Survival and growth of Japanese cedar (*Cryptomeria japonica*) planted in tree shelters to prevent deer browsing: a case study in southwestern Japan

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Abstract

Tree shelters are used in forestry to prevent large herbivores from browsing on young trees. Although tree shelters can generally prevent browsing damage while the young trees are within the tree shelters, they have been observed to fail in some cases. In this study, to clarify the protective capacity of tree shelters against damage due to deer browsing, the condition of tree shelters on planted Japanese cedar (*Cryptomeria japonica*) seedlings 2 to 7 years after installation was investigated at 42 sites in southwestern Japan where the density of sika deer (*Cervus nippon*) is high. The results showed that tree shelters failed for three reasons. Firstly, the shelter had collapsed or incline and could no longer protect the saplings within. Secondly, the saplings in the shelters died relatively shortly after they were planted. Thirdly, and possibly most importantly, the saplings are browsed upon by deer after they extended beyond the top of the shelter. Since there was no correlation between the damage rate and the number of years after planting, it is likely that the damage occurred immediately after the young trees protruded form the shelter. Shelters with a height of only 140 cm, which are widely used in Japan, may be too short to completely prevent herbivory damage by deer.

Keywords: *Cervus nippon*; multi-site study; seedling mortality; sugi

Introduction

Tree shelters have been demonstrated to promote increases in tree height (Potter 1991; Redick and Jacobs 2020). This is partly due to the effect they have on improving the microclimate inside the tree shelters, which are also referred to as micro-greenhouses (Kjelgren et al. 1997; Bergez and Dupraz 2000; Oliet and Jacobs 2007). In addition, shelters can increase the survival rate of young trees through protecting the trees from damage by browsing herbivores (Potter 1991; Redick and Jacobs 2020; Abe 2022).

In Japan, seedlings of Japanese cedar (*Cryptomeria japonica*) have been widely planted in commercial forests (Masaki et al. 2017). However, since around the 1990s, damage due to sika deer (*Cervus nippon*) has become increasingly problematic (Takatsuki 2009). By the late 1990s, tree shelters began to be used to prevent deer from browsing and fraying damages by deer, but early reports on their application are scarce and not many have been published in English (e.g., Nakamura and Amikura 1998; Hirosawa 2002; Sumiyoshi and Tazitsu 2002; Akashi and Fukuchi 2003). Further, the length of the study periods employed in those studies were typically short (approx. three years) as the materials used to construct early versions of the shelters deteriorated easily (Nakamura and Amikura 1998; Hirosawa 2002; Sumiyoshi and Tazitsu 2002). However, since that time, the types of materials used to construct tree shelters have improved to the extent that they can now be used for extended periods in the field. Studies using these new shelters have generally reported good initial growth of the sheltered seedlings (Maruyama and Suzuki 2002), but problems with seedling mortality have occasionally been reported (Saito et al. 2019). It has been speculated that some of the problems with seedling mortality can be attributed to the fact that the saplings do not develop resistance to frost damage in late autumn as the temperature inside the shelter is relatively higher than that of the colder outside air, resulting in seedlings dying more easily when temperatures decrease in winter (Hirosawa 2002; Akashi and Fukuchi 2003; Saito et al. 2019).

The purpose of this study was twofold. First, we sought to evaluate the condition of installed tree shelters over time in the field. Second, we examined the effectiveness of tree shelters for protecting cedar seedlings against damage by browsing deer at sites where deer densities are high and the climate is warm in southwestern Japan.

