International Journal of GEOMATE, May., 2021, Vol.20, Issue 81, pp.93-99
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2021.81.6215
Geotechnique, Construction Materials and Environment

ESTIMATION OF HABITAT SUITABILITY AREA OF ENDANGERED SPECIES USING MAXENT IN FUKUSHIMA PREFECTURE, JAPAN

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*Corresponding Author, Received: 2 July 2020, Revised: 8 Feb. 2021, Accepted: 19 Feb. 2021

ABSTRACT: Fukushima Prefecture is the third largest area in Japan and which has diverse natural environment such as Mt. Bandaisan, Lake Inawashiro, and the Bandai highlands with beautiful ponds and lakes. However, since the valuable and rich nature and habitat for endangered species have been destroyed by rapid urbanization and infrastructure development. Thus, the purpose of this research is to analyze the time-series change of habitat area for four endangered species: the golden eagle (*Aquila chrysaetos*), northern goshawk (*Accipiter gentilis*), Japanese macaques (*Macaca fuscata*), and Asian black bear (*Ursus thibetanus*). Maximum entropy modeling (MaxEnt) software was used to model species distributions and to estimate the habitat suitability area. As the result, it was concluded that the total suitable habitat area increased slightly for the golden eagle, but the suitable habitat area for the other three species decreased. In addition, the potential suitable habitat areas by multiplying the numerical values obtained from MaxEnt by the area also decreased by 3.57% for the Japanese macaque, by 7.44% for the northern goshawk, and by 1.92% for the black bear between 1976 and 2014. Thus, this research suggested the necessity of conservation of their habitat area.

Keywords: MaxEnt, GIS, Endangered Species, Green Area

1. INTRODUCTION

Fukushima Prefecture is the third largest of Japan's 47 prefectures and extends over 150 km from the Pacific coast to the mountains of northeastern Honshu. The prefecture features diverse natural landscapes such as Abukuma highlands, Mt. Bandaisan, Lake Inawashiro, and the Echigo Mountains with beautiful ponds and lakes as shown in the Fig.1. However, the number of endangered species in the region has been increasing since the 1970s because of habitat loss caused mainly by rapid urbanization and infrastructure development.

Fig. 1 Map of Fukushima Prefecture, Japan

Regarding land-use change, numerous researches have analyzed areas and green coverage based on land use classification. A research by Hashimoto et al. [1] on umbrella species, which require large habitats and specific conditions, elucidated their winter habitat preferences in the Lake Inba basin. Field research has also been conducted on raptors, which involved evaluating the impacts of environmental factors on the birds using the jackknife method. Ikemi et al. [2] performed quantitative analysis regarding the impact of artificial landform changes on biodiversity through a time-series analysis of land use changes. Harada et al. [3] conducted quantitative analysis of the extent of degradation of a forest environment by means of a tree census. Iwasaki et al. [4] investigated the changes in land use until the 1980s and the linked increased damage to agricultural products caused by the expansion of the habitat of Japanese macaques. Li et al. [5] researched the impact of environmental variables and land use in Nagoya City on the habitat of raccoon dogs (*Nyctereutes procyonoides*) and Japanese weasels using maximum entropy modeling (MaxEnt) analysis, albeit without performing a broad-based analysis. Matsuura et al. [6] created vegetation models, for the Yatsu Higata tidal flats and estimated the size of the environment required by the gray-faced buzzard eagle. However, the gray-faced buzzard eagle also lives in habitats such as mountains under conditions different from those of tidal flats. Such habitats were not estimated in this research and require further study. Kamata et al. [7] proposed methods of forest zoning on the basis of land productivity and mountain disaster risk. However, performing analysis concerning wildlife habitats is also necessary. Miyamoto [8] indicated focal points for proposing marine protected areas by applying MaxEnt to the Emperor Seamount Chain using limited data. Pan et al. [9] estimated the suitable habitat area for the Chinese alligator, which is a critically endangered crocodilian, and predicted its distribution in Anhui Province, China using MaxEnt. West et al. [10] developed a presence-only model of invasive cheat grass (*Bromus tectorum*) distribution in Rocky Mountain National Park, Colorado, USA between 2007 and 2013 with limited data for comparison with the results of a generalized linear model. Remya et al. [11] represented current and future habitat suitability distribution of *Myristica dactyloides Gaertn*, a medicinally and ecologically important tree species, using MaxEnt to enable implementing a sustainable conservation or adaptation strategy. Pratumcharta et al. [12] predicted the distribution of *Bithynia siamensis goniomphalos* in Thailand on the basis of environmental and climatic factors and also indicated that altitude, land cover, normalized difference vegetation index, precipitation in the driest month, land surface temperature and, soil pH affected its distribution. Emad et al. [13] compared the habitat suitability similarity between MaxEnt, Random Forest and ensemble modeling approaches and it was concluded that MaxEnt is capable of producing distribution maps of comparable accuracy to other methods. Cory and John [14] indicated that both methods of MaxEnt and Maxlike are similarly valuable for predicting species distributions in terms of relative differences in occurrence probability.

