Assessing the impact of deer on young trees in a Sugi (*Cryptomeria japonica*) plantation based on field signs

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Abstract

Predicting the level of damage caused by deer browsing in young plantations is important for selecting appropriate damage control measures. In this study, we examined a method for assessing the level of deer damage in young Sugi (*Cryptomeria japonica*) plantations by observing field signs of deer. First, a questionnaire survey was conducted to obtain information about the damage caused by deer browsing on planted trees and the extent of field signs, such as browsing marks and deer fecal pellets in young plantations where deer-proof fences were installed. The extent of field signs was recorded as qualitative data (i.e., "None", "A few", and "Many"). A multiple correspondence analysis (MCA) of these relationships revealed a relationship between the extent of deer damage in young plantations and the presence of five field signs (browsing marks, bark stripping marks, fecal pellets, trails and tracks). Based on the coordinate values of each field sign obtained using the MCA, the extent of each field sign was scored, and the total value was calculated as the deer impact score (DISco). When the relationship between the DISco and the extent of deer damage to planted trees was subjected to a logistic regression analysis (LRA), the DISco was found to be a significant explanatory variable and the LRA was an effective model (AUC of 0.7122 and 0.7794, respectively) for predicting the probability of stand damage and High stand damage. Therefore, the DISco was shown to be an effective tool for assessing the impact of deer in young Sugi plantations.

Keywords: sika deer, deer-proof fence, deer impact, field signs, planted trees

Introduction

Damage to natural vegetation and plantations caused by browsing deer has been widely reported (Gill 1992; Côté et al. 2004; Takatsuki 2009). In plantations, significant economic losses have been incurred due to deer browsing planted trees (Putman and Moore 1998; Côté et al. 2004). Damage caused by deer can be divided into two general types: browsing of branches and leaves shortly after planting, and bark stripping when the trees are mature (Iimura 1984; Gill 1992). The impact of deer browsing on planted trees is particularly large for several years after planting when the trees are relatively small (Iimura 1984).

As a result, a variety of damage control measures, including the installation of deer-proof fences, tree shelters and spray repellents, have been developed. Of these, fences and tree shelters have been used extensively in many young plantations to protect planted trees from deer damage (Masaki et al. 2017). However, it is difficult to completely protect planted trees from browsing deer using these protective tools alone. Even in young plantations where fences have been installed, there have been many reports of cases where deer have been able to cross the fence due to the fence being compromised in some way, e.g., entering through holes or over parts of the fence that have collapsed, and the deer have then caused extensive browsing damage inside the fence (Takayanagi and Yoshimura 1988; Takatsuki 2009; Oshima et al. 2014; Sakai 2018). Damage due to deer browsing has also been reported in some young plantations where tree shelters have been installed (Nomiya et al. *submitted to same JFR special issue*). It is presumed that the extent of damage due to deer browsing in the young plantations where fences and tree shelters have been installed is proportional to the deer impact level and/or population density, but this information is lacking. The protective effect, or contribution, of each damage control measure differs depending on the impact and/or population density of the deer. In addition, the installation of fences and tree shelters has a negative effect on income generation because of the high costs for materials and installation (VerCauteren et al. 2006; Takatsuki 2009). Consequently, if damage control measures can be implemented in proportion to the level of the impact or population density of deer, then optimum damage control measures could be selected, and the cost may be minimized. Thus, an index that can be used to assess the impact level of deer after planting is needed.

In Japan, the population density index (Ministry of the Environment 2015; Suzuki et al. 2021) estimated by the fecal pellet count method / fecal pellet group count method and the block count method (Maruyama and Furubayashi 1983; Iwamoto et al. 2000; Goda et al. 2008; Mizuki et al. 2020) are often used as indices for predicting the damage intensity caused by deer. However, these methods are time-intensive, even for one-point measurements. In addition, the resolution of the density map is approximately 5 km, which is effective for use as a wide-area index, such as the regional scale of deer population density (Suzuki et al. 2021); however, it is not possible to accurately predict the population density of a target plantation using this method. In addition, the relationship between the deer population density and the degree of forest damage by deer is not always correlated and can be influenced by a variety of factors (Ikeda 2005; Putman et al. 2011a, 2011b). It is therefore necessary to consider whether other indicators can be used as a proxy for assessing damage intensity by deer in the field.

Indices of damage intensity by deer include assessments of browsing intensity using the height and the proportion of flowering individuals of indicator plants (Williams et al. 2000; Fletcher et al. 2001; Pavlovic et al. 2014; Blossey et al. 2017 Curtis et al. 2021), the degree of decline of understory vegetation, and the change in stand structure in the forests (Fujiki et al. 2010; Planning Committee, The Society of Vegetation Science 2011; Ohashi et al. 2014). However, evaluations based on indicator species require the ability to identify species, which can be difficult for non-experts. In addition, in surveys of large areas and/or different climatic zones, the same plants do not always grow on the forest floor, so it is difficult to survey by indicator species. Surveys focusing on browsing marks and structural changes of the understory vegetation assume that the understory vegetation is well developed when deer are absent. Therefore, it is difficult to evaluate the degree of deer disturbance in forest stands that have poorly developed understory vegetation, such as in the dark forest floors of broadleaved evergreen forests and plantations (Kiyono 1990; Ito 1996; Ito et al. 2008; Yamagawa et al 2009).

