remote sensing

Technical Note

Development of a Monitoring Method Using UAVs That Can Detect the Occurrence of Bark Stripping by Deer

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Abstract: The occurrence of bark stripping associated with increased deer densities can severely damage forests. Identifying trends in bark stripping is crucial for forest management, but such data are often difficult to obtain through field surveys. Therefore, this study aimed to develop an efficient monitoring method using unmanned aerial vehicles (UAVs) that can detect the occurrence of bark stripping and enable long-term monitoring. The area around the Ochiai Pass in Higashi-Iya Ochiai, Miyoshi City, Tokushima Prefecture, Japan, was selected as the study area for the survey of *Abies homolepis*, which was found to be significantly bark-stripped by deer in the field. The location and root diameter of *A. homolepis* were measured, and the percentages of bark stripping and tree growth were visually determined. Simultaneously, normalized difference vegetation index (NDVI) and visible light orthomosaic images were produced using a UAV. A canopy polygon of *A. homolepis* was created, and the average value of the NDVI within the polygon was calculated. Where the bark stripping rate at the root edge was greater than 75%, the number of "partially dead" and "dead" trees increased significantly, indicating that bark stripping by deer was the primary cause of the death of *A. homolepis* in Ochiai Pass. In addition, the mean value of the NDVI was significantly lower, with a bark stripping rate of 75% or higher, indicating that the NDVI of the canopy of *A. homolepis* can be used to estimate individuals with a high bark stripping rate at the root tips, that is, those with a high probability of mortality. Furthermore, by extrapolating the results of the tree-by-tree survey to the nontarget *A. homolepis*, we detected 46 (8%) *A. homolepis* with an average NDVI value of 0.8 or less (i.e., those with a bark stripping ratio of 75% or higher and a high probability of mortality). Therefore, the utilization of remote sensing technology via UAVs, as demonstrated in this study, proves to be a potent means for monitoring the incidence of bark stripping.

Keywords: bark stripping; deer; forest management; UAV; NDVI

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1. Introduction

The occurrence of bark stripping associated with increased deer density causes serious damage to forests [1,2]. Bark stripping in natural forests induces a rapid decline in tree populations and drastic changes in the forest environment, causing serious damage to the affected trees and the forest as a whole [2,3]. Therefore, understanding trends in bark stripping and analyzing its causes are essential for forest management [3]. Research has been conducted in various regions on the causes of bark stripping, and various factors related to bark stripping have been identified [4,5]. Data on trends in the occurrence of bark stripping for use in analyzing these factors should be obtained through field surveys. In addition, the factors that cause bark stripping vary by region because of differences in deer preferences by location [2]. Therefore, predicting the universal occurrence of bark stripping is challenging. In addition, data on bark stripping are crucial for understanding its trends and analyzing its causes. However, obtaining such data through field surveys is challenging, especially in large, inaccessible forests, where field surveys are labor-intensive [6].

Furthermore, long-term ongoing surveys are necessary to consider long-term forest management policies [7]. Therefore, developing a method to efficiently obtain data on the trend of bark stripping occurrence is desirable.

Data acquisition by unmanned aerial vehicles (UAVs) is faster and less expensive than by ground surveys and provides more detailed forest data than other remote sensing platforms such as satellites or aircraft [8]. Remote sensing uses a wider spectral range than human eyes and can provide accurate and detailed estimates of forest vegetation health [6,9]. New low-cost remote sensing techniques using UAVs can help assess forests in a timely and affordable way [10]. For example, the effectiveness of UAV-based remote sensing techniques has been demonstrated in applications such as monitoring woodworm outbreaks [10,11]. Magstadt et al. [9] used hyperspectral imagery acquired from a UAV platform to demonstrate the possibility of distinguishing between healthy redwoods (*Sequoia semperviren*) and redwoods that had been bark stripped by black bears (*Ursus americanus*). Numerous studies have assessed forest health using the canopy's vegetation index, albeit often on a community-by-community basis. However, the advent of UAVs, which are capable of acquiring high-spatial-resolution images, now allows for assessment on a single-tree basis. However, no applied example of obtaining data on the incidence of bark stripping by deer exists.

Based on the above, this study aimed to develop an efficient monitoring method using a UAV platform that can detect the occurrence of deer bark stripping and enable long-term continuous surveys.