Extant researches comprise the evaluation of lands and forests using geographic information systems, as well as the evaluation of habitats for target species using MaxEnt. However, few researches have been conducted on the impacts of urban development, including transportation infrastructure development, over time and in a wide area within wildlife habitats.

Therefore, in this research, we analyzed the time-series change of habitat areas for four endangered species: the golden eagle (*Aquila chrysaetos*), northern goshawk (*Accipiter gentilis*), Japanese macaques (*Macaca fuscata*), and Asian black bear (*Ursus thibetanus*) using MaxEnt software for modeling species distributions.

2. DATA

The wildlife habitat data used in MaxEnt were obtained from the Fukushima Red Data Books I [15] and II [16] compiled in 2002 and, plotted in QGIS. They were then converted into comma separated values data so as to be usable in MaxEnt. Having examined various habitat data, these were found to be the most suitable for analysis and further use. The habitat data were gathered using a mesh of 10 km × 10 km. At the time of plotting, the points were placed in the land-use category that occupied the largest portion of the mesh.

Table 1 shows the environmental variables used in MaxEnt. According to the digital national land information [17], seven environmental variables were used and arranged in MaxEnt using QGIS: land use subdivision data concerning Fukushima Prefecture from 1976, 1987, 1991, 2006, 2009, and 2014; mean elevation in 2009; mean inclination angle in 2009; mean annual temperature, mean annual precipitation, and deepest annual snow cover, calculated from the mean of the past 30 years; road edge data created between 2015 and 2016 by the Geographical Survey Institute of Japan [18]. Road edge data was obtained by calculating distance from the road with the raster distance tool in QGIS and digitizing it for analysis.

Table 1 Data sets input into MaxEnt

Data	Mesh size	Year	Source
Land use	100m	2014	Geospatial Information Authority of Japan
		2009	
		2006	
		1997	
		1991	
		1987	
		1976	
Average slope angles	10m	2009	
Average altitudes	10m	2009	
Average rainfall amount	1 km	2010	
Annual average temperature	1 km	2010	
Deepest snowfall in the year	1 km	2010	
Distance from nearest road	-	2016	

Fig. 2 shows the analyzed target species. The target species were selected from the Fukushima Red Data Books I and II. The selection criteria were: habitat conditions considered to be related to each environmental variable used in the research, species with a large habitat (because of the use of data from a 10 km × 10 km mesh), and the condition that the Fukushima Red Data Books recorded sufficient habitat data. As for the extent of habitat data, to ensure consistent accuracy, we selected those with 15 or more meshes indicating confirmed habitat.

As a result, the golden eagle and the northern goshawk, two raptors with a particularly large habitat, which are listed in Category I threatened species, were selected among birds. Two vulnerable species, the Japanese macaques and the Asian black bear were selected among mammals. Japanese macaques and black bears are vulnerable species, and although their conservation priority was not especially high in 2002, they were selected because of the increasing necessity of measures for conservation and animal protection that were expected in the future.