However, a method for evaluating the impact of deer has been developed using deer signs, such as fecal pellets and evidence of bark stripping (Akashi et al. 2013). This method simply records the extent of field signs attributable to deer, and can be implemented easily by forestry managers in a short space of time. However, it is expected that the type and impact of field signs will differ depending on the climatic zone, vegetation and amount of snowfall. In addition, few studies have clarified the relationship between the impact of deer and forestry damage caused by deer.

Consequently, in order to predict forestry damage by deer, it is necessary to investigate the type and extent of field signs in relation to the degree of forestry damage.

The purpose of this study was to develop a method for assessing the level of forestry damage attributable to deer in a young Sugi (*Cryptomeria japonica*) plantation using a simple survey of field signs. Since the most common deer damage control measures in Japan include the installation of deer-proof fences, the extent and intensity of damage to planted trees inside the fences was used as an index of forestry damage levels. Thus, the following three analyses were carried out in young Sugi plantations (1- to 3-years old) in this study: 1) In order to clarify the protective effect of fences, we examined the effect of installing fences and the incidence of compromised fences on browsing damage by sika deer in young plantations; 2) The relationship between the extent of damage by deer in the plantation and the extent of field signs (e.g., browsing marks and deer fecal pellets) around the young plantation was clarified; 3) Field signs were scored and the Deer Impact Score (DISco), i.e., an index of the extent of forest damage after planting, was determined.

Methods

1. Study area

This study targeted the Kyushu and Shikoku regions of southwestern Japan (Fig. 1). Most parts of these areas belong to warm temperate and cool temperate zones, with natural vegetation that consists mostly of evergreen broadleaf forests and deciduous broadleaf forests, respectively. However, 50–60% of the forests in these areas are coniferous plantations such as Sugi (*Cryptomeria* *japonica*) and Hinoki (*Chamaecyparis obtusa*) (Masaki et al. 2017). In addition, many plantations have reached the age at which the stands can be harvested, and the area of clear-cutting and re-planting is increasing. Sika deer (*Cervus nippon*) are widely distributed in many areas of these forests. In some areas, deer densities have been estimated to be 50 deer·km^{-2} or more (Ministry of the Environment 2015). Sika deer have caused extensive damage to natural and cultivated vegetation over wide areas of the Kyushu and Shikoku regions (Ohashi et al. 2014; Suzuki et al. 2021).

2. Data collection

1) Distribution of questionnaires

The extent of damage to planted trees caused by browsing sika deer and the extent of field signs of sika deer in the surrounding afforested areas were investigated using a questionnaire survey. In May 2018, we sent questionnaires to the Kyushu Regional Forest Office, the Shikoku Regional Forest Office, and the Kyushu Branch Office of Forest Management Center. The questionnaires were completed by forest officers and workers. By December 2018, 320 completed questionnaires had been collected. Of the collected questionnaires, 237 questionnaires could be used for the analysis.

2) Damage to deer-proof fencing and planted trees

In the Kyushu and Shikoku areas of Japan, it is common to install deer-proof fences made of nylon mesh (approximately 1.8 m high with a mesh size of 5 to 15 cm) in planted areas that are frequented by deer. In cases where the deer-proof fence was compromised by holes and/or collapsed, the browsing damage to planted trees can be extensive (Takayanagi and Yoshimura 1988; Oshima et al. 2014; Sakai 2018). Therefore, in the questionnaire survey, we also examined whether a fence had been installed and whether or not the fence had been compromised.

In Japan, browsing damage to planted trees by sika deer most typically occurs at heights of up to about 150 cm in plantations (Ikeda 1998; Sasaki et al. 2013; Nomiya et al. 2019). Therefore, in this study, we conducted a questionnaire survey on young Sugi plantations that were 3-years old or younger in order to target forest stands with a planted tree height of approximately 150 cm or less.

The browsing intensity of planted Sugi trees caused by sika deer was divided into five categories, focusing on the degree of browsing marks and tree crown shape, with reference to deCalesta et al. (2016) (Fig. 2). Planted trees with no browsing marks were classified as "Not browsed". Planted trees with the same tree crown shape as “Not browsed” and with browsing marks observed through careful observation were classified as "Lightly browsed". Planted trees with the same tree crown shape as “Not browsed” and with extensive evidence of browsing marks were classified as "Moderately browsed". Planted trees with unusual tree crown shapes that appeared like topiaries due to repeated browsing were classified as “Heavily browsed”. Planted trees with only the main stem remaining due extensive browsing of leaves and branches were classified as “Severely browsed”.

Furthermore, the distribution of the browsing intensity for each planted tree in the plantation was recorded as one of four types: None, A few, Many and All over. "None" indicates that planted trees in each browsing-intensity category did not occur in the planted area. “A few” indicates that planted trees in each browsing-intensity category can be found with careful observation. “Many” indicates that planted trees in each browsing-intensity category can be found easily in the planted area. “All over” indicates that planted trees in each browsing-intensity category are distributed throughout the planted area.

