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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

Anthropogenic disturbance modifies various ecological traits of wildlife. The magnitude of the effects will change depending on spatial scale. Therefore, for wildlife conservation, the effective spatial scale at which the disturbance has the greatest effects on wild populations must be determined. This study examined the influence of anthropogenic disturbance on two ecological traits (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), hunting risk, and densities of feral domestic dogs and wild monkeys. The effects of land use were analyzed at various spatial scales and a model selection procedure (generalized mixed model) was used to examine significant variables [illegible] ecological traits at each spatial scale. Combinations of selected variables differed with ecological traits and spatial scales. The spatial scale of the best model was defined as the most effective spatial scale for each ecological trait. Deer density was affected positively by areas of natural grassland and monkey density, and negatively by areas of forestry, mixed forest and agricultural land at the most effective spatial scale. For the daily activity pattern, larger areas of agricultural land, smaller natural grassland areas and higher hunting risk reduced diurnal and induced nocturnal activity. The most effective spatial scale explaining population density was smaller than that of daily activity pattern. This study showed that agricultural land, forestry areas and hunting risk affected deer ecology as anthropogenic disturbance. However, each disturbance factor modified different ecological traits or modified both ecological traits at different spatial scales. Detecting the appropriate spatial scales at which anthropogenic disturbance should be managed is essential for wildlife conservation.

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Introduction

Anthropogenic disturbance influences wildlife populations worldwide ([illegible] 200[illegible]) and alters their ecology in various ways. The population density (e.g., Hockin et al., 1992; Blom et al., 200[illegible]; Silva-R[illegible] and Sieving, 2012), activity pattern (e.g., Kilpatri[illegible] Lima, [illegible]; 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) and other ecological traits (Hockin et al., 1992) will change depending on the type and magnitude of disturbance. Identical disturbance may affect different ecological traits of wildlife (Gill et al., 2001; Kilgo et al., 1998). The influences of anthropogenic disturbance on wildlife ecology are complex, and can have both negative and positive effects on species (e.g., Fletcher and Hutto, 2008; Markovchick-Nicholls et al., 2008).

Habitat transformation is a major disturbing factor for wild populations, altering numbers of individuals through modifications of resource availability and shelter sites. Such a disturbance may favor some wildlife species. For example, the density of raccoons (*Procyon lotor*) has increased in urban and suburban areas (Riley et al., 1998) following considerable habitat modifications. Furthermore, the abundances of some fruit bats (Phyllostomidae) are greater in farmland or secondary forests than in primary forests (Willig et al., 2007). However, habitat transformation often induces negative impacts on wild populations. The density of the Japanese monkey (*Macaca fuscata*) decreases in areas with coniferous plantations (Hill et al., 1994) and ungulates tend to avoid exposed areas without shelter sites (Mysterud and Ostbye, 1999).

Hunting and control measures also alter population density, activity pattern and habitat use of wildlife. White-tailed deer (*Odocoileus virginiana*) show significant shifts of core-area use and daily activity pattern between the prehunt and hunt period

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(Kilpatrick and Lima, 1999). In addition, the existence of domestic dogs (*Canis familiaris*) induces alert and flight behaviors in wildlife (Hockin et al., 1992; Miller et al., 2001; Sweeney et al., 1971), and decreases the densities of certain species (Silva-Rodriguez and Sieving, 2012).

Thus, wild populations may be exposed to various types of anthropogenic disturbance that may have both negative and positive impacts. To cope with disturbance, wildlife may change density, activity pattern and other ecological traits as a result of the trade-offs between negative and positive impacts (Gill et al., 1996a).

To evaluate anthropogenic disturbance on wild populations, we should consider the extent of the effects across space, because the magnitude of disturbance on wildlife varies with spatial scales (Coulon et al., 2008). Therefore, responses of wild populations to disturbance, as well as to natural factors, depend on spatial scales (Anderson et al., 2005). Many studies have fixed the scales (buffer sizes) in advance by referring to ecological bases, such as home range sizes of individual animals (e.g., Boyce et al., 2003; Fletcher and Hutto, 2008; Zweifel-Schielly et al., 2009). However, we cannot identify ecologically meaningful scales exactly *a priori* (Zweifel-Schielly et al., 2009). Ideally, we should use the spatial scale at which the factors show the most significant effects on wild populations for analyses; otherwise the significant factors may not be detected. Therefore, for wildlife conservation, we must detect the most effective spatial scale and manage the significant anthropogenic disturbance at that scale.

This study examined the effects of anthropogenic disturbance on two ecological traits (population density and daily activity pattern) of Japanese sika deer (*Cervus nippon*). In this study, forestry areas, agricultural lands, hunting risk and feral dogs are regarded as [illegible] of anthropogenic disturbance, and we quantified the effects o[illegible] factors as well as those of natural factors. We analyzed the e[illegible]ts of land use at various spatial scales to detect the most effective s[illegible]tial scale. We then made the following three predi[illegible]ncerni[illegible] anthropogenic disturbance. Prediction 1: deer [illegible]sity [illegible] be negatively affected by forestry areas, hunting ri[illegible]d dog [illegible]sity, and positively affected by agricultural lands. Ind[illegible]co[illegible]tations may decrease natural resourc[illegible] deer [illegible]tsuma, 2007; Gill et al., 1996b), hunting and dog[illegible]uld directl[illegible]d indirectly decrease deer numbers (Kilpatric[illegible]a, 1999; Si[illegible]odriguez and Sieving, 2012), whereas agr[illegible]ltura[illegible]ducts may attract deer. Prediction 2: hunting risk, [illegible]cultural lan[illegible]d forestry area will modify daily activity pat[illegible] because human [illegible]ities are likely to restrict diurnal activi[illegible]r deer [illegible]ysterud and Ostbye, 1999). As a result, deer diurna[illegible]ivit[illegible]ll decrease and nocturnal activity will increase unde[illegible]isturba[illegible]. Prediction 3: the most effective spat[illegible]e wi[illegible]er b[illegible]ween ecological traits (deer density an[illegible]ily a[illegible]ity pat[illegible]ecause different anthropogenic disturba[illegible]s may [illegible]volve dens[illegible]y and activity through different mechani[illegible]

