

Understanding 20 Years of Vegetation Change in Deer-Impacted Grasslands

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Highlights

What are the main findings?

- The deer browsing reduced the cover of *S. hayatae* and increased the cover of *M. sinensis*, but the extent of these changes was spatially heterogeneous.
- Using UAV-mounted LiDAR, we estimated the densities of *S. hayatae* and *M. sinensis*, which are important for understanding vegetation changes.

What is the implication of the main finding?

- In grassland management, understanding spatial and temporal changes in vegetation is important.
- The combination of small-scale field sampling and remote sensing is an excellent approach to obtain important information for grassland management.

Abstract

The impact of *Cervus nippon* browsing on vegetation in grasslands in Japan has become pronounced. In obtaining useful information for the management of grasslands affected by *C. nippon* browsing, we aimed to clarify the relationship between changes in the cover of *Sasa hayatae* and *Miscanthus sinensis* under the browsing impact of *C. nippon* and the distribution of grassland species based on vegetation survey data from two time periods and to use UAV-mounted LiDAR data to determine the distribution of *S. hayatae* and *M. sinensis* that have a significant impact on vegetation change on an areal basis. The study area was approximately 23 ha around the Ochiai Pass in Higashi Iya Ochiai, Miyoshi City, Tokushima Prefecture. A vegetation survey was conducted in 2022 at the same 35 sites as in 2002 to understand the changes in vegetation. The ordination using nonmetric multidimensional scaling (NMDS) revealed that the entire study site was not changing along the same directionality of succession, although *C. nippon* browsing likely returns the *S. hayatae*-dominated grassland to *M. sinensis*-dominated grassland at the study site. It was found that sites with high *M. sinensis* cover in 2022 exhibited higher diversity of grassland plants. The impact of deer browsing was suggested to increase *M. sinensis* coverage and contribute to the survival of grassland plants. Using UAV-mounted LiDAR, we estimated the densities of *S. hayatae* and *M. sinensis*, which are important for understanding vegetation changes in the study site. This allowed us to spatially identify areas critical for conserving grassland plant diversity and areas strongly affected by deer browsing.



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Keywords: *Sasa hayatae*; *Miscanthus sinensis*; grassland; *Cervus nippon*; browsing; UAV; LiDAR; NMDS

1. Introduction

In North America, Europe, Japan, and New Zealand, high-density deer have an altered vegetation structure and species composition [1]. In Japan, the range of *Cervus nippon* continues to expand [2]. Deer browsing reduces the number of plants that deer do not prefer to browse (hereafter, unpalatable species) [3–7], allowing unpalatable and browse-resistant plants to dominate [3–5,8]. In general, ferns [9] and browse-tolerant gramineous and sedge plants [5], which are often unpalatable species, will become dominant. The continued dominance of unpalatable or browse-tolerant plants may not restore vegetation to its original state even after deer control [10,11], and vegetation does not recover to its original state more than 20 years after deer browsing has been reduced [11,12].

In Japan, grassland biomes are not found except for grasslands in high mountains and coastal areas. Grasslands in mountainous and lowland areas are maintained by human disturbances such as mowing, grazing, and burning [13]. Even in these grasslands, the impact of deer has become more pronounced, and the disappearance of *Sasa hayatae* and the dominance of *Miscanthus sinensis* caused by the browsing of *C. nippon* have been reported [14]. Some species are unique to grasslands (hereafter grassland species), and changes in vegetation caused by the browsing of *C. nippon* have made it a challenge to conserve these species [15]. Plant communities are spatially diverse, and responses to a given browse pressure likely vary within and among plant communities [16,17]. In general, grassland plant communities are in the process of secondary succession, and community dynamics are diverse depending on the type, intensity, frequency, and duration of disturbance [15]. Therefore, understanding entire grassland as having the same directionality of succession, such as progression or regression, is difficult [18].

In grassland management, understanding the spatial and temporal changes in vegetation with high spatial resolution is important [19,20], and remote sensing is an effective tool for this purpose [21]. Remote sensing of grasslands has primarily used optical imagery, such as near-infrared [21]. LiDAR, which has recently emerged, can be used to measure information about vegetation that cannot be measured optically with high spatial resolution [20]. Optical measurements primarily capture surface information of vegetation, whereas LiDAR can obtain information within the vegetation. For example, it is used to understand forest floor topography and stratification in forests. While vegetation research using LiDAR often focuses on forests, it can also be applied to grassland. Although some studies have used LiDAR data to classify grassland types [22], monitoring grasslands using LiDAR data has not been well studied [20]. Furthermore, the latest technology, UAV-mounted LiDAR, can remarkably reduce the cost of data acquisition, which is a drawback of conventional aircraft-mounted LiDAR [23]. Therefore, the development of methods for monitoring grasslands using UAV-mounted LiDAR is an important research topic.

This study aimed to obtain useful information for the management of grasslands affected by *C. nippon* browsing by (1) clarify the relationship between changes in the cover of *S. hayatae* and *M. sinensis* under the browsing impact of *C. nippon* and the distribution of grassland species based on vegetation survey data from two time periods and (2) using UAV-mounted LiDAR data to determine the distribution of *S. hayatae* and *M. sinensis* that have a significant impact on vegetation changes on an areal basis and estimate locations that are important for grassland species conservation.

2. Materials and Methods

2.1. Study Site

The study site was a 23-ha area around the Ochiai Pass in Higashi Iya Ochiai, Miyoshi City, Tokushima Prefecture (Figure 1). The study site is located in the Kenzan mountain range in the eastern part of the Shikoku Mountains at an elevation of 1560 m above sea level. The climatic zone of the study site is cool temperate. The study site was a grassland dominated by *M. sinensis* until around 1990, but around 2005, it became a grassland dominated by *S. hayatae* [24]. At present, *S. hayatae* is distributed mainly along the ridge, interspersed with trees such as *Abies homolepis* (Figure 2). The establishment of grasslands in the study site is due to the influence of previous human disturbances, such as fire burning [25]. No human disturbance is currently occurring in the study site. In Japan, the impact of browsing damage on vegetation has become more pronounced because of the increase in deer population density. According to a survey conducted by the Shikoku Regional Forest Office in 2011, the density of *C. nippon* in the vicinity of the study area was remarkably high at 49.5 deer/km², which has had a great impact on vegetation. In the study site, the effects of *C. nippon* browsing were also observed, including the browsing scars of *S. hayatae* and the death of shrubs caused by browsing damage. In addition, *A. homolepis* has died because of bark stripping by *C. nippon* [26]. Understanding the relationship between the distribution of *S. hayatae* and *M. sinensis*, which have significantly larger abundances than other species, and grassland species, as well as the impact of *C. nippon* browsing on these two species, are crucial for managing the study site.

