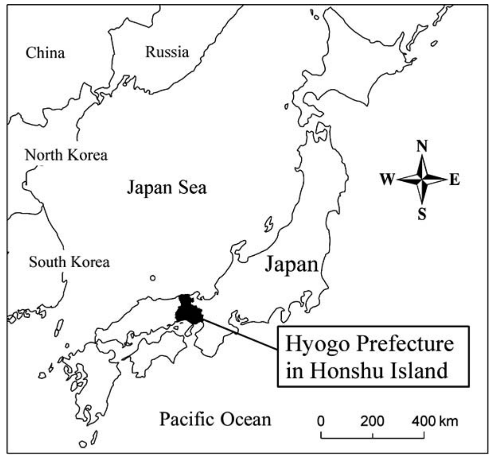

Fig. 1. Location of Hyogo Prefecture on Honshu Island, Japan.

Study area

This study was conducted in Hyogo Prefecture (approx. 7,800 km^2), Honshu Island, Japan (Fig. 1). The study area is bordered by the sea in the north and the south. Except for a large plain in the southern part of the study area where the urban area is located, most of the area is a montane zone (Fig. 2). Small cities, towns, and agricultural land are scattered within the montane zone. The study area is composed of 39 municipalities (9–698 km^2), which are either cities or towns. The human population is approximately 5.38 million and the population density is 689 persons/km^2. Approximately 71% of the area is covered by forest (5,611 km^2). Approximately 40% and 20% of the forest consists of conifer plantations and secondary forests of Japanese red pine (*Pinus densiflora*), respectively (Hyogo Prefecture 2014). Approximately 40% (2,202 km^2) of the forest area is natural forest dominated by broad-leaved trees, chiefly Fagaceae species. The broad-leaved forests below 300–600 m above sea level (asl) consist mostly of secondary forest dominated by *Q. serrata,* and those above 300–600 m asl consist mainly of primary or secondary forest dominated by *F. crenata* or *Q. crispula* (Miyawaki 1984).

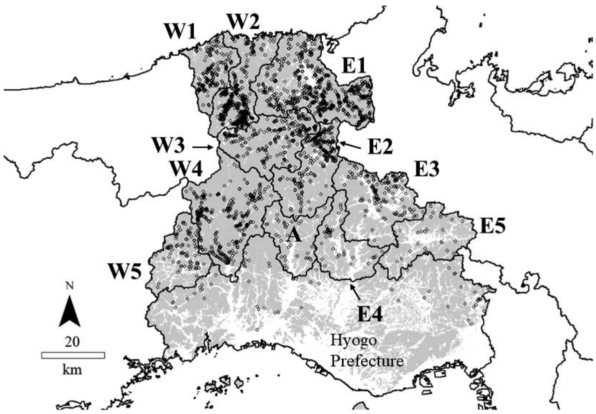

Fig. 2. Points where records of signs of Asiatic black bear (*Ursus thibetanus*) occurrence were obtained during autumn seasons from 2005 to 2018 in Hyogo Prefecture on Honshu Island, Japan. Circles indicate the recorded points of signs of bear occurrence. Unbroken lines indicate borders of municipalities and prefectures. Forest areas are shown by shading.

Asiatic black bears are mainly distributed in the north of the study area (Hyogo Prefecture 2017). The conservation policies of successive prefectural governments since 1996 led the bear population to increase after the early 2000s (Japan Wildlife Research Center 2010, Sakata et al. 2011, Hyogo Prefecture 2017). Consequently, conflicts between humans and bears in and around residential areas have increased in recent years (Inaba 2011, Hyogo Prefecture 2017).

Methods

Records of bear occurrence

The government of Hyogo Prefecture has collected records of bear sign—such as actual bear sightings, footprints, scratch marks, and bear-caused crop damage—from local residents in the form of a monitoring database since 2001. The information in these records has been utilized as a basis for preventive action against human–bear conflict by the local offices of the prefectural or municipal governments. Extraordinary numbers of bears occurred in and around residential areas within the study area in 2004; therefore, local residents fully recognized the necessity of reporting signs of bears as a basis for preventive action by these local government offices, and hence, the rate of reporting of signs of bears by local residents was higher after 2004. I collected records of bear sign within residential areas and within 200 m of residential areas from this database for the months of September through November (the Fagaceae masting season) for the years 2005–2018. For the present study, I selected the 11 of 39 municipalities (ranging from 241 to 698 km^2 in land area), those that had >30 records of bear sign from those 14 years, which constituted a sufficient sample size to analyze the data statistically (Fig. 2). I analyzed all the records of bear sign ($n = 4{,}028$) obtained from these municipalities.

