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Original Investigation

Impact of anthropogenic disturbance on the density and activity pattern of deer evaluated with respect to spatial scale-dependency

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ABSTRACT

This study examined the influence of anthropogenic disturbance (agriculture, forestry, hunting and feral domestic dogs) on the population density and daily activity pattern of deer. We quantified the effects of land use (broad-leaved forest, mixed coniferous/broad-leaved forest, natural grassland, subalpine vegetation, forestry area, and agricultural land), along with hunting pressure, and densities of feral domestic dogs and wild macaques on deer. The effects of land use were analyzed at various spatial scales and a model selection procedure (generalized mixed model) was used to examine the effects of factors on density and daily activity pattern of deer at each spatial scale. The combinations of influential factors differed between density and daily activity pattern and changed with spatial scale. The spatial scale with the smallest Akaike's Information Criterion value was defined as the effective spatial scale for each of density and daily activity pattern. Deer density was affected positively by the percentage of area covered by broad-leaved forest, natural grassland and macaque density, and negatively by percentage of area covered by agricultural land and mixed forest at the effective spatial scales. For the daily activity pattern of deer, agricultural land, forestry area, natural grassland, subalpine vegetation and dog density reduced diurnal and increased nocturnal activity. Crepuscular activity increased with hunting pressure and subalpine vegetation, and decreased with agricultural land. Thus, daily activity pattern was sensitive to more types of anthropogenic disturbance than density. Detecting the appropriate spatial scales at which significant anthropogenic disturbance should be managed is essential for effective wildlife conservation.

Introduction

Anthropogenic disturbance influences wildlife populations worldwide (Baillie et al., 2004) altering various aspects of their ecology, which may include population density (e.g., Blom et al., 2004; Hockin et al., 1992; Silva-Rodriguez and Sieving, 2012), activity pattern (e.g., Kilpatrick and Lima, 1999; Presley et al., 2009), habitat use (e.g., Coulon et al., 2008; Fletcher and Hutto, 2008; Hockin et al., 1992; Markovchick-Nicholls et al., 2008), reproductive success and energy budget (Hockin et al., 1992), depending on the type and magnitude of disturbance. A single type of disturbance may affect multiple aspects of wildlife ecology (Gill et al., 2001; Kilgo et al., 1998). Anthropogenic disturbance influences wildlife in complex ways, and may have both negative and positive effects (e.g., Fletcher and Hutto, 2008; Markovchick-Nicholls et al., 2008).

Habitat transformation is a major factor affecting wild populations by altering the availability of resources, including food and shelter sites. Examples of species whose populations have increased in response to such disturbance include raccoons (*Procyon lotor*), whose density has increased in urban and suburban areas (Riley et al., 1998) following considerable habitat modifications, and some species of New World fruit bats (Phyllostomidae), which are more abundant in farmland or secondary forests than in primary forests (Willig et al., 2007). However, in most cases the effects of habitat transformation on wildlife populations are negative. For example, the density of the Japanese macaque (*Macaca fuscata*) decreases in areas with coniferous plantations (Agetsuma et al., 2015; Hill et al., 1994) and ungulates may avoid artificially exposed areas without shelter sites (Mysterud and Ostbye, 1999).

Hunting and control measures also alter the population density, activity pattern and habitat use of some wildlife species. For example, white-tailed deer (*Odocoileus virginianus*) exhibited significant shifts in core-area use and daily activity pattern between the pre-hunt and hunt periods (Kilpatrick and Lima, 1999). In addition,

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domestic dogs (*Canis familiaris*) induce alert and flight behaviors in some wildlife species (Hockin et al., 1992; Miller et al., 2001; Sweeney et al., 1971), and may decrease the population density of certain species (Silva-Rodriguez and Sieving, 2012).

To evaluate the effects of anthropogenic disturbance on wildlife populations, we should consider the extent of the effects across space, because the magnitude of the effects of disturbance on wildlife may vary with spatial scale (Coulon et al., 2008), and then responses of wildlife to anthropogenic disturbance and natural factors may depend on spatial scales (Anderson et al., 2005). Many studies have selected the spatial scales for analysis (buffer sizes) by referring to some ecological factor, such as the range size of individual animals (e.g., Boyce et al., 2003; Fletcher and Hutto, 2008; Zweifel-Schielly et al., 2009). However, we cannot accurately identify ecologically meaningful scales a priori (Zweifel-Schielly et al., 2009). Ideally, we should use the spatial scale at which the factors show the most significant effects on wildlife populations for analysis, otherwise significant factors may not be detected. Furthermore, for wildlife conservation, we should manage significant anthropogenic disturbances at the effective spatial scale.

