DOI https://doi.org/10.1016/j.landurbplan.2010.04.014
Link to published journal article:
http://www.sciencedirect.com/science/article/pii/S0169204610000897?via%3Dihub

Risk of Agricultural and Property Damage associated with the Recovery of Japanese Monkey Populations

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1. Introduction

Human-wildlife conflicts have arisen and intensified across the world and are fundamentally connected with increases in human populations and their activities (Thirgood, Woodroffe & Rabinowitz, 2005). In some cases, however, the conflicts have been intensified by the increase and spread of wildlife populations, as a result of protection activities or the loss of a sound ecosystem caused by human activities (Belant, 1997; Messmer, 2000). In Japan, these conflicts have been recorded since the seventeenth century (Tsukamoto, 1983). The Japanese monkeys (*Macaca fuscata*), which inhabit many parts of the Japanese islands, have become one of the most serious mammalian pests in Japan, owing to their agility, high intelligence, and excellent climbing ability (Watanabe, 2000; Sprague & Iwasaki, 2006). At present, there are no effective countermeasures against the damage caused by this species, except for the establishment of a robust enclosure (Watanabe, 2000). In 2007, the total agricultural damage caused by monkeys reached ¥1,600,000,000 (ca. US$144,000,000) (Ministry of Agriculture, Forestry and Fisheries of Japan, unpublished data). To put this figure into context, in 2007, the gross agricultural production in Japan's mountainous regions was approximately ¥700,000,000,000 (ca. US$6,300,000,000). Property damage (e.g., broken roof tiles, home intrusions) has also increased in several regions of Japan (Sprague & Iwasaki, 2006). Therefore, there is an urgent need to establish a valid management procedure for maintaining a balance between damage control and monkey conservation (Watanabe, 2000).

The human-monkey conflict appears to be more serious in the northern Tohoku district (Fig. 1). Monkeys inhabiting the district prior to the Second World War sustained overhunting by local residents for food and medical supplies; consequently, the species became locally extinct in several regions across the district (Mito, 1992) (Fig. 2). Therefore, the Japanese Ministry of Environment Red List describes the species as having endangered regional populations. In recent decades, the remnant populations have gradually recovered (Fig. 2). There are three reasons for this: 1) in 1947, a hunting ban was enacted for monkey protection; 2) the main predator for monkeys (*Canis lupus*) became extinct in the beginning of the twentieth century; and 3) in recent years, snow accumulation has declined with winter warming (Watanabe, 2000; Agetsuma, 2007). Since the 1980s, this recovery has concurrently caused serious damage to district communities (Watanabe, 2000). Policymakers in affected communities have difficulties in establishing a social consensus around the conservation of these monkey populations and mediating the damage that they cause (Maruyama, 2006). In order to adopt a comprehensive approach to conflict resolution, it would be effective to identify the risk of damage caused by contact between the monkey populations and human communities and to consider a reasonable management plan for the district, which supports regional populations as well as minimizes the overall risk of damage. There have already been several efforts to predict wildlife damage, using modeling damage patterns (Naughton-Treves, 1998; Tourenq et al., 2001; Sitani, Walpole, Smith, & Leader-Williams, 2003). However, only a few risk management approaches have been executed (LeLay, Clergeau, & Hurbert-Moy, 2001; Fernández, Kramer-Schadt, & Thulke, 2006).

In this study, we develop a simplified technique to assess the risk of damage caused by monkeys based on the risk triplet concept (Kaplan & Garrick, 1981), and apply the technique to all the municipalities in the northern Tohoku district (n = 100). We then compare all the risk figures in order to identify the municipalities where precautionary actions should be taken to efficiently minimize the overall risk of damage.

2. Study area and subjects

2.1. Study area

The northern Tohoku district (36,500 km^2) comprises three prefectures: Aomori, Akita, and Iwate. It is located in the northernmost part of the main island of Japan (Fig. 1). The district is a mountainous area located in a cool, temperate climatic zone. There is a backbone range, the Ōu mountain chains, located along the prefectural boundary between Iwate and Akita. The western range is a heavy snowfall area, receiving a maximum 1–5 m each year. The district is covered with mountainous forests (71.7% of the area) that are dominated by deciduous broadleaf species such as *Fagus crenata* and *Quercus crispula*, and coniferous plantations of *Cryptomeria japonica* trees (Biodiversity Center of Japan, 1998). Human residential areas are restricted to small areas of flat lowland, and paddy fields, fruit orchards, and vegetable farms are distributed around them; these areas account for 20.1% of the district (Fig. 1). Due to such geographic constraints, most of the human settlements, including farmland and excepting several regional hub cities, lie directly adjacent to mountainous forest. The district is a typical depopulated area in Japan, and farming is one of the few principle income sources for local residents.

2.2. Study subjects

Japanese monkeys are a gregarious forest mammal with a frugivorous and folivorous diet (Fooden & Aimi, 2005). The species is a diurnal mammal and naturally moves in troops within its territories. The average troop comprises 10–100 individuals (Takasaki, 1981), and solitary males and small male groups naturally move around the troops. The maximum longevity and mean population growth rate of wild monkeys under natural conditions are approximately 20 years and 3%, respectively (Fooden & Aimi, 2005).

There are four isolated local populations (LPs) of monkeys within the district—Shirakami LP, Tsugaru LP, Shimokita LP, and Goyozan LP. The range areas as of 2003 were about 2,000 km^2, 400 km^2, 800 km^2, and 150 km^2, respectively (Fig. 2). As of 2003, the population sizes were >2,200 individuals for

Shirakami LP (Aomori & Akita Prefectures, unpublished data), unknown for Tsugaru LP, >1,300 individuals for Shimokita LP (Aomori Prefecture, unpublished data), and around 100 individuals for Goyozan LP (Oi, 2002). These LPs are remnants of past overhunting, and their distributions had increased by 1.5 times between 1978 and 2003 (Biodiversity Center of Japan, 2004). This recovery, however, has caused critical damage among fruit orchards, rice paddies, and root vegetable farms in the district; for example, the agricultural damage in 2005 amounted to ¥240,000,000 (ca. US$2,160,000) in the Shirakami Mountains, ¥40,000,000 (ca. US$360,000) in the Tsugaru Peninsula, ¥65,000,000 (ca. US$585,000) in the Shimokita Peninsula, and ¥400,000 (ca. US$3,600) in the Goyozan Mountains, according to local governments' unpublished reports of data captured through hearing-based surveys of all the farmers living in these areas. Moreover, property damage frequently occurred in Aomori Prefecture, with 11 out of 40 municipalities there sustaining constant monkey-inflicted damage in 2006. In Iwate and Akita, those ratios were two out of 35 and four out of 25, respectively.

