CHANGE IN HABITAT SELECTION BY JAPANESE MACAQUES AND HABITAT FRAGMENTATION ANALYSIS USING TEMPORAL REMOTELY SENSED DATA IN NIIGATA PREFECTURE, JAPAN

Shota MOCHIZUKI [1] and Takuhiko MURAKAMI[2]
[1]*Graduate Student, Graduate school of science and technology, University of Niigata, 8050, Ikarashi-2no-cho, Nishi-ku, Niigata 950-2181, Japan; Tel: +81-25-262-6627; Fax: +81-25-262-6627*
E-mail:mochi.sho@gmail.com

[2]*Associate Professor, Graduate school of science and technology, University of Niigata, 8050, Ikarashi-2no-cho, Nishi-ku, Niigata 950-2181, Japan; Tel: +81-25-262-6627; Fax: +81-25-262-6627*
Email: muratac@agr.niigata-u.ac.jp

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ABSTRACT: The aim of this study was to evaluate changes in macaque habitat selection during a 29-year period. We focused on the 1970s, when little crop damage was caused by Japanese macaques (Macaca fuscata), and the 2000s, when the damage became remarkable. Landsat/MSS from 1978 and ALOS/AVNIR-2 from 2007 were employed for land-cover mapping. For the 2007 land-cover classification, we applied an object-oriented image classification and a classification and regression tree. The Kappa coefficient of the 2007 land-cover map was 0.89. For the 1978 land-cover classification, change detection using principal component analysis and object-oriented image classification were applied to reduce resolution difference errors. The Kappa coefficient of the 1978 land-cover map was 0.84. We applied a Random Forest model for machine learning and data mining to predict the habitat selection of macaques. Several important environmental factors were identified for macaque habitat selection: the ratio of coniferous forest to farmland, distance to farmland, and maximum snow depth. The Random Forest model was extrapolated to the 1978 land-cover map. Over the 29-year period, coniferous forest changed to broad-leaved forest and/or mixed forest within the macaque habitat area. Coniferous forests were not selected as food resources by Japanese macaques. Furthermore, large-scale patches of farmland were used as food resources over the 29-year period. These changes indicated that habitat selection by Japanese macaques changed over the study period. The results show that the home range of macaques expanded, and macaques may now be distributed over a wider area as a result of changes in landscape configuration. Thus, forest planning, such as sustainable management of artificial conifer forests, is important for reducing crop damage.

1. INTRODUCTION

Human–wildlife conflicts can result in crop and forestry damage (Conover, 2002). Such conflicts present serious problems worldwide. To plan wildlife management, we must first understand the details of resource selection by wildlife, considering landscape structure (Manly *et al*., 2002). In Japan, the conflict caused by mid-sized mammals is significant. Japanese macaques live the farthest north of any nonhuman primate species (range 30°21–41°08’N) and utilize various habitat types (Wada and Tokida, 1981). Japanese macaque is known worldwide as the “snow monkey.” The behavior of macaques is quite varied (Yamada and Muroyama, 2010). Therefore, management of macaque habitat is necessary for the effective management.

The spatial configuration of landscape patches influences ecological characteristics. Landscape configuration is the physical distribution and spatial character of patches within a landscape mosaic. Thus, it is necessary to quantify land-cover type and the landscape mosaic. Remotely sensed data can represent surface conditions over long periods, allowing for evaluations of land-cover changes such as forest fragmentation within wildlife habitats. Furthermore, predictive habitat models that can account for environmental factors related to human–wildlife conflict are effective for wildlife management. Models can help assess the impact of changing land use and identify potential conflicts with human activities (Hansen *et al*. 2001).

We used temporal remotely sensed data to detect changes in landscape configuration. The impacts of forest fragmentation on spatial habitat selection by wildlife were also evaluated. In this study, we focused on the 1970s, when little damage was caused by macaques, and the 2000s, when the damage became remarkable. Using LANDSAT/MSS data in 1978 and ALOS/AVNIR-2 data in 2007, a habitat-selection map for Japanese macaques was created in two stages, aimed at evaluating the change over a 29-year period. The objective of this study was to determine changes in habitat selection in response to forest fragmentation. In particular, change in habitat selection was predicted from the change in forest configuration.

2. STUDY AREA AND DIGITAL DATA

The study area was Shibata city, Niigata Prefecture, Japan (37° 57’ N, 139° 19’ E, 532 km^2, Fig. 1). Elevation ranges from -19 to 1496 m above sea level. The forest cover of the study area was 64%. Crops in this region have been damaged by macaques since the late 1970s, and the area affected has expanded gradually. The main crops damaged are paddy rice, soybean, and potato. Twelve troops of Japanese macaques were studied using data acquired from June to November during 2005–2007 by hunters. The information gathered included location data obtained by VHF-radio-tracking. Two location points per day for each of the 12 troops were acquired with 1,989 total points collected.