3) Field signs of sika deer

Field signs of sika deer were investigated in mature Sugi (*Cryptomeria japonica*) and Hinoki (*Chamaecyparis obtusa*) plantations and forest roads adjacent to the young plantations where the browsing intensity of the planted trees was investigated. As field signs of sika deer in the questionnaire, we recorded bark stripping of mature Sugi and Hinoki individuals in plantations (bark stripping), browsing marks on understory woody species in mature plantations, browsing marks on understory herbaceous species in mature plantations, browsing marks on roadside vegetation, dominance of unpalatable plants, deer fecal pellets, deer carcasses and/or bones, deer antlers, deer tracks, deer trails and sightings (see Table 2). The degree of bark stripping, browsing marks and the dominance of unpalatable plants were recorded in three categories (“None”: no signs can be found, “A few”: signs can be found with careful observation, and “Many”: signs can be easily found). Regarding the dominance of unpalatable plants, the skill in identifying plant species is considered to affect the responses in the questionnaire, so "unknown" was added to the response items. The extent of deer fecal pellets, carcasses and/or bones, antlers, tracks, trails and sightings were recorded in two categories: "presence" or "absence".

3. Data analysis

1) Level of stand damage

Based on the distribution of the deer browsing intensity for each planted tree in the young Sugi plantation (Fig. 2), the level of stand damage caused by the deer was classified into four stages (Table 1). If all the planted trees were not browsed, then the level of stand damage was classified as "No damage (SDLv.0)". When the browsing intensity of the planted tree in plantation was only "lightly browsed", the stand damage level was classified as a "Low damage (SDLv.1)". If the browsing intensities of the planted trees "Heavily browsed" and "Severely browsed" are distributed in the "Many" and "All over" categories in the plantation, the stand damage level was classified as " High damage (SDLv.3)". The stand damage level between SDLv.1 and SDLv.3 was set to "Medium damage (SDLv.2)".

2) Relationship between stand damage level and deer fence status

In order to clarify the impact of the presence of a fence, or areas where the fence was compromised, on the level of stand damage in a young plantation, the magnitude and proportion of stand damage was calculated for each area where fences were installed and where they were compromised.

3) Calculation of deer impact score (DISco)

A multiple correspondence analysis (MCA) was performed to clarify the relationship between the level of stand damage and the field signs of sika deer. In the analysis, in order to eliminate the protective effect of the deer-proof fence, we only analyzed data for young plantations without deer-proof fences or plantations which had fences that were compromised (see Table 3). For the MCA, we used the responses for deer fecal pellets, browsing marks on roadside vegetation, bark stripping marks, deer trails and tracks as analysis items in the questionnaire survey (see the discussion section for details). In addition, we considered an easier method to investigate field signs of sika deer in the field. Thus, we classified the extent of three signs (deer fecal pellets, browsing marks of roadside vegetation, and bark stripping marks) into two categories, "presence" and "absence," and performed a similar MCA analysis. R 4.0.4 (R Core Team 2021) and FactoMineR package (Husson et al. 2020) were used for the analysis.

Based on the relative distance of the coordinate values of each field sign obtained by MCA, the degree of each field sign was assigned a score. We summed the scores for the degree of each field sign, and determined the total value of the scores as the Deer Impact Score (DISco), which is an indicator of the impact level of deer on forest stands.

In order to verify the validity of the DISco calculated from the field signs of sika deer, the relationship between the DISco and stand damage levels was analyzed using a generalized linear model (GLM). For the GLM analysis, we performed two types of logistic regression analysis (LRA) with different objective variables. In the two types of LRA, the explanatory variable was DISco. In the first LRA, the objective variable was the presence or absence of stand damage in the young plantation (binary data with the damaged plantation taken as 1, regardless of the stand damage level), and the probability of stand damage was estimated. In the second LRA, the objective variable was the presence or absence of the "High stand damage" in the plantation (binary data with the plantation of SDLv.3 as 1), and the probability of High stand damage was estimated. To evaluate the accuracy of the LRA, we used a receiver operating characteristic (ROC) curve (Hanley and McNeil 1982). The area under the curve (AUC), which ranged between 0.5 and 1.0, was calculated based on the ROC, with greater accuracy denoted by values closer to 1.0. R 4.0.4 (R Core Team 2021), was used for the GLM.

Results

1. Field signs associated with sika deer

Table 2 shows the number of responses for each of the field signs obtained by the questionnaire survey. Questionnaires containing blank items were excluded from the analysis. The responses for the degree of bark stripping numbered 94, 96, and 24 for "None", "A few", and "Many", respectively. The responses for the degree of browsing marks on understory woody species numbered 130, 73, and 5 for “None”, “A few”, and “Many”, respectively. The responses for the degree of browsing marks on understory herbaceous species numbered 129, 64, and 2 for “None”, “A few”, and “Many”, respectively. The "*NA*" for the browsing marks on these understories indicates that the browsing marks could not be observed due to underdeveloped understory vegetation. The responses for the degree of browsing marks on roadside vegetation numbered 119, 81, and 14 for “None”, “A few”, and “Many”, respectively. The responses for the degree of deer fecal pellets numbered 62, 122, and 30 for “None”, “A few”, and “Many”, respectively. The responses for the degree of dominance of unpalatable plants were 82 and 47 for “A few” and “Many”, respectively. However, the number of "unknown" responses was 85, accounting for about 40% of the total in terms of the degree of dominance of unpalatable plants. Deer carcasses and/or bones, antlers, tracks, trails and sightings were confirmed at 37, 8, 126, 94 and 89 sites, respectively.

