Various scarification treatments produce the different regeneration potentials for trees and forbs through changing soil properties

Haruka Yamazaki [a]* and Toshiya Yoshida [a]

[a] Field Science Center for Northern Biosphere, Hokkaido University; 250 Tokuda, Nayoro, 096-0071, Hokkaido, Japan

* Corresponding author: halyamazaki@fsc.hokudai.ac.jp

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Soil scarification removed surface layers including nutrients and buried seeds. The purpose of this study was to evaluate the success of alternative practices which intentionally leave the surface soil (screening and replacing) along with the standard scarification. We focused on soil properties, the density of buried seeds, the invasion of competitive vegetation, and the regeneration of tree species. There were significant differences in soil properties among the treatments. Soils that were treated with the replacing treatment had the highest water contents from the surface layer to the deep layer in the lower slope in particular. On the other hand, there were higher densities of tall forb germinated from rhizomes, which are likely to shade tree species, with the replacing particularly in the lower slope locations. The residual buried seed densities in the soil were estimated to be significantly higher in the screening than the replacing. *Phellodendron amurense*, producing seed bank and having dry tolerance, exhibited the greatest seedling density with the screening. However, there was no significant difference between screening and replacing in *Betula* species which has higher water demands. In conclusion, it is important that screening and replacing should be used properly according to the site condition and target tree species. The replacement had the advantage of retaining higher water content, but it is suggested that the screening is a better option when intended for regeneration from buried seeds and when many tall forb species grow alongside dwarf bamboo prior to treatment.

Keywords: Surface soil disturbance; selection of silvicultural practice; buried seeds; tall forb species; assisted natural regeneration

Introduction

An increased expectation for ecosystem services has raised awareness of the importance of nature conservation even in primary industries (Butchart et al. 2010; Benayas and Bullock 2012). However, sustainable management with due consideration of conservation generally remains underdeveloped in forestry (Siry et al. 2005), resulting in an increasing global emphasis on the close-to-nature concept, which aims to harmonize timber production with ecosystem resilience (Kohm and Franklin 1997; Messier et al. 2013).

Close-to-nature forest management generally promotes natural regeneration as a method for establishing new forests. It has been reported that planted forests with simple structures for economic efficiency have greatly modified natural patterns and processes, resulting in decreased ecosystem resilience (Thompson et al. 2009). By contrast, natural regeneration allows forest establishment from naturally dispersed seeds or vegetative propagation (e.g., sprouting), resulting in more natural forests that contain tree species and genetic traits that are better suited to local conditions (Schütz 1999; Finkeldey and Ziehe 2004). Furthermore, natural regeneration has various economic advantages compared with planted forests, as tree species that are difficult to grow by planting (e.g., many broadleaf species) can be produced and management costs can be reduced by eliminating the need for planting operations (Shono et al. 2007; Gonza´lez-Rodrı´gues et al. 2011). However, there is a major disadvantage in natural regeneration, i.e., its reliance on natural seed dispersal; its success varies depending on the level of seed production and the suitability of the understory conditions (Löf et al. 2012; Fløistad et al. 2018). Therefore, assistance practices are often employed to improve the site conditions for seed germination and seedling establishment (Löf et al. 2012; Nyland 2016).

Such assistance practices that are employed vary greatly depending on the local conditions at a particular site (Löf et al. 2012). In Hokkaido, north Japan, dwarf bamboos can vegetatively reproduce from the root system, causing regeneration failure among target tree species (Narukawa and Yamamoto 2002; Noguchi and Yoshida 2004; Yoshida et al. 2005); therefore, removal of entire bamboo plants using heavy machinery (known as scarification) has been widely performed since the 1960s (Umeki 2003).

Scarification is considered to have a relatively high success rate, producing secondary forests of *Betula* species, which are typical native pioneer trees (Umeki 2003; Prévost et al. 2010). Consequently, the increased commercial demand for the timber of *Betula* species in recent years (Ito et al. 2018) has resulted in the use of this method as a candidate alternative to conifer planting in this region, which is consistent with the close-to-nature concept.

When carrying out scarification, an appropriate method should be used that considers both the site conditions and species characteristics. Indeed, scarification has occasionally been shown to have a negative effect on the target species, with regeneration failing in some instances, likely due to the vigorous growth of competitive vegetation, such as tall forb species (Zaczek 2002; Yoshida et al. 2005; Fløistad et al. 2018). Therefore, a quantitative evaluation of the influence of scarification on not only the target tree species but also competitive vegetation is required.

In this study, we paid special attention to the practices leaving surface soil in the scarification treatment. In standard soil scarification, the surface soil layers where the root systems of dwarf bamboos are concentrated are largely removed. However, this also results in large amounts of nutrients (Aoyama et al. 2009; Yildiz et al. 2009) and any buried seeds (Osumi and Sakurai 1997; Reyes et al. 2014) being lost from the site. Consequently, in recent years, alternative practices have been proposed that intentionally leave the surface soil at the site. These techniques have been reported to increase the growth of regenerated target trees (Aoyama et al. 2009) as well as the number of emerged seedlings from buried seeds (Sato 1998; Goto and Tsuda 2007). However, no studies to date have considered the detailed procedure for leaving the surface soil or the possible effects on competitive vegetation.

We previously compared two different practices for leaving the surface soil known as "screening" and "replacing" (see the Materials and methods section for details), and unexpectedly found that the number of seedlings that germinated from buried seeds varied significantly between these, possibly indicating that both the amount and quality of the soil that is left is important (Yamazaki and Yoshida 2018). Therefore, the purpose of the present study was to evaluate the success of these scarification practices along with the standard method in terms of soil properties, the density of buried seeds, the invasion of competitive vegetation, and the regeneration of tree species. In terms of soil properties, the moisture condition is particularly important in determining the initial establishment of seedlings just after germination (Madsen 1995; Resco de Dios et al. 2005). Therefore, we focused on the surface soil water content and related soil characteristics (McNabb et al. 2001; Ares et al. 2005; Siegel-Issem et al. 2005). We used the results to evaluate the suitability of each practice for increasing the success of regeneration depending on the target tree species and site conditions.

Materials and Methods

Study site and treatments

This study was carried out in the Uryu Experimental Forest of Hokkaido University in Hokkaido, northern Japan. Mean annual temperature and precipitation are respectively 3°C and 1400mm, with the maximum snow depth over 200cm. The forest is largely dominated by a mixed conifer-broadleaf stand consisting mainly of *Abies sachalinensis* (Fr. Scham.) Masters, *Querucus crispula* Blume., *B. ermanii* Cham. and *B. platyphylla var. japonica* (Miq.) Hara (the nomenclature was followed by Yonekura and Kajita 2003).