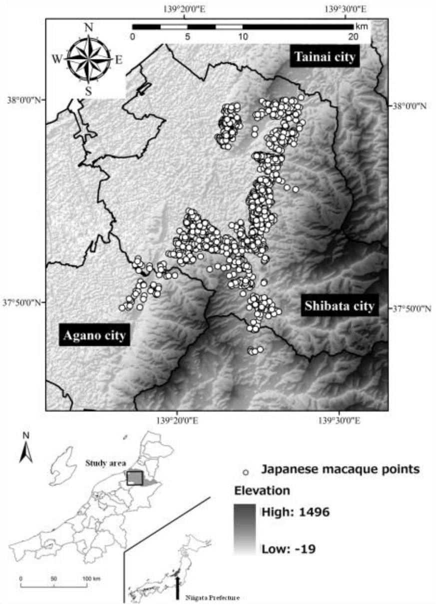


Fig. 1. Study area

Two scenes of remotely sensed imagery were acquired. A MSS image acquired on July 29, 1978 was used to represent the study area with little crop damage in the late 1970s. An AVNIR-2 image was acquired on August 12, 2007, to represent a more recent landscape composition that had experienced remarkable crop damage. We used the digital number in an observation wavelength band and the normalized difference vegetation index (NDVI), which shows vegetation quantity, to classify the land-cover of the study area. NDVI is defined as *NIR-RED/NIR+RED*, where *RED* and *NIR* are the digital numbers of the visible red and near-infrared bands, respectively.

3. METHODS

3.1 Land-cover classification and spatial pattern for 2007 and 1978

Land-cover for 2007 was classified by object-oriented classification using AVNIR-2 data. We used the commercial software eCognition ver. 4. An AVNIR-2 data were segmented with scale: 10, shape: 0.3, and compactness: 0.4. We defined seven classes: broad-leaved, conifer, grassland, farmland, urban, bare land, and water. A CART system (Breiman *et al.*, 1984) model was applied using image object features that were the mean and standard deviance of the DN and NDVI. The classification training data were extracted from the area in which land covering could be clearly checked using an aerial photograph from 2006. We applied the Kappa coefficient and standard error for the accuracy assessment (Stehman and Czaplewski, 2003). The overall accuracy was 91.8%, and the Kappa coefficient was 0.89 (Table 1). The standard error of each class was low. However, the reliability of the classification of grassland and bare land was low, based on standard error.

A 1978 land-cover map was derived for the change detection analysis to minimize the errors caused by differences in spatial resolution. First, the NDVI composite image was prepared by stacking AVNIR-2 and MSS imagery. In this study, the correction of intensity and change detection were extracted by applying principal component analysis. In principal component analysis, the first principal component can be expected to show almost the same effect as a radiometric collection technique like the pseudo-invariant target method (Hall *et al.*, 1991). In addition, the second principal component is expressed as the change detection from a past to a more recent view. The threshold value was determined with the nearest-neighbor method for the second principal component imagery and was classified into the three classes: “NDVI plus,” “NDVI minus,” and “no change.” Then, only the changed area was masked to the MSS imagery, and the object-oriented image classification was applied for the masked area. In the segmentation, the parameters were scale: 4, shape: 0.3, and compactness: 0.4. Seven classes of land-cover type were defined like the 2007 classification. The classification training data were extracted from the area for which land cover could be clearly checked using aerial photographs from 1975 as reference data. The overall accuracy was 88.7%, and the Kappa coefficient was 0.84 (Table 1). However, the reliability of the classification of grass land, bare land, and water areas was low based on standard error. The error produced from the resolution differences between satellite imagery could be reduced by applying change detection using principal component analysis and object-oriented image classification. This method was effective because land-cover changes occurred not in a pixel unit but in a fixed domain.