2. Level of damage in each forest stand

In the young plantation without deer-proof fences, SDLv 0 and 1 were observed at 19 (82.6%) and 4 (17.4%) stands, respectively, and SDLv 2 and 3 were not observed in any of the stands (Table 3). Of the 214 young plantations where deer-proof fencing was installed, 56% (120 stands) were found to be compromised by having holes or having collapsed (Table 3). Among the plantations where the deer-proof fencing was intact, SDLv 0 was observed at 76 stands (80.9%), SDLv 1 was observed at 14 stands (14.9%), SDLv 2 was observed at 3 stands (3.1%), and SDLv 3 was observed at 1 (1.0%) (Table 3). Among the plantations where the deer-proof fencing was compromised, SDLv 0 was observed at 29 stands (24.2%), SDLv 1 was observed at 24 stands (20.0%), SDLv 2 was observed at 43 stands (35.8%) and SDLv 3 was observed at 24 stands (20.0%) (Table 3).

3. Relationship between stand damage level and field signs of sika deer

Figure 3 shows the results of the MCA, which was used to analyze the relationship between stand damage level and field signs. When the degree of deer fecal pellets, bark stripping marks and browsing marks were evaluated on three levels (“None”, “A few” and “Many”), the coordinate value for Dimension 1 was small for "None" for all field signs (Fig. 3 (a)). The coordinate value for Dimension 1 with SDLv.0 was smaller than that for the other stand damage levels (SDLv. 1, 2 and 3). The coordinate values for Dimension 2 were high for the "Many" degree of field signs, which is considered to be strongly influenced by deer, and small for the "A few" degree of field signs, which is considered to be weakly influenced by deer. The Dimension 2 coordinate values for “Presence” of deer trails and deer tracks were between the "Many" and "A few" degrees of field sings. In addition, as the coordinate value for Dimension 2 increased, the stand damage level also increased except for SDLv. 0. In other words, Dimension 1 of the MCA was effective for distinguishing between the presence or absence of stand damage caused by deer, and Dimension 2 ranked the stand damage level.

When the degree of field signs was simplified (MCA analysis using all field signs as binary data “Presence” or “Absence”), the “Presence”/“Absence” of field signs and stand damage levels were effectively classified by Dimension 1 of the MCA. However, there was no apparent relationship between the stand damage level and Dimension 1 and 2 of MCA (Fig. 3 (b)).

4. Calculation of the DISco

Based on the results of the MCA, the "None" field sign category was assigned a value of 0 (Table 4). Then, based on the relative coordinate distance for Dimension 2 in the MCA of each field sign, the degree of field signs (i.e., bark stripping marks, browsing marks and deer fecal pellets) was assigned a value of 1 for "A few" and 3 for "Many" (Table 4). The degree of field signs for "Presence" of deer trails and tracks was assigned a value of 2 (Table 4). The summed value of these field signs was up to 13, and was used as the Deer Impact Score (DISco) to evaluate the level of stand damage by sika deer.

5. Relationship between DISco and level of stand damage

In the LRA, which analyzed the relationship between the presence or absence of stand damage and the DISco, the DISco was found to be a significant explanatory variable (p = 0.001). The AUC obtained for the LRA was 0.7122, indicating that the model was effective for predicting the probability of stand damage by sika deer. The probability of stand damage increased linearly between 0 and 8 for the DISco, and was saturated when the DISco was 8 or above (Fig. 4 (a)).

In the LRA of the relationship between the presence or absence of High stand damage and the DISco, the DISco was found to be a significant explanatory variable (p <0.001). The AUC obtained for the LRA was 0.7794, indicating that the model was effective for predicting the probability of High stand damage. With an increase in the DISco, the probability of High stand damage increased (Fig. 4 (b)). Thus, the probability of High stand damage by sika deer was predicted to be approximately10% for DISco 2 and approximately 30% for DISco 8.

Discussion

1. Relationship between stand damage by deer and broken fences

Compromised fences (i.e., holes and collapsed fences) were observed in approximately 60% of the young plantations (Table 2). Broken fences and damage to planted trees inside fences have been reported previously (Takatsuki 2009; Oshima et al. 2014; Sakai 2018). Deer damage (SDLv 1-3) was confirmed in 75% of the plantations where the fences were broken, and high damage (SDLv 3) was observed in 20% of the plantations (Table 2). On the other hand, in plantations where the fences were not broken, plantations with SDLv 2 and 3 were few (3% and 1%, respectively) (Table 2). Therefore, uncompromised fences have a highly protective effect. However, in cases where fences are compromised with a high probability, then it is very difficult to protect the planted trees by installing only a deer fence.

2. Field signs used for DISco

In this study, the DISco was calculated using five field signs: deer fecal pellets, bark stripping marks in a mature plantation, browsing marks on roadside vegetation, deer tracks and deer trails. Among the questionnaire survey items, the degree of browsing damage to understory vegetation (woody and herbaceous species), the dominance of unpalatable plants, deer carcasses/bones, deer antlers and sightings were excluded from the field signs considered for calculating the DISco for the following reasons.