Materials and Methods

The survey sites are scattered throughout the Kyushu and Shikoku regions (30°59′N–34°40′N, 129° 33′E–134°44′E) in southwestern Japan (Figure 1). Deer are found in high densities in Kyushu and Shikoku, with some mountainous areas having deer densities exceeding 30 deer/km^2 (Ministry of the Environment of Japan 2015). Consequently, deer-proof fencing is required when trees are planted in commercial forests in these areas. In the high elevation areas of Shikoku, the forest floor vegetation is known to have been altered significantly by deer (Takatsuki et al. 2021). In Hita City in Kyushu, and Ikeda City in Shikoku, both of which are close to the areas where the survey sites were concentrated, the mean annual temperatures were 15.8°C and 14.3°C, average August temperatures were 27.4°C and 31.6°C, annual precipitation from 1991 to 2020 (Japan Meteorological Agency, 2021) was 1876 mm and 1498 mm, and the altitudes of the meteorological stations were 83 m and 214 m, respectively. Field surveys were conducted at 42 where tree shelters were installed 2 to 7 years after planting Japanese cedar seedlings at altitudes of 200–1220 m. Japanese cedar is the most common and important silvicultural species in Japan. At the time of the survey, the young cedar trees ranged from approximately 30 cm to over 300 cm in height; for the sake of convenience, all of the young trees in this size range are referred to as saplings in this study. The installed tree shelters (PhytoshelterTM, Phytoculture Control Co. Ltd., Osaka, Japan) are composed of polypropylene and measure 10 cm in diameter by 140 cm in height. The tree shelters, which have three small holes in the lower section for ventilation, are attached to two hollow steel stakes with plastic lock ties. The number of study sites was 5, 9, 19, 4, 3, and 2 for each forest age from 2 to 7 years. The 7-year planting site was where this type of shelter was installed soon after its launch.

At each survey site, we used 2 to 4 transects that included 50 tree shelters (100 to 200 tree shelters in total), and recorded the condition of the tree shelter itself, the survival of saplings, the extent of browsing damage to the saplings, and the sapling height. The state of the tree shelter was judged as “normal” when the vertical inclination was within 30°, “inclined” when it was more than 30° (the sapling trunk is forced to grow along the inclination of the tree shelter, forming a bent trunk), and “collapsed” if the tree shelter was bent in the middle or did not maintain its original tubular shape. The causes of inclination and collapse were natural disturbances, such as strong winds and falling rocks. We also recorded tree shelters as being “broken” when the cause of collapse was due to deer. “Broken” tree shelters were distinguished from those that underwent natural collapse based on the presence of scars on the broken tree shelter from bites and/or antler rubbings. The state of the saplings was classified into four categories: dead in the tree shelter; healthy; browsing damage on shoots protruding above the tree shelter; and damaged after collapse of the tree shelter. Regarding the topographical conditions, the slope direction (measured using a minimum of 30 transects in each cardinal direction) and slope angle (0° to 48°, average 26°) were measured for each transect using a clinometer.

We defined “severe damage” by deer to saplings in tree shelters as damage that would interfere with normal tree growth. In addition to the death of the planted seedlings due to browsing damage, damage such as deformation of the main stem, which makes it impossible to obtain straight lumber, were also recorded as severe damage.

To clarify whether microclimatic conditions in the tree shelter affected sapling survival, the effects of on-site factors on sapling mortality rates in the normal tree shelters along each transect were analyzed using a generalized linear model (GLM). In the model, the independent variables were slope direction, slope angle, altitude, and ages after planting, and the dependent variables included whether saplings were dead or alive. The error structure was assumed to have a binomial distribution.

All statistical analyses were performed using the R 4.1.0 software package (R Core Team 2021).

Results

At 35 of the 42 sites (83.3%) surveyed, more than 80% of the tree shelters were upright and undamaged (i.e., Normal; Figure 2). The remaining seven sites had fewer than 80% normal tree shelters, with more than 20% of the tree shelters broken by deer (6 sites) or 19% of the tree shelters being collapsed on a steep slope (1 site). Together, the collapsed and inclined tree shelters accounted for 4% of the total number of the tree shelters. At three sites, more than 10% of the tree shelters had collapsed, and the highest number of inclined shelters at a site was 9%.

In the normal tree shelters, saplings of cedar protruded from the top of the tree shelter 2 to 3 years after planting and grew to a height of over 2 m after 5 years (Figure 3). More than 70% of surviving saplings protruded from the height of tree shelter at 3 years after planting (Figure 3).

Sapling mortality in normal shelters was low (mean 9.0% per transect), and no dead saplings were observed in 26 of the 133 transects. There was no relationship between mortality and age after planting (Kruskal-Wallis, $p = 0.62$). Since 71.7% of the dead saplings in the normal tree shelters were less than 70 cm tall and almost the same height as the seedlings that were planted, it appears that the saplings died shortly after planting (Figure 4).

GLM analysis of the mortality rate per transect revealed that slope direction and elevation both had a significant effect on the mortality rate, while slope angle and age after planting showed no such effect (Table 1). In terms of slope direction, north-facing slopes had significantly lower mortality rates than the other slopes, and higher elevations had higher mortality rates, but the differences were minor (Table 1).

