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Scale dependent effects in resource selection by crop-raiding Japanese macaques in Niigata Prefecture, Japan

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A B S T R A C T

A resource selection function is one that yields values proportional to the probability of use of a resource unit. This quantity is influenced by the heterogeneity of landscape structures, which occurs over multiple spatial scales. To provide input into wildlife management strategies, we investigated the scale dependency and functional responses of Japanese macaques using multiple scale analysis. The multiple buffers with radii of 100, 500, 1000, 1500, 2000, and 2500 m were defined as the spatial scale. Crop damage was predicted at the within-home range scale, using the Random Forests algorithm with environmental variables linked to resource selection of Japanese macaques. Sixteen environmental variables were defined, covering aspects of landscape configuration, human disturbance, topography, and adopted countermeasures. Crop damage was most accurately predicted within a buffer zone of 1000 m, although radii exceeding 1000 m were also highly accurate. Although the importance of variables differed among spatial extents, the functional responses for each environmental variable were independent of spatial extent. These results suggest that the limiting factors of crop damage depend on spatial extent, while functional responses in resource selection remain constant across spatial extents. We also compared a multi-scale gradient map with a typical binary map to demonstrate the uncertainty in damage predictions at different spatial scales. Our results may aid wildlife management planning, for which differences in resource selection across different spatial scales are critically important.

Introduction

Habitat selection is a hierarchical process. At the highest level, selection is constrained by the geographic range of the species; at the lowest, it relates to the species' dietary needs and preferences (Manly, McDonald, Thomas, McDonald, & Erickson, 2002). Habitat selection behaviors (e.g., foraging, nesting, resting, moving) are modulated by environmental factors such as type of land-cover, landscape configuration, and habitat connectivity over specific spatial scales (Johnson, 1980; Orians & Wittenberger, 1991). Habitat selection, which is frequently defined as a species' behavioral adjustment to heterogeneously distributed environmental factors (Boyce & McDonald, 1999; Johnson, 1980; Rosenzweig, 1981), is an important component of animal ecology. Habitat selection comprises four hierarchical orders at varying spatial scales; namely, the geographic distribution of the species, the selection of home range within that distribution, resource use within the home range, and the exploitation of specific food items within the resource (Johnson, 1980). While geographic distribution and home range selection usually depend on broad environmental features, habitat use within a home range is influenced by the distribution of resources at smaller spatial scales (Rettie & Messier, 2000). Hence, the scale of a home range is largely determined by foraging behavior (Morris, 1987). To appropriately manage wildlife ecosystems, ecologists must understand the preferred foraging habitat of their focal species.

Resource selection functions (RSFs) yield models that predict the proportional probability that an animal will use a given resource unit (Manly et al., 2002), incorporating the influence of spatial scale and heterogeneity on habitat selection. To estimate an RSF, resource use within a landscape structure is compared with overall resource availability (Boyce et al., 2003). Furthermore, an animal's behavioral response to environmental factors can be evaluated from partial dependence in RSFs (Gillies et al., 2006; Godvik et al., 2009; Mauritzen et al., 2003). Environmental factors based on landscape elements generally refer to the scale effect, defined in terms of grain and extent (Turner, Gardner, & O'Neill,

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2001). Landscape grain is the minimum resolution of the data (i.e., the cell size of landscape distribution), while extent defines the area used by an animal (i.e., the overall study area or a particular landscape type). In ecological studies, grain and extent may be defined as the finest spatial scale of habitat heterogeneity to which an organism responds (Kotliar & Wiens, 1990; Thompson & McGarigal, 2002). Therefore, hierarchal habitat selection is regarded as an adaptation to spatial heterogeneity in resource availability (Levins, 1968). The hierarchical process of habitat selection suggests that different environmental factors determine habitat selection at different spatial scales (Kie, Bowyer, Nicholson, Boroski, & Loft, 2002). Even within a home range, resource selection depends on heterogeneous environmental factors, such as type of land-cover, configuration, and habitat connectivity. It is often assumed that a species selects resources that best satisfy its life requirements and that high-quality resources will be preferred over low-quality ones. The availability of natural resources is generally non-uniform, and use may alter with changing availability. Therefore, to properly evaluate resource selection, resources that are actually used by the focal organisms should be compared with those that are most available (Indermaur, Winzeler, Schmidt, Tockner, & Schaub, 2009; Manly et al., 2002; Marzluff, Knick, & Millspaugh, 2001), and disparity in resource selection and availability should be considered when implementing wildlife management or conservation strategies.