Browsing marks on the understory vegetation (woody and herbaceous plants) in mature plantations are also one of the indicators of the degree of deer damage (Fujiki et al. 2010; Kishimoto et al. 2010). However, the development of understory vegetation differs depending on the light environment in the forest floor, and there are forest stands where understory vegetation is underdeveloped regardless of deer damage (Kiyono 1990; Ito 1996; Ito et al. 2008; Yamagawa et al 2009). In this study, due to the underdeveloped understory of the plantations, we could not confirm the existence of browsing marks on the understory vegetation in some plantations (Table 2). Therefore, observations of the browsing marks in the understory may underestimate the amount of browsing marks. On the other hand, the roadside environment is considered to be a good place to observe browsing marks because the vegetation grows in a relatively well-lit environment, and because it is easy to access these areas in surveys. Therefore, the degree of browsing marks was evaluated based on roadside vegetation rather than understory vegetation.

As deer browsing intensity increases, the number of favorite plants decreases and the number of unpalatable plants increases (Horsley et al. 2003; Suzuki et al 2008; Takatsuki 2009). Therefore, this dominance of unpalatable plants is considered to be a useful proxy for indexing the population density and/or impact of deer. In forest stands where the impact of deer is high, there is a risk that browsing marks cannot be observed due to the disappearance of favorite plants. Therefore, the dominance of unpalatable plants may be an important indicator of deer impact. However, in the questionnaire survey, approximately 40% of respondents answered that the dominance of unpalatable plants was "unknown" (Table 2). This questionnaire survey targeted forest officers and workers, but it is probable that they were unable to identify unpalatable plants due to differences in their plant identification ability; consequently, the dominance of unpalatable plants was considered to be a relatively unreliable parameter for use as a proxy of deer abundance. Therefore, dominance of unpalatable plants were not used in the calculation of DISco. However, unpalatable plants that are often observed in forest stands have been clarified (Koda and Fujita 2011; Hashimoto and Fujiki 2014), and should be used as an indicator of deer impact level in the future. Plant identification workshops should therefore be held before future surveys in order to provide investigators with the necessary information on unpalatable plants.

There were few field signs of deer carcasses/bones and antlers in the questionnaire survey (Table 2). This may be due to the narrow observation area and the limited timing of the survey in the questionnaire. The death of a deer is an accidental event, and the shedding of antlers in sika deer is limited to spring (Miura 1984). In addition, visual inspection may be affected by the season and time of the survey (Akashi et al. 2013). Therefore, these field signs were excluded from the DISco calculations.

3. Validity and use of DISco

The results of the MCA analysis showed that the presence or absence and amount of deer field signs (deer fecal pellets, bark stripping marks, browsing marks, deer trails and tracks) corresponded to the level of stand damage caused by sika deer (Fig. 3 (a)). Among these field signs, the level of stand damage tended to be higher in plantations where deer fecal pellets, bark stripping marks and browsing marks were recorded as "Many" (Fig. 3 (a)). On the other hand, the relationship between the level of stand damage and field signs was unclear when all of the field signs were reduced to binary data (presence or absence) for the purpose of simplifying the field sign investigation (Fig. 3 (b)). Therefore, recording the amount of deer fecal pellets, bark stripping marks and browsing marks in three categories (“None”, “A few” and “Many”) is important for assessing the level of stand damage by deer in young plantations.

The DISco (Table 4) calculated using field signs and based on the results of MCA could generally explain the probability of stand damage and high stand damage in young plantations (Fig. 4). A comprehensive evaluation of multiple types of field signs (Akashi et al. 2013) can have a positive effect on the calculation of DISco. In addition, it has been reported that the probability of deer damage corresponds to the DISco, even in cases where deer damage is evaluated at tree shelter construction sites after planting (Nomiya et al. *Submitted to same JFR special issue*). Therefore, the DISco can roughly predict the probability of damage (damage risk) by deer after planting of Sugi, and this index can be used as a tool to evaluate the level of stand damage. In addition, the DISco could also be applied to evaluations of the protective effect of not only fences, but also tree shelters and repellents, and will lead to the appropriate selection of damage controls.

However, application of the DISco in low-density deer habitats may require caution. In terms of stand damage probability prediction (SDLv.1 or higher), damage is observed even if the DISco value is 0 (Fig. 4 (a)). Therefore, a simple survey of field signs may overlook habitats containing few deer. In particular, in forests, where the population density of deer is extremely low, it may be effective to establish line transects and carefully observe browsing marks (Otani et al. *Submitted to same JFR special issue*).

The method for assessing the deer impact level by the DISco described in this study has several advantages compared to other indicators of population density and deer damage level. First, the survey methods required for calculating the DISco are extremely simple. Investigators only need to check five field signs, and the time required for surveys is approximately 10 minutes (Yamagawa *unpublished data*). The surveys of field signs are conducted on forest roads (including working roads) and in mature Sugi (*Cryptomeria japonica*) and Hinoki (*Chamaecyparis obtusa*) plantations, so they can be conducted in easily accessible locations. For example, the DISco survey can be performed when a forest is visited for other reasons. Taken together, these factors mean that it is possible to conduct surveys over a wide area and in numerous locations. In addition, if the number of survey sites increases in the future, the DISco data can be mapped using location information.