Survey of Fagaceae species

Visual surveys of mast production by *F. crenata, Q. crispula*, and *Q. serrata* were carried out by wildlife managers of the prefectural government across the study area. The numbers of fixed points for these surveys were 15 for *F. crenata,* 14 for *Q. crispula,* and 216 for *Q. serrata* (Fig. 3). These sample sizes were determined according to the composition ratio of each species in the study area. Surveys at each fixed point for each species were carried out in early September, before the mature mast falls, each year from 2005 to 2018. An investigator observed the crowns of 10 mature trees/species using binoculars at each fixed point and then visually classified the mast production level per tree into 1 of 4 ranks, according to the number (n) of masts per square meter in the projective cover of the crown of a tree ("0": $n < 1$; "1": $1 \leq n < 5$; "2": $5 \leq n < 10$; and "3": $n \geq 10$).

Investigators determined the mast production level at a fixed point based on the mean of the ranks of 10 trees/species at that point. The mean mast production level for each species was calculated using data from all fixed points for each year. This mean (hereafter, "mast index") was used as the annual index of the mast production level for that species across the study area. Forests dominated by *F. crenata* or *Q. crispula* are not present in several municipalities, whereas forests dominated by *Q. serrata* are distributed abundantly across all municipalities (Fig. 3). Thus, the mast index for the unit of municipality was calculated for *Q. serrata*. Yokoyama et al. (2011) showed that the greatest diameter of the home range of a global positioning system (GPS) –collared bear increased to approximately 20 km in a poor mast year in the study area. To summarize the data by municipality, the units of 3 different spatial scales were designated as the land area of each municipality, the area within 10 km of the edge of the land area of each municipality, and the area within 20 km of the edge of the land area of each municipality, with reference to Yokoyama et al. (2011). The means of mast production level per unit were calculated and used as the mast index of *Q. serrata* by municipality at each spatial scale.

In addition to the 3 Fagaceae species surveyed, it has been observed that the masts of *Q. variabilis* and

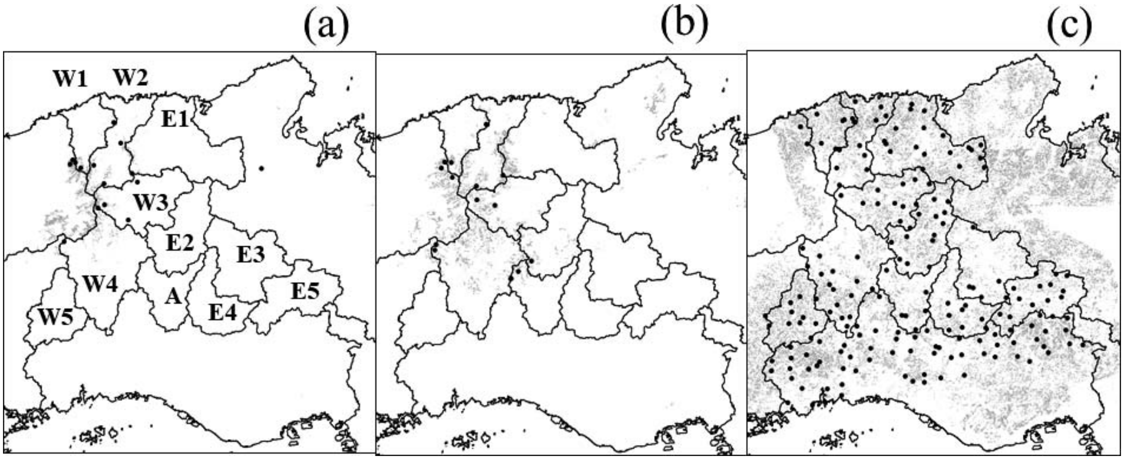

Fig. 3. Fixed points for visual surveys of *Fagus crenata* (a), *Quercus crispula* (b), and *Q. serrata* (c) mast production from 2005 to 2018 in Hyogo Prefecture on Honshu Island, Japan. Circles indicate fixed points for visual surveys. Gray zones represent the distribution of forest stands dominated by each species. Unbroken lines indicate borders of municipalities and prefectures.

C. crenata, the forth- and fifth-most dominant Fagaceae species, are also consumed by bears in the study area (D. Fujiki, unpublished data). However, observations by Fujiki (unpublished data) indicate that the annual mast production of both of these species fluctuates little; therefore, I did not include data for these species in the present study.