Two types of serious damage were attributed to deer. One type was the destruction of tree shelters by deer, which occurred at 16 sites (8.9% on average), resulted in severe damage to the saplings within the shelters (Figure 5a). In cases where tree shelters were broken, heavily browsed saplings (38.4%), dead saplings (40.3%) and no saplings (21.3%) were observed. The percentage of shelters destroyed was highest (> 96%) at two sites in Shikoku, and rates of damage exceeded 20% at another four sites (Figure 2; Broken). Another type of serious damage was severe browsing of branches protruding from the shelters (Figure 5b-d); this occurred at 29 sites (20.4% on average) even when the shelter condition was normal. Stems that were dragged out of the tree shelter were expected to break or get caught in the shelter's connection (Figure

5b), causing the trunk to bend (Figure 5c). In cases where branches protruding above the shelter were browsed repeatedly, saplings would not be able to grow any further (Figure 5d). The rate of severe browsing damage was highest (99%) at a site in Shikoku, and rates above 20% were observed at the other 15 sites (Figure 6). There was no association between age after planting and either shelter destruction (Kruskal-Wallis, $p = 0.88$) or severe browsing ($p = 0.71$).

Discussion

Causes of tree shelter failure

From the results of the multi-site survey, it was found that there were three reasons for why tree shelters failed to protect young trees. The first reason, which was due to the tree shelter being damaged by natural conditions, was generally low (4% on average) in this survey (Figure 2; Collapsed and Inclined). If the tree shelter is supported by sturdy, well-driven stakes and maintained regularly, then the loss of young trees will be reduced.

The second reason was failure of seedling establishment within the tree shelters, which occurs even when the tree shelter was standing and stable. Since the height of the dead saplings was similar to that of standard-size seedlings that are used for planting in Japan, it can be assumed that most of the saplings died relatively soon after planting. Although the average mortality rate of saplings was low (9%), the proportion of individuals that die in the first season of planting was high (71.7%). Mortality was slightly higher at higher elevations and on slopes not facing north, implying that the temperature in the tree shelter may have affected the survival of pre-rooted saplings immediately after planting, as has been reported in areas with cold climates (Hirosawa 2002).

The third reason was due to damage caused by deer browsing, which was the most significant reason for shelter failure. When deer break the tree shelters, the saplings in the shelter are extensively browsed. Furthermore, even if the tree shelter is in a normal condition, if the saplings exceed the height of the tree shelter, browsing by deer can occur frequently, causing more damage than would typically have been caused when the tree shelter was damaged by deer. Although relatively few reports have documented the extent of sapling damage after the trees protrude from the tree shelters, it is not uncommon for grown saplings to be severely damaged at this stage (Sumiyoshi and Tazitsu 2002; Ikeda 2006; Maltoni et al. 2019).

Period of damage occurrence

In this study, there was no relationship between the rate of severe damage and the number of years after planting, i.e., severe damage was not the result of cumulative deer browsing for a long period of time, suggesting that the damage, especially browsing damage, occurred shortly after the saplings protruded from the tree shelters. The cedar saplings surveyed protruded from the tree shelter at 2–3 years after planting, reaching an average height of 180 cm in the fourth year after planting (Figure 3). Considering that sika deer can browse up to a height of approximately 180 cm (data from Kyushu: Ikeda 1998; Nomiya et al. 2019), it is considered that saplings are most vulnerable in the third to fourth year after planting.

Effect of tree shelter height

Although most of the tree shelters used in Japan are 140 cm-long, tree shelters measuring 180 cm in length have been proposed to be more effective for preventing damage by medium-sized deer, including sika deer (Hodge and Pepper 1998; Trout and Brunt 2014). In saplings of Japanese cedar, sika deer in Kyushu typically browsed on branches 75–110 cm high, but occasionally deer browsed on branches up to almost 160 cm in height (Nomiya et al. 2019). Therefore, as revealed in this study, in areas where deer browsing pressure is high, a 140 cm-long tree shelter may not be sufficient for preventing completely the serious damage that deer cause after the saplings extend beyond the top of the shelter.

Irrespective of deer browsing pressure, the use of taller tree shelters may decrease browsing damage. However, while taller tree shelters can protect saplings from deer browsing, they may be more susceptible to leaning or falling over in the wind (Akashi and Fukuchi 2003) and are more expensive in terms of materials costs. Future studies on the durability and construction costs of shelters deployed in southwestern Japan where typhoons are common are therefore necessary.