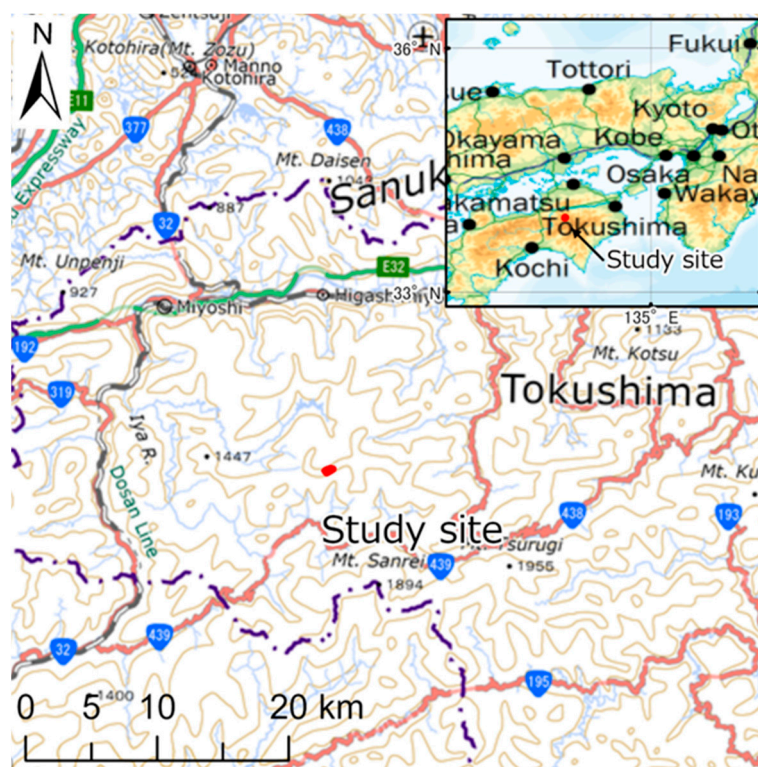


Figure 1. Map of the study site. This map is based on the GSI Tiles collection published by Geospatial Information Authority of Japan.



Figure 2. Aerial view of the study site. *Sasa hayatae* is distributed mainly along the ridge, interspersed with trees such as *Abies homolepis*.

2.2. Vegetation Survey

A vegetation survey was conducted in 2022 at the same 35 sites as in 2002 to understand the changes in vegetation. The 2022 survey was conducted at approximately the same locations as in 2002 by importing the locations of the 2002 survey sites into a single positioning GNSS (Garmin GPSMAP 66i) and confirming them in the field. The survey method was the same for both years. A 2 m × 2 m quadrat for the herbaceous community and a 5 m × 5 m quadrat for the woody community were set up. The layers were divided into the first subtree layer (T1), second subtree layer (T2), shrub layer (S), and herbaceous layer, and the species occurrence and percent cover were recorded for each layer. The 2002 survey was conducted from September 6 to September 8, and the 2022 survey was conducted in October 11 and October 12.

The vegetation survey results were used for ordination to understand the relationship between the distribution of *S. hayatae* and *M. sinensis* and grassland species. The percent cover of each layer in 2022 was used as the species data. In addition, the percent cover of *S. hayatae* in 2002 (*S. hayatae* cover 2002) and 2022 (*S. hayatae* cover 2022), the 20-year change in percent cover (Change in *S. hayatae* cover), the percent cover of *M. sinensis* in 2002 (*M. sinensis* cover 2002) and 2022 (*M. sinensis* cover 2022), and the 20-year change in percent cover (Change in *M. sinensis* cover) were used as environmental factor data. The data were ordinalized using nonmetric multidimensional scaling (NMDS). The 20-year change in percent cover was calculated by subtracting the 2002 survey data from the 2022 survey data. Through ordination, survey sites and species are plotted in a two-dimensional space, allowing similarities to be identified from their spatial distribution and relationships with environmental factors to be understood. The R language (version 4.3.2, R Foundation for Statistical Computing) was used for statistical analysis, and the "vegan" package was used for NMDS.

2.3. Estimation of the Density of *S. hayatae* and *M. sinensis*

The data acquired using the UAV-mounted LiDAR were used to estimate the density of *S. hayatae* and *M. sinensis* as indicators of vegetation change in an areal basis. DJI L1 was used on a DJI Matrice 300. In this case, the horizontal field of view was 70.4°; the vertical field of view was 4.5°; the scan rate was 480,000 points/s, and the system accuracy

was 10 cm horizontal and 5 cm vertical. Using UgCS (SPH Engineering, Latvia, EU), a flight route was created with a flight altitude of 60 m and a sidelap of 70%. The created flight route was imported into the DJI Pilot2 and measured at a flight speed of 5 m/s. Simultaneously, A DJI D-RTK 2 mobile station was installed, and the position was corrected by real-time kinematics. 12 October 2022 data were measured. The measured data were postprocessed in DJI Terra to obtain a 3D point cloud model. Three-dimensional point cloud model processed using GreenValley LiDAR360 v8.0. After removing outliers from the 3D point cloud model, the ground surface point cloud was classified using default parameters. A 5 cm × 5 cm digital terrain model (DTM) was created by interpolating the point cloud of the ground surface using the triangulated irregular network method. DTM was used to correct the height of the 3D point cloud model from elevation to ground level (normalization). The normalized 3D point cloud model was extracted at 10 cm intervals up to 2 m above ground level, and a 10 m × 10 m grid was used as the aggregation unit to calculate the number of point clouds and the mean reflection intensity for the first return at each 10 cm interval.

Using Esri ArcGIS, grid aggregation values were extracted from vegetation survey points. The correlation between *S. hayatae* cover 2022 and grid aggregate values (the number of point clouds and the mean reflection intensity), and the correlation between *M. sinensis* cover 2022 and grid aggregate values, were calculated separately for each 10 cm interval.

3. Results

3.1. Vegetation Survey

Sixty-three species in 40 families were identified during the 2022 survey (Table 1). One species was on the Red List of the Ministry of the Environment; four species were on the Red List of Tokushima Prefecture, and 15 species were unpalatable species of *C. nippon* [27]. The stress value, which indicates the fit quality when plotted in two dimensions using NMDS, was 0.17. A stress value between 0.1 and 0.2 is considered a moderate fit. In NMDS, a table indicating how well environmental factors explain the variation in the two-dimensional plot is obtained, and the strength of the fit for environmental factors is indicated by the Pr value (Table 2). Environmental factors that were significant were the *M. sinensis* cover 2022, change in *S. hayatae* cover, and change in *M. sinensis* cover. The distribution of the survey sites and vectors of environmental factors is shown in Figure 3. The survey sites were classified into nine classes based on their spatial grouping in the coordinate space, and their distribution is shown in Figure 4. The distribution of species and vectors of environmental factors is shown in Figure 5. More species were distributed in areas with high *M. sinensis* cover 2022 than in areas with high *S. hayatae* cover 2022. The endangered species were distributed in areas with increasing *M. sinensis* cover and areas with little change in *S. hayatae* cover and *M. sinensis* cover. Furthermore, unpalatable species of *C. nippon* were randomly distributed.