This study examined the effects of anthropogenic disturbance on population density and daily activity pattern of Japanese sika deer (*Cervus nippon*). Forestry areas, agricultural land, hunting pressure and feral domestic dogs were regarded as forms of anthropogenic disturbance, and we quantified the effects of these factors, as well as those of natural factors. We analyzed the effects of land use at various spatial scales to determine the effective spatial scale. We then made three predictions concerning anthropogenic disturbance. Prediction 1: deer density will be negatively affected by forestry areas, hunting pressure and dog density, and positively affected by agricultural land. This is based on findings that the availability of natural resources for deer is much reduced in coniferous plantations (Agetsuma, 2007; Gill et al., 1996), that hunting and dogs can directly and indirectly decrease deer numbers, respectively (Kilpatrick and Lima, 1999; Silva-Rodriguez and Sieving, 2012), while agricultural crops may attract deer. Prediction 2: hunting pressure, agricultural land and forestry area will modify the daily activity pattern of deer because human activity is likely to restrict diurnal activity of the deer (Mysterud and Ostbye, 1999). As a result, diurnal activity will decrease, while crepuscular and nocturnal activity will increase under these types of disturbance. In addition, dog density also will modify the daily activity pattern of deer, because the presence of predators may influence deer activity (Kamler et al., 2007). Prediction 3: at the effective spatial scale, influential factors will differ between deer density and daily activity pattern because density and activity may be modified through different mechanisms.

Material and methods

Study area and subjects

Yakushima is a roughly circular, mountainous island (peak elevation 1936 m) of 505 km^2 located in Kagoshima Prefecture, southern Japan (30°N, 130°E). Approximately 13,500 residents live in more than 20 villages around the coast. Most of the settled areas are at less than 100 m above sea level (a.s.l.). Agricultural fields including orange orchards, rice paddies, vegetable fields and pastures lie below approximately 200 m a.s.l. The natural vegetation shows zonation (Fig. 1) with elevation (Ohsawa et al., 2006;

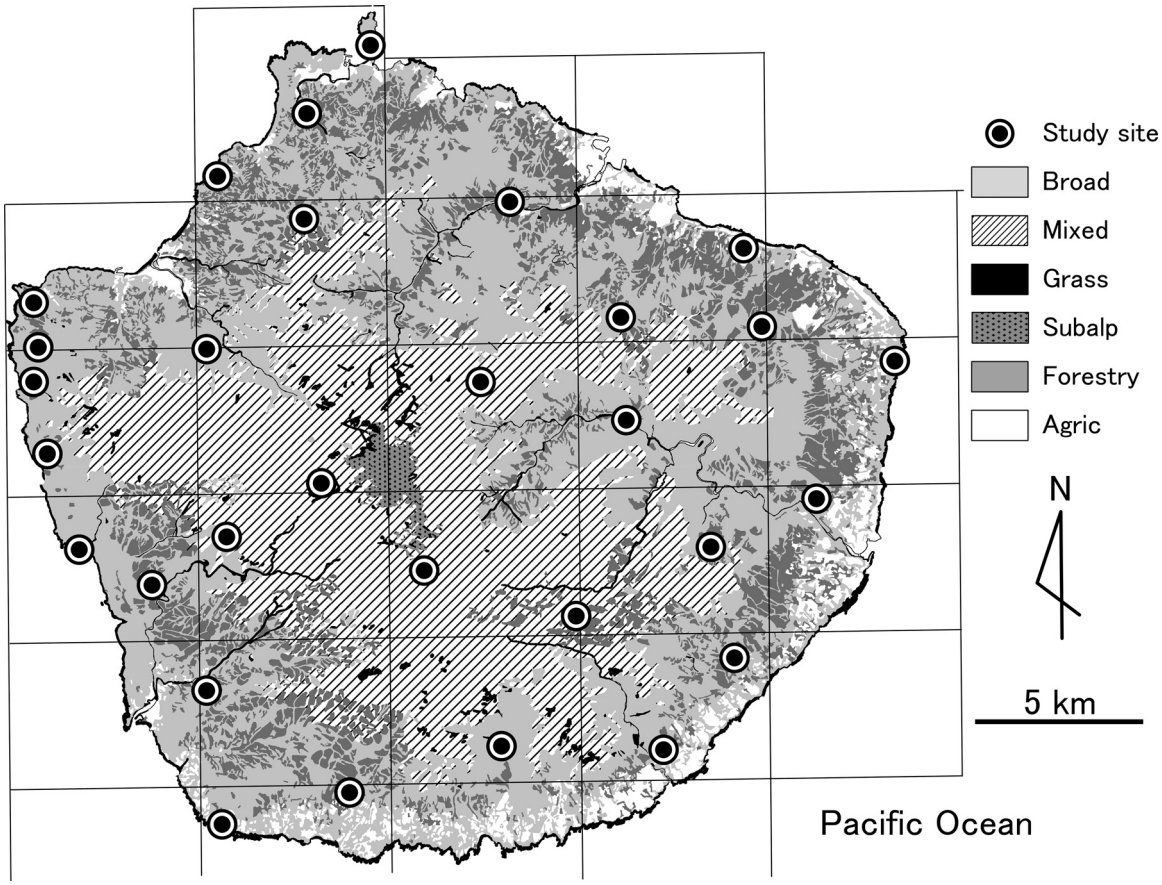

Fig. 1. Land use and study sites on the island of Yakushima. Symbols for study sites indicate gravity points of analyzed camera locations at the sites. Broad, broad-leaved forest, Mixed, mixed coniferous/broad-leaved forest; Grass, natural grassland; Subalp, subalpine vegetation; Forestry, forestry area; Agric, agricultural land. Natural grassland occurred in very narrow strips near the coast, rivers and cliffs. The number of hunted deer was summarized using cells of about 4.6 km × 6 km shown on this map.