2. Materials and Methods

2.1. Study Site

The area (about 23 ha) around Ochiai Pass in Higashi-Iya Ochiai, Miyoshi City, Tokushima Prefecture, Japan, was selected as the study site (Figure 1). The area belongs to the cool-temperate zone and the Turugisan Mountain Range, which is located in the eastern part of the Shikoku Mountains at an elevation of 1560 m. The study area was dominated by *Miscanthus sinensis* until around 1990 but has recently become dominated by *Sasa hayatae* [12]. *S. hayatae* is distributed mainly along the ridge, and trees such as *Abies homolepis* are scattered throughout the area. The dominance of *S. hayatae* is attributable to prior human management of the area, such as fire burning [13]. Currently, no human management is in place. Furthermore, in Japan, the impact of feeding damage on vegetation has become more pronounced owing to the increase in deer population density. According to a survey conducted by the Shikoku Regional Forest Office in 2011, the density of deer in the surrounding area of the study site is extremely high, at 49.5 deer/km^2, which is a critical condition for maintaining the forest ecosystem. In the study area, the effects of deer feeding damage have been observed, including feeding scars on *S. hayatae* and the death of shrubs owing to feeding damage. It is important for forest management in Japan to determine the impact of deer feeding damage on vegetation types such as those found in Ochiai Pass and to predict future succession.

2.2. Tree-by-Tree Survey

A. homolepis, which is frequently skinned by deer in the field (Figure 2), was selected for this study. It has been reported in Nikko [14] and Odaigahara [2] that *A. homolepis* is easily bark stripped by deer. In addition, the recovery of *A. homolepis* is difficult because even the formative layer is foraged when it is bark-stripped [2].

Three survey lines (approximately 50 m wide and 200 m long) were established in the study area, and the locations of *A. homolepis* were recorded using a global navigation satellite system (GNSS) (Garmin GPSMAP 66i, Garmin International, Ltd., Kansas City, MO, USA) with single positioning. The diameter at the root edge was measured, and the percentage of bark stripping to diameter was visually determined in 10% increments. The growth conditions of the trees were visually judged and classified into three levels: not dead, partially dead, and dead. The survey dates were 28 and 29 May 2022.

Figure 1. Study site.

Figure 2. *A. homolepis* with bark stripping at the root edge.

2.3. Data Acquisition by UAV

A MicaSense Altum (AgEagle Aerial Systems Inc., Wichita, KS, USA) and a DJI P1 (SZ DJI Technology Co., Ltd., Shenzhen, China) were simultaneously mounted on a DJI Matrice 300 real-time kinematic (RTK). The Altum is a multispectral sensor with five sensors that record visible to near-infrared wavelengths (400–900 nm) and one sensor that records thermal infrared wavelengths (8000–14,000 nm). Except for the thermal infrared sensor, the resolution of the five sensors is 2064 × 1544 pixels. The DJI P1 has a built-in full-frame sensor and can capture still images with an effective pixel count of 45 MP. The lens used was a DJI DL 35 mm F2.8 LS ASPH (FOV 63.5°). Using UgCS (SPH Engineering, Latvia, EU), a flight route with 4 mm ground resolution and 60% sidelap was created with the Altum sensors, and the created flight route was imported into DJI Pilot2 and photographed (on 28 May 2022, between 10:00 and 14:00; the weather was clear). A light sensor (DLS 2) was connected to the Altum to record irradiance and sun angle correction information, and a calibration panel for reflectance correction was taken before takeoff. A DJI D-RTK

2 mobile station was installed at the time of acquisition, and RTK was used to correct the positional information. The acquired images were processed using photogrammetry to produce orthomosaic images (4.03 cm/pixel for the Altum and 1.38 mm/pixel for the P1). The Altum images were processed by correcting the reflectance with the calibration panel images and the parameters acquired by the DLS 2. Photogrammetry was processed using Agisoft Metashape Pro. ver 1.7.0 (Agisoft LLC, St. Petersburg, Russia).

2.4. Data Analysis

The positions of *A. homolepis* located by a single improvised GNSS will be off by a few meters. Therefore, using GIS, points were created based on the locations of *A. homolepis* as located by a single improvised GNSS. Then, the point locations were corrected by referring to the visible light orthomosaic image.