The study site was established in large canopy openings created by past logging and wind-fall disturbances on gentle slopes (slope inclinations 10-12°) in 0.5 ha of a natural stand. The understory was mainly covered with dense dwarf bamboo, *Sasa senanensis* (Franch. et Sav.) Rehder. The soil type is brown forest soil that is most common target for scarification treatment. Three experimental areas were located in the center of the canopy openings. Two study-plots, each with an area of 48m^2 (4 × 12 m), were established in the upper and lower parts of the slop. Each set of the plots was located within the horizontal distance of approximately 20m (differences in elevation were approximately 3.5m). There is a forestry road at the top of the upper study-plots, and we established the ditch to limit a direct inflow from the road.

In each of these study plots, we set three subplots (4m square), and three different practices of soil scarification were assigned to each.

(1) Scarification: It is a standard treatment in which a power shovel (HITACHI, ZX27U-3) was used to remove understory vegetation with surface soil (up to 5–10 cm depth). The resulting debris was piled outside the area.

(2) Screening: The understory vegetation was removed by clamping the bucket of the power shovel, in which the entire plant including the root system is removed. As much soil as possible is shaken off the root debris so as to retain the soil at the site.

(3) Replacing: The surface soil with understory vegetation was removed from the site using a power shovel, similar to the standard scarification process. However, the soil was subsequently replaced using a power shovel after a certain period; the duration of 4 weeks was selected in this case to prevent recolonization of dwarf bamboos from root stocks (Aoyama et al. 2009).

The treatments were conducted in the subplots (with c.a. 1 m^2 marginal area added) during the summer of 2015.

Soil properties survey

We investigated soil properties of each sub-plot in 2016 and 2017 (1-2 years later after the treatment). In summer, 2016, soil hardness was measured with a tester (Fujiwara Scientific Co. Ltd., Yamanaka's Soil Hardness tester) at three depths (0-5cm, 5-10cm and 10-20cm) on the soil profile installed in the marginal area of the sub-plot, and the average of nine repetitive measurements of each sub-plot was used as a representative value. Also, in summer 2017, we brought back soil samples from three soil depths (0-2.5cm, 2.5-5cm and 5-10cm) of 25cm square in the sub-plot to the laboratory. Plant-debris (many were dead but some were alive) were derived from the soil using the sieve (4-mm mesh) and washed, and their dry weights (75°C, 48h) were used as representative measures of plant-debris density. Soil surface temperature was measured with the data logger (Onset Computer Corporation, UA-002-08), at one depth (1-2 cm depth) in the sub-plot. We used the data of 12:00 p.m. in 7 days period (after around no precipitation after 7 days) in summer, 2017, when the soil was considered to be the driest.

Soil samples were also collected systematically in the sub-plot at four depths (0-2.5cm, 2.5-5cm, 5-10cm and 10-20cm; one repetition for each sub-plot) using on semicircle-auger (Daiki Rika Kogyo Co. Ltd., 5cm in diameter) for measuring soil water content. The sampling was carried out also after no precipitation around 7 days during the summer, 2016. Although it was momentary data, we think that it is sufficient for discussing differences in regeneration among the treatment, because the period is considered to be most severe for living environment for seedlings. We carefully removed plant-debris and stones using the sieve (2-mm mesh), and weighted the sample before and after drying (105 °C, 24 h) to determine water contents.

At last, we evaluate fine scale soil surface micro-topography in 2017. We took 70 pictures of the square quadrats, using a digital camera (Nikon Co. Ltd., Coolpix-A). Before taking pictures, we carefully removed all the vegetation and litter to keep the intact surface geometry. 3D-models of the surface were constructed from the pictures using the SfM (Structure from Motion) technology (Agisoft LLC, Photo-Scan). We took ground surface levels resolution with a 2cm a square (1600 points quadrat^{-1}) on GIS (Esri, Inc., Arc-GIS ver.10.4), and their variance value in each sub-plot was used as an index of soil surface roughness.

Buried seed density

The three practices were conducted at another adjacent location (4m square with three replications) to evaluate the effect on buried seed density. We used industrial glass beads of 2mm in diameter (hereafter pseudo-buried seeds), which was equivalent to the seed size of *Betula* species, for this experiment. Before conducting the practices, we dispersed the pseudo-buried seeds in two ways; for the surface layer, we sowed 70 beads / m^2 evenly by hand. On the other hand, we buried at the intersection of every 50 cm so that there are 70 beads / m^2 respectively for the depths 5cm and 10cm. (totally 210 beads / m^2). Then, after the practices, we extracted all soil to depth 10cm in the 25cm square frame with 4 replications for each treatment. The glass beads in the samples were counted, and were used as an index of residual density of buried seeds in each treatment. We note that, in general, most of buried seeds of tree species are existed in the surface layer (buried seeds of *Betula* species were present at a depth of 5cm or less; Osumi and Sakurai 1997), and their germination rates decrease greatly when the depth exceeds 10cm (Benvenuti et al. 2001).

Vegetation

We collected all the germinated seedlings and juveniles in each sub-plot regularly (approximately two-weeks interval) during the whole growing season (June – August) in 2016. We note that the effect of human interventions was negligible, as the sampling was finished before conducting the series of soil collections. Seedlings and juveniles were identified by species and their germination origins (from seed or from rhizome). We noted that it was difficult to identify species of many seedlings among the two *Betula* species immediately after the germination. Therefore, we treated seedlings of these two species as *Betula* spp. in this study.

Analysis

The statistical differences among treatments was tested using a generalized liner mixed model (GLMM) in which the three study areas (i.e. canopy openings) was considered as a random effect. The treatments, slope location, and their interaction were used as predictor variables. We assumed a Gaussian distribution with an identity-link function for soil properties and assumed a Poisson distribution with a log-link function for the densities of seedlings or juveniles of the main seven plant species (2 tree species and 5 competitive species). We selected a final model using AIC value, and carried out the multiple comparisons by Tukey's test. The statistical differences in buried seed density among treatments were tested using a generalized liner model (GLM) and the subsequent by Tukey's test. R 3.1.2 was used (R Development Core Team 2019) for the analyses.