The land use classification of each period was based on digital national land information [17]. Land use subdivision meshes have different land use categories from year to year. To unify land use classifications and be able to perform analysis over time, we created a new classification that integrates land use into nine categories: rice fields, other agricultural land, forests, wastelands, built-up area, roads and transit corridors, other land, rivers and lakes, and seaside areas.

Fig. 2 Target species

3. RESULTS

3.1 Land Use Area Comparison

Table 2 shows a comparison of land use areas in Fukushima Prefecture. Between 1976 and 1997, the area of rice fields decreased consistently. The area of other agricultural land increased in the same period but decreased after 1997, resulting in a total area that was only 0.3% larger in 2014 than it was in 1976. Forested area decreased between 1976 and 2006 but recovered considerably after 2009. Despite conservation activities such as afforestation, the number of high-quality forests is likely decreasing because of the decline of forestry. Wasteland area decreased significantly between 1976 and 2014. Built-up area increased consistently. The land that is considered unsuitable as a wildlife habitat, such as built-up areas, roads and transit corridors, and other land increased by 82.7% between 1976 and 2014. The green ratio, including rice fields, other agricultural land, forests, and wastelands, decreased by 2.9% between 1976 and 2014. Since 2009, roads and railways have been divided into two categories. This accounts for the significant decrease in the area of roads and transit corridors after 2009. Prior to 2009, only one category was used for both types. Furthermore, in the applied land use subdivision mesh, the land use category that occupies the largest area in a 100 m × 100 m mesh constitutes the land use of that entire mesh. Thus, even if the area for roads and railways itself did not decrease, a newly built-up area in the surroundings might have come to occupy the larger share in the mesh, thus leading to the land use designation to be changed from roads and transit corridors to built-up area.

3.2 Suitable Habitat Area

Fig. 3 shows suitable habitat areas for the four target species according to MaxEnt between 1976 and 2014. The habitat suitability for the target species is expressed on the map as a value between 0 and 1. Habitat suitability increases, represented by a change in color from blue to green, yellow, orange, and red. White dots are habitat plot data confirming location of the target species.

For the golden eagle, suitable habitat is situated mainly in the southwest and north, for example in Oze National Park and Aizukomagatake, which features rich natural environment. In a comparative evaluation of suitable habitats for the period 1976–2014, almost no significant change was determined regarding the habitat suitability map.

Table 2 Comparison result of area of each land use

(1,000ha)

Land use	1976	1987	1991	1997	2006	2009	2014	Comparison between 1976 and 2014 (%)
Rice fields	162.1	157.0	155.0	149.0	149.0	146.8	145.2	-10.4%
Other agricultural land	89.6	96.6	96.5	103.0	95.2	87.4	89.9	0.3%
Forests	1002	997	992	972	971	1015	1009	0.7%
Wastelands	41.4	33.2	32.9	31.0	31.2	15.3	13.7	-66.9%
Buildup Area	36.5	43.0	42.8	54.8	57.3	62.6	63.2	73.2%
Traffic sites	1.6	2.5	6.6	8.1	10.5	1.3	5.4	237.5%
Rivers, Lakes and Ponds	35.1	35.2	35.0	40.9	36.4	30.1	33.6	-4.3%
Coastal Area	14.2	2.8	2.7	18.2	25.2	2.6	1.9	-86.6%
Others	9.3	12.5	16.1	18.8	26.8	18.1	18.0	93.5%