To assess the composition of the forest in each municipality, I classified the natural forest in the study area into 5 types, in which the dominant species were *F. crenata, Q. crispula, Q. serrata, Pinus densiflora,* or other trees, based on a 1:25,000 vegetation map provided by the Ministry of Environment (Biodiversity Center of Japan 2017). I then summarized the vegetation data according to the total area of each type of natural forest or conifer plantation by each municipality. I analyzed points or polygon data included on the map, as well as the summaries of the total area of each forest type, using the Spatial Analyst extension of ArcGIS 10.4 (ESRI, Redlands, California, USA).

Generalized linear mixed models

I analyzed the effects of the mast indices of *F. crenata, Q. crispula,* and *Q. serrata* on bear occurrence in each municipality using generalized linear mixed models (GLMMs; Zuur et al. 2009) with Poisson distributions and log link functions. For these models, the response variable was the number of bear sign recorded in the autumn of a year in and around residential areas in a municipality ("bear occurrence"), and the 7 explanatory variables used were the mast index of *F. crenata* (Fc), the mast index of *Q. crispula* (Qc), the mast index of *Q. serrata* (Qs), the municipality (Area), the number of years since 2005 (YEAR), the interaction between Fc and Area, and the interaction between YEAR and Area. The reason that Area was included as an explanatory variable was that the bear occurrence level was very different among municipalities (Fig. 2). The reason that YEAR was included as an explanatory variable was to quantify the effect on bear occurrence of a factor that gradually exerts influence over many years and that is not explained by mast indices. Examples of factors that could be explained by YEAR are an increase in population size and an increase in reporting rate (Fujiki 2018). The effect of YEAR may differ among municipalities, so I included this interaction as an explanatory variable. The magnitude of the effect of the mast index of a Fagaceae species may differ among municipalities if the spatial distribution of the forests dominated by the species is heterogeneous in the study area. Therefore, I included the interaction between Fc and Area as an explanatory variable. I did not include the interaction between Qc and Area, however, because a multicollinearity problem occurred among explanatory variables. I did not include the interaction between Qs and Area as an explanatory variable because forests dominated by *Q. serrata* were homogeneously distributed in the study area. Instead, I investigated the extent to which the spatial scale of the mast index of *Q. serrata* affected bear occurrence in a municipality as described below. I set each year as the random factor.

The analysis process was as follows. First, I constructed 4 GLMMs that included all explanatory variables, but were different in unit size for calculating Qs values, by calculating the mast index of *Q. serrata* according to the distance from the edge of the land area of each municipality (0 km, 10 km, 20 km, and the entire study area [All]). The Akaike Information Criterion (AIC) is a technique that is commonly used to compare nested models (Burnham and Anderson 2002). Lower values of AIC generally indicate a better fitting model than do larger values. Thus, I selected the model with the lowest value of AIC from among the 4 GLMMs. Next, I constructed GLMMs with all possible combinations of the 7 explanatory variables, using the data set of Qs calculated from the spatial scale selected by AIC, and evaluated them based on AIC.

In this study, I considered an explanatory variable to have a statistically significant effect when the estimated coefficient of the variable did not include zero in a 95% Wald confidence interval ($\Pr(>|z|) < 0.05$) based on Wald statistics (z-value). I performed statistical modeling using Program R (R ver.3.1.2, http://www.r-project.org).

Evaluation of model accuracy

I compared the performance of models among the GLMMs using different numbers of key species for the following 5 models: 1 model in which I chose the lowest AIC score among the GLMMs, with 3 Fagaceae species as explanatory variables (3sp-BM); 1 model in which I chose the lowest AIC score among the GLMMs, with 2 Fagaceae species as explanatory variables (2sp-BM); and 3 models in which I chose the lowest AIC score among the GLMMs, with either Fc, Qc, or Qs as the explanatory variable (Fc-BM, Qc-BM, and Qs-BM, respectively). I calculated the expected values of bear occurrence in each year from 2005 to 2018 in each municipality, based on parameters estimated in each model, and then calculated the coefficients of determination (R^2) based on the data sets of observed values obtained from monitoring and the expected values calculated from each model.

Results

In most municipalities, bear occurrence tended to fluctuate in a cyclical manner from year to year (Fig. 4a). In 2006 and 2010, bear occurrences were extremely high, at 28.1 times and 38.6 times the previous years' values, respectively, over the entire study area.