Table 1. The accuracy of land-cover classification in 2007 and 1978

	Broad	Conifer	Grass	Farm	Urban	Bare	Water
Land-cover in 2007							
PA (%)	89.2	88.7	78.8	90.8	89.2	74.1	100
SE	0.002	0.006	0.020	0.001	0.009	0.022	0.000
UA (%)	93.5	85.5	49.8	95.9	86.8	78.2	100
SE	0.002	0.005	0.017	0.002	0.008	0.023	0.000
Overall accuracy=0.92, Kappa=0.88, 95 % confidence limits for kappa: 0.857 ... 0.920							
Land-cover in 1978							
PA (%)	87.5	86.7	68.3	81.9	92.9	65.8	93.2
SE	0.002	0.006	0.021	0.002	0.011	0.032	0.000
UA (%)	89.6	75.3	46.3	92.4	86.8	70.6	100
SE	0.002	0.005	0.020	0.002	0.009	0.033	0.018
Overall accuracy=0.88, Kappa=0.84, 95 % confidence limits for kappa: 0.807 ... 0.881							

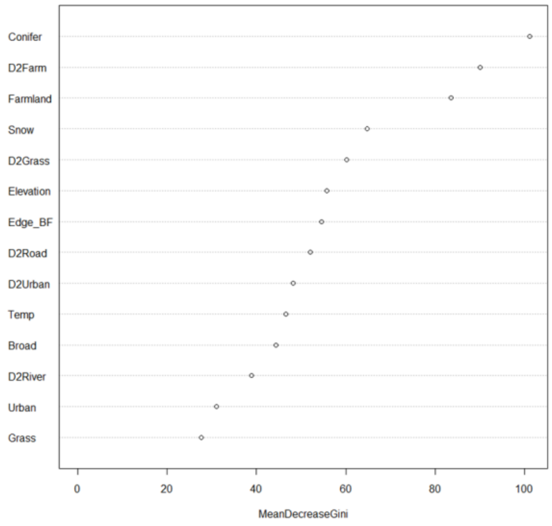
The area within the forest and the landscape structure less than 300 m from the forest boundary, which is the main habitat for the macaques, was extracted, and the change in forest configuration from 1978 to 2007 was evaluated. Quantification and comparison of the spatial pattern of forest patches between time periods was conducted using landscape indices. We used FRAGSTATS 3.3 (McGarigal *et al*., 2002) and applied six landscape indices that represented the patch fragmentation: number of patches, edge density, mean patch size, area-weighted mean patch size, mean shape index, and area-weighted mean shape index. In this study, we used patch-based metrics and area-weighted metrics to restrict the bias of each metric (Linke *et al*., 2009).

3.2 Statistical analysis

We analyzed habitat selection within home ranges of Japanese macaques. A use-availability approach was designed. The location data comprised a total of 1,989 data points and were treated as habitat-use points by macaques. As a sample of availability, the same number of habitat use points was distributed within the home range, defined by the 100% minimum convex polygon method. These random location data were treated as habitat availability points (n = 1,989). The use-availability data were divided into model training and verification data. Environmental variables related to the habitat selection of Japanese macaques were selected using a deductive approach. We selected 14 variables: elevation, maximum snow depth, mean temperature in winter, the amount of edge between broad-leaved deciduous forests and farmland, distance to river, grass land, farmland, urban land, and road, the ratio of broad-leaved deciduous forest, coniferous forest, grassland, farmland, and urban land. We used the Random Forests method (Breiman *et al*., 2001) to examine the relationship between use-availability and each environmental variable. This approach combines many different trees based on bootstrap samples of the training data set. We built 500 trees by default. The number of variables to randomly select was chosen to minimize the final regression error. We assessed predictive accuracy using the AUC. Finally, the optimal model was extrapolated to the land-cover map created from the 2007 AVNIR-2 imagery and the 1978 MSS imagery. The map of predicted occurrences, which is the habitat selection response for 2007 and 1978, was created using the Random Forest results.

4. RESULTS

The change in habitat configuration from 1978 to 2007 was evaluated using fragmentation analysis. The number of patches within macaque habitat decreased. The mean patch size and mean shape index increased over the 29-year study period. Edge density increased in forest and decreased in grassland, farmland, and urban area. Area-weighted mean patch size increased in forest and grassland but decreased in farmland and urban area. The area-weighted mean shape index decreased only in urban areas. Broad-leaved deciduous forests and coniferous forests showed similar tendency toward fragmentation. However, the ratio of change in forest fragmentation differed.



The importance of predictor variables was evaluated by the Random Forest model. Highly ranked variables were the ratio of coniferous forest, ratio of farmland, distance to farmland, and snow depth (Fig. 2). The AUC was 0.96 for the Random Forest model, indicating that the habitat selection of Japanese macaques was predicted by the model with high precision. Potential maps of the occurrence, which is the result of habitat selection for 1978 and 2007 are shown in Fig. 2 (a), (b) and (c). To evaluate changes in the main habitats of Japanese macaques, these maps depicted only the forest region and areas less than 300 m from the forest boundary. From 1978 to 2007, habitat selection within the macaque habitat changed substantially. These figures show that the relative occurrence of Japanese macaques changed considerably from 1978 to 2007 as a result of changes in habitat selection.