Material and Me[illegible]s

Study area and subjects

Yakushima is a roughly circular mountainous island (peak 1936 m, area 503 km^2; Fig. 1) located in Kagoshima Prefecture, southern Japan (30°N, 130°E). Approximately 13,500 residents live in more than 20 villages mainly located less than 100 m above sea level (a.s.l.). Agricultural fields including orange orchards, rice paddies, pastures and artificial facilities lie below approximately 200 m a.s.l. Intensive logging of evergreen broad-leaved forests were conducted below approximately 800 m a.s.l. from the 1960s to 1970s. Following logging, coniferous trees (*Cryptomeria japonica*)

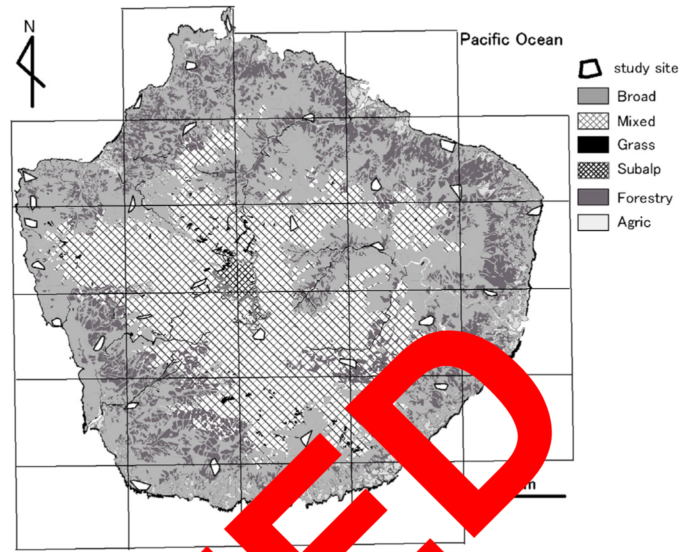

Fig. 1. Land use and [illegible]y sites on [illegible]and of [illegible]shima. Study sites are expressed by minimum co[illegible]polygons surr[illegible] cameras within each study site. Broad: broad-[illegible]st, Mixed: m[illegible]oniferous/broad-leaved forest, Grass: natural grass[illegible]d, Sub[illegible]balpine vegetation, Forestry: forestry area, Agric: agricultural land. Natural gra[illegible]distributed very thinly around the coast and rivers. The n[illegible]f hunted deer [illegible]ummarized in approximately 4.6 km × 6 km cells on [illegible]ap.

w[illegible] planted [illegible]ely (Agetsuma, 2007). The area from approxima[illegible]800–1[illegible]m a.s.l. is dominated by mixed forests including conif[illegible]rgreen and deciduous broad-leaved trees. In the sub-[illegible]lpine region (above 1800 m a.s.l.), vegetation comprises shrubs [illegible]odendron and grasslands of dwarf bamboo (*Pseudosasa* [illegible]owa[illegible]ii). Thus, in this island, natural vegetation forms zonation with changing altitude (Fig. 1) (Ohsawa et al., 2006; Tagawa, 1994).

The annual precipitation varies with location and ranges from 2500–8700 mm (Environment Agency, 1984). Along the coast, the annual mean temperature is approximately 20 °C, which corresponds to the margin between subtropical and warm temperate zones (Tagawa, 1994). However, above 1000 m a.s.l., the climate is much cooler, with snowfall in winter and an annual mean temperature of approximately 10 °C (Ohsawa et al., 2006).

The subject of this study is a subspecies of the Japanese sika deer (*Cervus nippon yakushimae*) that is endemic to Yakushima and Kuchinoerabujima (38 km^2), an island located 12 km northwest of Yakushima. *C. n. yakushimae* has the smallest body size among the subspecies of Japanese sika deer (Izawa et al., 1996). The deer population, which decreased greatly from the 1960s to 1970s due to habitat destruction (Agetsuma, 2007), has been recovering since the 1990s. The deer inhabit most regions of the island, ranging from the coast to the subalpine zone. However, population density varies considerably with location (Agetsuma, 2007; Koda et al., 2011).

The staple diet of the deer comprises leaves, fruits and seeds of woody plants (Takatsuki, 1990), which are available largely as forest litter (Agetsuma et al., 2011). The deer also feed on food dropped from trees by Japanese monkeys (*Macaca fuscata yakui*) that also inhabit most regions of the island. This accounts for 7% of time spent feeding for deer in a broad-leaved forest (Agetsuma et al., 2011). Because monkeys can provide relatively higher quality foods (fruits and seeds) from tree canopies (Agetsuma et al., 2011), monkeys attract deer in the forest (Koda, 2012).

The mean annual range size of an individual of deer in a broad-leaved forest, expressed as 90% fixed kernel, is 12 ha (7–17 ha, $n = 4$) for adult females and 36 ha (4–78 ha, $n = 4$) for adult males (Agetsuma et al., 2005). They have very stable ranges lasting for years; however, some adult males occasionally emigrate 4–8 km

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