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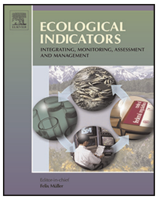

Appropriate vegetation indices for measuring the impacts of deer on forest ecosystems

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ABSTRACT

Increasing deer density can cause serious degradation of forests in the Americas, Europe, and Asia. To manage deer impacts, evaluating their current impacts on forest ecosystems is necessary, usually via vegetation indices. However, the relationship between vegetation indices and absolute deer density, while taking into account tree size, snow depth, light condition, and the type of understory vegetation, has never been investigated. We examined the relationship between various vegetation indices and absolute deer density in 344 study plots in the deciduous broad-leaved forest of Yamanashi Prefecture, central Japan. In each plot, debarking and browsing, along with the coverage and maximum height of understory vegetation, were surveyed. Estimated deer densities for 82 5 × 5-km mesh units ranged from 0.8 deer/km^2 to 32.7 deer/km^2. The percentages of debarked trees within a plot ranged from 0 to 84%. Debarking was promoted by high deer density, small tree size, and thick snow. The effect of tree size on debarking was stronger than that of deer density. Occurrence of browsing on understory vegetation was higher at higher deer densities, and where understory vegetation was dominated by evergreen dwarf bamboo. Coverage and maximum height of understory vegetation were unaffected by deer density but increased with canopy openness and the dominance of dwarf bamboo in the understory. Overall, we predict that debarking of small trees living in heavy snow areas should occur even at low deer densities ($<$10 deer/km^2). Browsing on dwarf bamboo should occur at intermediate deer densities (10–30 deer/km^2), while debarking of thick trees living in low snow areas should occur only at high deer densities ($\geq$30 deer/km^2). Our study shows that debarking and browsing on understory vegetation are appropriate indices for evaluating deer impacts on forest ecosystems, but that tree size, snow depth, and the type of understory vegetation should also be considered.

1. Introduction

Deer abundance is increasing in the Americas, Europe, and Asia (Stewart and Burrows, 1989; Fuller and Gill, 2001; Rooney, 2001; Iijima et al., 2013). Accordingly, serious impacts of deer on forest ecosystems, including tree debarking (Akashi and Nakashizuka, 1999; Verheyden et al., 2006; Vospernik, 2006; Kiffner et al., 2008; Takeuchi et al., 2011), reduction of sapling density (Horsley et al., 2003; Kumar et al., 2006; Gill and Morgan, 2010; Randall and Walters, 2011; Nuttle et al., 2014), browsing on saplings and understory vegetation (Takatsuki, 1989; McLaren et al., 2000; Morellet et al., 2001; Rooney and Waller, 2003; Heuze et al., 2005; Akashi et al., 2011), changes in species diversity and/or composition of understory vegetation (Stewart and Burrows, 1989; Horsley et al., 2003; Beguin et al., 2011; Suzuki et al., 2013; Filazzola et al., 2014), and soil disturbance (Beguin et al., 2011) have been documented. Such deer impacts would be irreversible (Waller and Alverson, 1997; Horsley et al., 2003; Côté et al., 2004; Tanentzap et al., 2012) given sufficiently high deer density over time. Thus, assessing deer impacts in the early stages of population increase is especially important.

Accessible and affordable monitoring tools are needed as part of a management strategy for reducing deer impacts on forest ecosystems (Filazzola et al., 2014). Vegetation indices (e.g., cover and height of understory vegetation, intensity of browsing and debarking by deer) have often been used to evaluate deer impacts on forest ecosystems, and many empirical studies have examined the relationship between vegetation indices and deer density. These studies have shown that high deer density results in a higher debarked tree ratio (Kiffner et al., 2008), higher browsing intensity on understory vegetation (Takatsuki, 1989), and lower height and coverage of understory vegetation (Kaji et al., 2004; Nuttle et al., 2014). However, many vegetation indices are affected by factors other than deer density; e.g., tree debarking ratio is affected by tree

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size (Akashi and Nakashizuka, 1999; Nagaike and Hayashi, 2003) and snow depth (Honda et al., 2008; Kiffner et al., 2008). Likewise, understory vegetation coverage (Morecroft et al., 2001; Kraft et al., 2004; Massé and Côté, 2012) and species composition (Filazzola et al., 2014; Nuttle et al., 2014) are significantly affected by light levels, and in turn the type of understory vegetation affects browsing behavior. For example, evergreen dwarf bamboo is thought to be an important winter food for deer (Borkowski et al., 1996), with higher nutritional value than bark (Ando et al., 2004). However, the relative impact of deer density and other factors on the vegetation indices is unknown.

Absolute deer density should be considered when comparing the relative impacts of deer density and other factors on vegetation indices because the relationship between absolute deer density and both deer density indices and relative deer density is likely to differ among study areas. However, few studies have used absolute deer density (cf. Rooney and Waller, 2003; Gill and Morgan, 2010) because precise estimates (Morellet et al., 2007) are difficult to make except in enclosure experiments (Stewart and Burrows, 1989; Horsley et al., 2003; Ito and Hino, 2005; Forsyth et al., 2007; Beguin et al., 2011). Many studies have used deer density indices like catch per unit effort (Kiffner et al., 2008) and pellet or pellet group counts (Takatsuki, 1989; McLaren et al., 2000; Randall and Walters, 2011; Suzuki et al., 2013). Relative (e.g., low vs. high deer density), not absolute, deer density has generally been considered in reviews of the relationship between vegetation indices and deer density (Mysterud, 2006; Putman et al., 2011; Tanentzap et al., 2012). However, constructing multiple deer enclosures with variable deer densities is challenging. Recently, absolute deer density has been estimated by Bayesian modeling (Yamamura et al., 2008; Iijima et al., 2013); in these cases, estimated absolute deer density could be used to clarify the effect of deer density on vegetation indices.

