Effects of Sika Deer and Conifer Plantations on the Density and Diversity of Current-Year Tree Seedlings in Lowland Forests on Yakushima Island, Japan

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Introduction

Sika deer populations have dramatically increased recently, producing increasing damage to forest vegetation in several areas in Japan (Takatsuki 1989; Takatsuki and Gorai 1994; Akashi and Nakashizuka 1999; Yokoyama et al. 2001; Tsujino et al. 2004). Grazing and browsing by high-density sika deer populations cause a loss of forest floor vegetation (Takatsuki and Gorai 1994; Tsujino and Yumoto 2004), a decrease of mature trees owing to bark stripping (Akashi and Nakashizuka 1999; Yokoyama et al. 2001), and an increase of some special plant species, which are not preferred by sika deer (Kaji and Yajima 1991). Large-scale logging and planting of commercial crops have also damaged ecological functions of forests and have eroded the public benefit provided by forests (Agetsuma 2007).

We should note first that most natural vegetation has already been disturbed by forest transformation (Agetsuma 2007). Thus in this study, we examined vegetation changes in the forest in relation to sika deer herbivory and human impacts such as conifer plantations. To clarify the effects of sika deer and conifer plantations on changes of forest vegetation, we established deer exclusion fences in three study sites, which showed differences in sika deer population density and percentage of area occupied by conifer plantations, and counted newly germinated and established current-year tree seedlings in summer and winter.

Methods

The study sites were located on Yakushima Island (30˚20' N, 131˚30' E), which has an area of ca. 503 km^2 and lies ca. 70 km south of Kyushu, Japan. The study area was in a warm-temperate forest at an altitude between 200 and 600 m on the western and northwestern part of Yakushima Island. The geology is granite. The forest consists mainly of broad-leaved evergreen trees of Fagaceae, Hamamelidaceae, Myrsinaceae, and Lauraceae (Tagawa 1980; Tsujino et al. 2006; Agetsuma et al. unpubl. data).

Three study sites with differences in the percentage of plantation area and sika deer population density were selected: the Seibu area (SE, ca. 250 m asl, Fig. 1), the Nagata area (NA, ca. 550 m asl, Fig. 1), and the Isso area (IS, ca. 500 m asl, Fig. 1). The estimated sika deer population density was greatest in SE and lowest in IS (Agetsuma et al. 2003; Agetsuma 2007), and the disturbance ranking, calculated as the percentage of total area occupied by conifer plantations, was IS > NA > SE (Hill et al. 1994).

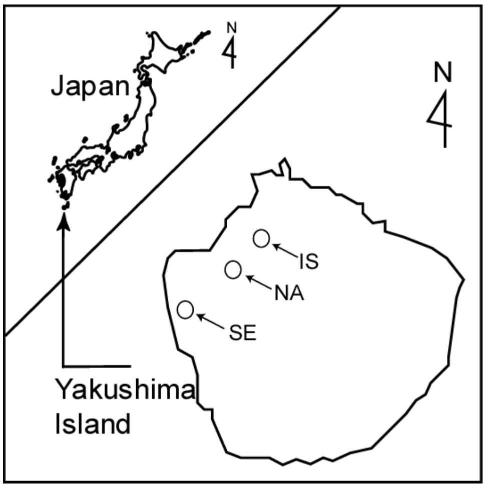

Fig. 1. Study sites on Yakushima Island, Japan. IS, NA, and SE indicate the Isso area (500 m asl), Nagata area (550 m asl), and Seibu area (250 m asl), respectively.

A subspecies of sika deer, *Cervus nippon yakushimae*, inhabits the whole area of Yakushima Island (Kagoshimaken Sizenaigo Kyokai 1981). The body weights of adult male and female *C. n. yakushimae* are 24–50 kg and 19–25 kg, respectively (Kagoshimaken Sizenaigo Kyokai 1994; Agetsuma et al. 2003; Komiya 2002). The deer population density on Yakushima Island may vary according to altitude, forest type, and degree of human impact. Natural predators of deer are absent. Deer were hunted in some areas on the island that suffered substantial damage to agriculture, but not in the study area. In broad-leaved evergreen forests in Japan, the leaves and fruits of evergreen and deciduous plants and graminoids are the primary food for sika deer (Takatsuki 1988; Takatsuki 1990; Asada and Ochiai 1996; Tsujino and Yumoto 2004; Agetsuma and Agetsuma-Yanagihara 2006).