Second, the DISco is less sensitive to the species composition and structure of understory vegetation. Surveys that cover extensive areas, especially those that span more than one climatic or vegetation zone, will often show differences in the composition of the plants growing on the forest floor (Williams et al. 2000; Fletcher et al. 2001; Pavlovic et al. 2014; Blossey et al. 2017; Curtis et al. 2021), which is considered to be difficult to survey using specific indicator plants. In addition, stand structure, such as the coverage of understory vegetation and the presence or absence of browsing lines, are also important indicators of the degree of deer impact (Fujiki et al. 2010; Kishimoto et al. 2010; Ohashi et al. 2014). However, deer impact cannot be evaluated by these indicators in stands where the understory vegetation is originally underdeveloped. In this study, the level of stand damage by deer could be evaluated comprehensively using field signs that are not easily affected by the climatic and vegetation zone, such as roadside browsing marks, bark stripping marks, fecal pellets and deer trails. Therefore, this method can be applied in different regions.

Conclusion

In this study, we clarified a method for assessing the level of stand damage by sika deer after planting Sugi in southwestern Japan using a simple survey of field signs in conjunction with a deer impact index used in northern Japan (Akashi et al. 2013). This simple method is less dependent on an individual investigator's abilities and can be used by many people. In order to apply the DISco more widely in the forestry field, it is necessary to improve the prediction accuracy and clarify the relationship with other indicators. Damage caused by deer is also affected by the amount of food resources (amount of favorite plants) and landscape structure around the target area (Oi and Suzuki 2001; Royo et al. 2017). Future studies should also consider the abundance of favorite plants on browsing, dominance of unpalatable plants, and landscape structure as predictors of deer damage.

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Tables and Figures

Table 1. Levels of stand damage by sika deer

Stand damage level		Description
SDLv.0	None	No browsing observed
SDLv.1	Low	Only the browsing intensity "lightly browsed" was observed in the young plantation
SDLv.2	Medium	Between SDLv.1 and 3
SDLv.3	High	Browsing intensities "Heavily browsed" and "Severely browsed" can be easily observed in the young plantation

Stand damage levels were classified based on the distribution of browsing intensity for planted trees (Figure 2) in young Sugi plantations.

Table 2. Number of questionnaire responses on field signs associated with sika deer

Field signs	No. of responses
Bark stripping *	
None	94
A few	96
Many	24
Browsing of understory woody plants	
None	130
A few	73
Many	5
*NA***	6
Browsing of understory herbaceous plants	
None	129
A few	64
Many	2
*NA***	19
Browsing of roadside vegetation *	
None	119
A few	81
Many	14
Dominance of unpalatable plants	
A few	82
Many	47
unknown	85
Deer fecal pellets *	
None	62
A few	122
Many	30
Deer carcasses and/or bones	
Presence	37

Absence	177
Deer antlers	
Presence	8
Absence	206
Deer tracks *	
Presence	126
Absence	88
Deer trails *	
Presence	94
Absence	120
Sighting	
Presence	89
Absence	125

* Field signs used to calculate DISco.

** *NA* includes forest stands where understory vegetation was underdeveloped and browsing marks could not be investigated

Table 3. Number of forest stands and level of stand damage by sika deer

Damage level		Fence not installed stands		Fence installed stands			
				Fence not broken		Fence broken	
SDLv.0	**None**	19	(82.6%)	76	(80.9%)	29	(24.2%)
SDLv.1	**Low**	4	(17.4%)	14	(14.9%)	24	(20.0%)
SDLv.2	**Medium**	0	(0.0%)	3	(3.1%)	43	(35.8%)
SDLv.3	**High**	0	(0.0%)	1	(1.0%)	24	(20.0%)
Total		23		94		120	

Table 4. Field signs used to calculate DISco and scores obtained

Field signs	Scores
Bark stripping	
None	**0**
A few	**1**
Many	**3**
Browsing of roadside vegetation	
None	**0**
A few	**1**
Many	**3**
Deer fecal pellets	
None	**0**
A few	**1**
Many	**3**
Deer tracks	
Absence	**0**
Presence	**2**
Deer trails	
Absence	**0**
Presence	**2**