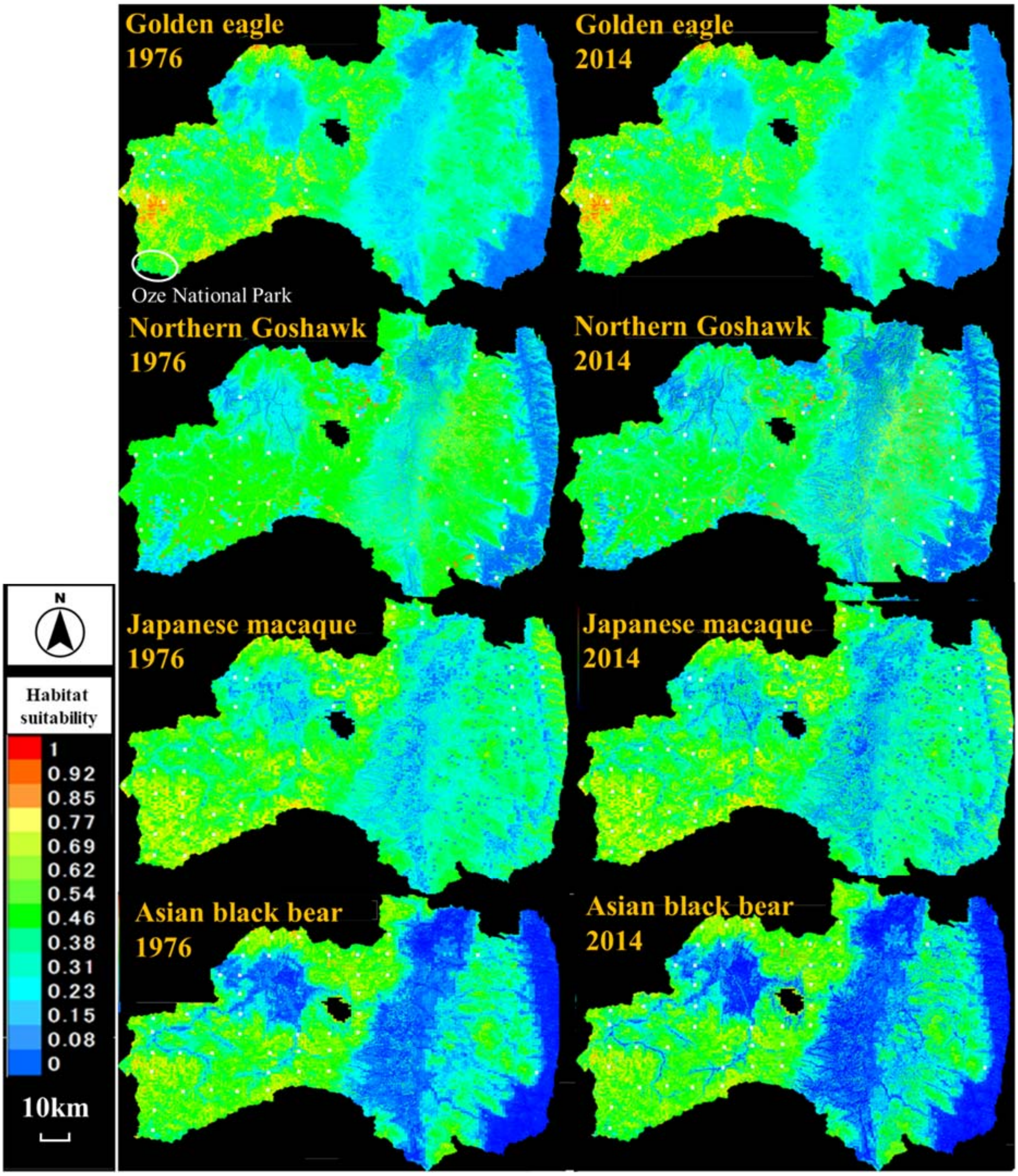

Fig. 3 Suitable Habitat Area Estimated by MaxEnt

The habitat suitability map for the northern goshawk shows that there are numerous suitable habitats, for example, in the mountains and the northern areas, between Hamadori and Nakadori, located in eastern and central Fukushima Prefecture, respectively. The most considerable change in the habitat suitability map between 1976 and 2014 is in Nakadori, Fukushima Prefecture, where habitats with a low degree of suitability have gradually been increasing. The same tendency can be seen in the Aizu region and the nearby mountainous areas, which are highly affected by recent urban development.