In addition, risk management for human–wildlife conflicts is an urgent global issue (Conover, 2002). In Japan, crop damage by Japanese macaques, known worldwide as the snow monkey, is significant. Japanese macaques forage on several crops, including rice, corn, and soybean (Mochizuki & Murakami, 2011a), which causes serious economic loss (1500 million yen per year or 15 million US dollars; Ministry of Agriculture, Forestry & Fisheries, 2009). Japanese macaques are the northernmost dwellers among nonhuman primate species (range: 30°21′–41°08′N). They inhabit environments as diverse as cool-temperature deciduous forests, warm-temperature evergreen forests, and human settlements, including farmland (Suzuki, 1965; Wada & Tokida, 1981; Yamada & Muroyama, 2010). Over the past half-century, numerous studies have been conducted on the ecology and behavior of Japanese macaques, many of which are based on direct field observations of individuals and troops (Yamagiwa, 2010) and include evaluations of resources specific to macaque habitats (Hanya, 2010). Typically, Japanese macaques prefer evergreen and deciduous broad-leaved forests as foraging sites and avoid coniferous plantations (Imaki, Koganezawa, & Maruyama, 2006). Crop damage by Japanese macaques has been increasing for several decades (Watanabe & Muroyama, 2005). However, quantitative and landscape-scale assessments of habitat selection by macaque troops remain limited. Previous studies reported that crop-raiding macaques frequently used both forest edges around human settlements and deciduous broad-leaved forests throughout the year (Imaki et al. 2006). However, the use of human settlements and/or farmlands may differ among study sites with varying vegetation types (Yamada & Muroyama, 2010). Because the behavior of macaques varies and depends on the regional environment, it is essential to understand the behavior of Japanese macaques in all inhabited regions and to consider the hierarchical process of resource selection over multiple spatial scales. This understanding would allow for more effective management of crop-raiding Japanese macaques to minimize human–wildlife conflicts in this region.

In this study, we investigated the effects of scale on RSFs of crop-raiding Japanese macaques. Changes in the spatial extents of the home ranges of 13 macaque troops were evaluated using radio-tracking data collected from 2008 to 2009. To determine the relative foraging selection within the estimated home range of each troop, proportional crop use was compared with proportional crop availability. Proportional resource use and availability were determined from circular buffers centered on damaged and undamaged crop locations. Six buffer sizes (100, 500, 1000, 1500, 2000, and 2500 m) were applied, and comparisons using RSFs were made across all six spatial extents. Scale dependency was assessed by comparing a typical risk map based on the finest spatial extent of crop damage with a multi-scale gradient map of the risk probability of crop damage.

Materials and methods

Study area

The study area was within the city of Shibata, Niigata Prefecture, Japan (37°57′N, 139°19′E, 532 km^2; Fig. 1). In 2009, the population density in Shibata was approximately 190 people per km^2. Elevation ranges from −19–1496 m above sea level. The study area is predominantly composed (64%) of secondary forest dominated by oak (*Quercus* L.) and conifer plantations of Japanese cedar (*Cryptomeria japonica*) and Japanese red pine (*Pinus* L.). The mean annual temperature and precipitation in this region is 12.5 °C and 1109 mm, respectively, and the maximum snow depth is 950 mm between December and March (climate data were provided by Japan Meteorological Agency).

Crops in this region have been damaged by macaques since the late 1970s (Agetsuma, 2007), and the affected area has gradually expanded with macaque population growth. An investigation in Shibata revealed the presence of 14–17 troops collectively containing 700 to 800 individuals (Niigata Prefecture, 2007). Troops have been radio-tracked since 2004 by the Hunters Association in Shibata. As of 2012, 13 troops of crop-raiding Japanese macaques have been monitored. Monitoring is performed from May to November, when crop damage by Japanese macaques is the most serious. With the increasing intensity of crop damage, the risk of life-threatening injuries to humans through home invasion by macaque trespassers has also increased. Although annual crop damage fluctuates, economic losses average approximately 15 million yen per year in Shibata (Mochizuki & Murakami, 2011a). The main crops raided by Japanese macaques are rice (*Oryza sativa*), soybean (*Glycine max*), potato (*Solanum tuberosum* L.), and corn (*Zea mays* L.).

Data collection: crop damage and the home range of Japanese macaques

We radio-tracked Japanese macaques from May to November (the season of maximum crop damage) in 2008 and 2009. In each of 13 troops of crop-raiding Japanese macaques, we collared two or three individuals and obtained their location data through VHF radio-tracking, a widely used wildlife tracking technique. We used LT-01 (Circuit Design, Inc.) transmitters and IC-R20 (Icom, Inc.) receivers. The location data were acquired by six-element Yagi antennae and receivers, which received signals from transmitters attached to individual macaques. These highly directional antennae are often used for animals that are difficult to observe in their native habitat (White & Garrott, 1990). Two location points per day were acquired for each of the 13 troops. The estimated radio-tracking error was 100 m.

Using the location data for the collared Japanese macaques, home range sizes were estimated using the 100% minimum convex polygon method (100% MCP: Mohr, 1947) in the geospatial modeling environment (GME: Beyer, 2010) ArcGIS 10 (ESRI Inc.). Many methods are available for estimating home ranges, including MCP (Mohr, 1947), grid cell count (Siniff & Tester, 1965), and fixed