Table 1. List of species in the survey. CR: Critically Endangered, EN: Endangered, NT: Near Threatened, These are Red List categories.

Family	Scientific Name	Red List		Unpalatable Species
		Tokushima Pref.	Ministry of the Environment	
Amaryllidaceae	<i>Allium thunbergii</i>			
Anacardiaceae	<i>Toxicodendron orientale</i> subsp. <i>orientale</i>			
Araliaceae	<i>Kalopanax septemlobus</i>			

Table 1. Cont.

Family	Scientific Name	Red List		Unpalatable Species
		Tokushima Pref.	Ministry of the Environment	
Asteraceae	<i>Cirsium japonicum</i> var. <i>horridum</i>			•
Asteraceae	<i>Crassocephalum crepidioides</i>			•
Asteraceae	<i>Erechtites hieraciifolius</i>			•
Asteraceae	<i>Ixeridium dentatum</i>			
Asteraceae	<i>Solidago virgaurea</i> subsp. <i>leiocarpa</i>			
Blechnaceae	<i>Struthiopteris niponica</i>			
Campanulaceae	<i>Adenophora triphylla</i> subsp. <i>aperticampanulata</i>			
Caryophyllaceae	<i>Stellaria sessiliflora</i>			
Clethraceae	<i>Clethra barbinervis</i>			
Dennstaedtiaceae	<i>Hypolepis punctata</i>			•
Elaeagnaceae	<i>Elaeagnus umbellata</i> var. <i>umbellata</i>			
Ericaceae	<i>Lyonia ovalifolia</i> var. <i>elliptica</i>			•
Ericaceae	<i>Rhododendron kaempferi</i> var. <i>kaempferi</i>			
Ericaceae	<i>Rhododendron tsurugisanense</i>	NT		
Ericaceae	<i>Vaccinium oldhamii</i>			
Ericaceae	<i>Vaccinium smallii</i> var. <i>versicolor</i>			
Fagaceae	<i>Quercus crispula</i> var. <i>crispula</i>			
Gentianaceae	<i>Gentiana scabra</i> var. <i>buergeri</i>			
Gentianaceae	<i>Tripterospermum japonicum</i>			•
Geraniaceae	<i>Geranium shikokianum</i> var. <i>shikokianum</i>	NT	NT	
Haloragaceae	<i>Gonocarpus micranthus</i>			
Hydrangeaceae	<i>Hydrangea hydrangeoides</i>			•
Hydrangeaceae	<i>Hydrangea paniculata</i>			
Hypericaceae	<i>Hypericum erectum</i>			
Hypericaceae	<i>Hypericum sikokumontanum</i>			
Juncaceae	<i>Juncus decipiens</i>			•
Lamiaceae	<i>Comanthospace japonica</i>			•
Lamiaceae	<i>Glechoma hederacea</i> subsp. <i>grandis</i>			
Lardizabalaceae	<i>Akebia trifoliata</i>			
Liliaceae	<i>Tricyrtis macropoda</i>	EN		
Lycopodiaceae	<i>Lycopodium dendroideum</i>			•
Oleaceae	<i>Fraxinus sieboldiana</i>			
Onagraceae	<i>Circaea alpina</i> subsp. <i>alpina</i>			
Osmundaceae	<i>Osmunda japonica</i>			•
Oxalidaceae	<i>Oxalis nipponica</i> subsp. <i>nipponica</i>	CR		
Pinaceae	<i>Abies homolepis</i>			
Poaceae	<i>Arundinella hirta</i>			
Poaceae	<i>Carex</i> sp.			
Poaceae	<i>Miscanthus sinensis</i>			•
Poaceae	<i>Poaceae</i> sp.			
Poaceae	<i>Sasa hayatae</i>			
Polygalaceae	<i>Polygala japonica</i>			
Polygonaceae	<i>Fallopia japonica</i>			
Primulaceae	<i>Lysimachia japonica</i>			
Rosaceae	<i>Potentilla hebiichigo</i>			
Rosaceae	<i>Rosa multiflora</i>			•
Rosaceae	<i>Rubus crataegifolius</i>			
Rosaceae	<i>Rubus illecebrosus</i>			
Rosaceae	<i>Rubus palmatus</i> var. <i>coptophyllus</i>			
Rosaceae	<i>Sorbus commixta</i>			
Rubiaceae	<i>Galium trifidum</i> subsp. <i>columbianum</i>			
Salicaceae	<i>Salix sieboldiana</i> var. <i>sieboldiana</i>			
Sapindaceae	<i>Acer micranthum</i>			
Sapindaceae	<i>Acer rufinerve</i>			•

Table 1. Cont.

Family	Scientific Name	Red List		Unpalatable Species
		Tokushima Pref.	Ministry of the Environment	
Sapindaceae	Acer sieboldianum			•
Symplocaceae	Symplocos coreana			
Thelypteridaceae	Thelypteris pozoi subsp. mollissima			
Urticaceae	Pilea pumila			
Viburnaceae	Viburnum furcatum			
Violaceae	Viola sp.			

Table 2. Environmental factors explain the variation in the two-dimensional plot.

Factors	Code	R2	Pr(>r)
S. hayatae cover 2002	SC2002	0.06	0.35
S. hayatae cover 2022	SC2022	0.08	0.26
M. sinensis cover 2002	MC2002	0.10	0.19
M. sinensis cover 2022	MC2022	0.57	0.00
Change in S. hayatae cover	CiSC	0.17	0.05
Change in M. sinensis cover	CiMC	0.21	0.02