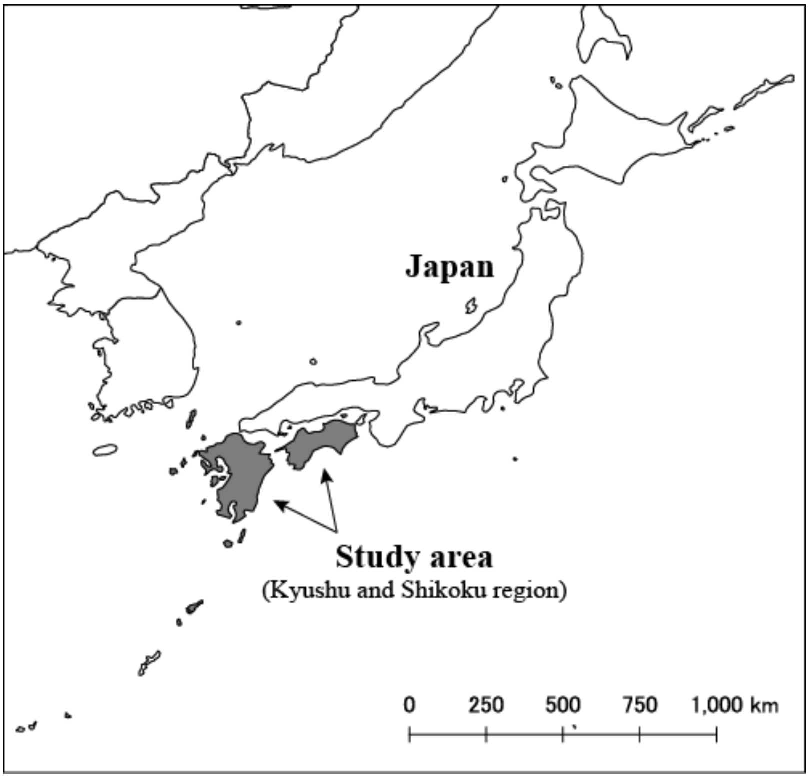
Figure legends

Figure 1. Location of study area

Figure 2. Browsing intensity of planted trees
The browsing intensity of planted Sugi trees caused by sika deer was divided into five categories, focusing on the degree of browsing marks and tree crown shape.

Fig. 3 Multiple correspondence analysis (MCA) map with active variable categories (degree of field signs) and supplementary variable categories (level of stand damage by sika deer).
(a) Results of analyzing the degree of field signs (deer pellets, bark stripping marks and browsing marks) as three-level variables (“None”, “A few” and “Many”).
(b) Results of analyzing the degree of all field signs as two levels (“presence” and “absence”).
The abbreviations in the figure indicate the type of field signs (BS: bark stripping, RB: browsing marks on roadside vegetation, DP: deer fecal pellets, TL: deer trails, TC: deer tracks).

Figure 4. Probability of deer browsing damage at stand level (a: stand damage (SDLv. 1 or higher), b: high stand damage (SDLv. 3)) estimated by logistic regression analysis (LRA).
The dashed line indicates the 95% confidence interval.



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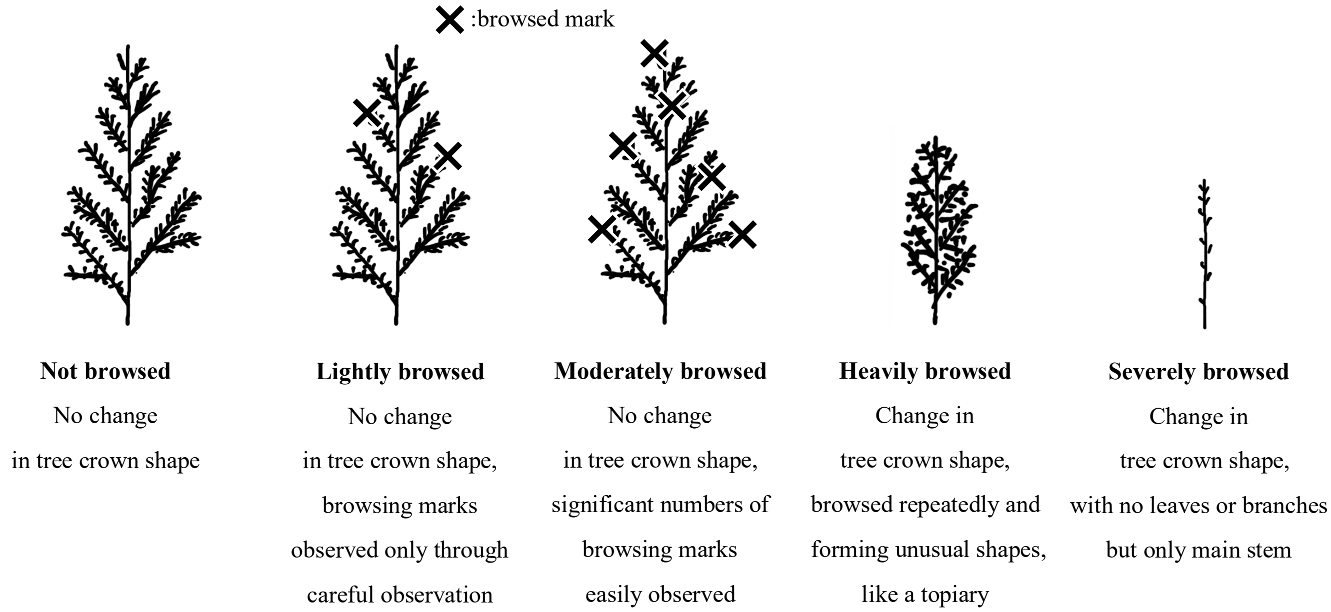