3. Methods

3.1. Outline of the risk assessment procedure

Risk is generally defined as the probability that something undesirable (called an endpoint) will happen, and risk assessment involves the quantification of this probability (Rowe, 1977). On the basis of the risk triplet concept (Kaplan & Garrick, 1981), risk can be quantified by identifying the possible endpoints relating to an event of interest (E), estimating the likelihood that these endpoints will occur (L), and predicting the social impacts of these endpoints on subject areas when the event occurs (I). Then, the risk for endpoint i (E_i) is typically calculated by multiplying L_i and I_i. Using this method, the authors invented a simplified technique to assess the damage risk related to the recovering monkey populations, by undertaking a large-scale evaluation of environmental space and human land use. We preliminarily identified two endpoints for assessing risk: agricultural damage as a hazard for farmers (E_a) and property damage as a hazard for the general public (E_p). Then, as the index of "*L*," we adopted the species accessibility to each community. The agricultural and property damage caused by monkeys, with a few exceptions, will occur in a community once the species distribution reaches it (Watanabe, 2000). It is therefore reasonable to assume that the probability of damage occurrence is dictated by how readily the species can access a subject community. Next, as the index of "*I*," we assigned the regional weakness to damage by monkeys; in the common risk assessment procedure, the degree of negative impact when the endpoint occurs is determined by vulnerability to the hazard (Chardon, 1999; LeLay et al., 2001). Finally, we calculated the risk for each agricultural and property damage, by multiplying species accessibility and regional weakness to each damage.

3.2. Species accessibility

First of all, we computed the likelihood that agricultural and property damage would occur (*L*), by evaluating species accessibility. Given that the monkey distribution was expected to expand more easily in areas with higher habitat suitability (Iwasaki & Sprague, 2005), it is possible to estimate roughly the spatial diffusion of the species by using a geographical accessibility analysis, based on a species niche evaluation (Peterson & Vieglais, 2001; Peterson & Robins, 2003). We then adapted an ecological-niche factor analysis, or ENFA (Hirzel, Hausser, Chessel, & Perrin, 2002), to evaluate the species niche and generate a habitat suitability map of the species. Niche-based modeling, including an ENFA, assumes that the species is not randomly distributed in terms of their ecological and physiological preferences with respect to various environmental features (e.g., altitude, vegetation, climate, and terrain). A primary characteristic of the modeling is that it summarizes the environmental variables into a few uncorrelated "composite factors" that can explain the species' presence, which is the same as the principle component analysis (PCA) procedure. The ENFA technique, however, differs from PCA in that the factors produced directly via an ENFA have two ecological meanings. One is species marginality, which indicates how far the mean of the species distribution differs from the mean of the overall distribution of available conditions in the entire reference area. The other is species specialization, which shows how specialized the species distribution is, compared to the overall distribution of environmental variables in the entire reference area. The first of the composite factors produced by ENFA explains 100% of the marginality and some specialization; the second and subsequent factors explain the remainder of the specialization. ENFA also provides general clues about the subject species' niche (i.e., total marginality and total specialization), by integrating all these species marginality and specialization factors. Total marginality values range from 0 to 1, and as this value increases, the species distribution becomes more biased with respect to the mean available habitat conditions in the reference area. Meanwhile, total specialization ranges from 1 to ∞; as this value increases, the width of species niche decreases. For a detailed description of an ENFA, see Hirzel et al. (2002).

For modeling a suitability map of a species, an ENFA requires only proof of that species' presence. We prepared a species map with raster-based grids, defined by the horizontal coordinate system of the Tokyo UTM Zone 54N. For this map, a dataset pertaining to the species presence, derived from the "Sixth National Survey on the Natural Environment Report" (Biodiversity Center of Japan, 2004), was used. This survey provides the distribution of Japanese monkeys in 2003 at 5 × 5-km resolution, an area size that roughly corresponds with the home range of monkey troops in cool-temperate forests (Watanabe, 2000). Every five years, this national survey of Japanese mammals is conducted nationwide; animal distributions are mapped, using all direct and indirect evidence of the presence of the subject mammals as provided by local officials, the hunters' union, the forestry cooperative, the agricultural union, the national forest rangers, and the national park rangers of each area (Biodiversity Center of Japan, 2004). This national survey, however, occasionally includes some minor misinformation about species distribution. In generating the present species map, we collected direct evidence of species presence by conducting supplemental hearings with local field researchers, knowledgeable residents, and prefectural officers, between July and October 2006. As a result, the reformed species map comprises 140 presence points (rightmost map in Fig. 2). Because the subject monkey populations in this study were remnant ones, the number of available presence points of the species was not really abundant. However, it is reasonable to consider that these presence points contain enough information to explain the species-habitat relationship at the population level, given that human influences on the animals' habitat occupation have been quite small during the past 50 or more years, due to species conservation policies (see the Introduction section).

The marginal environment that determines the distribution of monkeys is naturally regulated by primary resources such as food and refuge, which are defined by conditions of vegetation, land use, climate, and topography (Fooden & Aimi, 2005). Specifically, Iwano (1980) examines historical changes in the distribution of monkey populations and argues that heavy snowfall regions, high-elevation environments, and steep terrain conditions have the most negative influence on species habitat occupation. Meanwhile, Mitani & Ikeguchi (1997) repeatedly conduct univariate analyses to quantify the influence of various environmental factors on the monkey distribution; they assert that breeding populations of the species in cool-temperate zones are likely to cover lower parts of the broad-leaved forests, thus avoiding human activities. With the exception of these studies, there are few studies concerning landscape-scale evaluations of monkey-habitat relationship; therefore, in light of these limited developments, we used all the possible environmental variables for the present ENFA (Table 1). In general, as more and more input variables are introduced to a multivariable analysis, multicollinearity and redundancy increase. As with PCA, however, ENFA has the advantage of being able to deal skillfully with this problem (Hirzel et al., 2002). For each input variable, we arranged raster maps with 500 × 500-m resolution (Tokyo UTM Zone 54N). Matching consistency of scale with environmental variables and species presence data is of key significance in quantifying species-environment relationships (Van Horne, 2002). Hence, in keeping with the finer scale of grid resolution (500 × 500 m) used in the present ENFA, a two-dimensional moving average, or moving window technique (called BLOCK STATISTICS in ArcGIS 9.1 [ESRI, Redlands, CA, USA]), was used. That is, each variable map was transformed into a new one, storing the mean of the probabilities assigned to the nearest cells of each category within a square moving window of 5 × 5 km for matching the original resolution of the species map; the species map was then downscaled to a 500 × 500-m resolution. This process also contributed to the transformation of variable maps with a Boolean dataset (presence/absence data type) into those with a quantitative dataset (frequency data type); only the latter type of dataset can be utilized in ENFA. To improve the performance of the predictive model, it is necessary to optimize the normality of distributions of each environmental variable. We therefore transformed the distribution of each variable by using a Box-Cox transformation (Sokal & Rohlf, 1981).