Table 1. Numbers of seedling observation quadrats(1-m^2) at the three study sites.

	Number of Quadrats		
Study Site	Fenced	Unfenced	Total
Seibu Area	27	27	54
Nagata Area	17	22	39
Isso Area	22	22	44
Total	66	71	137

Six deer exclusion fences, each with a perimeter of ca. 80 m and an area of ca. 0.02 ha, were established and were duplicated at each site, at the Seibu and Isso areas in August 2003 and at the Nagata area in August 2004 (Table 1). An unfenced area of similar size was also selected in the vicinity of each fenced area. These study quadrats were divided into sub-quadrats of 5 × 5 m, and a total of 137 seedling observation quadrats (1 × 1 m) were established at the southwest corner of each sub-quadrat in fenced and unfenced quadrats in December 2003 (Table 1).

A seedling census was conducted for all living current-year tree seedlings in early summer (late May to early July) and winter (December to February). Most tree seedlings in this area germinated from April to June; the seedling growing season was summer to autumn; and seedling growth and mortality decreased in winter.

Thus, we defined current-year tree seedlings as seedlings less than 1 year old. We counted the number of current-year tree seedlings for each tree species in summer and winter, to compare seedling recruitment and establishment between fenced and unfenced quadrats and among study sites. We collected data four times at SE and IS in winter, three times at SE and IS in summer, three times at NA in winter, and two times at NA in summer. Thus, the replication numbers were 3 for SE, 2 for NA, and 3 for IS in summer, and 4 for SE, 3 for NA, and 4 for IS in winter.

A generalized linear model with a stepwise procedure was used to assess the relationship among the number of current-year tree seedlings (NSE), number of species (NSP), census season (SEA), study site (SIT), and fence treatment (FEN), starting from a full model with interactions:

Model 1

NSE ~ SEA + SIT + FEN + SEA:SIT + SEA:FEN + SIT:FEN + SEA:SIT:FEN

Model 2

NSP ~ SEA + SIT + FEN + SEA:SIT + SEA:FEN + SIT:FEN + SEA:SIT:FEN

where SEA (summer or winter), SIT (Seibu, Nagata, or Isso area), and FEN (fenced or unfenced quadrats) are categorical variables with two or three modalities. The colon indicates an interaction. We used Akaike's information criterion (AIC, Akaike 1973) for the model selection, with the minimum AIC as the best-fit estimator.

Results and discussion

A statistical analysis of the number of current-year tree seedlings selected the full model of the regression as that with the minimum AIC value (AIC = 4923.24). In both summer and winter, the mean number of seedlings per quadrat was greater in fenced quadrats than in unfenced quadrats (Fig. 2). In NA and SE, the high-density sika deer population probably grazed on newly germinated seedlings soon after germination, and the difference in seedling density between fenced and unfenced quadrats was great, especially in summer. On the other hand, newly germinated seedlings in IS were not browsed as much owing to the low density of sika deer in IS, and the difference in seedling density between fenced and unfenced quadrats was small. In winter, seedling establishment numbers were different between fenced and unfenced quadrats at each study site, probably because of feeding pressure and physical disturbance by sika deer.

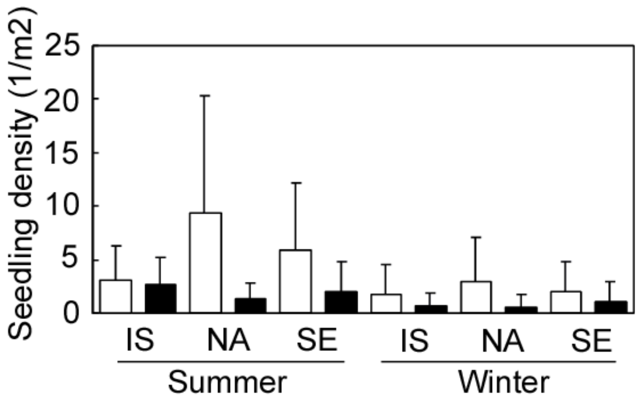

Fig. 2. Mean (mean + SD, white and black bars) numbers of current-year tree seedlings per 1-m^2 quadrat. White and black indicate fenced and unfenced quadrats, respectively. IS, NA, and SE indicate the Isso area, Nagata area, and Seibu area, respectively.