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Disclosure statement

No authors have potential conflicts of interest to report.

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Table 1. Results of generalized loglinear model used to assess the effect of site parameters on sapling mortality rate.

	Estimate	Std. error	Odds ratio	95% confidence interval		*p* value
				Lower	Upper	
Intercept	-3.542	0.324	0.015	0.015	0.055	< 0.001
Slope direction						
East	0.391	0.153	1.480	1.090	2.000	0.011
South	0.707	0.149	2.030	1.510	2.710	< 0.001
West	0.662	0.151	1.940	1.440	2.610	< 0.001
Direction of standard north						
Slope angle	0.008	0.005	-	-	-	0.127
Altitude	0.001	0.000	-	-	-	< 0.001
Ages after planting	-0.041	0.049	-	-	-	0.402

AIC (Akaike's Information criterion): 810.98, Null deviance: 572.18 (df: 117), Residual deviance: 524.24 (df: 111), McFadden's pseudo R-squared: 0.084

Figure 1. Map of the Kyushu and Shikoku regions in southwestern Japan. Closed circles and open squares indicate the 42 survey sites and two meteorological observation sites, respectively.

Figure 2. Tree shelter status as a percentage at the survey sites. Normal: standing straight and maintaining original tubular shape; Broken: damage caused by deer; Collapsed: damage caused by natural disturbance; Inclined: leaning an angle of more than 30°. Gray dots indicate the data points obtained at each survey site.

Figure 3. Frequency distribution of average height of Japanese cedar (*Cryptomeria japonica*) saplings surviving in a normal tree shelter by age after planting. Height of the tree shelter is 140 cm. White circles indicate the average height of the saplings at all survey sites. Gray dots indicate the data points obtained at each survey site.

Figure 4. Height distribution of dead Japanese cedar (*Cryptomeria japonica*) saplings in normal tree shelters. Height of the tree shelter is 140 cm.

Figure 5. Severe damage caused by deer browsing on Japanese cedar (*Cryptomeria japonica*) saplings. (a) Broken shelter: Sometimes the deer break or remove the tree shelters to browse on the saplings inside, which often results in sapling death. (b) Drag-out damage: Tips of branches that are out of reach are browsed upon after the main stem was dragged out of the tree shelter. Stems that are dragged out of the shelter often break off or become trapped along the seam of the shelter. (c) Crank-shaped stem: Stems that become caught in the seam of the shelter and grow crooked. (d) Repeated browsing damage: If the top shoot is eaten repeatedly when it protrudes from the tree shelter, the sapling typically forms a dome-shaped crown at the top of the tree shelter and cannot grow any further.

Figure 6. Extent of severe browsing by deer after exceeding the tree shelter height at different ages after planting. Gray dots indicate the data points at each survey site.