After composing those environmental variables via an ENFA, we selected a few significant composite factors for further analysis, by using the broken-stick technique (Hirzel et al., 2002). To compute the species habitat suitability using an ENFA, we used the "distance geometric-mean algorithm," a commonly used approach that maintains the good generalization power of a model (Hirzel & Arlettaz, 2003). The index of habitat suitability ranged from 0 (unsuitable) to 100 (optimal). To verify the performance of the model, we used a *k*-fold cross-validation technique (Fielding & Bell, 1997; Boyce, Vernier, Nielsen, & Schmiegelow, 2002) with $k = 10$, a commonly used number in the ENFA models. To improve the performance of the habitat suitability model by using an "area-adjusted frequency cross-validation technique" (Boyce et al., 2002), we reclassified the habitat suitability values of each map into five classes (called "bins") of equal size: unsuitable (0–20), rather unsuitable (20–40), suitable (40–60), suboptimal (60–80), and optimal (80–100). The Boyce Index, on the basis of a Spearman rank correlation (Boyce et al., 2002), was then computed as an index of model accuracy. We performed all operations using the BIOMAPPER 3.2 software (Hirzel, A.H., Hausser, J., & Perrin, N., Lausanne, Switzerland: retrieved September 30, 2009, from http://www.unil.ch/biomapper/).

We then created a map of species accessibility using a least-cost analysis, which calculates preferable landscape connectivity for the species (Adriaensen et al., 2003); there were three steps therein. First, a cost surface, or species unsuitability map, was created, storing the reciprocal value of the habitat suitability index. Each cell value of this surface accounted for the impedance of crossing each individual cell. Second, a cost distance map, or species inaccessibility map, was created, storing the least accumulative cost distance value, starting from the current species presence origins and traveling through that cost surface. This cost distance map showed how much it would cost each cell to return to a source of species presence via the lowest-cost path. This procedure was performed using the COSTDISTANCE function in ArcGIS 9.1. Third, this cost distance map was transformed into a species accessibility map, through a reciprocal transformation. For the risk computation, we prepared the accessibility map, indicating the mean value of each municipality in the district. For simplification, the influence from some small isolated populations located in the neighboring area downward from the district (Biodiversity Center of Japan, 2004) was disregarded, because the distribution of those populations was unlikely to expand into the district in the foreseeable future.

3.3. Regional weakness to damage by monkeys

We separately calculated regional weakness to the two endpoints (i.e., agricultural and property damage), which had been utilized as indices of social impacts in the present risk assessment. Primate crop raiding naturally has a tendency to occur in agricultural land located adjacent to forests (Naughton-Treves, 1998; Hill, 2000). In particular, it has been reported that Japanese monkeys have a common inclination to raid only farmland located within 200 m of the forest edge (Muroyama, 2003; Yoshida, Hayashi, Kitahara, & Fujisono, 2006). We calculated the total area of farmland, for each community in the district, within 200 m of the edge of continuous forests that were directly linked to areas of current distributions of monkey populations. These results were applied as the index of regional weakness to agricultural damage (I_a). The index of regional weakness to property damage (I_p) was then calculated using a similar method: by measuring the total area of dwelling land within 200 m from the forest edge for each community. Finally, each index was normalized by multiplying 100/each maximum value, so that the resulting index ranged from 0 (resistant to damage) to 100 (vulnerable to damage). For this analysis, we used geographic information with a resolution of 20 × 20 m derived from the "National survey on the natural environment," from Biodiversity Center of Japan.

We calculated both indices of regional weakness by focusing only on human land use. Some other factors might also influence this weakness, such as cultivated crop species, population aging rates, human population densities, and local economic potentials. To simplify the procedure for quantifying coarse-scale risks, we decided not to consider those factors, on the grounds that the cultivated crop species were not widely different among municipalities in northern Tohoku (due to its cold climate); in addition, human depopulation and aging have occurred as common phenomena across the entire district.

3.4. Building the risk map

We calculated the risk for two endpoints, agricultural damage (E_a) and property damage (E_p), using the following formulae: risk for $E_a = L \times I_a$ and risk for $E_p = L \times I_p$ (Fig. 3). To facilitate interpretation of the results, the damage risks calculated in each community were classified using the optimal-break classification algorithm (Jenks & Caspal, 1971), which can create an optimal number of classes in the data by minimizing variance within a class and maximizing variance between classes. We then used the relative risk levels of 1 (low) to 5 (high) and finally created a risk map by allocating to each municipality's geographical space a classified risk value.

4. Results

4.1. Species accessibility

To generate the species suitability map, three significant composite factors were retained by using the broken-stick technique (Table 2). These three factors accounted for all of the total marginality and 55.5% of the total specialization. Coefficients on the marginality axis (composite factor 1), ranging from −1 to 1, showed that the species essentially preferred mountainous, broadleaf forests, away from artificial environments, according to the positive values of "standard deviation of altitude," "average slope," "maximum snow depth," "distance to arterial traffic," and "distribution of broadleaf forests," as well as the negative value of "farmland distribution"; the absolute value of each factor was >0.3. The second largest variance of specialization (17.8%) attributed to the first factor showed that monkeys were rather sensitive to shifts from the optimal conditions on this axis: the breadth of the optimal species niche was restricted in the environmental space containing mountainous broadleaf forests. The subsequent factors accounted for more specialization, mostly regarding altitude, farmland distribution, broadleaf and conifer forest distribution (as shown in composite factor 2), and minimum temperature (as shown in composite factor 3); this indicates that the optimal niche breadth of the species was narrowed in these factors. The total species marginality and specialization values were 0.82 and 1.47, respectively, suggesting that the species habitat widely differed from the mean conditions in the reference area and was somewhat restrictive vis-à-vis the range of conditions it could withstand.

A suitability map of the species was constructed, using these three composite factors (Fig. 4). The present cross-validation procedure involving five bins provided a mean Boyce index of 0.76 (SD = 0.29). This means that the model was fairly accurate in predicting performance. This suitability map showed that 50.0% of the study area was unsuitable, 16.0% was rather unsuitable, 17.0% was suitable, 11.4% was suboptimal, and 5.6% was optimal as a species habitat. The present monkey distribution included 30.0% of the optimal area, 14.2% of the suboptimal area, 9.6% of the suitable area, 10.3% of the rather unsuitable area, and 3.3% of the unsuitable area. These results indicate that the greater part of each area possessing preferable habitat conditions remains untouched by the current species distribution.

Based on the constructed suitability map, the species accessibility value for each municipality was calculated using a least-cost analysis; that value was then allocated to a geographical space (Fig. 5). As shown in this map, an area with high accessibility was located in or adjacent to the current distributions of all LPs, except for the Shimokita LP, which shows a geographical bottleneck due to the structure of the peninsula.

4.2. Regional weakness to monkey-inflicted damage

The map of regional weakness to agricultural damage showed that 70.0% of the municipalities within the district had low weakness values (0–20) (Fig. 6). The areas with moderate to high weakness values (40–100) represented a minority, accounting for only 7.0% of all municipality areas; in this group, only one municipality was within the species distribution range. The mean weakness value among municipalities already affected by agricultural damage (n = 17) was 9.5 (SD = 6.0). As for regional weakness to property damage, 75.0% of all municipality areas showed low weakness values (0–20). The first and second weakest municipalities (60–100) accounted for 6.0% of the municipalities and were located in Aomori and Akita, each containing three municipalities. The mean weakness value among municipalities already affected by property damage (n = 17) was 16.7 (SD = 15.0). These results indicated that neither agricultural nor property damage occurred to any great extent among municipalities possessing higher weakness values.