Increased reflectance due to tree stress is best observed between the red and near-infrared regions (650–700 nm), an important region for the early detection of tree stress [6]. To assess stress due to bark stripping in *A. homolepis*, the NDVI was calculated from orthomosaic images at near-infrared (NIR: 842 nm center and 57 nm bandwidth) and red (R: 668 nm center and 14 nm bandwidth) wavelengths.

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{R}}{\mathrm{NIR} + \mathrm{R}}$$

The tree canopy allows for the observation of leaf discoloration and defoliation, which are important in estimating tree health. These two variables are closely related to tree stress, which can be estimated by observing the tree canopy [15]. We manually created crown polygons of *A. homolepis* by displaying an NDVI orthomosaic image in the GIS at a scale of 1/60 (Figure 3). In addition, a visible light orthomosaic image was consulted when deciphering the tree canopy to confirm its location. Crown polygons were also created for *A. homolepis*, which were not surveyed in the tree-by-tree survey. The mean NDVI values within the crown polygons were calculated using the zone statistics function of the GIS. For the *A. homolepis* that were the subject of the tree-by-tree survey, the results of the field survey (the diameter at the root edge and the percentage of bark stripping to diameter) were combined with the mean NDVI using the spatial coupling function of the GIS. ESRI Arc GIS 10.8.2 (Esri Japan Corporation, Tokyo, Japan) was used for the GIS. The number of individuals per growth status of *A. homolepis* was tabulated for each class of bark stripping rate and tested using the Fisher establishment method. The relationship between the percentage of bark stripping and the mean NDVI is shown in a box-and-whisker diagram and tested using the Tukey–Kramer method. Statistical analysis was performed using R version 4.1.2 (R Foundation for Statistical Computing, Vienna, Austria).

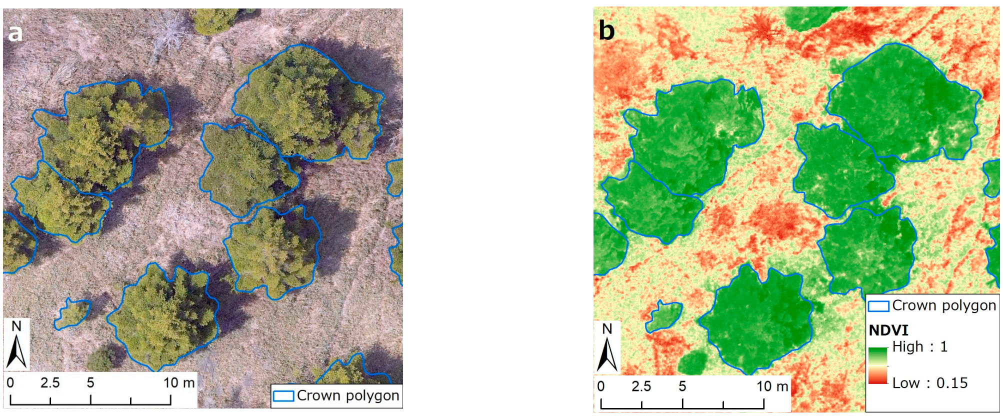

Figure 3. Examples of tree crown polygons. (**a**) Orthomosaic image of visible light (DJI P1); (**b**) orthomosaic image of NDVI.

3. Results

The results of the tree-by-tree survey showed 218 not dead, 23 partially dead, and 103 dead *A. homolepis* (Table 1). Figure 4 shows the distribution by growth conditions. The proportion of dead individuals was 30%, which were distributed throughout the survey area. The number of partially dead and dead individuals were significantly higher in the bark stripping rate of 75% or higher class ($p < 0.001$).

Table 1. Relationship between growth conditions and bark stripping rate at the root edge of *A. homolepis*.