Figure 1

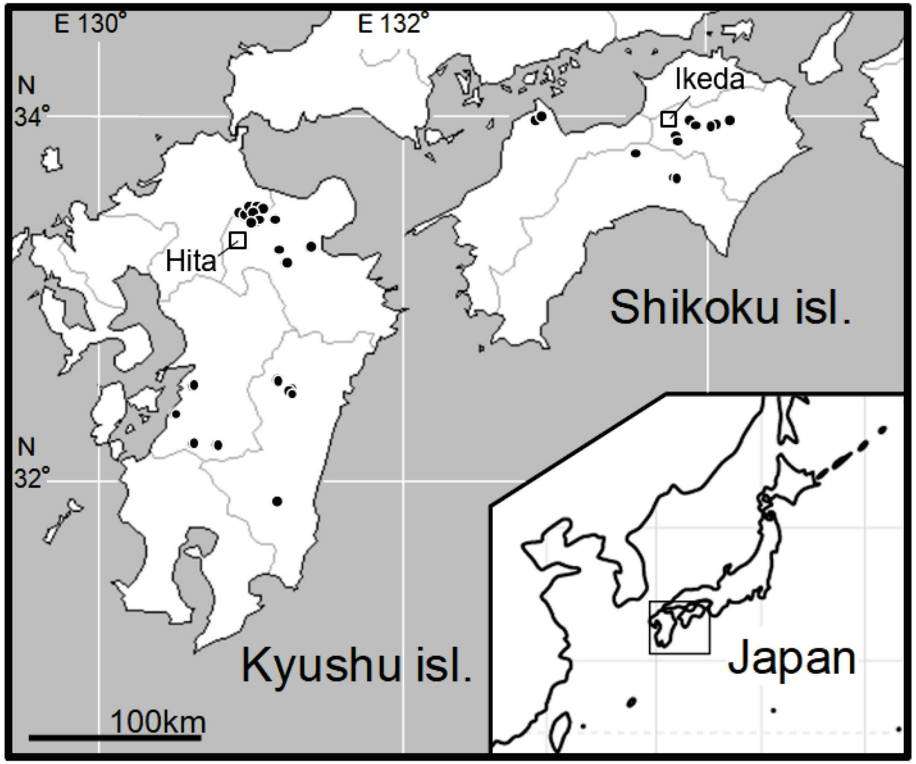

E 130°
E 132°
N
34°
N
32°
Ikeda
Hita
Shikoku isl.
Kyushu isl.
Japan
100km