Results

Soil properties

There were no significant effects of slope locations on ground surface level, soil hardness, plant-debris density and soil surface temperature (Appendix-table 1). The average of soil surface roughness (variance in height) was significantly high in the replacing (Fig. 1a, $p<0.01$), with no significant difference between the screening and the standard scarification (Fig. 1a, $p>0.05$). Soil hardness was significantly lower in the replacing at the all depths (Fig. 1b, $p<0.001$), while there was no significant difference between the screening and the standard scarification (Fig. 1b, $p>0.05$). Similarly, plant-debris density was significantly more abundant in the replacing (Fig. 1c, $p<0.001$), with no significant difference between the screening and the standard scarification (Fig. 1c, $p>0.05$). Soil surface temperature was significantly lower in the replacing than in the screening (Fig. 1c, $p<0.05$), and it was tendency lower in the replacing than in the standard scarification.

Soil water contents were significantly high in the lower slope-location in the shallower two depths (0-2.5cm, 2.5-5cm) in the standard scarification (Fig. 2ab, $p<0.05$), and three depths (0-2.5cm, 2.5-5cm, 5-10cm) in the replacing (Fig. 2acd, $p<0.05$). In contrast, in the screening, the difference was significant only at the depth 2.5-5cm (Fig. 2b, $p<0.05$). In the upper slope the differences among the treatments were not found, except for 5-10cm depth (Fig. 2abd, $p>0.05$). On the other hand, in the lower slope, soil water contents were significantly high in the two treatments leaving surface soil than the standard scarification (Fig. 2, $p<0.01$), and they were significantly high in the replacing than the screening in many depths (Fig. 2acd, $p<0.05$).

Buried seed density

The residual pseudo-buried seeds densities in the soil greatly varied among the treatments (Fig. 3a, Appendix-table 2). In the standard scarification, the density was extremely low, showing less than 5% ($p<0.001$). Between the two treatments leaving surface soil, the density was significantly higher in the screening (>50%) than the replacing (around 35%; $p<0.05$).

Vegetation

The numbers of the seedlings of *Betula* spp. and *Phellodendron amurense*, which were main tree species, were not influenced by the slope-location (Appendix-table 2, $p>0.05$), while they were significantly less abundant (less than a quarter) in the standard scarification (Fig. 3, $p<0.001$). Between the two treatments leaving surface soil, there was no significant difference in *Betula* spp. (Fig. 3b, $p>0.05$), but they were significantly more abundant in the screening than the replacing in *P. amurense* (Fig. 3c, $p<0.01$).

The recovery of *S. senanensis* was very few in all the plots the study period (data not shown). Among the main competitive species, *Rubus idaeus* L. subsp. *melanolasius* Focke and *Cirsium kamtschaticum* Ledeb. ex DC. germinated mostly by seeds (100 and 95%, respectively). The effects of the treatment were different by the locations between the two species (Fig. 4ab, $p<0.05$). In the upper slope, seedlings of *R.idaeus* subsp. *melanolasius* were significantly more abundant in the replacing, followed by the screening (Fig. 4a, $p<0.01$). In contrast, in the lower slope, they were significantly more abundant in the screening, following by the replacing (Fig. 4a, $p<0.01$). With regard to the slope location, they were more abundant in the upper slope in the replacing and the standard scarification (Fig. 4a, $p<0.05$). On the other hand, in the upper slope, seedlings of *C. kamtschaticum* were significantly more abundant in the standard scarification (Fig. 4b, $p<0.05$). In the lower slope, they were significantly more abundant in the screening (Fig. 4b, $p<0.05$).

Fallopia sachalinensis (F.Schmidt) Ronse Decr., *Petasites japonicas* (Siebold et Zucc.) Maxim. subsp. *giganteus* (G.Nicholson) Kitam. and *Aralia cordata* Thunb. germinated mainly from rhizomes (96, 76 and 29%, respectively). Again, the effects of the treatment were different by the slope locations for these species (Fig. 4cde, $p<0.05$). In the upper slope, juveniles of *F. sachalinensis* were significantly more abundant in the screening and the standard scarification, and they were relatively less in the replacing (Fig. 4c, $p<0.05$). In this slope, juveniles of *P. japonicas* subsp. *giganteus* were significantly more abundant in the two treatments leaving surface soil (Fig. 4d, $p<0.05$), and the appearance of *A. cordata* showed a similar trend (but not statistically significant) among the treatments (Fig. 4e). In the lower slope, all of these species showed the tendency that juveniles were more abundant in the replacing; differences were significant in *F. sachalinensis* and *A. cordata* (Fig. 4ce, $p<0.001$), and juveniles appeared only in the replacing in *P. japonicas* subsp. *giganteus* (Fig. 4d). With regard to the slope location, juveniles of *F. sachalinensis* were significantly more abundant in the lower slope in the replacing (Fig. 4c, $p<0.001$), while they were significantly more abundant in the upper slope in the screening and the standard scarification (Fig. 4c, $p<0.01$). Juveniles of *A. cordata* were significantly more abundant in upper slope in the screening (Fig. 4e, $p<0.01$).

Discussion

Effects of treatments on soil properties

The three treatments that were examined in this study each exhibited specific soil properties, with a large difference even being observed between the replacing and screening, despite both leaving the surface soil in place.

Soils that were treated with the replacing had the highest water contents from the surface to the deep layer in the lower slope (Fig. 2), possibly due to this treatment producing a soil condition that water could easily infiltrate. Generally, the soil water content closely relates to porosity rate of the soil (represented partly by soil hardness) because large numbers of macro-pores increase the water infiltration ability (Beven and Germann 1982; McNabb et al. 2001). Consequently, the existence of coarse rhizomes in the soil with the replacing (Fig. 1c) may have caused macro-pores to occur (Beven and Germann 1982), increasing the porosity rate of the soil. This possibility is supported by the finding that the surface soil temperature, which is generally negatively correlated to soil porosity, was significantly lower with the replacing (Fig. 1d; Matsumoto and Okubo 1977). The undulating surface layer being created by the higher plant debris density with this treatment (Fig. 2a) also seem to contribute to maintain its relatively high soil water condition. In addition, we think that the formation of a crust layer as a result of soil surface compaction combined with the disappearance of vegetation and the litter layer (Norton 1987; Onda and Yukawa 1995) may be related to this result, as this would block the penetration of water into the soil and is expected to be enhanced with the screening compared with the replacing.

There were no significant differences in soil water content between treatments in the upper slope (Fig. 2abd), suggesting that the effects of these treatments on soil properties depend on the topographic condition. It is likely that a high water permeation ability will promote desiccation in the upper slope when the water supply is less abundant (Siegel-Issem et al. 2005), resulting in the more compacted soil that resulted from the screening having an increased water holding capacity owing to excessive penetration (Gomez et al. 2002; Page-Dumroese et al. 2006). In support of this, it was noted that there was only a small difference in the soil water content between the upper and lower slope locations with the screening (Fig. 2acd). Like the screening, the standard scarification also produced compacted soil, which explains the low soil water content that occurred with this treatment.