Tree Growth Conditions	Bark Stripping Rate at Root Edge (%)					Total
	0	**5–25**	**25–50**	**50–75**	**75–100**	
Not dead	13	17	33	28	127	218
Partially dead	1	1	4	1	16	23
Dead	1	1	0	1	100	103
Total	15	19	37	30	243	344

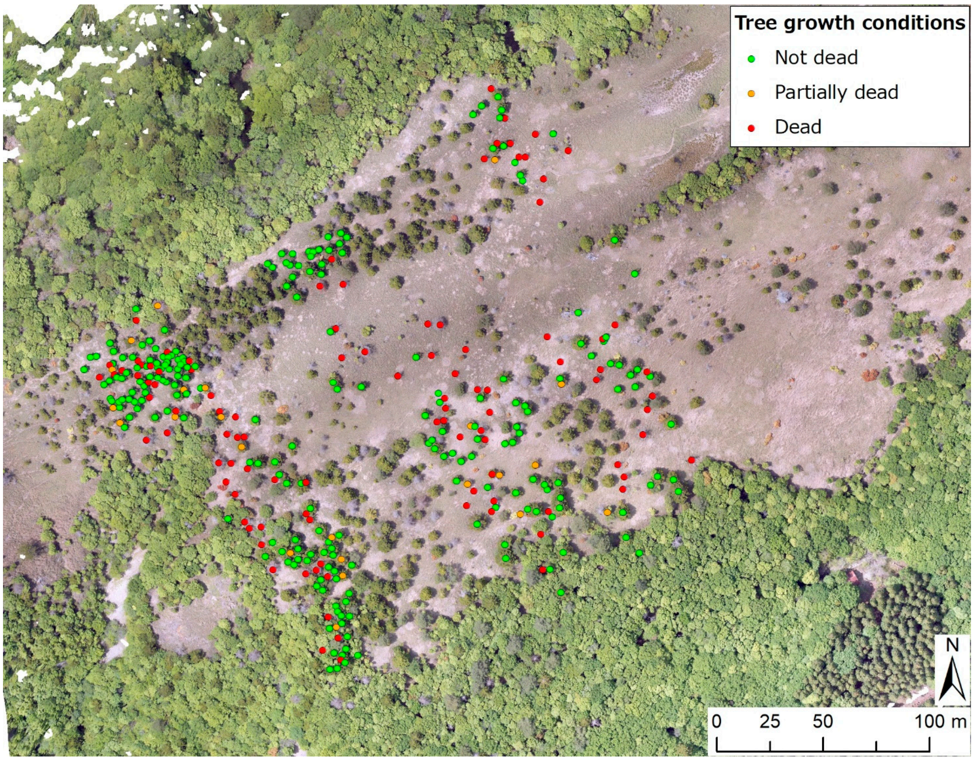

Figure 4. Growth conditions of *Abies homolepis*.

Figure 5 shows an image of the NDVI distribution for the entire shooting area; the NDVI was lower in the grassland and higher in the forest. Figure 6 shows the mean NDVI within the canopy polygons of the target trees of the tree-by-tree survey. Individuals with a high mean NDVI tended to be concentrated in areas with a high tree density. The mean NDVI was significantly lower in the bark stripping rate of 75% or greater class (Figure 7). Outliers were observed in the classes with a bark stripping rate below 75%, and the quartile range was wider in the bark stripping rate of 75% or greater class. From Figure 7, if the mean NDVI was less than 0.8, the individual likely had a bark stripping rate of 75% or greater. Therefore, the number of individuals per growth conditions, classified by a threshold of 0.8, is shown for each class of bark stripping rate (Table 2). Even among not dead trees, 4% to 12% were found to have the mean NDVI of less than 0.8. In the bark stripping rate of 75% or greater class, individuals with a mean NDVI of 0.8 or greater were included in 25% of partially dead trees and 1% of dead trees. The mean NDVI within the crown polygons of *A. homolepis* not included in the tree-by-tree survey was 0.8, as shown in Figure 8. A total of 46 individuals (8%) had a mean NDVI of 0.8 or less.