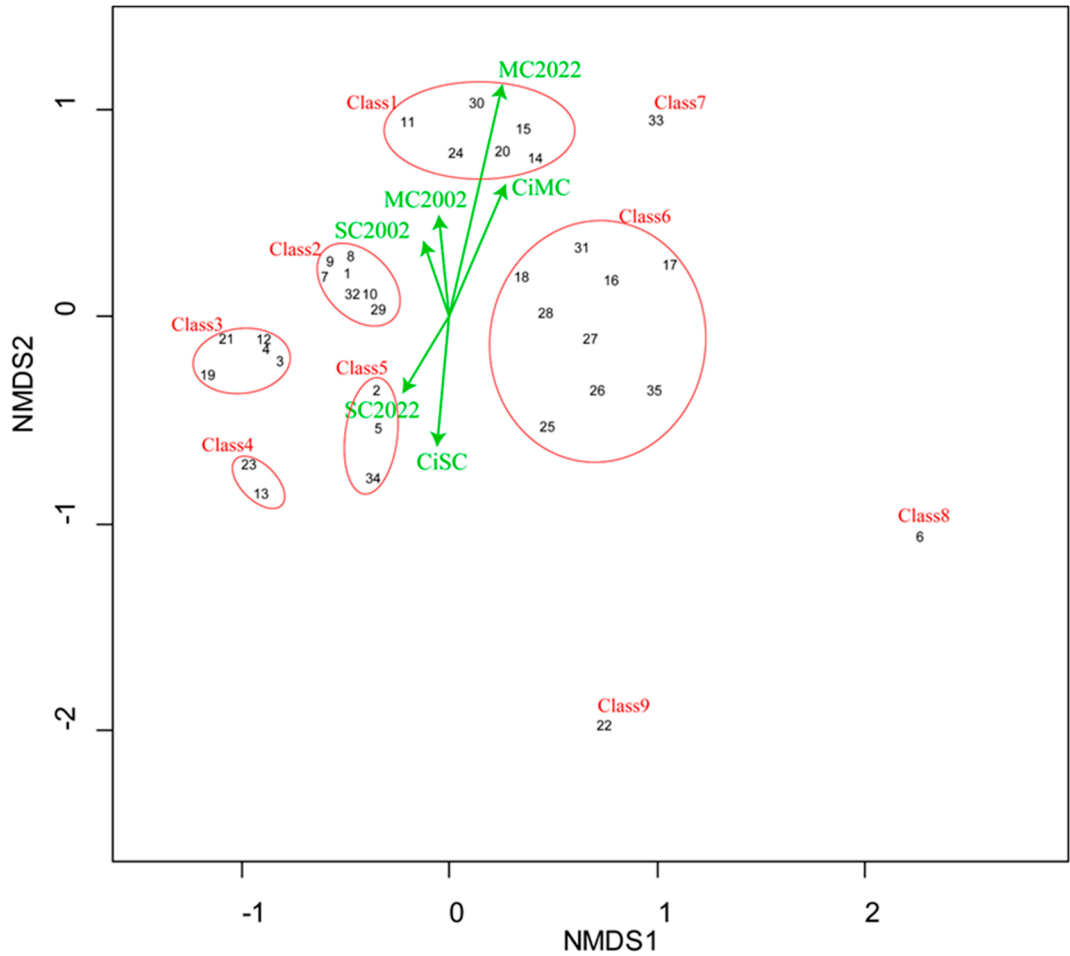


Figure 3. Results of sites ordination using NMDS. Numbers indicate sites positions; green arrows represent environmental factor vectors (See Table 2 for the environmental factor codes). Sites were grouped into nine classes based on spatial clustering (red box and text).

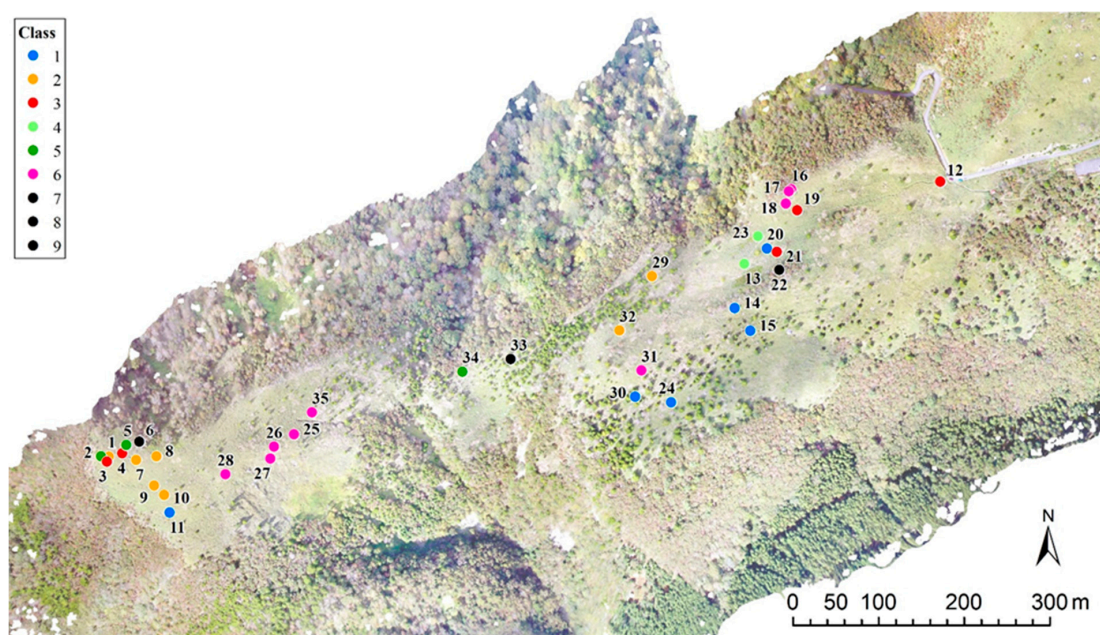


Figure 4. Distribution of nine classes classified from the NMDS results.