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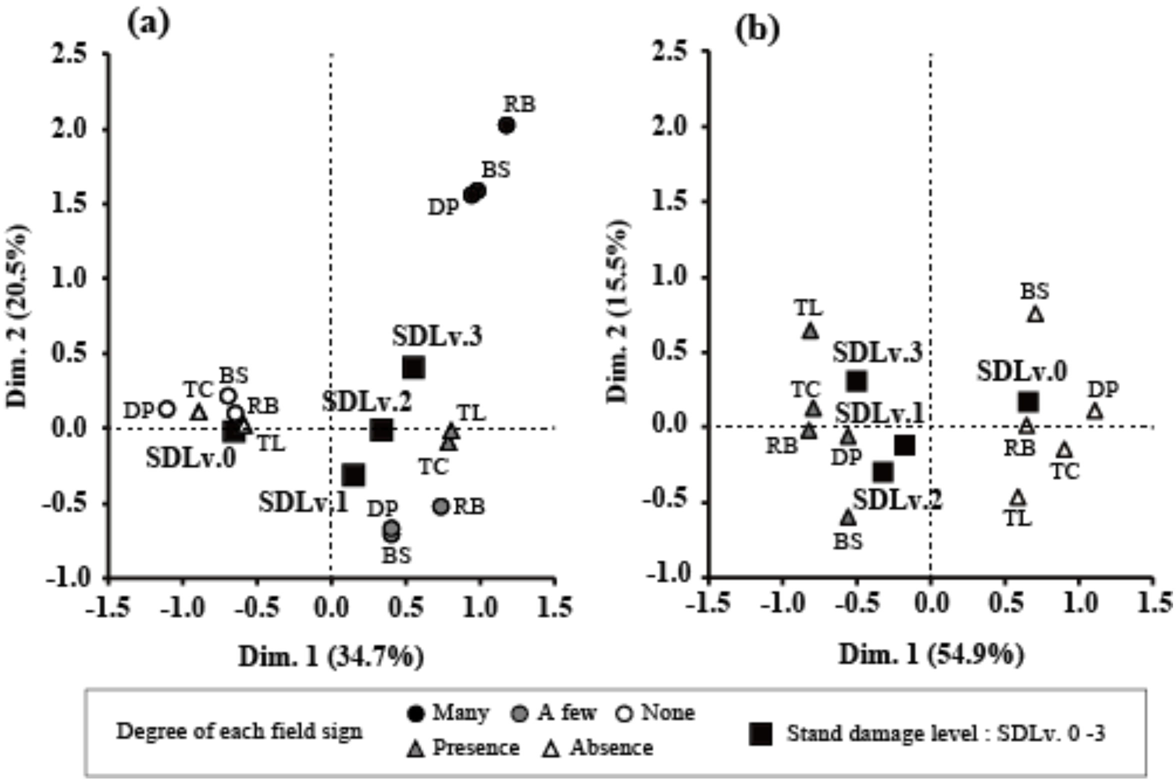

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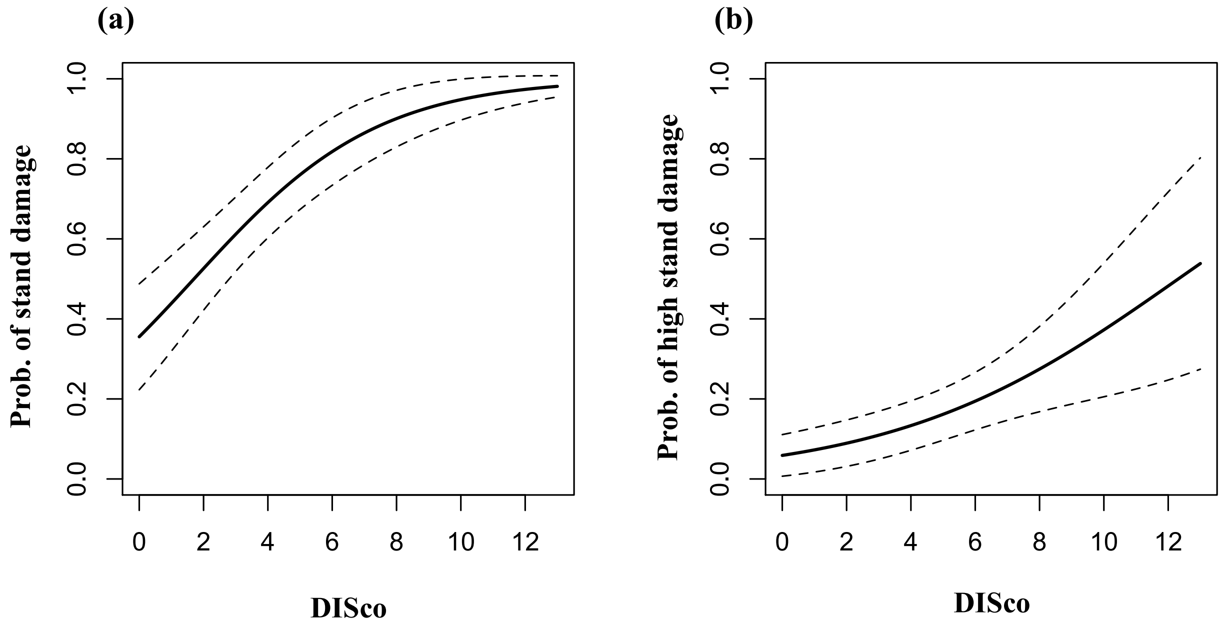

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