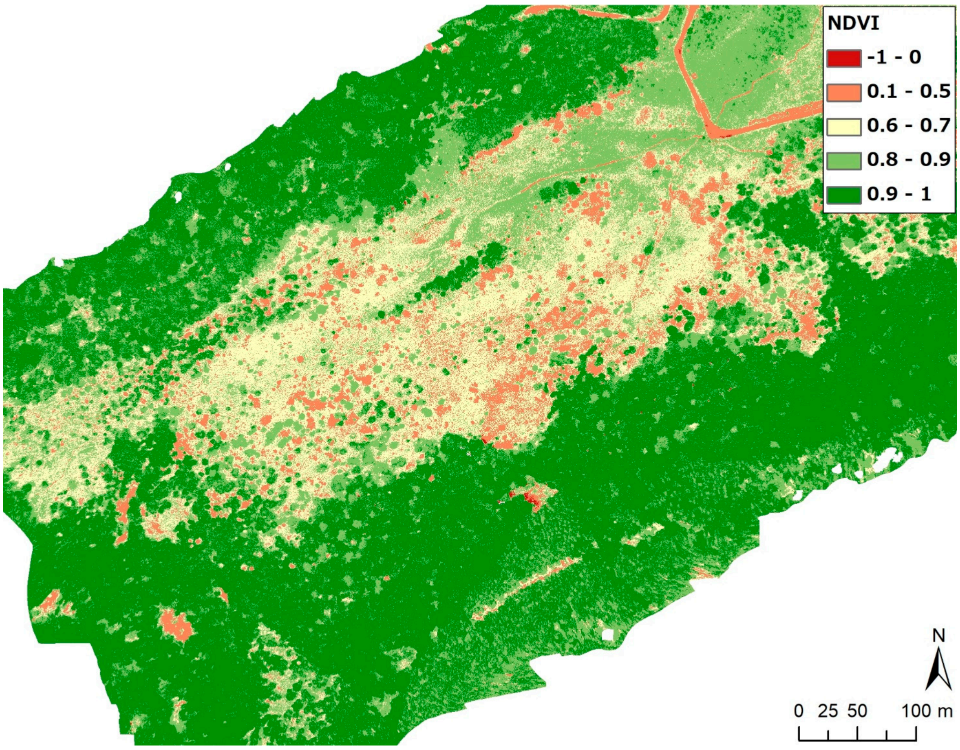

Figure 5. NDVI of the entire shooting range.

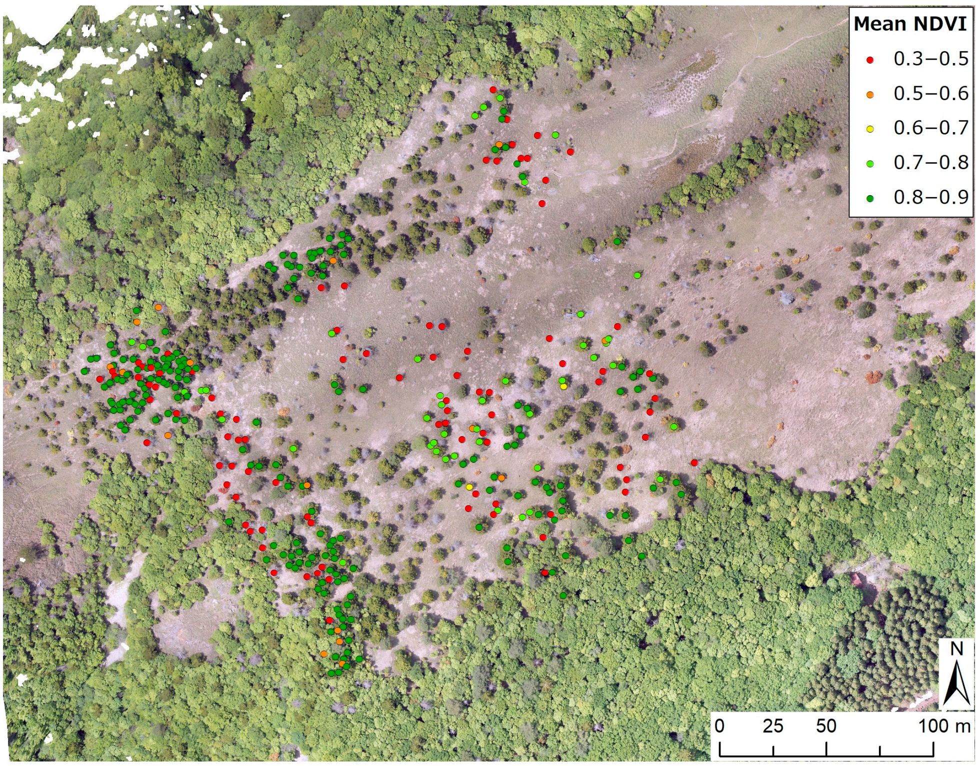

Figure 6. Mean value of NDVI within the canopy polygon of the tree-by-tree survey.