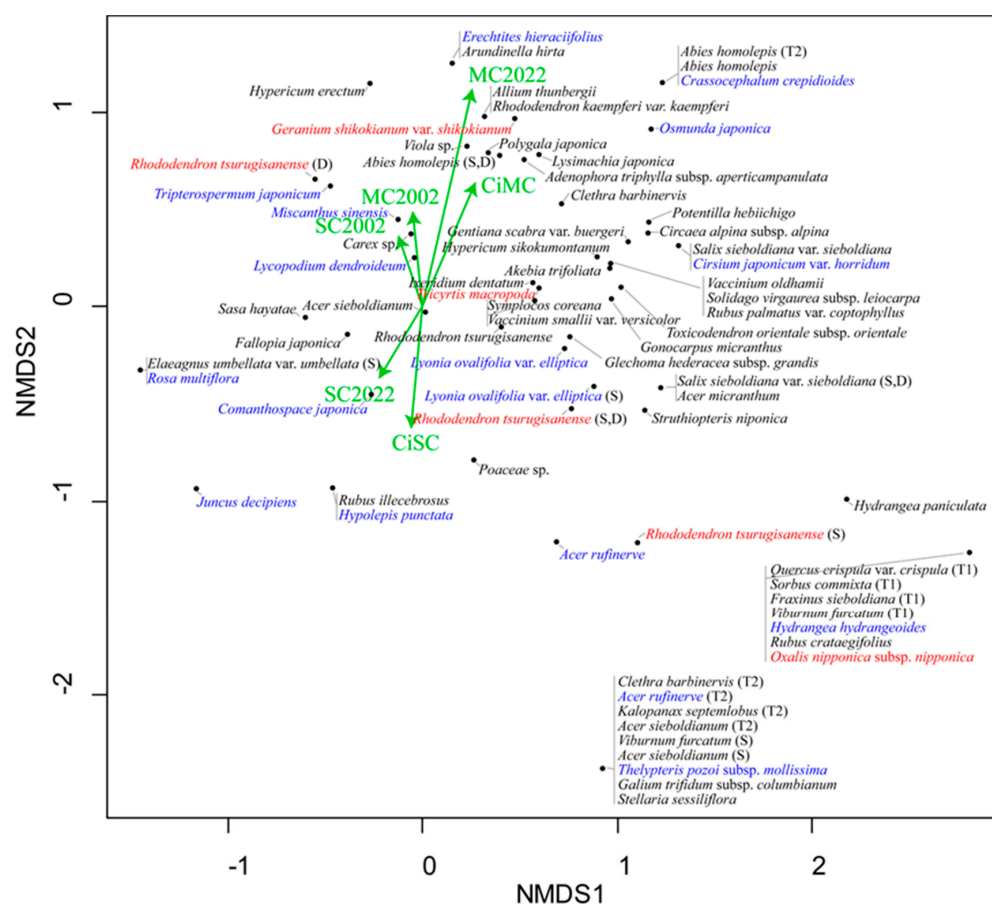


Figure 5. Results of species ordination using NMDS. Green arrows indicate vectors of environmental factors (See Table 2 for the environmental factor codes). Red text, endangered species; blue text, unpalatable species of *C. nippon*. Species were shown for each layer they appeared in and labeled with abbreviations (T1, T2, S); however, herbaceous layer was omitted. The mortal individuals are labeled D.

3.2. Estimation of the Density of *S. hayatae* and *M. sinensis*

The results of the 2022 vegetation survey showed that the mean and maximum vegetation heights of *S. hayatae* were 53 and 160 cm, respectively, and those of *M. sinensis* were 84 and 200 cm, respectively (Figure 6). The correlation between *S. hayatae* cover 2022 and grid aggregate values (the number of point clouds and the mean reflection intensity), and the correlation between *M. sinensis* cover 2022 and grid aggregate values, were calculated separately for each 10 cm interval (Table 3), with many R2 values < 0.01, all of which were low. In addition, a high correlation was determined between the mean values of the reflection intensity at heights of 0.7–0.8 m in *S. hayatae* and 1.4–1.5 m in *M. sinensis*, where R2 was the largest and the *p*-value was the smallest. The mean values of the reflection intensity at those heights and the *S. hayatae* cover 2022 and *M. sinensis* cover 2022 at the study sites are shown in Figures 7 and 8.

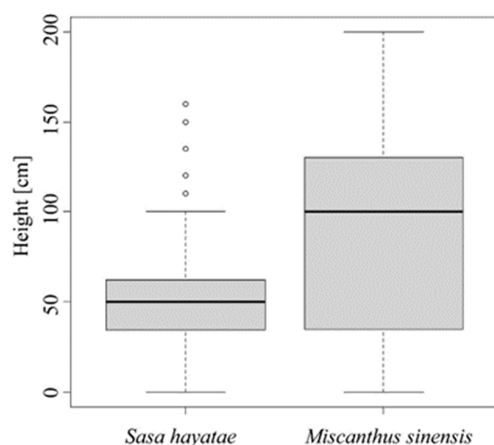


Figure 6. Measured vegetation height of *S. hayatae* and *M. sinensis*.

Table 3. The correlation between *S. hayatae* cover 2022 and grid aggregate values (the number of point clouds and the mean reflection intensity), and the correlation between *M. sinensis* cover 2022 and grid aggregate values. Correlations were calculated separately for each 10 cm interval. Number shows the number of point clouds of the first return, intensity shows the average value of the reflection intensity of the first return. Bold text shows R2 was the largest and the *p*-value was the smallest. Red shows R2 is largest and *p*-value is smallest; bold shows both requirements are met.

Height [m]	<i>Sasa hayatae</i>				<i>Miscanthus sinensis</i>			
	Number		Intensity		Number		Intensity	
	R2	<i>p</i>	R2	<i>p</i>	R2	<i>p</i>	R2	<i>p</i>
0–0.1	0.01	0.137	0.01	0.135	<0.01	0.387	<0.01	0.520
0.1–0.2	<0.01	0.281	<0.01	0.165	<0.01	0.505	<0.01	0.609
0.2–0.3	<0.01	0.713	<0.01	0.176	<0.01	0.888	<0.01	0.684
0.3–0.4	<0.01	0.644	<0.01	0.196	<0.01	0.512	<0.01	0.684
0.4–0.5	<0.01	0.544	<0.01	0.185	<0.01	0.228	<0.01	0.684
0.5–0.6	<0.01	0.336	<0.01	0.279	<0.01	0.223	<0.01	0.637
0.6–0.7	<0.01	0.271	<0.01	0.183	<0.01	0.585	<0.01	0.713
0.7–0.8	<0.01	0.652	0.02	0.086	<0.01	0.727	<0.01	0.719
0.8–0.9	<0.01	0.838	<0.01	0.252	<0.01	0.357	<0.01	0.891
0.9–1	<0.01	0.971	<0.01	0.254	<0.01	0.477	<0.01	0.757
1–1.1	<0.01	0.968	<0.01	0.210	<0.01	0.441	<0.01	0.698
1.1–1.2	<0.01	0.892	<0.01	0.270	<0.01	0.422	<0.01	0.780
1.2–1.3	<0.01	0.461	<0.01	0.397	0.01	0.127	<0.01	0.946
1.3–1.4	<0.01	0.243	<0.01	0.303	<0.01	0.715	0.02	0.090
1.4–1.5	<0.01	0.735	<0.01	0.237	<0.01	0.283	0.04	0.020

Table 3. Cont.