Suitable habitats for the Japanese macaque were identified in the northern part of Hamadori and in the north and southwest of Lake Inawashiro (black part in the center). For Japanese macaques, moderate-degree suitability habitats (yellow) were abundant, whereas highly suitable habitats (red and orange) were scarce. Because Japanese macaques may appear in urban areas in search of food, their habitat is considered widely distributed. Between 1976 and 2014, no significant change was found in the habitat suitability map. However, an apparent decrease of suitable habitats in the mountains is likely attributable to the increase of expressways.

The habitat suitability map of the Asian black bear shows suitable habitats in northern and southwestern Fukushima Prefecture. However, suitable habitats in these areas have decreased because of environmental changes as a consequence of deforestation as evidenced by a high contribution ratio of forest land.

3.3 Area under Curve and Contribution Rate

Table 3 shows the area under the curve (AUC) and contribution rate of respective environmental factors pertaining to each species. A model with an AUC value exceeding 0.7 is considered a favorable model. The closer the value to 1, the more superior is the model.

The AUC for the golden eagle was 0.775, a favorable result. Regarding the contribution ratio of the golden eagle, the land use contribution ratio was at 0.6% and therefore very low. Each environmental variable affects the golden eagle. For example, the mean slope angles and mean altitude have a large impact. The influence of these two environmental factors may be high because the golden eagle lives and nests on rocky spots in mountainous areas, such as steep cliffs. However, the land use contribution ratio was only 0.6%. Therefore, the impact of land use is not substantial. The highest contribution ratio is that of other agricultural lands.

The AUC of the northern goshawk was 0.765, which is a favorable result. The contribution ratios of land use and mean altitude for the northern goshawks were as high as 49.5% and 33.2%, respectively. Fig. 4 shows the detailed land use contribution ratio for the northern goshawk. Fig. 4 presents the contribution ratio showing which land uses are likely to influence habitat suitability and the likeliness of habitat suitability itself. Since raptors such as the northern goshawk catch their prey in grasslands, paddy fields, and wetlands, which are sites with favorable visibility, the contribution ratios of rice fields, other agricultural lands, and wastelands were high. By contrast,

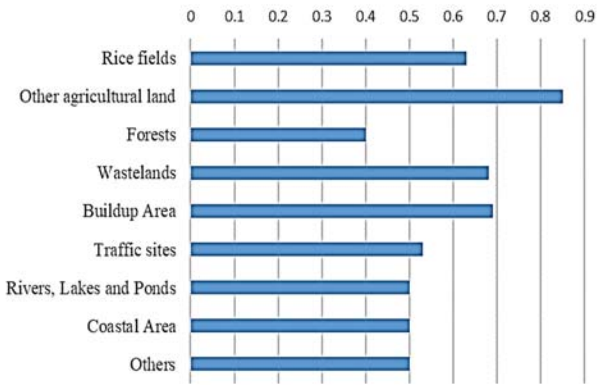

Fig. 4 Response Curve on Each Land Use of Northern Goshawks

forests exhibit reduced visibility and obstruct flight, resulting in a low contribution ratio.

The AUC for the Japanese macaque was 0.766, which was a favorable result. The highest contribution ratio for Japanese macaques was temperature, followed by the angle of inclination. Regarding Japanese macaques, all environmental variables contributed to a degree. Consequently, habitat suitability tended to be high only in areas where all environmental factors were well-balanced. The AUC for the black bear was 0.809, the highest among the four target species. In the case of the black bear, the contribution ratios were high for temperature, land use, and snowfall. This suggests that the black bear is easily affected by environmental factors related to temperature.