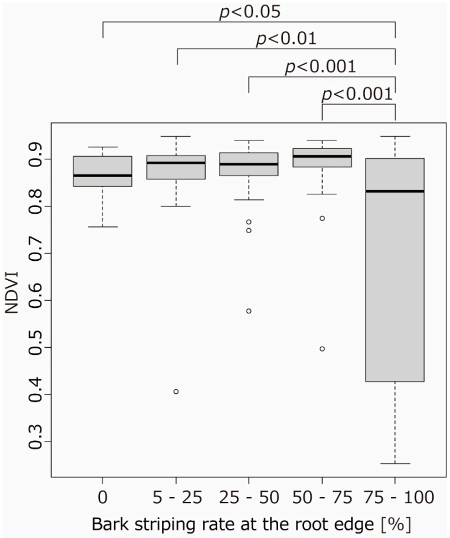

Figure 7. Relationship between the bark stripping rate at the root edge and the mean NDVI.

Table 2. Relationship between growth conditions and bark stripping rate at root edge, classified by a threshold of 0.8.

Tree Growth Conditions	**Bark Stripping Rate at Root Edge (%)**														
	0			**5–25**			**25–50**			**50–75**			**75–100**		
	Mean NDVI		**Total**	**Mean NDVI**		**Total**	**Mean NDVI**		**Total**	**Mean NDVI**		**Total**	**Mean NDVI**		**Total**
	≤0.8	**0.8<**		**≤0.8**	**0.8<**		**≤0.8**	**0.8<**		**≤0.8**	**0.8<**		**≤0.8**	**0.8<**	
Not dead	1	12	13	2	15	17	3	30	33	1	27	28	7	120	127
Partially dead	1		1		1	1	2	2	4		1	1	12	4	16
Dead	1		1	1		1				1		1	99	1	100
Total	3	12	15	3	16	19	5	32	37	2	28	30	119	124	243

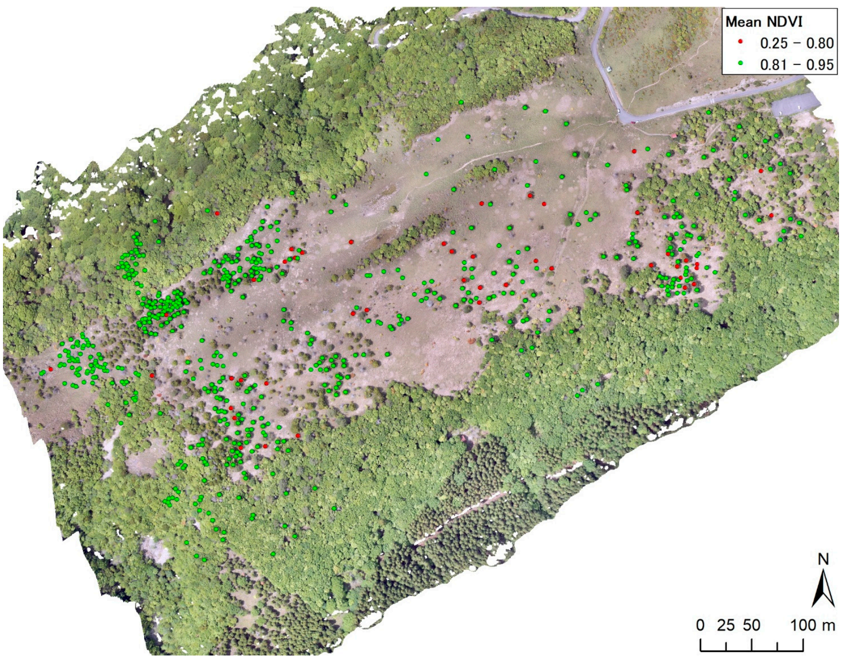

Figure 8. Mean NDVI for *A. homolepis* not included in the tree-by-tree survey. The threshold values were determined from Figure 7.

4. Discussion

4.1. Detection of Individuals with a High Bark Stripping Rate

That the numbers of partially dead and dead individuals were significantly higher in the bark stripping rate of 75% or higher class suggests that deer bark stripping is the cause of *A. homolepis* mortality at Ochiai Pass. This agrees with a report [2] that the leading cause of death of *A. homolepis* in Odaigahara is deer bark stripping. In addition, because *A. homolepis* are eaten down to their formative layers when skinned, deer bark stripping causes damage that is difficult to recover from [2]. We think that deer bark stripping also causes serious damage to *A. homolepis* in the Ochiai Pass.