Mast indices for all species, especially *F. crenata,* tended to show alternating peaks and troughs roughly every 2 years (Fig. 4b). The coefficient of variation (CV) of mast index in *F. crenata* (Fc = 111.3) was larger than that in the other species (Qc = 64.5, Qs = 44.1–63.3). The mast indices of *F. crenata* were zero at all survey points 5 times in 14 years, whereas the mast indices of *Q. crispula* and *Q. serrata* did not reach zero in any year.

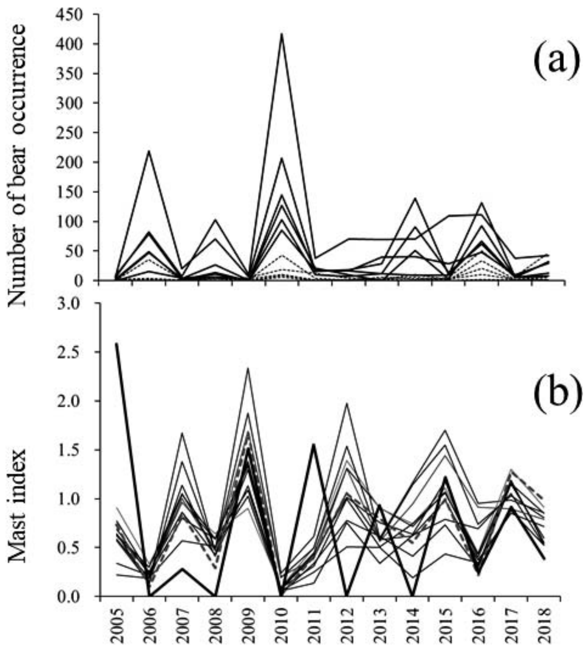

Fig. 4. Annual fluctuations in autumn Asiatic black bear (*Ursus thibetanus*) occurrence (a) and in mast indices of *Fagus crenata, Quercus crispula,* and *Q. serrata* (b) from 2005 to 2018 in Hyogo Prefecture on Honshu Island, Japan. Thick lines and broken lines in (a) indicate the number of bear occurrences in municipalities where *F. crenata* forests do and do not occur, respectively. Thick lines and broken lines in (b) indicate the mast indices of *F. crenata* and *Q. crispula,* respectively, across the study area. Thin lines in (b) indicate the mast indices of *Q. serrata* in each municipality, calculated for the area within 10 km of the edge of the land area of each municipality.

In comparisons of the AIC scores among the 4 GLMMs that differed in the unit size used to calculate the mast index of *Q. serrata* (0 km, 10 km, 20 km, and All), the 10-km model was the lowest, as well as the best predictive model (Table 1). Although the differences in AIC scores between the 10-km model and the 20-km model were small (ΔAIC = 1.8), the differences between the 10-km model and the other models were large (ΔAIC $\geq$ 5.1), which means that there was a difference in prediction capability between the 10-km model and the other models.

Table 1. Statistics for the 4 models that differ in the unit size used to calculate the mast index of *Quercus serrata* according to the distance from the edge of each municipality (0, 10, and 20 km and the entire study area [All]) in Hyogo Prefecture, Japan.

Rank	Model	AIC[a]	ΔAIC[b]
1	10 km	865.4	0.0
2	20 km	867.0	1.8
3	0 km	870.3	5.1
4	All	883.2	18.0

[a]AIC is Akaike's Information Criterion.
[b]ΔAIC is the difference between the 2 AIC values being compared.

Based on the 10-km model and comparison of the AIC scores among the GLMMs with all possible combinations of the 7 explanatory variables, the model including all 7 variables (3sp-BM) was selected as the best-fit model (Table 2). The model that included 6 variables, but did not include Qc, was selected as the second best-fit model (2sp-BM); the difference in AIC scores between the best and the second-best model was large ($\Delta AIC = 8.4$). The AIC score for the single-species models was the lowest for Fc-BM, followed by Qs-BM and Qc-BM. The difference in AIC scores between the best model and the single-species models was large ($\Delta AIC \geq 32.5$).