Effects on regenerated vegetation

Both the replacing and screening greatly increased the residual pseudo-buried seed density (Fig. 3a). However, the effects varied between these treatments, with more than half of the pseudo-buried seeds (55.2%) being maintained with the screening and 36.4% remaining with the replacing. This is likely due to the replacing involving plowing the surface soil and plant debris, resulting in many of the pseudo-buried seeds being moved to deeper layers.

The main tree species in the study area, *P. amurense*, exhibited the greatest seedling density with the screening, followed in turn by the replacing and the standard scarification (Fig. 3c). *P. amurense* produces a seed bank and these results clearly reflect the observed pattern for the residual pseudo-buried seed density (Fig. 3a). On the other hand, the two *Betula* species that were examined in this study had extremely low regenerating seedling densities with the standard scarification, despite previous reports of the emergence of abundant seedlings in the first year after this treatment (Umeki 2003), indicating a low level of seed production in the previous year. The seedlings of these *Betula* species were considered to have originated from buried seeds even though their life span is limited to one to several years (Osumi and Sakurai 1997).

Consequently, our finding that there was no difference in seedling density between the screening and replacing (Fig. 3b) despite the differences in their residual pseudo-buried seed density suggests that the germination and survival rates were higher with the replacing than with the screening. This tendency is consistent with the findings of a previous study considering the appearance of *B. maximowicziana* seedlings from buried seeds (Yamazaki and Yoshida 2018). We think that this is caused by the increased soil water content, which also closely related to the soil hardness and plant-debris density, in the replacing (Fig. 1bc, 2). The microenvironment of the surface soil greatly affects the germination and survival of *Betula* seedlings in the initial stages (Osumi and Sakurai 2002) and desiccation will have a particularly strong negative effect in scarified area, where compacted soil is exposed to direct solar radiation. Therefore, it seems that the replacing, which can maintain a higher soil water content, together with lower soil hardness and higher plant-debris density, provides more safe sites for *Betula* seedlings. In addition, the lower soil surface temperature in summer in the replacing (Fig. 1d), may have reduced the amount of stress experienced by the seedlings (Davidson et al. 1998).

Furthermore, the treatments also affected the germination of competitive species, which may become competitive depending on the site conditions. For *R. ideaeus* subsp. *nipponicus*, the number of seedlings that germinated was higher on the upper slope than on the lower slope and was lower with the standard scarification (Fig. 4a), reflecting the preference of this species for dry sites and its production of buried seeds (Prévost et al. 2010). By contrast, the highest abundance of *C. kamtschaticum* Ledeb. ex DC. seedlings appeared on the upper slope with the standard scarification treatment (Fig. 4b), indicating its similar preference for dry sites but suggesting that most seedlings originated from seeds that had not been buried.

The three tall forb species *F. sachalinensis*, *P. japonicas* subsp. *giganteus*, and *A. cordata* mostly reproduce asexually from crushed rhizomes (Tsuyuzaki 1987, 1989), so we initially expected that there would be a higher density of these species with the replacing due to the larger amount of plant debris in the soil (Fig. 1c), most of which contained rhizomes of the plants (48%–78% of the weight; Yamazaki, unpublished data). However, our results did not necessarily support this prediction, particularly in the upper slope locations (Fig. 4cde). Moreover, there was a tendency for the juvenile densities of these three species to be significantly higher on the lower slope with the replacing, while their emergence on the lower slope was extremely limited with the standard scarification and screening (Fig. 4cde), which was unexpected given their preference for relatively wet conditions (Tatewaki 1971; Umezawa 2007). The reason for this is unclear but we think that the scarifying depth of the treatment could be a causal factor; because the scarifying depth was at the same level between the slope locations in the present study, we suppose that most rhizomes were removed from the lower slope, while part of them were remained in the upper slope where the vertical roots were deeper (the formation of vertical roots is often promoted in many forb species growing in dry locations to allow them to use the water in the deeper layers; Weaver 1958; Nippert and Knapp 2007; Skinner and Comas 2010).

Implications for management

In this study, we clarified the effects of three different scarification treatments on soil conditions, which are expected to help us to predict the regeneration potential of target tree species more precisely. We found that there is no clear advantage of selecting the standard scarification treatment over the other two treatments, as it results in a lower density of pseudo-buried seeds (Fig. 3a) and growth of tree seedlings (Yamazaki and

Yoshida 2018), and importantly, does not necessarily bring about a greater reduction in the reproduction of tall forb species (Fig. 4).

The remarkable increase in growth of *Betula* seedlings by a treatment leaving the surface soil in place (Aoyama et al. 2009) would strongly support the trend of modern forestry aiming economic efficiency (Cossalter and Pye-Smith 2003). However, we clearly demonstrated that the replacing and the screening were totally different and had each advantages and disadvantages. Therefore we conclude that these two treatments should be used properly according to the site conditions and target tree species.

Since desiccation of the surface soil is the major limiting factor for seedling establishment (Madsen 1995; Resco de Dios et al. 2005; Yoshida et al. 2005), the high soil water content that was obtained with the replacing as a result of the complex surface soil structure is a distinct advantage. Therefore, we think that the replacing will be most suitable for tree species with higher water demands, such as *Betula* species. However, it was also apparent that the replacing had one potential risk; it could cause an increase in competitive vegetation, particularly for species that germinate from rhizomes. Therefore, use of the replacing should be avoided at sites where many tall forb species grow alongside dwarf bamboos prior to treatment, particularly when these occur on the lower slopes. While dwarf bamboos can generally be removed successfully by scarification, regeneration failure can occur after the treatment as a result of the rapid growth of competitive species in many cases. For example, it has been reported that *F. sachalinensis*, *P. japonicas* subsp. *giganteus*, and *A. cordata*, all of which were found in our study plots, often occur at low densities in dwarf bamboo grassland and sometimes form small patches under relatively wet soil conditions (Haruki et al. 1992). Most of these perennial tall forb species germinate from rhizomes, and their vigorous growth potential is very likely to shade target tree species in the initial stages of regeneration (Yamazaki, unpublished data).