That the numbers of partially dead and dead individuals were significantly higher in the bark stripping rate of 75% or higher class and that the mean value of NDVI was significantly lower in the bark stripping rate of 75% or higher class indicate that the NDVI of the crown of *A. homolepis* can be used to extract individuals with high bark stripping rates and a high likelihood of dying. In Odaigahara, it was reported that a significant proportion of the dead *A. homolepis* exhibited a bark stripping ratio of 70% or higher [2], thus the threshold value of 75% or higher for the bark stripping ratio obtained in this study is deemed appropriate.

The guideline for the NDVI threshold in such a case is 0.8. However, further validation is needed, as this was a one-time result at Ochiai Pass. The NDVI threshold of 0.8 is not an absolute value, because even the not-dead category contained individuals with a mean NDVI of 0.8 or less, and individuals with a mean NDVI of 0.8 or greater included partially dead and dead individuals in the bark stripping rate of 75% or greater class. Magstadt et al. [9] used hyperspectral images acquired with a UAV to classify healthy redwoods (*S. semperviren*) and redwoods that had been bark-stripped by black bears (*U. americanus*), but not recently skinned individuals. Therefore, individuals in the bark stripping rates of 75% or higher class could not be completely separated based on the mean NDVI alone, mostly owing to differences in the timing of bark stripping, even with the method used in this study. In Odaigahara, the peak of bark stripping occurs during the summer season [16]. In addition, the importance of analyzing changes in vegetation indices during two time periods in assessing tree health was highlighted [6]. Therefore, it is necessary to validate the results of this study in the future by analyzing the relationships between bark stripping, mortality, and NDVI variation at a higher temporal resolution in a multiperiod survey.

4.2. Usefulness as a Monitoring Method

By extrapolating the results of the tree-by-tree survey to nontarget *A. homolepis*, we detected 46 (8%) *A. homolepis* with a mean NDVI value of less than 0.8 (i.e., those with a bark stripping rate of 75% or greater and a high probability of mortality). Leaf discoloration and defoliation are closely related to tree stress, which can be estimated by observing the tree canopy [15]. Numerous studies have assessed forest health using the canopy's vegetation index, albeit often on a community-by-community basis. However, the advent of UAVs, which are capable of acquiring high-spatial-resolution images, now allows for assessment on a single-tree basis (e.g., [9]). We were able to show that UAV platforms can also be used to assess the health of the canopy of each individual *A. homolepis*. Even if the vegetation type differs from that of Ochiai Pass, this study's methods could be utilized if *A. homolepis* is present in the area. Additionally, it would be possible to evaluate the health of trees that are prone to bark stripping. Images collected using UAV platforms can assess tree canopy health over various spatial and temporal scales [9]. The methods in this study can also be used to assess the health status of *A. homolepis* at various spatial and temporal scales. We were able to present a platform for a universal forest monitoring method by continuing to validate threshold values through surveys in different forest types and at different times of the year.

Japanese deer (*Cervus nippon*) selectively use areas with shallow snow cover [17], and bamboo grass is a vital winter food resource [18]. Therefore, the risk of bark stripping increases at sites used by deer at high frequencies during winter and snowmelt [5]. However, the factors that cause bark stripping vary owing to differences in deer preferences by location [2]. Therefore, it will be effective in the future to use remote sensing technology with UAVs, as in this study, to understand the trends in bark stripping as a basis for monitoring before estimating the factors that cause bark stripping.