Figure 2

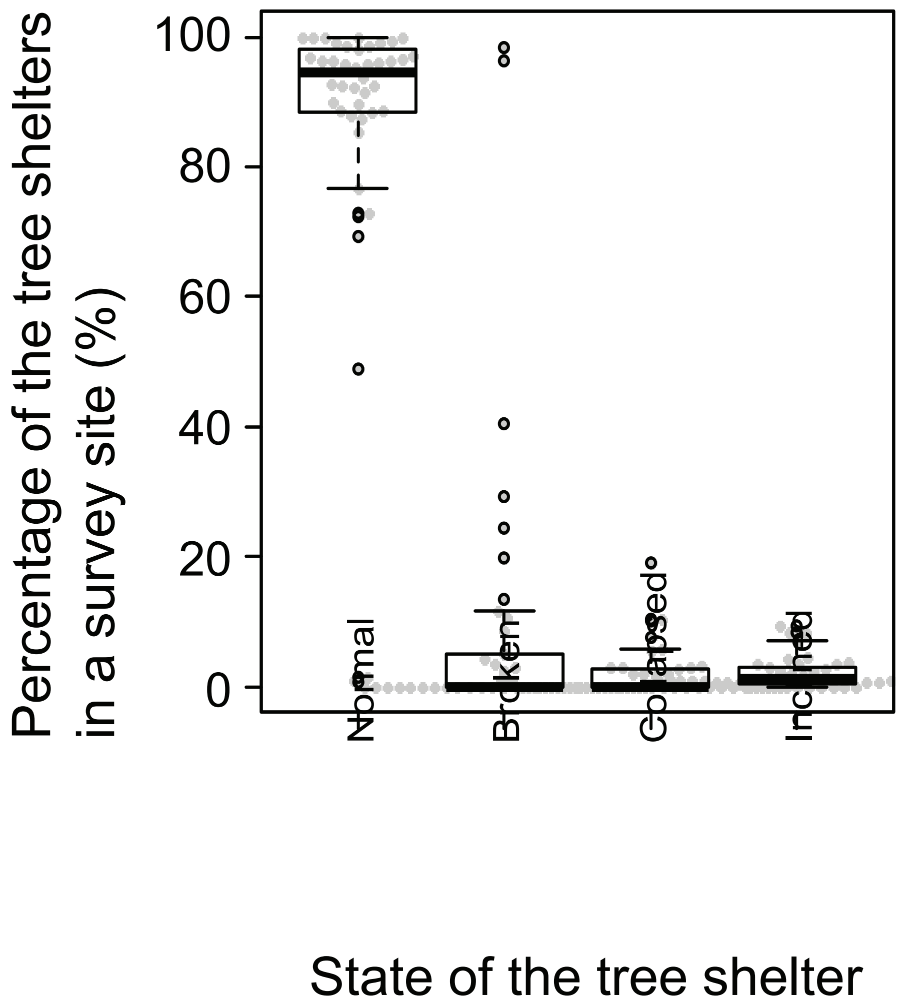
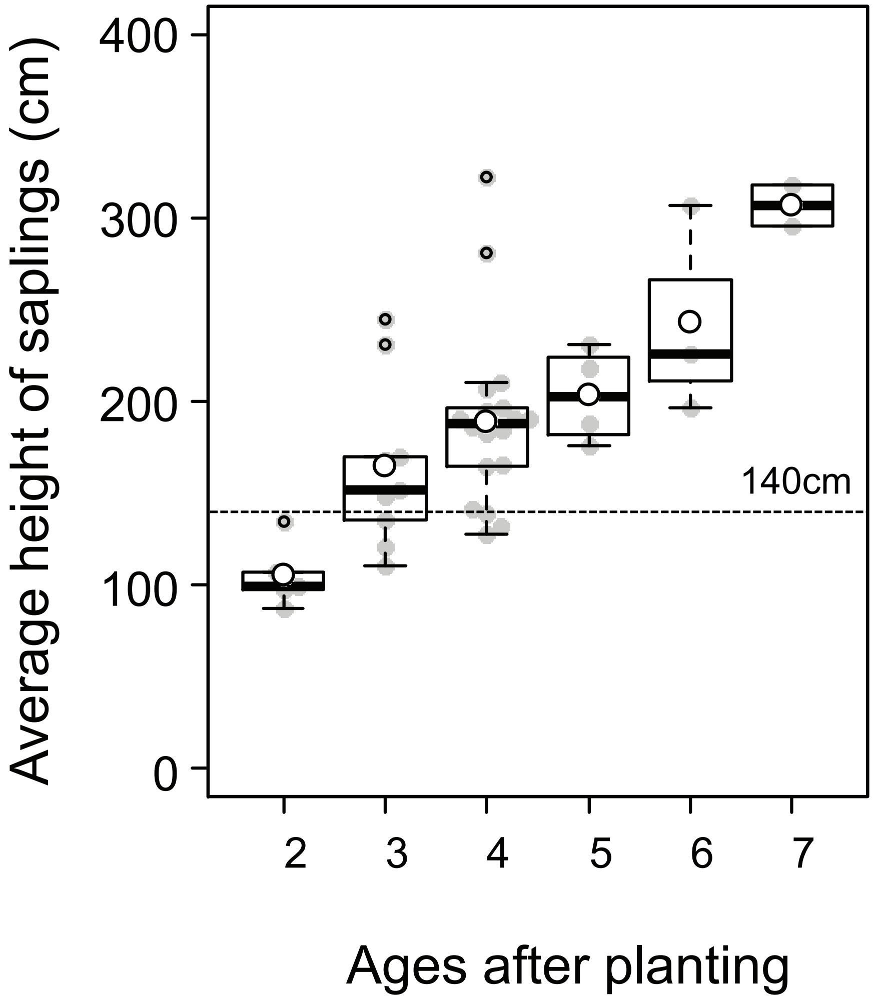
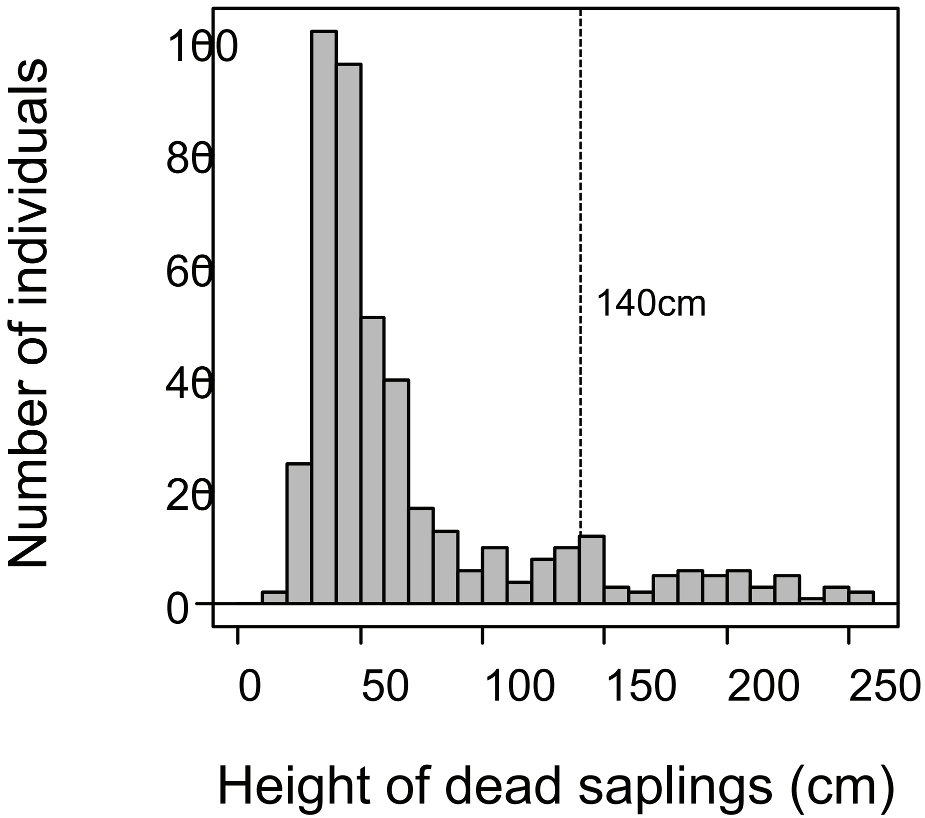