4.3. Relative risk assessment

In computing risk of agricultural damage, it was found that 7.0% of the municipalities in the district were at risk of levels 4 and 5; this high-risk group was located within the ranges of the Shirakami, Tsugaru, and Shimokita LPs (Fig. 7). These municipalities had already sustained serious monkey-inflicted damage. Twelve percent of the municipalities were classified as being at moderate risk (level 3); these were located in and around the Shirakami Mountains (three municipalities), the Goyozan Mountains (two), and the Tsugaru Peninsula (one); half of these municipalities had not yet encountered monkey damage problems. As for risk of property damage, municipalities at high risk (levels 4 and 5) accounted for 11.0% of the municipalities and were located in and around the Shirakami Mountains (seven municipalities), the Tsugaru Peninsula (two), the Shimokita Peninsula (one), and the Goyozan Mountains (one). All of these municipalities, except for one, have already sustained monkey-inflicted damage problems. Twelve percent of the municipalities were at moderate risk (level 3), and half of these had not yet experienced any monkey problems; this moderate risk group was located in and around the Shirakami Mountains (five municipalities) and the Tsugaru Peninsula (one). These results indicated that the Shirakami Mountains and these surrounding areas had the most pressing concerns regarding occurrences of both endpoints.

5. Discussion and conclusions

Scale-based issues should be considered some of the most sensitive ones to be carefully dealt with in the course of landscape analysis and wildlife habitat assessment (Trani, 2002). In the present risk assessment procedure, the resolution of available data for species presence is typical of such issues. Given that the habitat suitability map with a reasonable predictive performance was gained from the niche modeling, it is quite possible that the spatial scale associated with the species home range size is a fairly appropriate one for the evaluation of landscape-scaled features applied at the population level (cf. Haufler, Mehl & Roloff, 1996). This scale's appropriateness may be closely associated with the fact that the geographical scale required for the continued existence of monkey populations is sufficiently large, compared to the home range size (Koganezawa, 1995).

Only a few empirical studies examine the process underlying recent population expansions of the species into heterogeneous environmental spaces (Iwano, 1980; Iwasaki & Sprague, 2005). The factors limiting the monkey distribution have been broadly discussed; these include alpine regions, cold climates, large-scale conifer plantations, subarctic forests, and flat land with no cover (Iwano, 1980; Mitani & Ikeguchi, 1997; Iwasaki & Sprague, 2005). Our findings, as indicated in the composite factors produced via ENFA, empirically support these geography-related limiting factors. On the other hand, as Japanese monkeys are sometimes called a "weed species," the species has been recognized as an animal with high environmental adaptability (Richard, Goldstein, & Dewar, 1989; Fooden & Aimi, 2005). The potential species habitat in the northern Tohoku district, however, was rather limited, compared to the mean available habitat conditions in the district, as seen in the habitat suitability map (Fig. 4); this limitation is quantitatively indicated in the total marginality and specialization values. It is quite likely that this limitation of potential species habitat arises from the massive reclamation after World War II (Fooden & Aimi, 2005), when most lowland forests were cleared for farmland and urban development (Shimizu &

Sato, 2000). Consequently, only mountainous broadleaf forests have been left as potential species habitat—a fact corroborated by the marginality axis (Composite factor 1 in Table 2).

This heterogeneous potential habitat directly influenced species accessibility; however, this species accessibility did not exactly coincide with the risk for each municipality, because the geographical distribution of regional weakness to damage was distinctly different from that of species accessibility. Given that the potentially affected municipalities, i.e., those that are expected to sustain monkey-inflicted damage in the near future, are more vulnerable to damage than already-affected ones (Fig. 6), it is reasonable to consider that human-monkey conflicts in this district will worsen as monkey populations continue to recover (Watanabe 2000).

In such a predicted scenario, it is quite likely that conventional stopgap measures such as constructing guard fences, which are commonly instituted after serious animal-inflicted damage begins, are of little help in efficiently addressing expanding damage problems. Therefore, it is reasonable to suggest that municipalities at high risk, particularly in northern Akita and western Aomori, should first undertake some precautionary actions in advancing the dispersal front of monkey populations, regardless of whether or not damages have already appeared. Decreasing regional weakness to damage could be indispensable as a practical precautionary action; for this, it can be effective to consolidate human settlements scattered across regions (Fig. 1) wherever possible, by promoting the liquidation of real estate. In terms of land use design, intensive farming should be implemented in the portion of consolidated land that is distant from the forest edge. Considering that the numbers of derelict buildings and abandoned farmlands have recently increased with the declining human population throughout Japan (Hayashi, Maekawa, Saito, & Ichinose, 2008), this regional planning could be feasible and contribute to an efficient minimization of the overall risk of monkey-inflicted damage in this district.

To put this planning into practice, it is necessary for public stakeholders to recognize the potential risk inherent in future human-monkey relationships. The risk mapping approach, which we addressed here, can offer comprehensible information about the risk to a more general public (LeLay et al., 2001) and therefore, may encourage active risk communication among stakeholders; this could lead to comprehensive regional planning vis-à-vis human-wildlife conflict management.

For future research, there are several limitations and improvements that could be made to this risk assessment. Considering that the present assessment procedure does not efficiently detect fine-scale dispersal barriers for the species (e.g., precipitous cliffs, artificial constructions, and bare land without cover), its limitation may lie in finer-scale risk assessment such as damage risk for small-sized municipalities or individual settlements within a municipality. In addition, it should be noted that the ecological influence of each input variable utilized in the risk assessment might change when different scales are used. For example, at the population level, agricultural land is typically human-made open land and is characterized as a "geographical barrier" for monkeys because it prevents the diffusion of species populations, as indicated in the present ENFA. Meanwhile, at the individual or troop level, agricultural land may be evaluated not only in terms of geographical barriers but also as "attractive feeding sites" for monkeys that are accustomed to living close to human settlements (Watanabe, 2000; Muroyama, 2003). Hence, in the case of a fine-scale assessment of damage risk, our assessment procedure cannot be directly applied with finer-scale datasets; therefore, it is necessary to evaluate environmental space from several different species purposes (e.g., feeding site, cover, sleeping site, migration path) and comprehensively evaluate the landscape structure and patterns for species distribution expansion. Further multi-scale analyses of monkey-habitat relationships would contribute to enhancing the versatility of this risk assessment procedure.

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Table 1. Environmental variables included in the ecological-niche factor analysis for Japanese monkeys in northern Tohoku, Japan.