To identify the effects of sika deer and human impacts on tree seedling diversity in the forest, we compared the number of current-year tree seedling species among sites with different sika deer density and disturbance intensity. A statistical analysis of the number of species selected the full model with the minimum AIC value (AIC = 2896.95) (Fig. 3). The mean number of species per fenced quadrat was estimated to be greater at SE > NA > IS in summer and at NA > SE > IS in winter, and the difference between fenced and unfenced quadrats was estimated to be greater at SE > NA > IS in summer and NA > SE > IS in winter. This result indicates that human impacts, such as plantation areas, around the study sites limited the recruitment and establishment of current-year tree seedlings, especially in IS, probably because the conversion to conifer plantations decreased the natural forest area of seed sources. On the other hand, the mean number of species per unfenced quadrat was greater at IS > SE > NA in summer and in winter, with the difference between fenced and unfenced as above (SE > NA > IS in summer and NA > SE > IS in winter). This indicates that the feeding and/or physical disturbance owing to sika deer (Tsujino and Yumoto 2004) caused the decrease of seedling recruitment and establishment in unfenced quadrats, especially in SE and NA, and resulted in decreased seedling diversity.

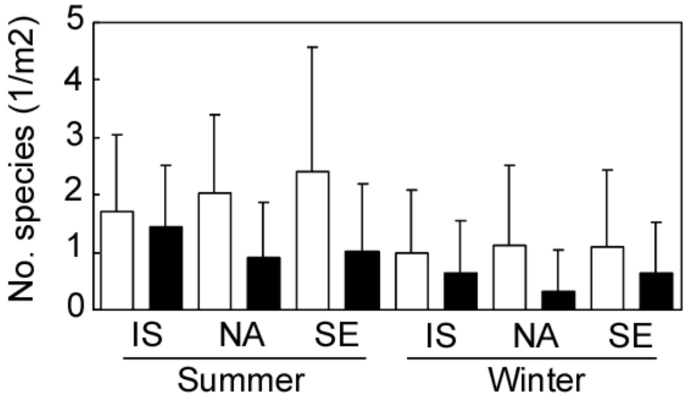

Fig. 3. Mean (mean + SD, white and black bars) number of species of current-year tree seedlings per 1-m^2 seedling observation quadrat.
White and black indicate fenced and unfenced quadrats, respectively.
IS, NA, and SE indicate the Isso area, Nagata area, and Seibu area, respectively.

In this study, we revealed two factors affecting tree seedling number and diversity: sika deer populations negatively affect both the number and diversity of current-year tree seedlings, and conifer plantations negatively affect the diversity of seedlings (Fig. 4). On the other hand, there is a negative relationship between sika deer population density and degree of human impact on the forest (Agetsuma 2007). We suggest that human impacts on a forest, such as conversion of natural forest to conifer plantation, have not only direct negative effects on tree seedling diversity, probably through a seed source effect, but also indirect positive effects by decreasing the sika deer density (Fig. 4). Thus, the effects of forest disturbances by humans are complex and include direct negative and indirect positive effects on tree seedling communities.

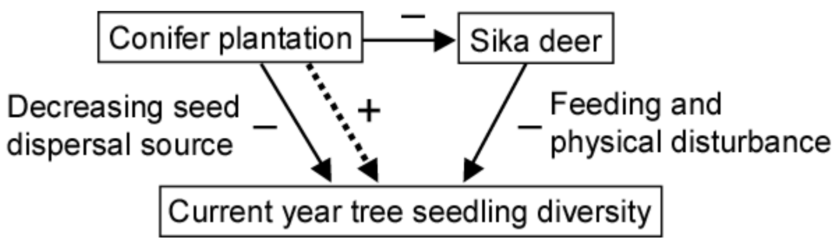

Fig. 4. Scheme showing the interactions among conifer plantations, sika deer, and current-year tree seedling diversity. Solid and broken lines indicate direct and indirect effects, respectively. Plus and minus signs beside arrows indicate positive and negative effects, respectively.