Height [m]	<i>Sasa hayatae</i>				<i>Miscanthus sinensis</i>			
	Number		Intensity		Number		Intensity	
	R2	p	R2	p	R2	p	R2	p
1.5–1.6	<0.01	0.645	<0.01	0.310	<0.01	0.303	0.03	0.038
1.6–1.7	<0.01	0.744	<0.01	0.316	<0.01	0.259	0.04	0.023
1.7–1.8	<0.01	0.676	<0.01	0.394	<0.01	0.321	0.04	0.026
1.8–1.9	<0.01	0.863	<0.01	0.592	<0.01	0.168	0.03	0.039
1.9–2	<0.01	0.743	<0.01	0.407	<0.01	0.336	<0.01	0.796

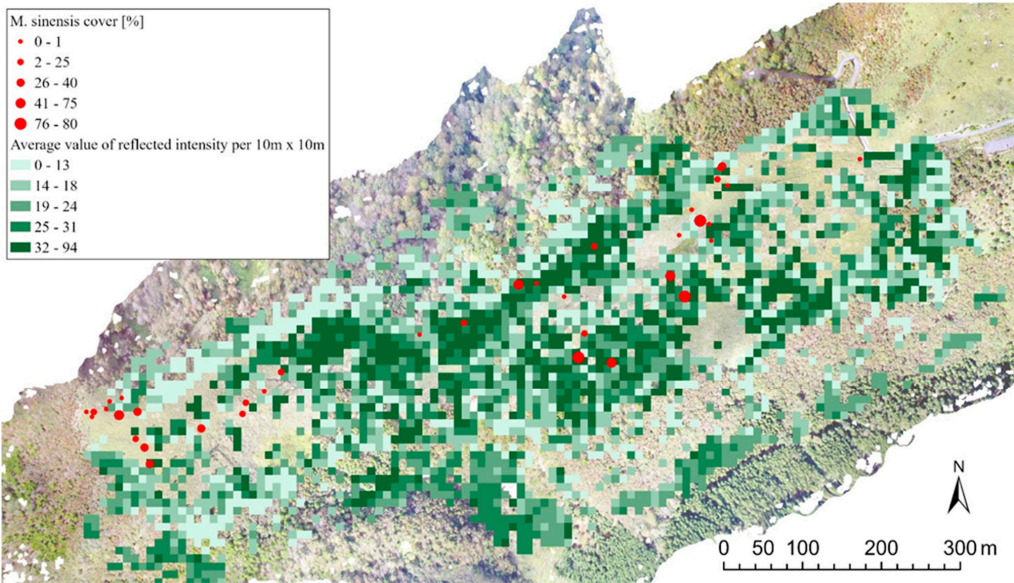


Figure 7. Measured *S. hayatae* cover in 2022 and the mean values of the reflection intensity at heights of 0.7–0.8 m in *S. hayatae*, where R2 was the largest and the *p*-value was the smallest.

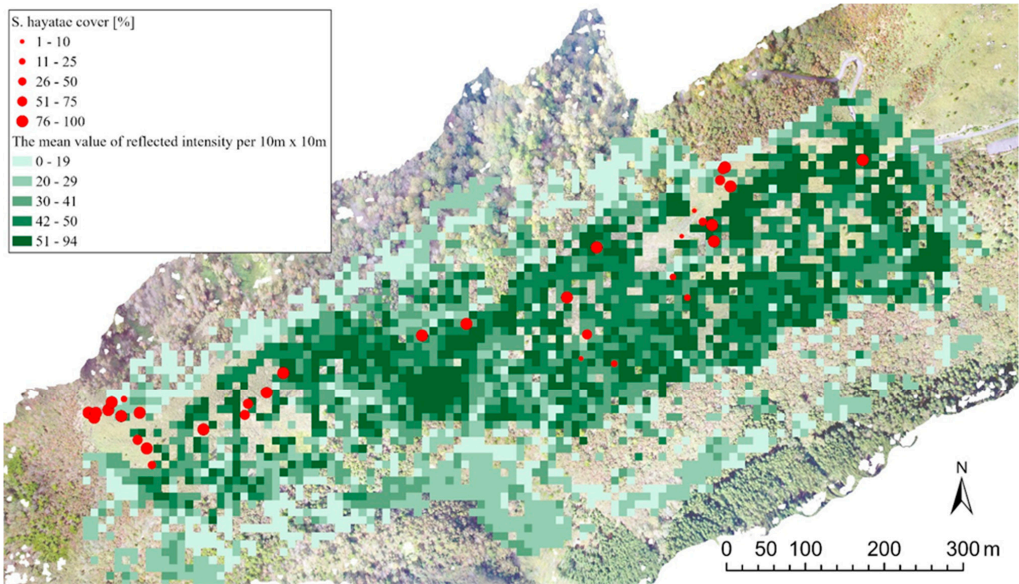


Figure 8. Measured *M. sinensis* cover in 2022 and the mean values of the reflection intensity at heights of 1.4–1.5 m in *M. sinensis*, where R2 was the largest and the *p*-value was the smallest.

3.3. Evaluation of Areas Important for Grassland Species Conservation

The nine NMDS classes were grouped into three categories based on their positions relative to the *M. sinensis* cover 2022 and the *S. hayatae* cover 2022: classes 1 and 7 were grouped into category a, classes 2, 3, and 6 into category b, and classes 4 and 5 into category c (Table 4). The mean values of the reflection intensity were calculated for *S. hayatae* at a height of 0.7–0.8 m and for *M. sinensis* at a height of 1.4–1.5 m, and *M. sinensis* cover 2022 and the *S. hayatae* cover 2022 were summarized for each of the a, b, and c categories (Figure 9). *M. sinensis* cover 2022, which was significant as an environmental factor in the NMDS results, better reflected the cover trends at the site. Based on the above, we considered that using the three categories a–c and the estimated *M. sinensis* cover 2022 could evaluate areas of high conservation importance for grassland species at the study site (Table 4). Category a, exhibiting high diversity of grassland species, is considered the most important for conservation. From the box-and-whisker plots of the mean values of the reflection intensity *M. sinensis* in Figure 9, thresholds of 0, 0–20, and 30–40 were set and their distribution within the study site is shown in Figure 10.