I used R^2 values to compare the 5 GLMMs (3sp-BM, 2sp-BM, Fc-BM, Qc-BM, Qs-BM) with different numbers of explanatory variables (key species). The results showed that the R^2 values were largest for the 3sp-BM model ($R^2 = 0.87, P < 0.001$; Table 3) and then decreased as follows as the number of included species decreased: 2sp-BM ($R^2 = 0.69$, $P < 0.001$), Qc-BM ($R^2 = 0.60$, $P < 0.001$), Fc-BM ($R^2 = 0.47$, $P < 0.001$), and Qs-BM ($R^2 = 0.44$, $P < 0.001$). The values of R^2 per municipality for 3sp-BM were statistically significant ($P < 0.05$) in all municipalities. The values were significant in 10 of 11 municipalities for 2sp-BM and Qc-BM, 4 of 11 municipalities for Fc-BM, and 5 of 11 municipalities for Qs-BM. When the values of R^2 among municipalities, as calculated using 3sp-BM, were compared, the values of the municipalities located in the western area of the study area (W1–W5) tended to be higher than those in the eastern area (E1–E5; Table 3). The R^2 value was largest ($R^2 = 0.94$, $P < 0.001$) in W4 and smallest in E5 ($R^2 = 0.31$, $P < 0.05$).

The distribution of *F. crenata* forest was almost limited to the municipalities W1–W4, which are located in the western area of the study area (Fig. 3a, Table 4). The distribution of *Q. crispula* forest is almost limited to 7 municipalities: W1–W4, plus A, E1, and E2 (Fig. 3b). The distribution of *Q. serrata* forest covers the entire study area, and *Q. serrata* forests solely dominate in Fagaceae forests in W5 and E3–E5 (Fig. 3c).

The 3sp-BM model showed great variation in the value of the coefficient of Fc among municipalities in the range of −0.29 to −2.07 (Table 5), and there was a significant correlation between the coefficient of Fc and R^2 for municipalities when an outlier (E4) was excluded from the data set ($r_s = -0.68$, $P < 0.05$; Fig. 5). Furthermore,

Table 2. Statistics for the top 5 models selected based on Akaike's Information Criterion (AIC), which were constructed to predict autumn Asiatic black bear (*Ursus thibetanus*) occurrence at the municipal level using the mast production data from 3 Fagaceae species (*Fagus crenata, Quercus crispula,* and *Q. serrata*) in Hyogo Prefecture, Japan, during 2005–2018. The models include only each single species with lowest AIC and the null model. BM = best-fit model; SM = second best-fit model.

		Explanatory variables[a]								
Rank	Model[b]	Fc	Qc	Qs	YEAR	Area	Fc:Area	YEAR:Area	AIC[c]	ΔAIC[d]
1	3sp-BM	+	+	+	+	+	+	+	865.4	0.0
2	2sp-BM	+		+	+	+	+	+	873.8	8.4
3	2sp-SM	+	+		+	+	+	+	881.9	16.5
4	Fc-BM	+			+	+	+	+	897.9	32.5
5	3sp-SM	+	+	+	+	+		+	904.2	38.8
8	Qs-BM			+	+	+		+	922.8	57.4
10	Qc-BM		+		+	+		+	936.1	70.7
52	Null								4,669.0	3,803.6

[a]Fc, mast index of *Fagus crenata;* Qc, mast index of *Quercus crispula;* Qs, mast index of *Q. serrata;* YEAR, the number of years since 2005; Area, each municipality.
[b]3sp-BM, 3 Fagaceae species as explanatory variables; 2sp-BM, 2 Fagaceae species as explanatory variables; Fc-BM, Fc as the explanatory variable; Qs-BM, Qs as the explanatory variable; Qc-BM, Qc as the explanatory variable.
[c]AIC is Akaike's Information Criterion.
[d]ΔAIC is the difference between the 2 AIC values being compared.

Table 3. Comparison of the coefficients of determination (R^2) between observed and expected values among models with different numbers of key Fagaceae species (*Fagus crenata, Quercus crispula,* and *Q. serrata*) as explanatory variables and among municipalities within each model, which was constructed to predict autumn Asiatic black bear (*Ursus thibetanus*) occurrence at the municipal level using the mast production data from these species in Hyogo Prefecture, Japan, during 2005–2018. BM = best-fit model.

	Model[a]				
Municipality	3sp-BM	2sp-BM	Qc-BM	Fc-BM	Qs-BM
W1	0.72***	0.53**	0.58**	0.14 n.s.	0.32*
W2	0.87***	0.88***	0.68**	0.51**	0.62***
W3	0.66***	0.71***	0.45*	0.47**	0.27 n.s.
W4	0.94***	0.78***	0.82***	0.35*	0.56**
W5	0.67***	0.47**	0.62***	0.27 n.s.	0.34*
A	0.69***	0.31*	0.64***	0.29 n.s.	0.25 n.s.
E1	0.52**	0.46**	0.34*	0.16 n.s.	0.17 n.s.
E2	0.59**	0.49**	0.36*	0.17 n.s.	0.20 n.s.
E3	0.78***	0.63***	0.61***	0.47**	0.47**
E4	0.46**	0.08 n.s.	0.79***	0.17 n.s.	0.05 n.s.
E5	0.31*	0.42*	0.10 n.s.	0.22 n.s.	0.17 n.s.
Total	0.87***	0.69***	0.60***	0.47***	0.44***