Category	Environmental variables	Source
Topography	Standard deviation of altitude	Digital elevation model (50-m mesh); Geographical Survey Institute, Japan
	Average altitude (m)	Digital elevation model (50-m mesh); Geographical Survey Institute, Japan
	Average slope (°)	Digital elevation model (50-m mesh); Geographical Survey Institute, Japan
Hydrology	Distance to river or lake (km)	Digital national land information; Ministry of Land, Infrastructure and Transport, Japan
Climate	Maximum annual snow depth (m)	Climate mesh data (mean value of 1971–2000, 1-km mesh); Japan Meteorological Business Support Center
	Minimum annual temperature (°C)	Climate mesh data (mean value of 1971–2000, 1-km mesh); Japan Meteorological Business Support Center
Land-use	Farmland distribution	Digital national land information; Ministry of Land, Infrastructure and Transport, Japan
	Distance to arterial traffic (km)	Digital national land information; Ministry of Land, Infrastructure and Transport, Japan
	Distance to human settlements (km)	Digital national land information; Ministry of Land, Infrastructure and Transport, Japan
Vegetation	Distribution of broadleaf forests	National survey on the natural environment (5th survey, 1998); Biodiversity Center of Japan
	Conifer distribution	National survey on the natural environment (5th survey, 1998); Biodiversity Center of Japan
	Grass distribution	National survey on the natural environment (5th survey, 1998); Biodiversity Center of Japan

Table 2. Variance explained by the first three (out of 12) composite factors, and coefficient values for each environmental variable, as calculated in the ecological-niche factor analysis for Japanese monkeys in northern Tohoku, Japan.

Environmental variables	Composite factor 1 Marginality (100.0%) Specialization (17.8%)	Composite factor 2 Specialization (24.5%)	Composite factor 3 Specialization (13.2%)
Standard deviation of altitude	0.32	0.09	–0.07
Average altitude	0.08	–0.44	0.80
Average slope	0.43	0.18	–0.21
Distance to river or lake	0.05	–0.01	–0.08
Maximum annual snow depth	0.42	0.20	0.07
Minimum annual temperature	0.09	–0.05	0.41
Farmland distribution	–0.45	–0.37	–0.13
Distance to arterial traffic	0.37	–0.09	0.14
Distance to human settlements	–0.16	0.01	0.07
Distribution of broadleaf forests	0.35	–0.60	–0.29
Conifer distribution	0.17	–0.46	–0.08
Grass distribution	–0.09	–0.07	–0.04

The coefficient sign has no meaning for specialization.

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Fig. 3. Schematic flow diagram of the construction of risk maps for agricultural and property damage.

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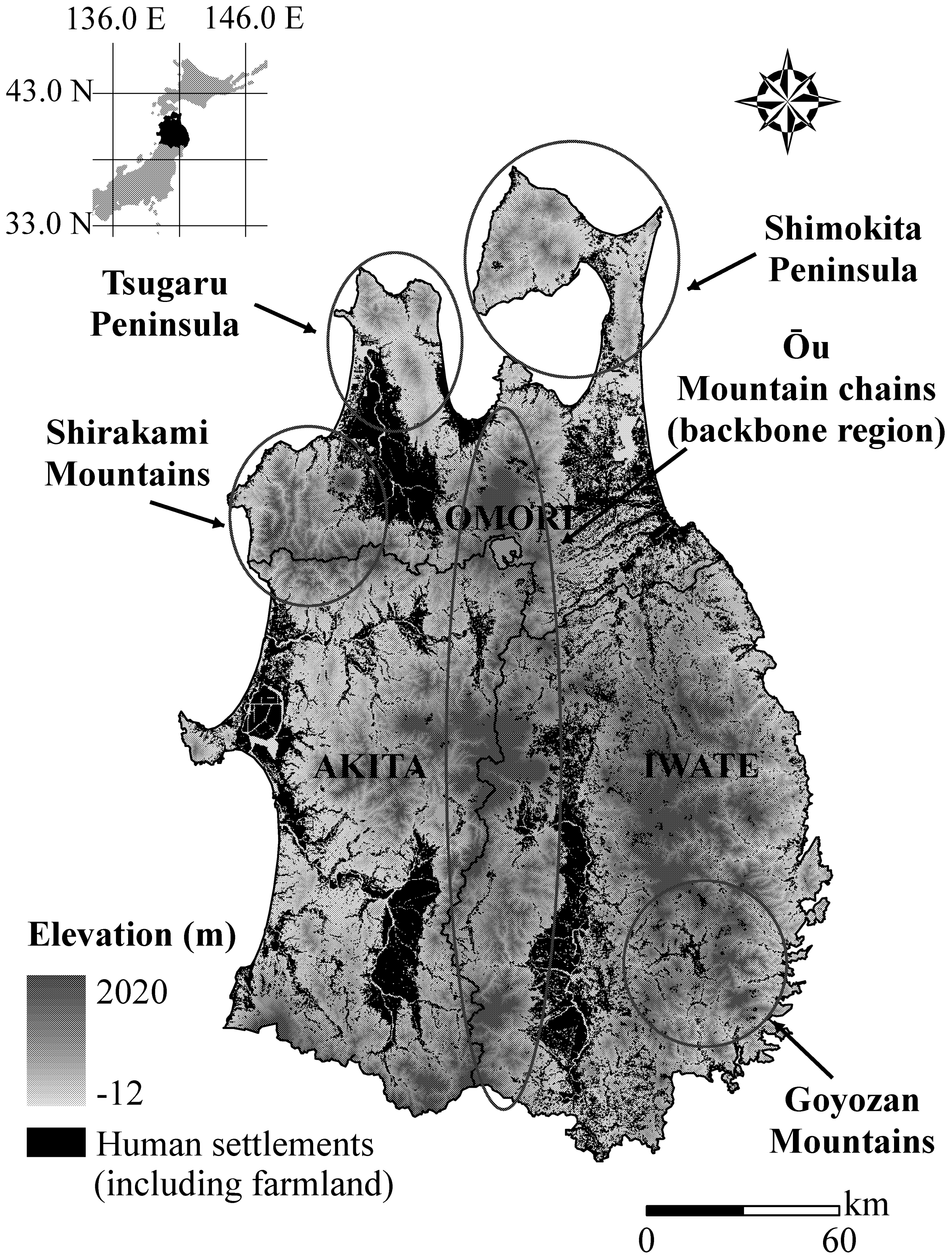
Fig. 5. Map of Japanese monkey accessibility to each municipality in northern Tohoku, Japan. The scale on the right shows the accessibility value (0 = difficult to access; 100 = easy to access). The white dots inside the map indicate the present distribution of the species.

Fig. 6. Regional weakness to damage caused by Japanese monkeys in northern Tohoku, Japan. The scale on the right shows the weakness value (0 = resistant to damage; 100 = vulnerable to damage). The black dots inside the maps show the present distribution of the species.

Fig. 7. Risk maps for agricultural and property damage caused by Japanese monkeys in northern Tohoku, Japan. The scale on the right shows the relative risk level (1 = low risk; 5 = high risk).