We sought to evaluate the relative effect of deer density and other factors on vegetation indices and to clarify which vegetation indices are most appropriate for measuring deer impacts on forest ecosystems by considering the effects of tree size, snow depth, light condition, and understory vegetation type. We conducted our study in Yamanashi Prefecture, central Japan. In Japan, Deer (*Cervus nippon*) have been expanding their distribution since the late 1980s (Takatsuki, 2009), and debarking and browsing have recently become serious problems (Takatsuki, 1989; Akashi and Nakashizuka, 1999; Ando et al., 2004), a trend that has also been observed in Yamanashi Prefecture (Nagaike and Hayashi, 2003; Jiang et al., 2005; Nagaike 2012; Nagaike et al., 2014).

2. Methods

2.1. Study site

Our study took place in Yamanashi Prefecture, central Japan, a region 4465.37 km^2 in size with 78% forest cover. Natural cool-temperate forest is common in the region, characterized by deciduous broad-leaved trees, including *Acer*, *Betula*, and *Quercus* spp. However, mixed forests of broad-leaved trees and conifers dominate at altitudes of 1500–2000 m, and evergreen conifer forests including *Abies*, *Picea*, and *Tsuga* spp. dominate over 2000 m. Across the region, estimated deer densities for 82 5×5-km mesh units ranged from 0.8 deer/km^2 to 32.7 deer/km^2 in autumn 2009 (calculated from Iijima et al., 2013). From this deer density range, we arbitrarily defined low, intermediate, and high deer densities as $<$10 deer/km^2 (56 mesh), 10–30 deer/km^2 (25 mesh), and $\geq$30 deer/km^2 (1 mesh), respectively. Mean maximum snow depth over 30 years (1×1-km mesh unit) was 8–37 cm (Japan Meteorological Agency, 2002).

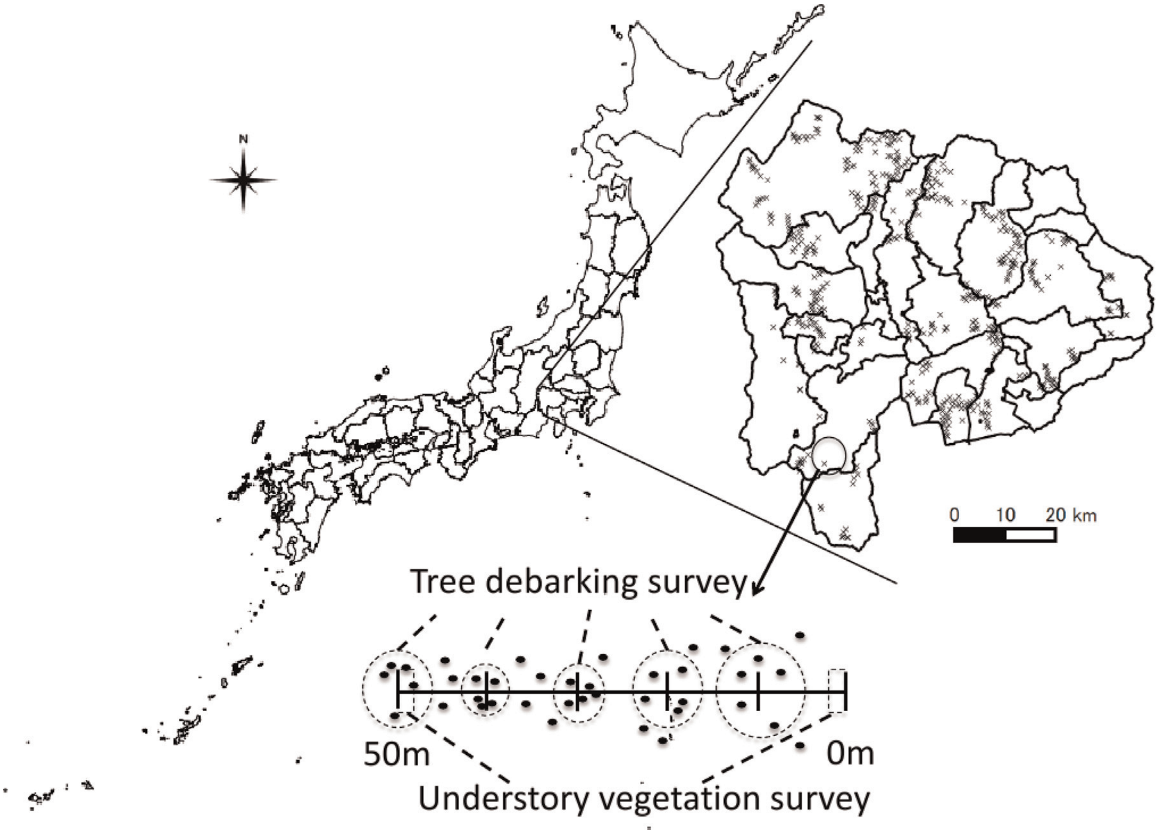

Fig. 1. Location of study plots. Square gray symbols indicate the research plots.This map was drawn by QGIS (Quantum GIS Development Team, 2014).