[a]3sp-BM, 3 Fagaceae species as explanatory variables; 2sp-BM, 2 Fagaceae species as explanatory variables; Fc, mast index of *Fagus crenata;* Qc, mast index of *Quercus crispula;* Qs, mast index of *Q. serrata;* Qc-BM, Qc as the explanatory variable; Fc-BM, Fc as the explanatory variable; Qs-BM, Qs as the explanatory variable.
***$P < 0.001$; **$P < 0.01$; *$P < 0.05$; n.s., not significant.

the coefficient of Fc was negatively correlated with the proportion of *F. crenata* forest in the municipalities when E4 was excluded ($r_s = -0.83$, $P < 0.01$; Fig. 6).

Discussion

Importance of considering mast production of multiple species and in surrounding areas when predicting black bear occurrence

Fujiki (2018) constructed a model to predict autumn bear occurrence in and around residential areas across a large area, based on mast production monitoring data for *F. crenata, Q. crispula,* and *Q. serrata*. He compared performances among models with different numbers of Fagaceae species as explanatory variables in order to investigate whether the use of multiple key Fagaceae species was effective in predicting bear occurrence. The results showed that model prediction accuracy increased as the number of Fagaceae species included in the model increased. The present study also compared performances among models with different numbers of Fagaceae species as explanatory variables at the

Table 4. Composition (%) of forest types among municipalities in Hyogo Prefecture, Japan, during 2005 to 2018.

	Natural forests[a]						
Municipality	Fc	Qc	Qs	Pd	Others	Conifer plantation	Total
W1	3.0	4.9	36.4	3.1	13.8	38.7	100.0
W2	4.4	11.7	28.0	5.6	8.0	42.3	100.0
W3	2.1	8.1	21.1	14.2	2.7	51.8	100.0
W4	2.4	9.9	15.5	4.9	2.9	64.4	100.0
W5	0.0	0.2	40.7	13.3	1.3	44.4	100.0
A	0.0	4.5	13.3	6.2	0.5	75.5	100.0
E1	0.6	4.1	33.9	20.1	1.5	39.8	100.0
E2	0.1	6.1	25.0	10.0	1.6	57.2	100.0
E3	0.0	0.3	11.9	21.1	1.2	65.4	100.0
E4	0.0	1.0	19.9	23.9	1.8	53.4	100.0
E5	0.0	0.0	21.3	51.6	0.6	26.4	100.0

[a]Fc, *Fagus crenata* forest; Qc, *Quercus crispula* forest; Qs, *Q. serrata* forest; Pd, *Pinus densiflora* forest; Others, other natural forests.

Table 5. Coefficients of each variable in the 11 municipalities for the best model, which is the one with the lowest AIC[a], created to explain the number of records of Asiatic black bear (*Ursus thibetanus*) signs at the municipal level using the mast production data from 3 Fagaceae species (*Fagus crenata, Quercus crispula,* and *Q. serrata*) in Hyogo Prefecture, Japan, 2005–2018.

	Coeff. values for each variable				
Municipality	Intercept	Fc[b]	Qc[c]	Qs[d]	YEAR[e]
W1	3.16 ***	– 0.65 *	– 1.11 ***	– 0.80 ***	0.19 ***
W2	5.08 ***	– 1.02 ***	– 1.11 ***	– 0.80 ***	0.07 *
W3	3.49 ***	– 0.80 n.s.	– 1.11 ***	– 0.80 ***	0.18 ***
W4	4.16 ***	– 0.77 n.s.	– 1.11 ***	– 0.80 ***	0.10 n.s.
W5	3.11 ***	– 0.29 ***	– 1.11 ***	– 0.80 ***	0.02 *
A	0.57 ***	– 0.57 n.s.	– 1.11 ***	– 0.80 ***	0.21 ***
E1	4.91 n.s.	– 0.35 ***	– 1.11 ***	– 0.80 ***	0.11 **
E2	3.80 ***	– 0.42 ***	– 1.11 ***	– 0.80 ***	0.13 ***
E3	1.44 ***	– 0.65 n.s.	– 1.11 ***	– 0.80 ***	0.26 ***
E4	– 1.38 ***	– 2.07 n.s.	– 1.11 ***	– 0.80 ***	0.75 ***
E5	0.64 ***	– 0.30 *	– 1.11 ***	– 0.80 ***	0.15 ***