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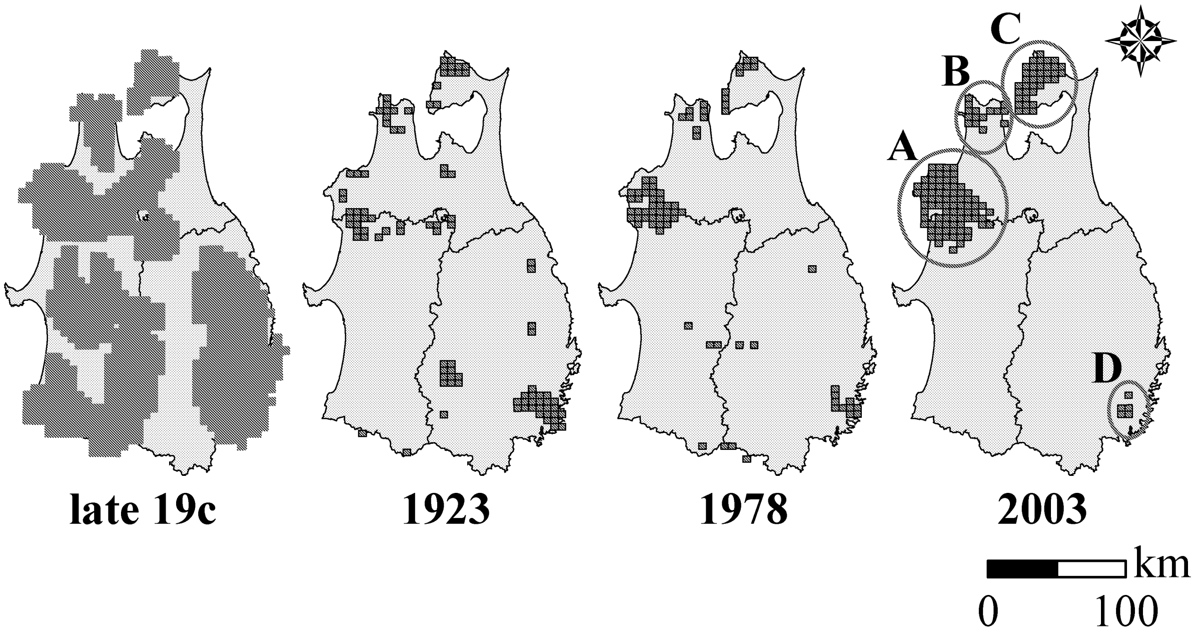

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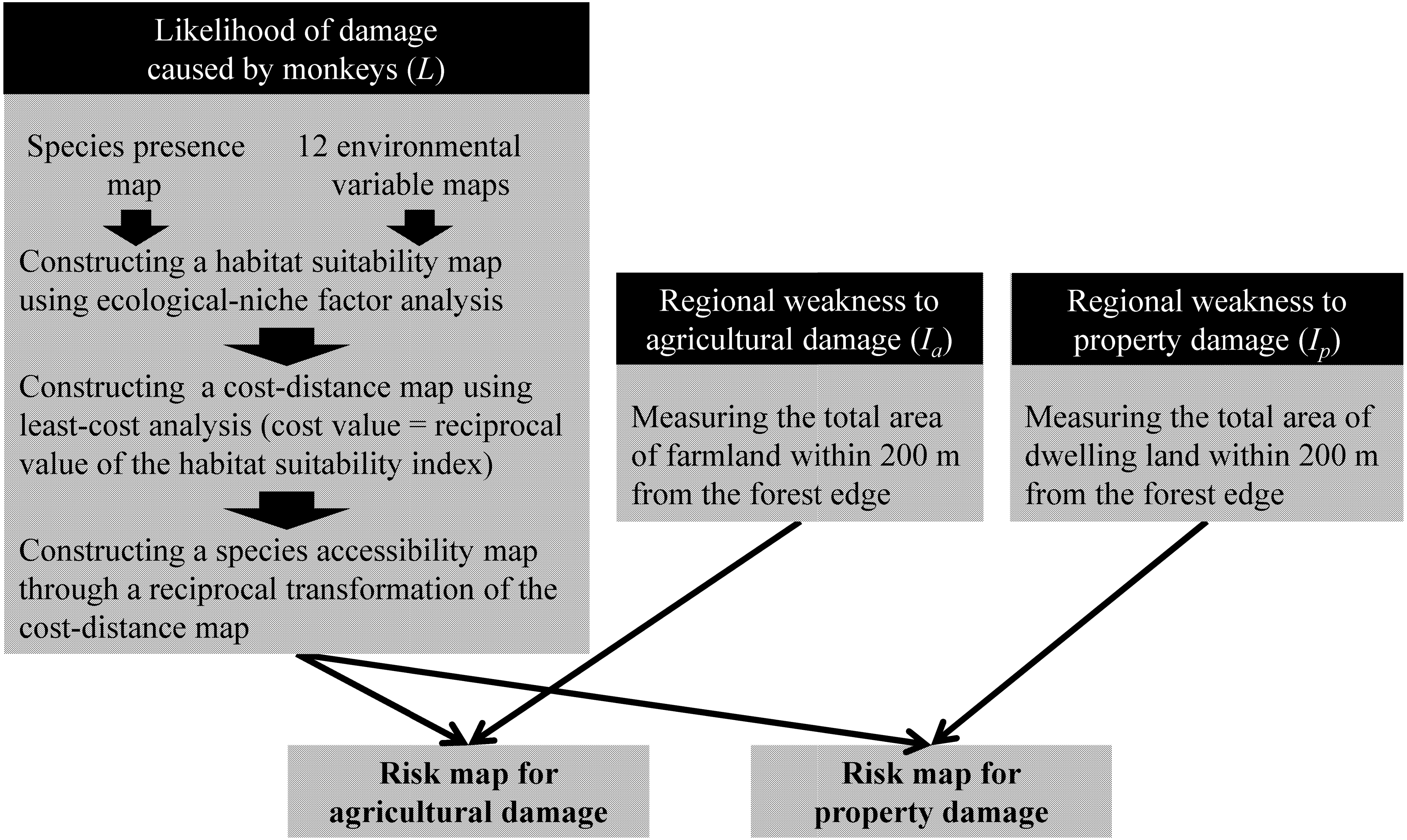