We clearly demonstrated that the screening maintains approximately 1.5 times the amount of pseudo-buried seeds in the soil than the replacing, indicating that it would be the most effective treatment for tree species that produce long-lived seeds such as *P. amurense*. Moreover, a distinct advantage of this treatment over the replacing is its greater ability to reduce the emergence of tall forb species that germinated from rhizomes on lower slopes. Therefore, screening is considered a more suitable option in dwarf bamboo grassland that is relatively wet and in which tall forb species occur.

There remains a need to further improve these treatments in the future. At first, it is required to monitor seedlings and competitive vegetation for a longer-term, because the current study only dealt with the first growing-season. Also, we have to pay attention to a possibility that the results may be specific to the site condition; further investigations are necessary in sites with different soil type and properties. In addition, the results of this study suggest that the scarification depth, that has rarely been considered in the past, needs to be changed depending on the location of the site. For instance, for a site that is on an upper slope where there is a possibility that the root systems of former vegetation are deeper, it would be better to apply more intense (i.e., deeper) scarification. Therefore, in this context, it is necessary to investigate the site-dependent distribution of root systems of major competitive plant species, and to determine the scarification depth that is most efficient for their removal.

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Figure 1. The average and standard deviation (n=8) of soil properties. Different letters indicate significant difference among the treatments (n.s.; not significant). For all the variables, because the effect of location was not significant (see Appendix-table 1) the data obtained from upper- and lower- slope were pooled and shown. For the soil hardness (b) and plant-debris density (c), only the result of the most surface layer was shown; the statistical differences among the treatment were same in the other depths.

Figure 2. The average and standard deviationfor each upper- and lower location (n=4) of soil water content in the four depths. Different letters indicate significant difference among the treatments (n.s.; not significant). The difference between the slope-locations is shown as text in each panel.

Figure 3. The average and standard deviation of residual pseudo-buried seed density (n=4) and emergences of tree seedlings (n=8). Different letters indicate significant difference among the treatments. For all the variables, because the effect of location was not significant (see Appendix-table 2) the data obtained from upper- and lower- slope were pooled and shown.

Figure 4. The average and standard deviation for each upper- and lower location (n=4) of emergences of seedlings or juveniles of competitive species. Bars indicate standard deviation. Different letters indicate significant difference among the treatments (n.s.; not significant). The difference between the slope-locations is shown as text in each panel.

Appendix-table 1. The results of the generalized liner mixed model (GLMM) explaining the soil properties. The explanatory variables were “Treatment”, “Location” and their interaction-. The study areas (canopy openings) were considered as a random factor. The coefficients and p-values (in parentheses) are shown. “NS” indicates the variable not selected in the final model.

Appendix-table 2. The results of the generalized liner mixed model explaining variables relate to vegetation recovery. The explanatory variables were “Treatment”, “Location” and their interaction. The study areas (canopy openings) were considered as a random factor. The coefficients and p-values (in parentheses) are shown. “NS” indicates the variable not selected in the final model.

Appendix

Appendix Table The results of the generalized liner mixed model (GLMM) explaining the soil properties.
The explanatory variables were "Treatment", "Location" and their interaction-. The study areas (canopy openings) were considered as a random factor.
The coefficients and p-values (in parentheses) are shown. "NS" indicates the variable not selected in the final model.

Soil properties		n		Intercept	Treatment		Location	Interaction		AIC		Random effect	
					Replacing (Rep)	Screening (Scr)	Lower (Low)	Rep : Low	Scr : Low			Study area	Residual
Soil surface micro-topography variance		8	Estimate	1.67	7.58	0.01	NS	NS	NS	111.28	Variance	0.00	0.16
			p-value	0.37	0.01	1.00	NS	NS	NS		Std.Dev.	0.00	4.03
Soil hardness	0-5cm	8	Estimate	17.33	-8.03	-1.82	NS	NS	NS	86.74	Variance	0.00	4.16
			p-value	0.00	0.00	0.18	NS	NS	NS		Std.Dev.	0.00	2.04
	5-10cm	8	Estimate	18.57	-8.08	-1.13	NS	NS	NS	81.46	Variance	0.00	3.10
			p-value	0.00	0.00	0.33	NS	NS	NS		Std.Dev.	0.00	1.76
	10-20cm	8	Estimate	19.72	-6.82	-0.90	NS	NS	NS	84.56	Variance	0.00	3.69
			p-value	0.00	0.00	0.47	NS	NS	NS		Std.Dev.	0.00	1.92
Plant-debris density	0-2.5cm	8	Estimate	5.90	34.00	8.16	NS	NS	NS	161.96	Variance	29.46	248.30
			p-value	0.47	0.00	0.43	NS	NS	NS		Std.Dev.	5.43	15.76
	2.5-5cm	8	Estimate	3.48	15.92	6.19	NS	NS	NS	126.59	Variance	3.22	35.41
			p-value	0.25	0.00	0.12	NS	NS	NS		Std.Dev.	1.79	5.95
	5-10cm	8	Estimate	1.00	21.91	6.57	NS	NS	NS	131.84	Variance	0.00	50.95
			p-value	0.76	0.00	0.17	NS	NS	NS		Std.Dev.	0.00	7.14
Soil temperature		8	Estimate	29.50	-2.56	0.97	NS	NS	NS	87.21	Variance	0.00	4.27
			p-value	0.00	0.07	0.47	NS	NS	NS		Std.Dev.	0.00	2.07
Soil water content	0-2.5cm	8	Estimate	19.88	1.34	4.98	3.83	4.08	-1.82	120.32	Variance	3.53	16.80
			p-value	0.00	0.75	0.25	0.37	0.50	0.76		Std.Dev.	1.88	4.10
	2.5-5cm	8	Estimate	31.30	5.10	-1.05	1.75	0.37	6.94	119.22	Variance	0.00	15.94
			p-value	0.00	0.23	0.80	0.67	0.95	0.25		Std.Dev.	0.00	3.99
	5-10cm	8	Estimate	29.73	10.54	7.36	0.67	3.04	1.01	92.13	Variance	0.65	3.55
			p-value	0.00	0.00	0.00	0.73	0.28	0.71		Std.Dev.	0.81	1.89
	10-20cm	8	Estimate	29.31	-1.24	8.94	-0.44	12.18	-6.81	117.38	Variance	0.00	16.35
			p-value	0.00	0.77	0.05	0.91	0.06	0.26		Std.Dev.	0.00	4.04

Appendix Table The results of the generalized liner mixed model explaining variables relate to vegetation recovery.
The explanatory variables were "Treatment", "Location" and their interaction. The study areas (canopy openings) were considered as a random factor.
The coefficients and p-values (in parentheses) are shown. "NS" indicates the variable not selected in the final model.