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References

1. Gill, R.M.A. A Review of Damage by Mammals in North Temperate Forests: 1. Deer. *For. Int. J. For. Res.* **1992**, *65*, 145–169. [CrossRef]
2. Akashi, N.; Nakashizuka, T. Effects of bark-stripping by Sika deer (Cervus nippon) on population dynamics of a mixed forest in Japan. *For. Ecol. Manag.* **1999**, *113*, 75–82. [CrossRef]
3. Ando, M.; Shibata, E. Why Do Cervids Strip the Tree Bark? *J. Jpn. For. Soc.* **2006**, *88*, 131–136. [CrossRef]
4. Akashi, N.; Terazawa, K. Bark stripping damage to conifer plantations in relation to the abundance of sika deer in Hokkaido, Japan. *For. Ecol. Manag.* **2005**, *208*, 77–83. [CrossRef]
5. Suzuki, M.; Fujiwara, A.; Kamoda, S.; Maehara, T.; Saito, H.; Matsui, M.; Iguchi, K.; Kaji, M.; Kamata, N. Factors Affecting the Probability of Bark-stripping by Deer in a Natural Forest: An Analysis Based on Tree Characteristics, Deer Habitat Utilization and Environmental Conditions. *J. Jpn. For. Soc.* **2011**, *93*, 213–219. [CrossRef]
6. Rullan-Silva, C.D.; Olthoff, A.E.; Delgado de la Mata, J.A.; Pajares-Alonso, J.A. Remote Monitoring of Forest Insect Defoliation—A Review. *For. Syst.* **2013**, *22*, 377–391. [CrossRef]
7. Tamura, A. Effects of Fencing for 7 Years on the Regeneration of Tree Species after Dwarf Bamboo on the Forest Floor Has Been Diminished by Sika Deer Browsing. *J. Jpn. For. Soc.* **2008**, *90*, 158–165. [CrossRef]
8. Guimarães, N.; Pádua, L.; Marques, P.; Silva, N.; Peres, E.; Sousa, J.J. Forestry Remote Sensing from Unmanned Aerial Vehicles: A Review Focusing on the Data, Processing and Potentialities. *Remote Sens.* **2020**, *12*, 1046. [CrossRef]
9. Magstadt, S.; Gwenzi, D.; Madurapperuma, B. Can a Remote Sensing Approach with Hyperspectral Data Provide Early Detection and Mapping of Spatial Patterns of Black Bear Bark Stripping in Coast Redwoods? *Forests* **2021**, *12*, 378. [CrossRef]
10. Näsi, R.; Honkavaara, E.; Blomqvist, M.; Lyytikäinen-Saarenmaa, P.; Hakala, T.; Viljanen, N.; Kantola, T.; Holopainen, M. Remote sensing of bark beetle damage in urban forests at individual tree level using a novel hyperspectral camera from UAV and aircraft. *Urban For. Urban Green.* **2018**, *30*, 72–83. [CrossRef]
11. Näsi, R.; Honkavaara, E.; Lyytikäinen-Saarenmaa, P.; Blomqvist, M.; Litkey, P.; Hakala, T.; Viljanen, N.; Kantola, T.; Tanhuanpää, T.; Holopainen, M. Using UAV-Based Photogrammetry and Hyperspectral Imaging for Mapping Bark Beetle Damage at Tree-Level. *Remote Sens.* **2015**, *7*, 15467–15493. [CrossRef]
12. Kogushi, S.; Kamada, M.; Hasegawa, K. Vegetation change relating to a change of management ad Ochiai-Pass in Higashi-Iyayama Village in Tokushima Prefecture, Shikoku, Japan. *Bull. Tokushima Pref. Mus.* **2005**, *15*, 1–20.
13. Kamada, M. Process of the establishment and maintenance of Sasa grassland in Tsurugi Mountains in Tokushima Prefecture, Shikoku, Japan. *Bull. Tokushima Pref. Mus.* **1994**, *4*, 97–113.
14. Kanzaki, N.; Maruyama, N.; Koganezawa, M.; Taniguchi, M. Tree barking by sika deer in Nikko, Tochigi prefecture. *Wildl. Conserv. Jpn.* **1998**, *3*, 107–117. [CrossRef]
15. Innes, J. *Forest Health: Its Assessment and Status*; Cab International: Cambridge, UK, 1993; 677p.
16. Ando, M.; Yokota, H.; Shibata, E. Why do sika deer, Cervus nippon, debark trees in summer on Mt. Ohdaigahara, central Japan? *Mammal Study* **2004**, *29*, 73–83. [CrossRef]
17. Takatsuki, S. Foot morphology and distribution of Sika deer in relation to snow depth in Japan. *Ecol. Res.* **1992**, *7*, 19–23. [CrossRef]
18. Yokoyama, M.; Kaji, K.; Suzuki, M. Food habits of sika deer and nutritional value of sika deer diets in eastern Hokkaido, Japan. *Ecol. Res.* **2000**, *15*, 345–355. [CrossRef]