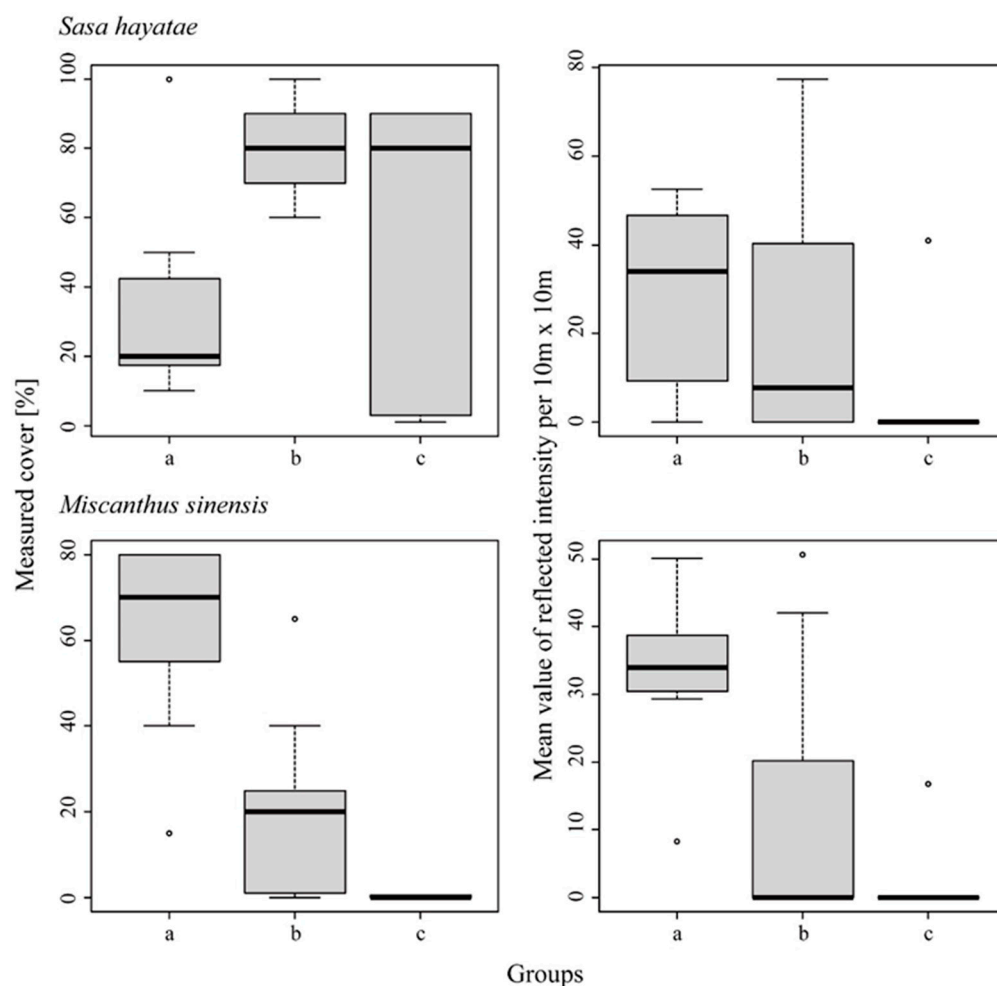


Figure 9. The mean values of the reflection intensity were calculated for *S. hayatae* at a height of 0.7–0.8 m and for *M. sinensis* at a height of 1.4–1.5 m and, and *M. sinensis* cover 2022 and the *S. hayatae* cover 2022 were summarized for each of the a, b, and c categories. The nine NMDS classes were grouped into three categories: classes 1 and 7 were grouped into category a, classes 2, 3, and 6 into category b, and classes 4 and 5 into category c.

Table 4. Evaluation of areas important for grassland species conservation. 30–40 is an important area for conserving the diversity of grassland species in the survey area.

Classes of NMDS	Three Categories Based on Their Positions Relative to the <i>M. sinensis</i> Cover 2022	Estimation of the Density of <i>M. sinensis</i> (The Mean Values of the Reflected Intensity at a Height of 1.4–1.5 m)	Grassland Plant Diversity
1 7	a	30–40	High
2 3 6	b	0–20	Low
4 5	c	0	Low
8 9	na		

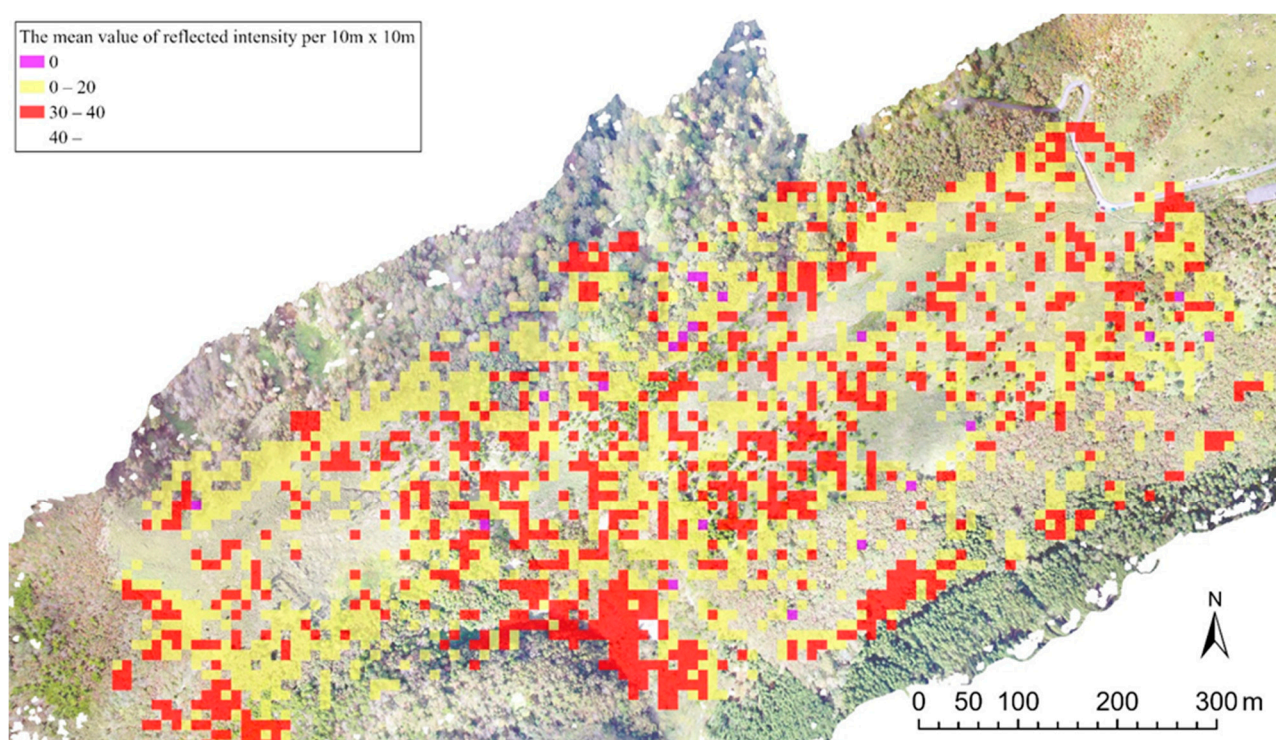


Figure 10. The areas are important for grassland species conservation. From the box-and-whisker plots of the mean values of the reflection intensity at a height of 1.4–1.5 m for *M. sinensis*, thresholds of 0, 0–20, and 30–40 were set. 30–40 is an important area for conserving the diversity of grassland species in the survey area.

4. Discussion

4.1. Vegetation Change

The study area had been a grassland dominated by *M. sinensis* until about 1990, but around 2005, it became a grassland dominated by *S. hayatae* [24]. In Japan, where the climax is forest, *M. sinensis* grasslands often persist because of human disturbances such as mowing, burning, and grazing [28,29]. At the study site, *M. sinensis* grasslands were also established by human disturbances such as burning [25]. *Sasa* species can grow vigorously and overwhelm *M. sinensis* even under *M. sinensis* dominance by receiving nutrients from

the parent plant through underground stems [30]. Therefore, the study site likely became a grassland dominated by *S. hayatae* around 2005, after human disturbance had ceased. *Sasa* spp. compete with tree seedlings for light availability, and their high cover prevents tree restoration [31]. Therefore, the vegetation in the study area can cause *S. hayatae* grassland to intersperse with trees such as *A. homolepis*.