Soil properties	n		Intercept	Treatment		Location	Interaction		AIC		Random effect	
				Replacing (Rep)	Screening (Scr)	Lower (Low)	Rep : Low	Scr : Low			Study area	Residual
Residual pseud-burid seed density	4	Estimate	-3.02	2.01	2.42	NS	NS	NS	618.43	Variance	NS	NS
		p-value	0.00	0.00	0.00	NS	NS	NS		Std.Dev.	NS	NS
Betula spp.	8	Estimate	0.16	0.51	0.52	NS	NS	NS	21.59	Variance	0.00	0.11
		p-value	0.31	0.03	0.03	NS	NS	NS		Std.Dev.	0.00	0.33
Phellodendron amurense	8	Estimate	0.22	0.25	0.63	NS	NS	NS	21.47	Variance	0.05	0.09
		p-value	0.28	0.20	0.00	NS	NS	NS		Std.Dev.	0.23	0.29
Rubus idaeus subsp. *nipponicus*	8	Estimate	2.33	3.23	1.98	-1.15	-1.83	0.40	88.15	Variance	0.45	2.89
		p-value	0.10	0.09	0.27	0.52	0.46	0.87		Std.Dev.	0.67	1.70
Cirsium kamtschaticm var. *kamtschaticum*	8	Estimate	0.98	-0.88	-0.85	-0.96	0.98	1.10	47.29	Variance	0.00	0.33
		p-value	0.04	0.16	0.16	0.13	0.26	0.21		Std.Dev.	0.00	0.58
Fallopia sachalinensis	8	Estimate	2.29	-0.75	-0.56	-2.27	4.79	0.81	99.51	Variance	4.74	4.32
		p-value	0.31	0.73	0.79	0.30	0.13	0.79		Std.Dev.	2.18	2.08
Petasites japonicus subsp. *giganteus*	8	Estimate	0.10	0.48	0.38	-0.10	0.00	-0.38	36.46	Variance	0.12	0.13
		p-value	0.77	0.22	0.33	0.78	1.00	0.49		Std.Dev.	0.34	0.37
Aralia cordata	8	Estimate	0.13	0.06	0.08	-0.08	0.17	-0.08	10.21	Variance	0.02	0.03
		p-value	0.46	0.74	0.65	0.65	0.53	0.75		Std.Dev.	0.14	0.18