Percentage of the tree shelters
in a survey site (%)
100
80
60
40
20
0
Normal
Broken
Collapsed
Inclined
State of the tree shelter

Figure 3



Average height of saplings (cm)
400
300
200
100
0
140cm
2
3
4
5
6
7
Ages after planting

Figure 4



Number of individuals
100
80
60
40
20
0
140cm
0
50
100
150
200
250
Height of dead saplings (cm)

Figure 5

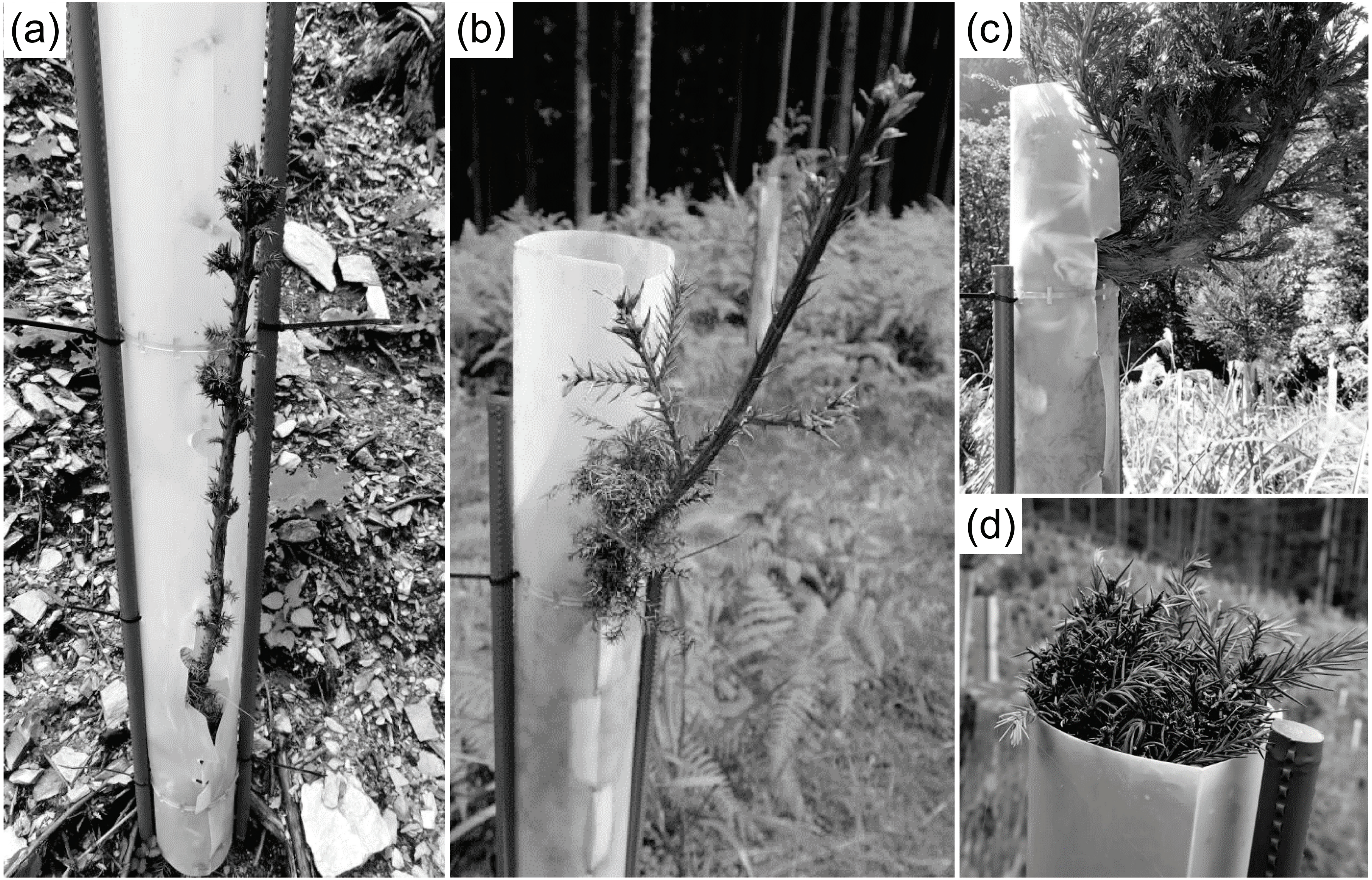
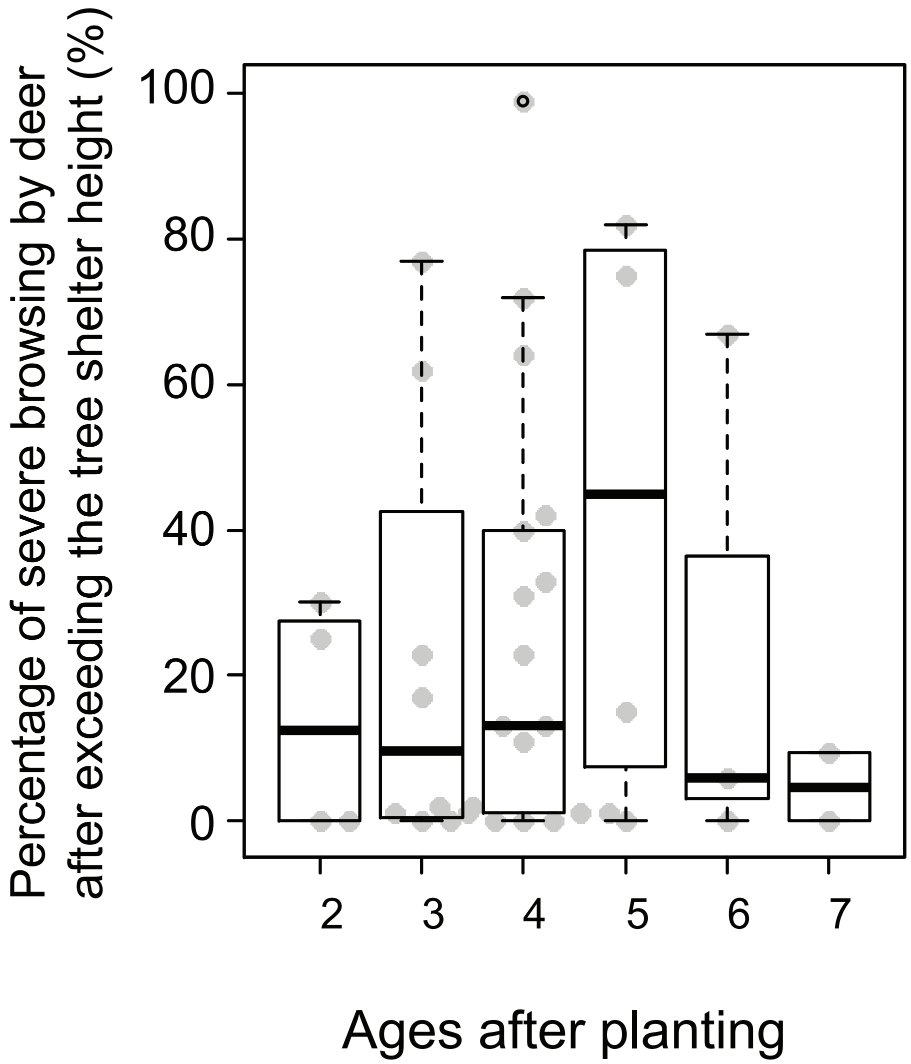


Figure 6



Percentage of severe browsing by deer
after exceeding the tree shelter height (%)
100
80
60
40
20
0
2
3
4
5
6
7
Ages after planting