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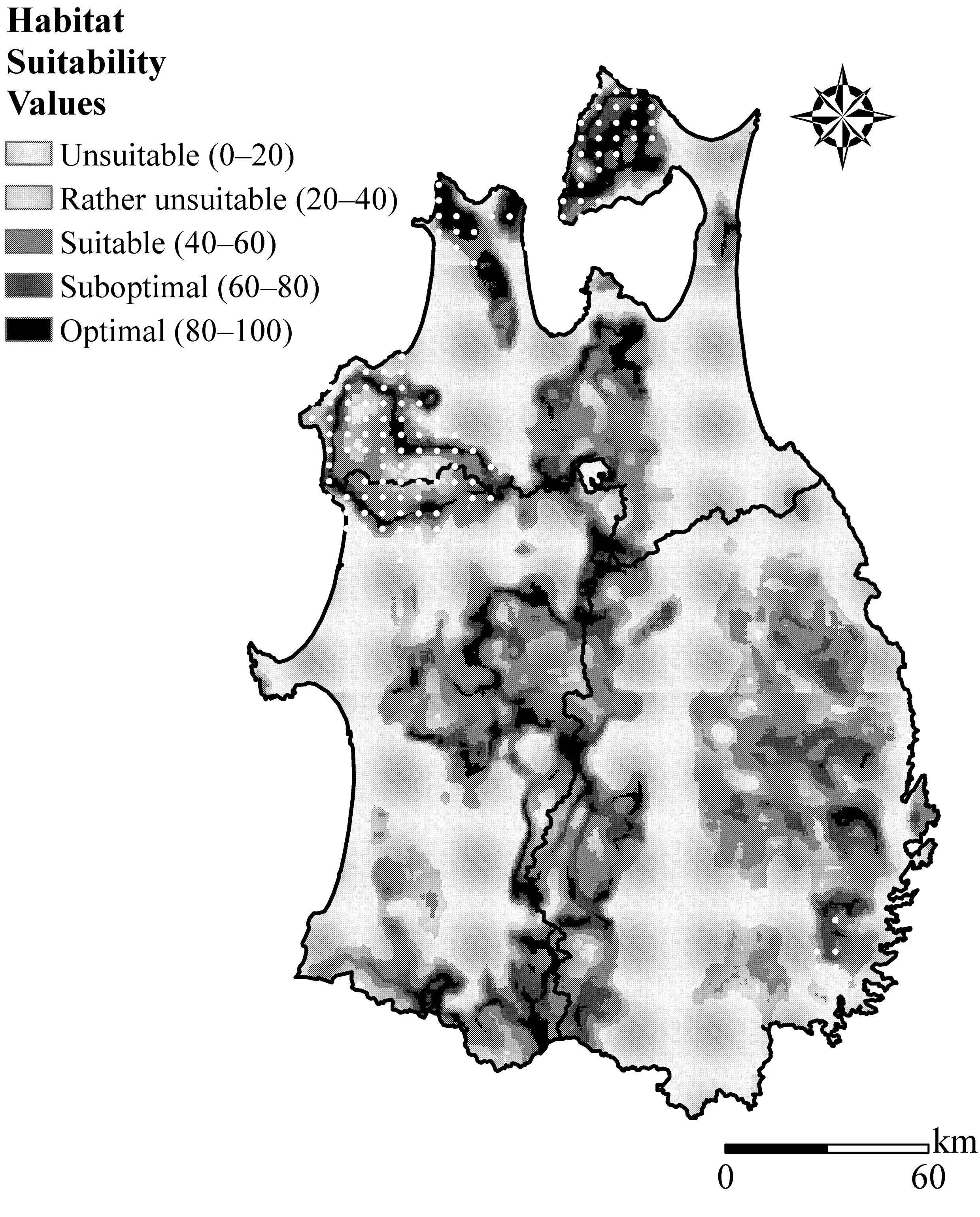

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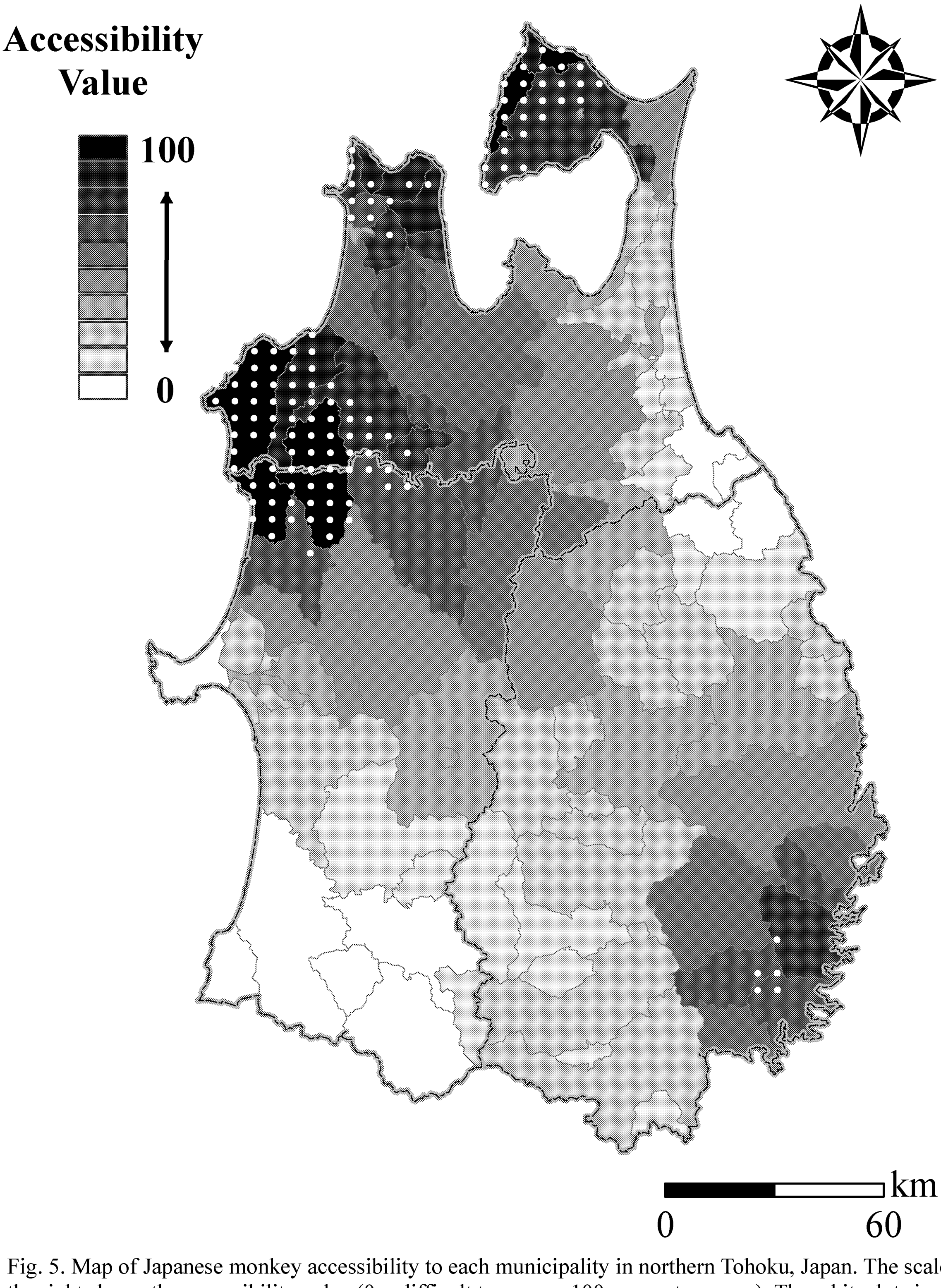