5. DISCUSSION

The fragmentation analysis showed decline in the coniferous forests in the study area. In particular, the ratios of change in edge density and area-weighted mean patch size were two times different between broad-leaved deciduous forests and coniferous forests. These results suggest that coniferous forest patches not only became smaller, but also became more similar in size during the 29-year period. The reduction in the number of patches indicates that coniferous forest changed in relation to other landscape structures. In grassland and farmland, as edge density decreased and mean-patch size increased, patches became larger and more connected. Conversely, large-scale patches disappeared from grassland as area-weighted mean patch size decreased. Similarly, with change in land use by agricultural development, area-weighted mean patch sizes increased in farmland. These results indicate that food resources increased from 1978 to 2007.

Our Random Forest modeling results indicated that coniferous forest was a risk factor, while farmland was an important food resource for macaques. Clear changes can be seen when comparing maps of relative occurrences of Japanese macaques in 1978 and 2007 (Fig. 2). The area in which the predicted value increased from 1978 to 2007 was related to the reduction in coniferous forest. The home range of Japanese macaques is thought to have increased with the decline in coniferous forest over the 29-year period. The relationship between the coniferous forest and the behavior of Japanese macaques has been previously studied (Izawa *et al*., 1985). These reports suggested that Japanese macaques inhabited the edge between forest and farmland due to the destruction of habitat that accompanied the expansion of coniferous forests. Crop damage by macaques increased in the late 1970s along with afforestation with artificial plantations of coniferous forest (Agetsuma, 2007). On the other hand, we suggest that the expansion of crop damage in the 2007 resulted from a decline in coniferous forest. Forestry activities are rarely performed in the study area at present. The afforestation area that consists of a coniferous forest had not been managed. Therefore, the broad-leaved deciduous forest is mixed in the coniferous forest. This transition from coniferous forest to broad-leaved deciduous forest suggests that the cultivated

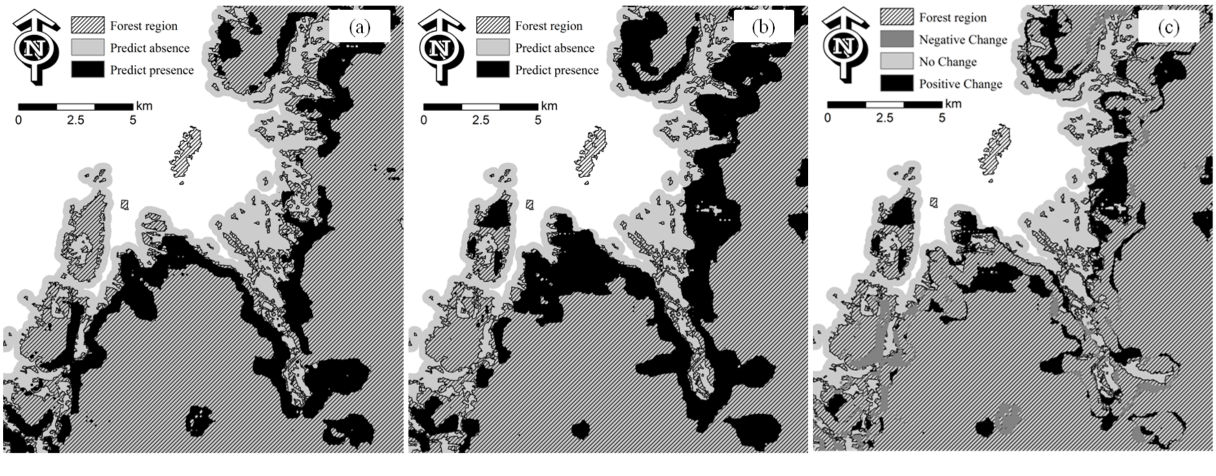


Fig. 2. The occurrence of Japanese macaques. The result of extrapolation in 1978 (a), and 2007 (b). Change in occurrence of Japanese macaques (c).

species of broad-leaved deciduous forest spread from farmland areas and continues to grow. From 1978 to 2007, the agricultural form changed greatly and, as a result, farmland became a large-scale food resource for Japanese macaques. The change in nutritional state resulting from consumption of agricultural products would also influence the expansion in macaque distribution. Forest influence and food resource configuration changes have direct effects on macaque habitat selection. Our results suggest that the distribution of Japanese macaques has expanded due to changes of the spatial configuration of forests and food resources from 1978 to 2007. At the same time, human–wildlife conflicts have occurred due to the changes in Japanese macaque habitat.

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