Sasa spp. are evergreen, with high above-ground biomass, and they are highly valuable as food for deer [32,33]. *Sasa* spp. also serves as winter food [2,34]. Grasslands dominated by *Sasa* spp. revert to *M. sinensis* grasslands upon resumption of human disturbances [29,30,33,35]. At the study site, the population density of *C. nippon* was high around 2011, and *C. nippon* browsing is considered to be a disturbance, causing a part of the grassland dominated by *S. hayatae* to return to the grassland dominated by *M. sinensis*. The identification of 15 (24%) unpalatable species of *C. nippon* in the 2022 vegetation survey indicates that the area has been affected by *C. nippon* browsing.

In the ordination using NMDS, environmental factors were considered significant for *M. sinensis* cover 2022, change in *S. hayatae* cover, and change in *M. sinensis* cover. The change in *S. hayatae* cover and *M. sinensis* cover as well as the *M. sinensis* cover 2022 caused by the changes affected the vegetation in the study area. The vectors of the change in *S. hayatae* cover and *M. sinensis* cover were in opposite directions, and the study sites were distributed in both directions. As mentioned earlier, the NMDS revealed that the entire study site was not changing along the same directionality as succession, although *C. nippon* browsing likely returns the *S. hayatae*-dominated grassland to *M. sinensis*-dominated grassland at the study site.

Class 1 areas tend to be dominated by herbaceous plants with above-ground parts near the ground surface. *C. nippon* forages on *M. sinensis* but only if they pinch the tips of *M. sinensis* leaves. Moreover, the young leaf stage is often foraged by *C. nippon* [33]. Unpalatable plants and browse-resistant species cover nearby edible species and protect them from browsing [33,36,37]. In addition, the change from grassland to *M. sinensis* grassland improves near-surface light conditions and increases the number of species and populations of grassland plants [30]. Thus, Class 1 is considered to be a place where *M. sinensis* cover increases because of *C. nippon* browsing and where grassland vegetation can grow because of improved light conditions and protection from browsing. Class 1 is important for the conservation of grassland species diversity in the study site because it contains the endangered grassland species *Geranium shikokianum* var. *shikokianum*.

Classes 2, 3, and 6 are the areas where a slight change in *S. hayatae* cover and *M. sinensis* cover is observed. Classes 2 and 3 are considered to be the areas where *S. hayatae* continues to dominate, in which the high cover of *S. hayatae* has resulted in few distributed species, and where only shrubs such as the pioneer species *Fallopia japonica* and the unpalatable species *Rosa multiflora* can grow. Class 6 is the area where *M. sinensis* continues to dominate. Apart from grassland plants, many species that are naturally distributed in the study site are found in the area, such as the endangered species *Tricyrtis macropoda* and *Rhododendron tsurugisanense*, which are important for the conservation of plant diversity in the study area.

Classes 4 and 5 are the areas where *S. hayatae* cover increased. Considering that only unpalatable and prickly plants are distributed in these areas, such areas are considered to be heavily influenced by *C. nippon* browsing. Class 4 is considered to be an over-humid area because of the distribution of *Juncus decipiens*.

Classes 7, 8, and 9 are considered as the areas in which the influence of forests is significant because of the distribution of woody plants. Class 7 is an area of increased *M. sinensis* cover, and Class 9 is an area of increased *S. hayatae* cover. Class 8, located in the middle of Classes 7 and 9, is important for the conservation of plant diversity in the study area because of the distribution of the endangered species *Oxalis nipponica* subsp. *nipponica*.

4.2. Estimation of the Density of *S. hayatae* and *M. sinensis*

The highest correlations of mean reflection intensity were determined at heights of 0.7–0.8 m for *S. hayatae* and 1.4–1.5 m for *M. sinensis*, where R^2 was the largest and p -value was the smallest. Considering that the height selected was between the third quartile of vegetation height and the maximum value for *S. hayatae* and *M. sinensis* (Figure 6), the point cloud data at the height where the above-ground parts of *S. hayatae* and *M. sinensis* were located were selected, which is considered a reasonable result. However, *M. sinensis* had maximum R^2 at heights of 1.6–1.7 m and 1.7–1.8 m, with slightly higher P values. Therefore, *M. sinensis* have a high potential for density estimation in the 1.4–1.8 m height range.

R^2 was <0.01 in most cases, all of which were low. When measured at an altitude of 100 m, the size of the DJI L1 beam at the ground surface was relatively large, measuring 50 cm $\times$ 5 cm. Therefore, in dense vegetation such as *S. hayatae* and *M. sinensis*, a single return may have captured the surface of multiple plants, which may have contributed to low R^2 . However, by using only the first return, the point cloud was limited to only the surface of the vegetation, and by using the average reflection intensity to reflect the density of the vegetation, the height at which the density of *S. hayatae* and *M. sinensis* could be best estimated was selected. In the future, comparative validation using different LiDAR systems can estimate density with a higher correlation.

4.3. Grassland Management

In grassland management, understanding spatial and temporal changes in vegetation is important [19,20]. Using NMDS enabled us to understand the relationship between survey site positioning and species. By analyzing the cover of the dominant species, *S. hayatae* and *M. sinensis*, as environmental factors, we could infer their relationship with 20 years of vegetation change. As a result, we were able to evaluate the spatial heterogeneity of *C. nippon* browsing impacts and identify important areas for conserving grassland species diversity.

We were also able to estimate the density of *S. hayatae* and *M. sinensis*, which are important for understanding vegetation changes in the study site, using UAV-mounted LiDAR data. Furthermore, by combining the results of NDMS and density estimation, we were able to identify important areas for the conservation of grassland species diversity in the study area and areas strongly affected by deer browsing. The combination of small-scale field sampling and remote sensing is an excellent approach to obtain important information for grassland management [38], which we demonstrated in this study. Furthermore, we could propose a method for monitoring grasslands using UAV-mounted LiDAR, which has rarely been studied. The method proposed in this study can be used to monitor spatial and temporal changes in vegetation and could be applied to the management of different types of grasslands.

5. Conclusions

At the study site, deer browsing reduced the cover of *S. hayatae* and increased the cover of *M. sinensis*, but the extent of these changes was spatially heterogeneous. It was found that sites with high *M. sinensis* cover in 2022 exhibited higher diversity of grassland species. The impact of deer browsing was suggested to increase *M. sinensis* coverage and contribute to the survival of grassland plants. Using UAV-mounted LiDAR, we estimated the densities of *S. hayatae* and *M. sinensis*, which are important for understanding vegetation changes in the study site. This allowed us to spatially identify areas critical for conserving grassland plant diversity.

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