[a]AIC, Akaike's Information Criterion.
[b]Fc, mast index of *Fagus crenata.*
[c]Qc, mast index of *Quercus crispula.*
[d]Qs, mast index of *Q. serrata.*
[e]YEAR, the number of years since 2005.
****P* $<$ 0.001; ***P* $<$ 0.01; **P* $<$ 0.05; n.s., not significant.

municipal level for the same purpose. The results also showed that the model prediction accuracy increased as the number of Fagaceae species included in the model increased.

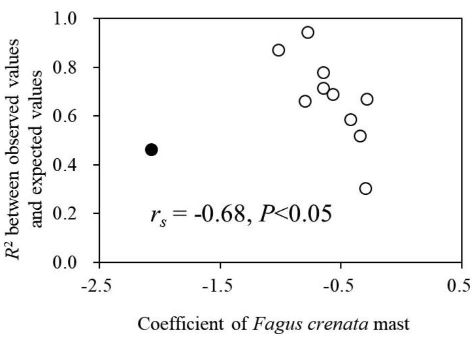

Fig. 5. Relationship between the coefficient of mast index of *Fagus crenata* and coefficients of determination, which indicate the relationships between observed and expected values of Asiatic black bear (*Ursus thibetanus*) occurrence from 2005 to 2018 in Hyogo Prefecture on Honshu Island, Japan, in the model with 3 Fagaceae species as explanatory variables (3sp-BM). Circles indicate the relationship for each municipality. The black circle indicates an outlier (E4) that was excluded from the data set for the correlation analysis.

Importantly, the following results were obtained in the 4 municipalities (W5, E3–E5) in which the Fagaceae forests were solely dominated by *Q. serrata*. First, prediction accuracy was low with the model Qs-BM, which considered only the effect of *Q. serrata* mast production

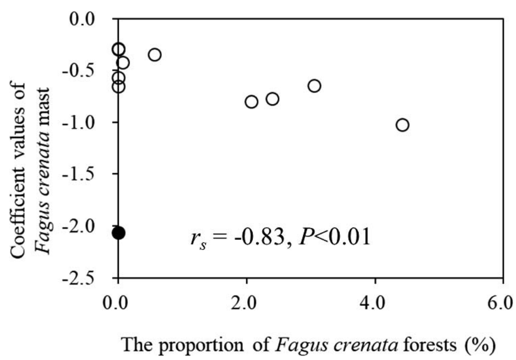

Fig. 6. Relationship between the proportion of *Fagus crenata* forest and the coefficient of mast index of *F. crenata* from 2005 to 2018 in Hyogo Prefecture on Honshu Island, Japan, in the model with 3 Fagaceae species as explanatory variables (3sp-BM). Circles indicate the relationship for each municipality. The black circle indicates an outlier (E4) that was excluded from the data set for the correlation analysis.

around each municipality. Second, prediction accuracy was greatly improved by adding the effects of *F. crenata* and/or *Q. crispula* mast production outside of the municipality in addition to *Q. serrata* mast production around the municipality (see 3sp-BM or 2sp-BM). I assume that some bear occurrences in these municipalities were due to bears that had moved from surrounding areas where *F. crenata* and/or *Q. crispula* forests occur. The results suggest that it is important to consider the effects of mast production in multiple dominant Fagaceae species, not only within a municipality, but also in surrounding areas, to predict bear occurrence with practical accuracy at the municipal level. A survey of the home ranges of GPS-collared bears in the study area (Yokoyama et al. 2011) showed that the greatest diameter of the home range of a GPS-collared female bear increased to approximately 20 km as the bear moved from village to village in a poor *F. crenata* mast year (2008). On the other hand, in an *F. crenata* mast year (2009), the home range of the same bear was limited to a narrow area in the mountains where *F. crenata* forests are abundant. In the Nikko region of eastern Japan, a GPS-collared female bear moved approximately 30 km over 3 days in a poor mast year (Kozakai et al. 2011). In the central mountains of Taiwan, a GPS-collared bear had a home range with a maximum diameter of approximately 30 km (Hwang et al. 2010). These studies suggest that some bears can move to areas 20–30 km away from the distribution area of *F. crenata* or *Q. crispula* forests in poor mast years for those species as they seek out alternative foods; they may then occur in and around residential areas. However, the effect of *F. crenata* mast on bear occurrence may be weaker in municipalities where *F. crenata* forests do not occur. The coefficient of Fc in 3sp-BM was negatively correlated with the proportion of *F. crenata* forest. In addition, the absolute values of the Fc coefficient were lower than those of the Qs coefficient in municipalities where *F. crenata* forests do not occur, when an outlier (E4) was excluded (Table 5). These results suggest that mast production in dominant Fagaceae forests has a stronger effect on bear occurrence when located nearer a municipality.