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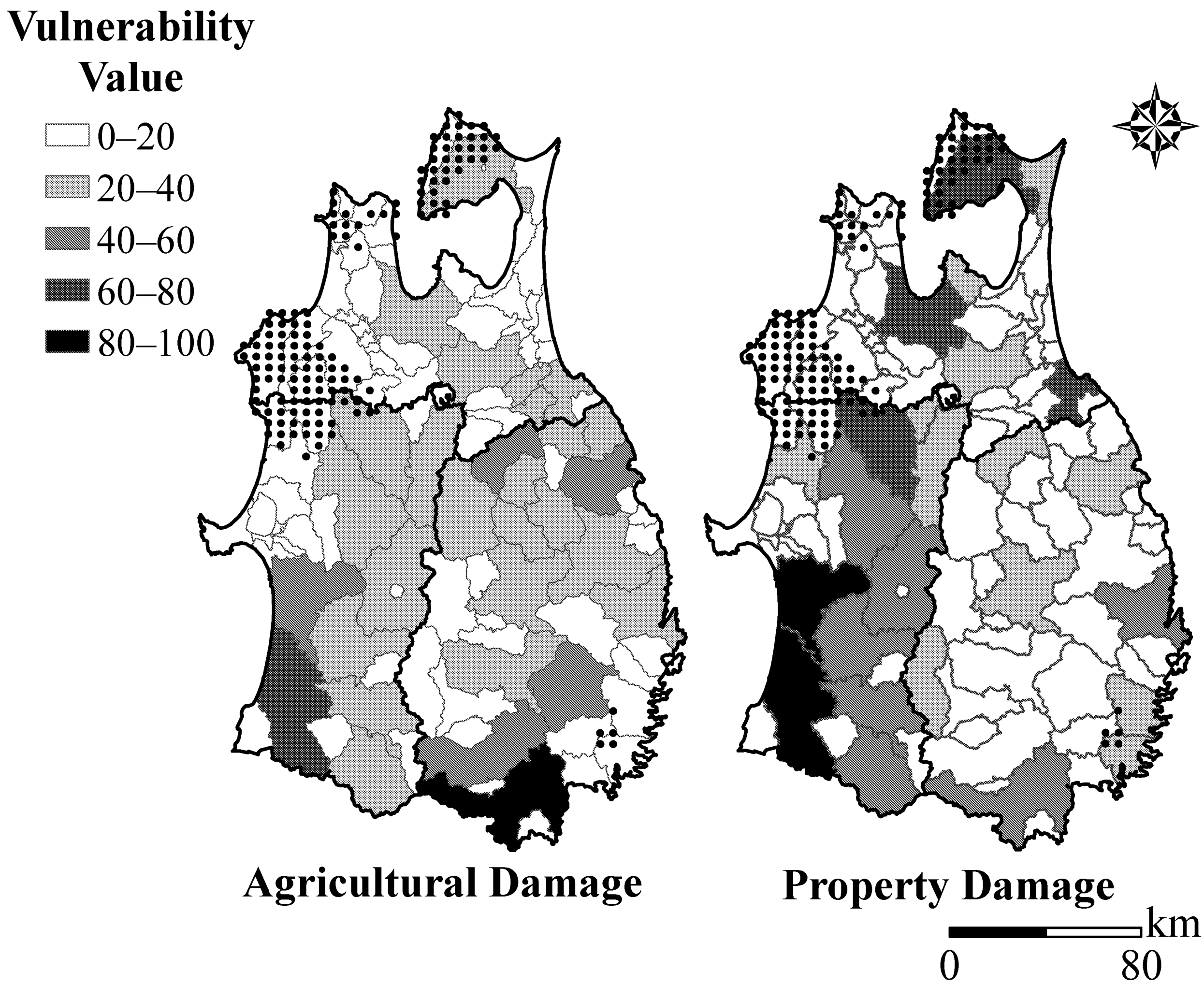

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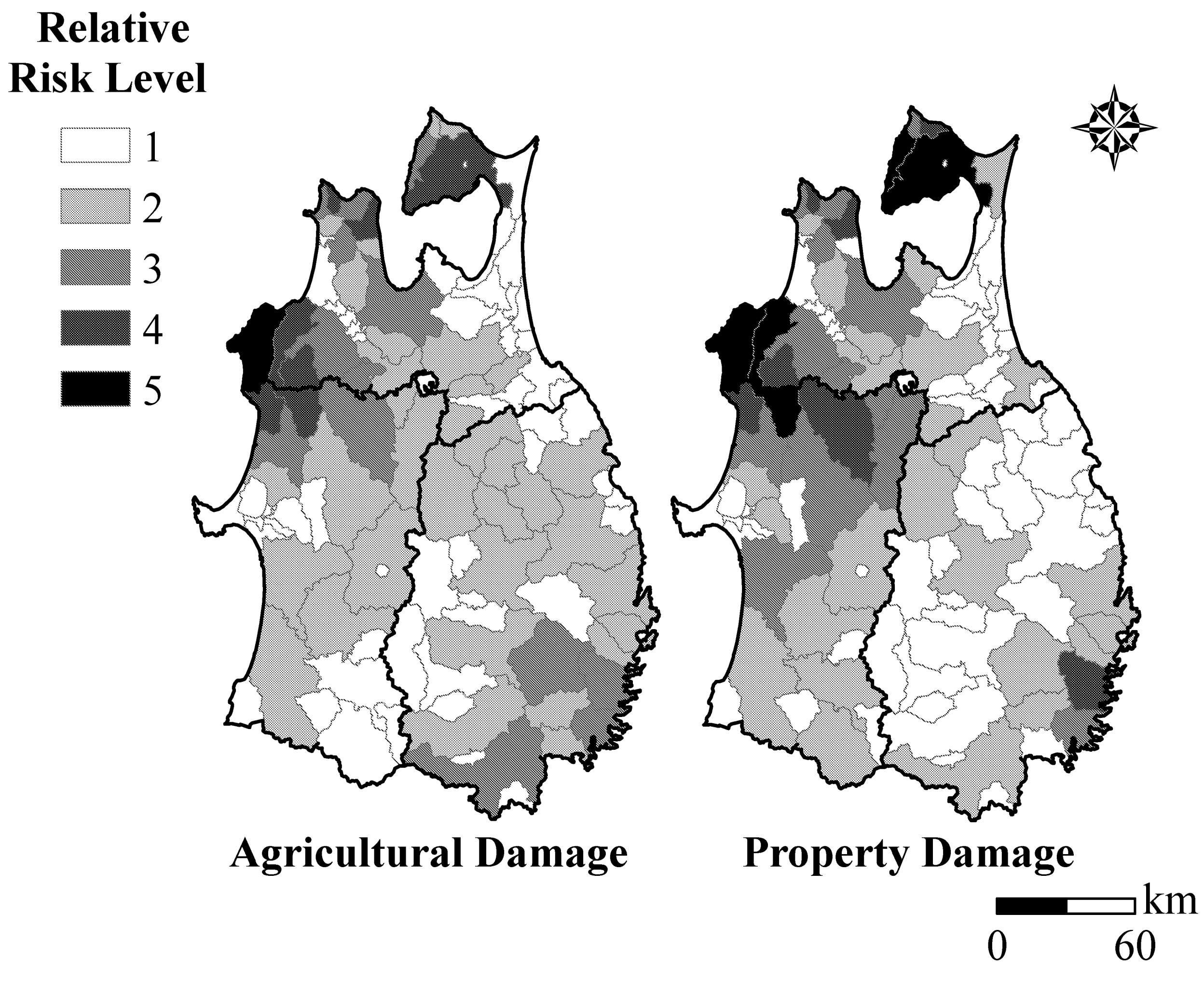

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