Figure 1

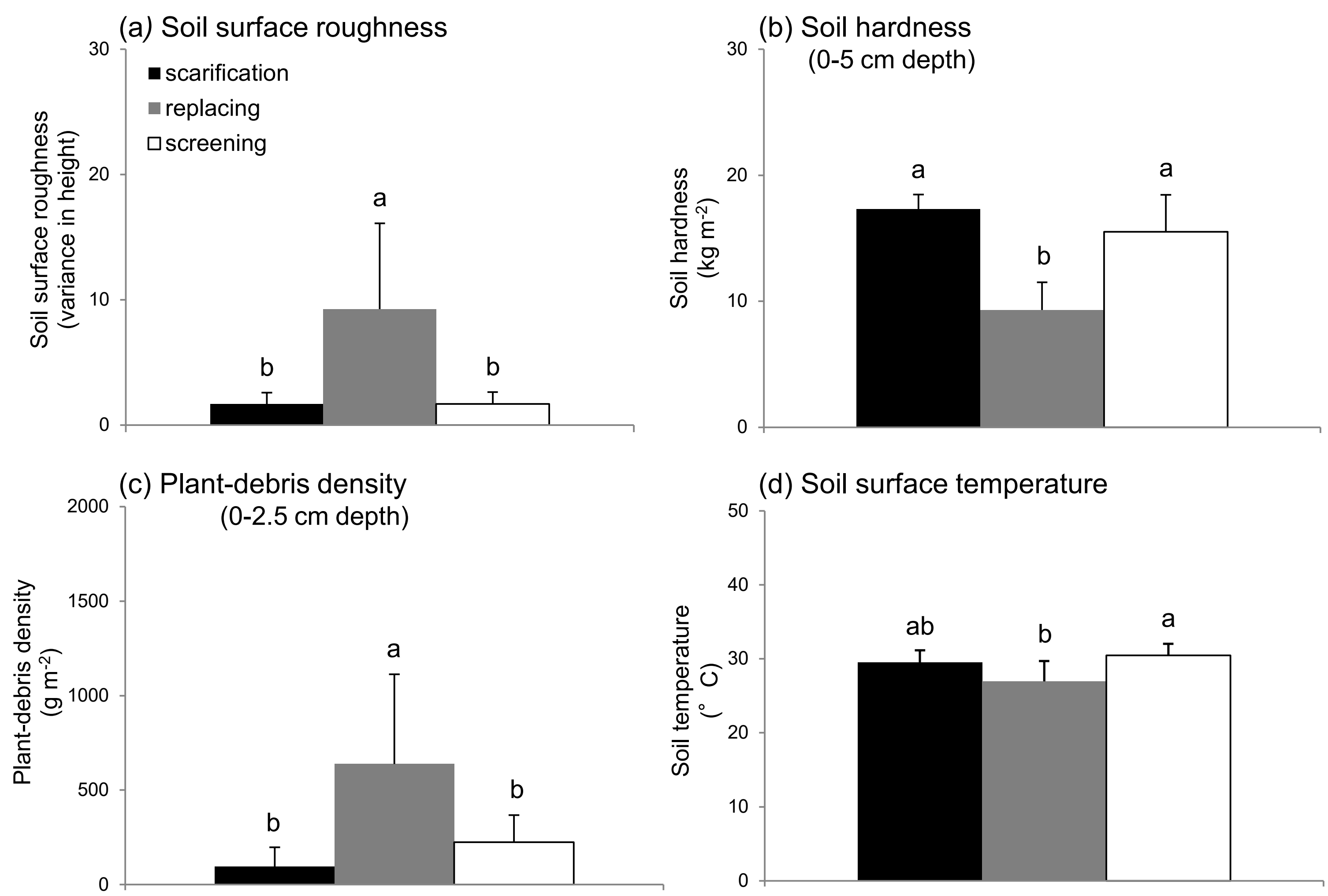
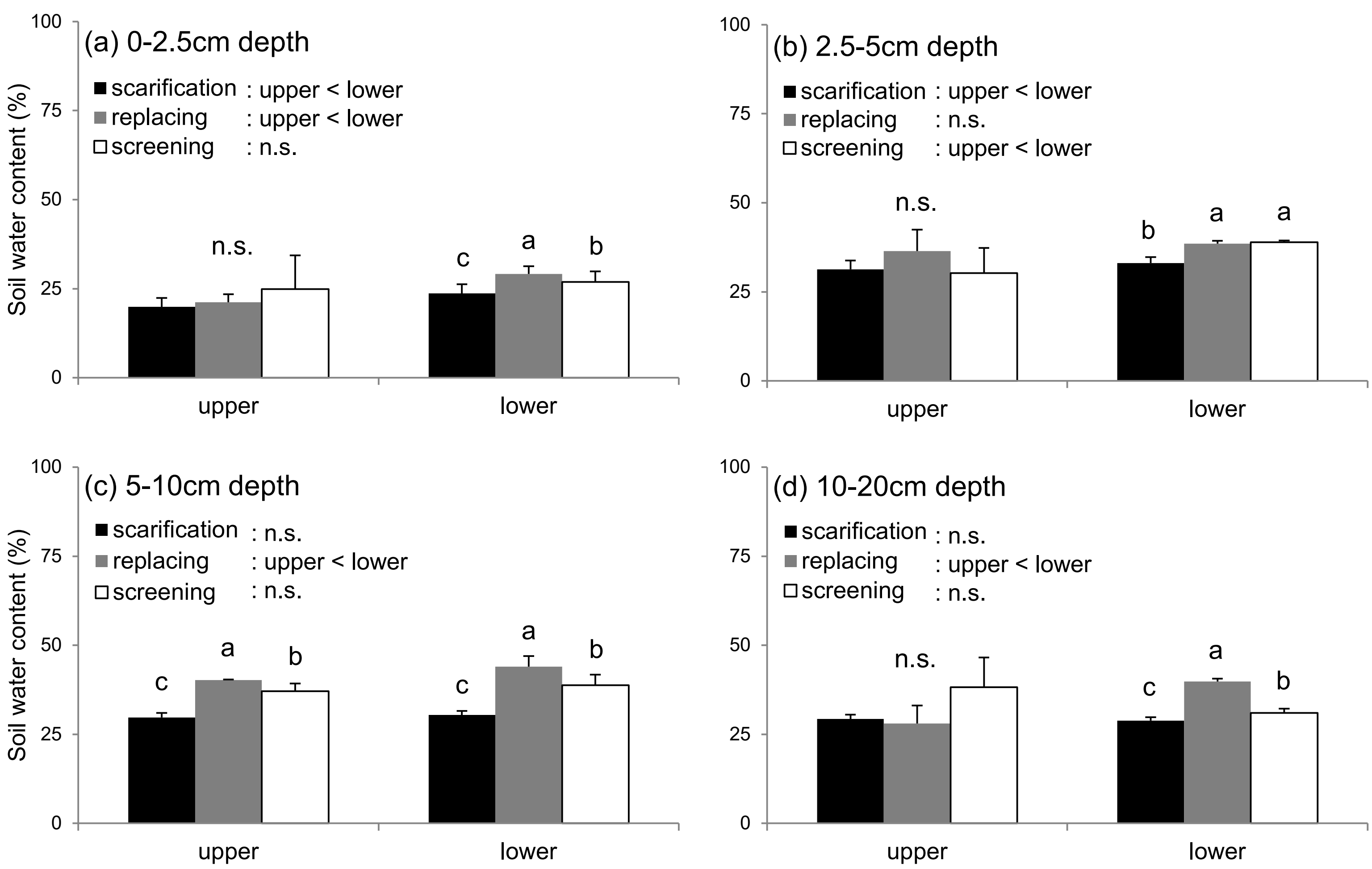
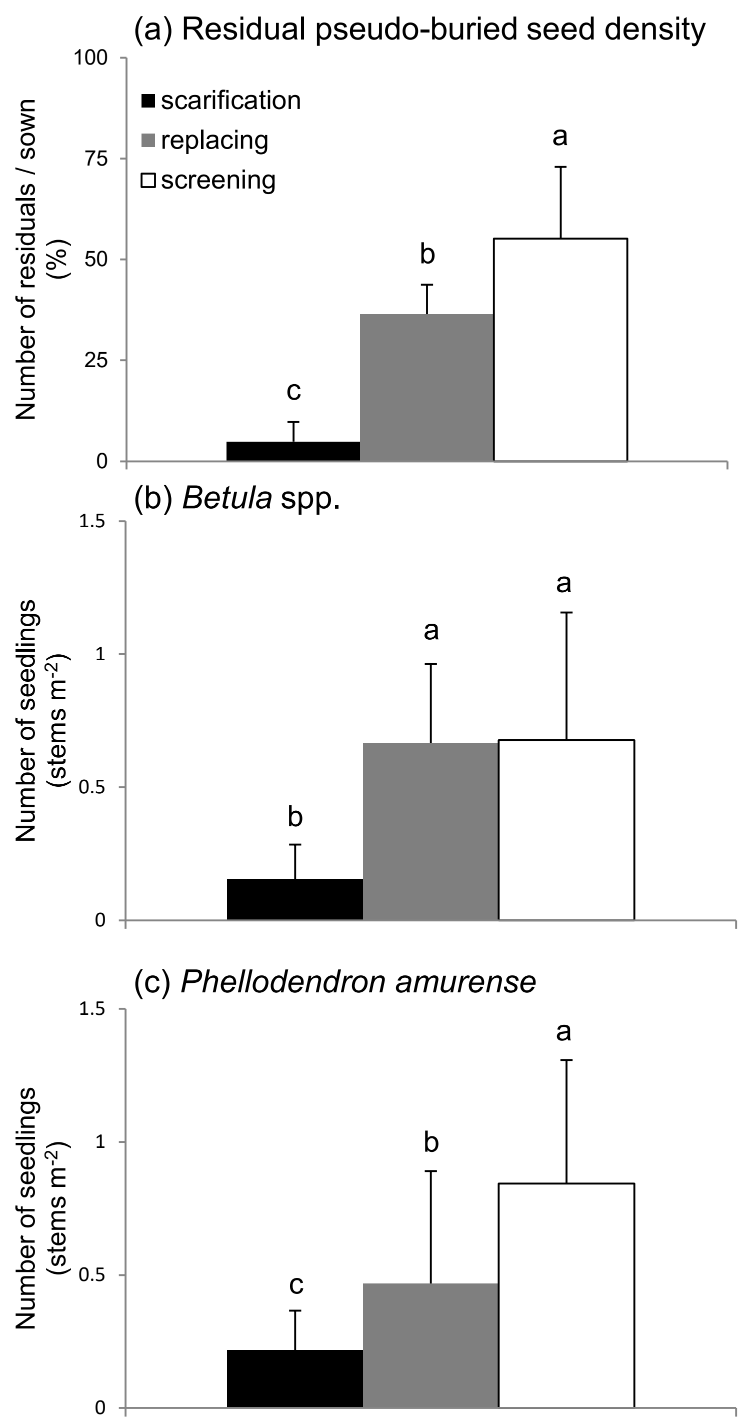