Factors affecting the accuracy of predictions of bear occurrence at the municipal level

The present study found that the prediction accuracy by 3sp-BM differed widely among municipalities. In one municipality (W4), bear occurrence was predicted with high accuracy using this model ($R^2 = 0.94$, $P < 0.001$), at the same level as that ($R^2 = 0.96$) of Fujiki's (2018) model for the entire study area. Meanwhile, in another municipality (E5), prediction accuracy with the same model was low ($R^2 = 0.31$, $P < 0.05$). Such differences in prediction accuracy among municipalities may be caused by differences among municipalities in the effect of *F. crenata* on bear occurrence. The 3sp-BM model indicated that values of R^2 between observed and expected values tended to be larger with larger absolute values of the coefficient of Fc in a given municipality. Further, the value of the coefficient of Fc was negatively correlated with the proportion of *F. crenata* forest in municipalities. These results suggest that the prediction accuracy of bear occurrence in a municipality tends to be higher as the proportion of *F. crenata* forests to the total forest area in the municipality increases. It is well-known that *F. crenata* mast production is spatially and temporally synchronized among stands at one or several prefectural scales in Japan (Suzuki et al. 2005, Masaki et al. 2008). On the other hand, the spatial synchrony of *Q. crispula* or *Q. serrata* mast production is lower and weaker (Mizutani et al. 2013, Fujiki 2018). The present study also indicated that the CV of the mast index of *F. crenata* was larger than that of *Q. crispula* and *Q. serrata*. The mast indices of *F. crenata* were zero at all survey points 5 times over 14 years, whereas the mast indices of *Q. crispula* and *Q. serrata* did not reach 0 in any year. Although *F. crenata* forests are abundant in the western part (W1–W4) of the study area, they are rare in the eastern part (E1–E5) of the study area. According to this difference in composition of forest types between the western and the eastern parts of the study area, there is a geographical trend in the accuracy of prediction of bear occurrence, which is higher in the west than in the east.

Direction of future research

The results of this study suggest that, to predict bear occurrence with practical accuracy at the municipal level, it is important to consider the effects of mast production by multiple dominant Fagaceae species, not only within a municipality, but also in the surrounding area. To predict bear occurrence with high accuracy at the municipal level, it is therefore important to identify the main habitats of the bears that occur in a municipality, preferably with the use of GPS collars. In addition, it is important to monitor mast production by all Fagaceae species that are dominant in the bears' main habitats.

The methods used to survey mast production by Fagaceae species may vary among adjoining prefectures in Japan (Mizutani et al. 2013, Fujiki 2018). However, by locating GPS-collared bears, it has been found that bears living in the eastern part of the study area often move between the eastern area and the adjoining prefecture (M. Yokoyama and Y. Morimitsu, University of

Hyogo, unpublished data). This may explain why prediction accuracy was low in municipalities bordering the eastern adjoining prefecture (E1, E5); it may be that factors affecting mast production and/or bear occurrence in the adjoining prefecture were not incorporated into the models constructed in the present study. Thus, in order to predict bear occurrence with high accuracy in municipalities bordering adjoining prefectures, models explaining the effects on bear occurrence of mast production in adjoining prefectures should be constructed by collecting mast production data using uniform methods in adjoining prefectures.

Using the method employed in the present study, based on monitoring of mast production by visual survey, it is impossible to predict mast earlier than the period of the mast maturation, from late August to September. However, it is desirable to predict autumn bear occurrence earlier in order to take preventive action against human–bear conflict well in advance. A technique to predict mast production in *F. crenata* in spring by monitoring flower bud production has already been established (Yasaka et al. 2001, Nakajima and Kodani 2013). In contrast, in *Q. serrata,* an approach to predicting mast production in early summer using the canopy reflectance values of individual trees obtained from hyperspectral imaging is still under development (Akita et al. 2008, Yao et al. 2008, Yao and Sakai 2010). In terms of the direction of future research, therefore, it is necessary to establish techniques to predict mast production at an earlier time point.

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