References

Agetsuma N, Sugiura H, Hill DA, Agetsuma-Yanagihara Y, Tanaka T. (2003) Population density and group composition of Japanese sika deer (*Cervus nippon yakushimae*) in ever-green broad leaved forest of Yakushima, southern Japan. Ecol Res 18: 475-483.

Agetsuma N. (2007) Ecological function losses caused by monotonous land use induce crop raiding by wildlife on the island of Yakushima, southern Japan. Ecol Res 22: 390-402.

Agetsuma N, Agetsuma-Yanagihara Y. (2006) Ecology of Yaku sika deer in the island of Yakushima (in Japanese). In: Ohsawa M, Tagawa H, Yamagiwa J (eds) World heritage, Yakushima. Asakura, Tokyo, pp 143–149.

Akashi N, Nakashizuka T.（1999） Effects of bark-stripping by Sika deer（*Cervus nippon*）on population dynamics of a mixed forest in Japan. Forest Ecol Manag 113: 75-82.

Asada, M. and Ochiai, K. (1996) Food habitats of sika deer on the Boso Peninsula, central Japan. Ecological Research 11: 89-95.

Hill DA, Agetsuma N, Suzuki S. (1994) Preliminary survey of group density of *Macaca fuscata yakui* in relation to logging history at seven sites in Yakushima Japan. Primate Research 10: 85-93.

Kagoshimaken Sizenaigo Kyokai. (1981) Yakusika no seisoku/bunnpu nikannsuru kinkyu chousa houkokusho. Kagoshimaken Sizenaigo Kyokai Chousahoukoku 5: 1-34 (in Japanese).

Kagoshimaken Sizenaigo Kyokai (1994) ‘Kendo Kamiyaku-Nagata-Yakusen Kairyoukeikaku Nitomonau Kankyoeikyo Monitoring’ Houkokusho. Kagoshimaken Sizenaigo Kyokai, Kagoshima (in Japanese).

Kaji K, Yajima T. (1991) Forage selection by introduced deer on Nakanoshima Island, and its effect on the forest vegetation. Proceedings of the International Symposium on Wildlife Conservation, in INTECOL 1990（ed. N.Maruyama *et al.*） pp. 52-55. Japan Wildlife Research Center, Tokyo.

Komiya T. (2002) Field Best Encyclopedia: Mammals in Japan. Gakken, Tokyo (In Japanese).

Takatsuki S. (1988) Rumen contents of sika deer on Tsushima Island, western Japan. Ecological Research 3: 181-183.

Takatsuki S. (1989) Effect of deer on plants and plant communities. Japanese Journal of Ecology 39: 67-80 (In Japanese).

Takatsuki S. (1990) Summer dietary compositions of sake deer on Yakushima Island southern Japan. Ecological Research 5: 253-260.

Takatsuki S, Gorai T.（1994） Effects of Sika deer on the regeneration of a *Fagus crenata* forest on Kinkazan Island, northern Japan. Ecological Research 9: 115-120.

Tsujino R, Yumoto T. (2004) Effects of sika deer on tree seedlings in a warm temperate forest on Yakushima Island, Japan. Ecological Research 19: 291-300.

Tsujino R, Noma N, Yumoto T. (2004) Growth of sika deer (*Cervus nippon yakushimae*) population in the lowland forests of Yakushima Island, Japan. Mammal Study 25: 105-111.

Tsujino R, Takafumi H, Agetsuma N, Yumoto T. (2006) Variation in tree growth, mortality and recruitment among topographic positions in a warm–temperate forest. Journal of Vegetation Science 17: 281-290.

Yokoyama S, Maeji I, Ueda T, Ando M, Shibata E.（2001） Impact of bark stripping by sika deer, *Cervus nippon*, on subalpine coniferous forests in central Japan. Forest Ecology and Management 140: 93-99.