(a) Soil surface roughness
Soil surface roughness (variance in height)
scarification
replacing
screening
30
20
10
0
a
b
b
(b) Soil hardness
(0-5 cm depth)
Soil hardness (kg m-2)
a
b
a
(c) Plant-debris density
(0-2.5 cm depth)
Plant-debris density (g m-2)
2000
1500
1000
500
a
b
b
(d) Soil surface temperature
Soil temperature (° C)
50
40
ab
b
a

Figure 2



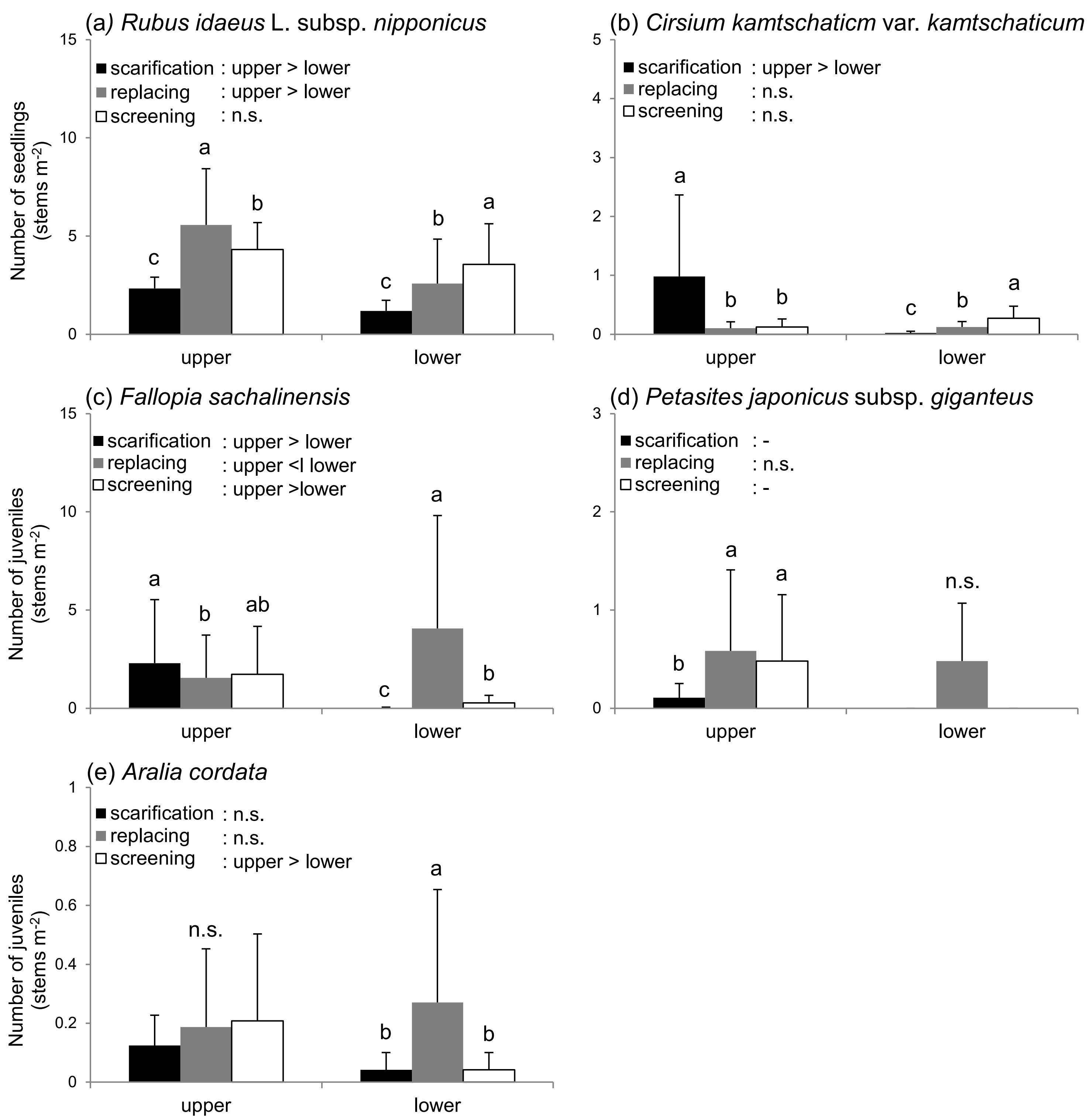
(a) 0-2.5cm depth
scarification : upper < lower
replacing : upper < lower
screening : n.s.
(b) 2.5-5cm depth
scarification : upper < lower
replacing : n.s.
screening : upper < lower
(c) 5-10cm depth
scarification : n.s.
replacing : upper < lower
screening : n.s.
(d) 10-20cm depth
scarification : n.s.
replacing : upper < lower
screening : n.s.
Soil water content (%)
n.s.
a
b
c
upper
lower
0
25
50
75
100

Figure 3



(a) Residual pseudo-buried seed density
Number of residuals / sown (%)
100
75
50
25
0
scarification
replacing
screening
a
b
c
(b) Betula spp.
Number of seedlings (stems m-2)
1.5
1
0.5
0
a
a
b
(c) Phellodendron amurense
Number of seedlings (stems m-2)
1.5
1
0.5
0
a
b
c

Figure 4



(a) Rubus idaeus L. subsp. nipponicus
scarification : upper > lower
replacing : upper > lower
screening : n.s.
Number of seedlings (stems m-2)
upper
lower
(b) Cirsium kamtschaticm var. kamtschaticum
scarification : upper > lower
replacing : n.s.
screening : n.s.
upper
lower
(c) Fallopia sachalinensis
scarification : upper > lower
replacing : upper <l lower
screening : upper >lower
Number of juveniles (stems m-2)
upper
lower
(d) Petasites japonicus subsp. giganteus
scarification : -
replacing : n.s.
screening : -
upper
lower
(e) Aralia cordata
scarification : n.s.
replacing : n.s.
screening : upper > lower
Number of juveniles (stems m-2)
upper
lower