3.4 Time-Series Change of Potential Suitable Habitat Areas

Table 4 and Fig. 5 show numerical values corresponding to the changes in potential suitable habitat areas in Fukushima Prefecture over time for each of the four species. From the data in the ASC file obtained by MaxEnt analysis, data pertaining to suitable habitats at a ratio of 0 to 1 were extracted and used to define potential suitable habitat areas by multiplying the numerical values by the area of

Table 3 AUC and Contribution Rate of Respective Environmental Factors

	AUC	Land use (%)	Average rainfall amount (%)	Annual average temperature (%)	Average altitudes (%)	Average slope angles (%)	Deepest snowfall in the year (%)	Distance from nearest road (%)
Golden eagle	0.775	0.6	0.8	1.8	32.7	52.0	0.3	11.9
Northern goshawk	0.765	49.5	5.2	0.0	33.2	1.2	10.8	0.1
Japanese macaque	0.766	15.3	6.6	28.2	5.1	23.3	11.9	9.7
Asian black bear	0.809	18.2	1.5	48.2	0.6	9.9	18.2	3.4

Table 4 Result of Potential Suitable Habitat Area between 1976 and 2014

	1976	1987	1991	1997	2006	2009	2014	Comparison between 1976 and 2014
Golden eagle	48.75	48.65	48.81	48.80	48.47	48.75	48.80	0.10%
Northern goshawk	50.76	51.40	50.76	51.40	51.22	48.01	46.99	-7.44%
Japanese macaque	54.28	54.04	54.18	53.61	52.40	52.33	52.35	-3.57%
Asian black bear	43.55	43.37	43.46	43.42	43.08	42.93	42.72	-1.92%

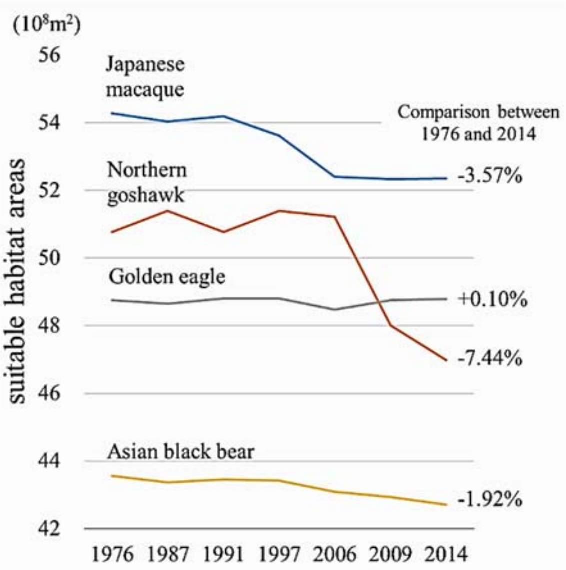

Fig. 5 Potential Suitable Habitat Areas of Each Species

each mesh (100 m x 100 m). A comparison between 1976 and 2014 confirmed a decrease in suitable habitat areas by 3.57% for the Japanese macaque, by 7.44% for the northern goshawk, and by 1.92% for the black bear. The suitable habitat areas for the golden eagle increased by 0.1%. The results suggest that a decrease in suitable habitats for wildlife because of urban development and transportation infrastructure has become increasingly likely.

Fukushima prefecture has relisted northern goshawk as Category II [19]. However based on this prediction, the species has a vulnerability of habitat without suitable conservations. While encountering or more serious accident related to black bear increases recently, and the latest result of research on population density of the black bear inside the prefecture supported the increase of the accident [20]. In the future, it needs to conduct the more detailed prediction of habitat of the black bear and to propose a policy of the ecological conservation and management for preventing the accident based on the potential habitat map.

4. CONCLUSIONS

In this research, MaxEnt was used to analyze suitable and potential habitat areas of four endangered species in Fukushima Prefecture over time, demonstrating the impact of rapid urbanization and infrastructure developments and the tendency for the area of suitable habitats to decrease for all target species except the golden eagle. The reduction rate of potential suitable habitat area for Northern goshawk was particularly high. This is due to the fact that Japan does not require compensatory measures for development by environmental impact assessment law. Thus, it is necessary to actively implement nature restoration projects against past development and to promote conservation policies and systems, such as defining areas of the natural environment to be protected.

For future research, the accuracy of the plot data for habitat areas should be improved by collecting more data and by including additional environmental variables for MaxEnt.

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