Significance and limitation of scarification treatments on early establishment of *Betula maximowicziana*, a tree species producing buried seeds: effects of surface soil retention

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

[a] Graduate School of Environmental Science, Hokkaido University; 250 Tokuda, Nayoro, 096-0071, Hokkaido, Japan; [b] Uryu Experimental Forest, Field Science Center for Northern Biosphere, Hokkaido University; Moshiri, Horokanai, 074-0741, Hokkaido, Japan

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

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We compared early establishment of *B. maximowicziana*, a commercially valuable tree species producing buried seeds, among the standard scarification and three alternative treatments in which surface soil was retained (soil replacing, screening and plowing). We found the efficiencies of the soil retention for the seedling emergence were clearly different among the treatments; the replacing and plowing caused significantly richer seedling emergence, whereas the screening resulted in lower emergence than the standard treatment. In total, the most abundant seedling emergence was estimated to have occurred in the case of higher soil water content with lower soil hardness. These seemed to be attributed to soil properties, induced differently by each treatment, and relatively high water demand characteristics of *B. maxomowicziana*. On the other hand, plowing showed low seedling density at the end of the second growing season despite its greater emergence, probably because of suppression from understory vegetation recovered from undisturbed root system. We conclude that replacing would be a best alternative for regeneration of *B. maxomowicziana*. The scarification treatments in which surface soil is retained can be evaluated to be positive or negative according to the site conditions, physiological characteristics of the target tree species, and recovery of other vegetation.

Keywords: site preparation; birch; natural regeneration; soil properties; soil water content

Introduction

Establishment of alternative silvicultural regime with close-to-nature concept poses a considerable challenge for forestry and forest-product industries of many countries and regions (Kohm and Franklin 1997; Messier et al. 2013). Regeneration is one of the most important processes for forest management as it dictates the long-lasting stand structure, including composition of tree species (Nyland 2016). In comparison with artificial regeneration with planting or sowing, natural regeneration that relies on seed dispersal or coppicing is generally more compatible with the close-to-nature concept because it largely reflects natural vegetation that is adaptable in the *in situ* environment (Schütz 1999). This approach is also beneficial in reducing the management cost (Shono and Cadaweng 2007), which results in this practice being a preferred option for many forest types.

However, natural regeneration is generally associated with high uncertainly in terms of both regeneration density and species composition (Nyland 2016); low seedling performance could result from various factors, including poor soil conditions (Hutchings et al. 2003) and competing vegetation (Noguchi and Yoshida 2004; Royo et al. 2006), and supplementary practices to improve these unfavorable conditions for desired regeneration outcomes are required. Therefore, persistent improvement of such a practice is an issue which should be addressed in many regions (Löf et al. 2012).

Mechanical site preparation, which is the practice using heavy machinery to remove competitive vegetation and to improve surface soil condition, is widely applied for reforestation, in particular the method that rely on natural seeding (Löf et al. 2012; Nyland 2016). Mechanical site preparation has some variations that differ in intensity and the method of treatment, and its effects on soil environments differ considerably depending on the type of practice (Bock and Van Rees 2002; Löf et al. 2012). The practice is expected to provide appropriate seed-bed conditions; however, in some cases, it results in regeneration failure, partly due to a mismatch between the selection of the practice and regeneration characteristics of a target species (Prévost et al. 2010; Soto et al. 2015).

In the present study, we targeted regeneration of *Betula maximowicziana* Regal, which is a major tree species occurring in the cool-temperature mixed forests of northern Japan (Hasegawa 2009). *B. maximowicziana* sometimes forms a mixed secondary forest with other birch species [*Betula ermanii* Cham. and *Betula platyphylla var. japonica* (Miq.) Hara] following soil scarification. *B. maximowicziana* has the highest commercial value because of its superior wood quality (Hasegawa 2009); however, a reliable practice to regenerate the species has not yet been developed. This species has a high reproductive ability, showing a relatively longer seed dispersal distance among wind-dispersed trees (up to several hundred meters; Osumi and Sakurai 1997). On the other hand, the species requires an extended time for sexual maturation of >50 years so that the majority of individuals attain seed production (Osumi 2005). Furthermore, the species shows masting years, where abundant seed production is only observed every 3 or 4 years (Osumi and Sakurai 1997).

The latter two characteristics of *B. maximowicziana* lead to uncertainty of its capacity for natural regeneration. However, the species has characteristics to mitigate against these negative factors; the majority of buried seeds are able to germinate even after several years (Osumi and Sakurai 1997). Therefore, retaining surface soil during the scarification practice has been thought to be effective in reducing the uncertainty of regeneration. Recently, scarification practice with leaving surface soil has attracted attention due to its potential to achieve rapid growth of regenerated seedlings (Aoyama et al. 2009). There are several practices with different treatments and intensities, such as replacing, screening and plowing of surface soil (Fig. 1; see details in Materials and Methods). Some previous studies have suggested a positive effect of such a practice on emergence of seedlings originated from buried seeds (Sato 1998; Sugita et al. 2006; Goto and Tsuda 2007). Nevertheless, no previous studies have evaluated the influence of the change in soil environmental conditions induced by retaining the surface soil. Because *B. maximowicziana* has relatively high water demand characteristics (Tabata 1964; Osumi and Sakurai 2002), a difference in treatments may change the effectiveness of retaining soil through possible changes in soil properties. More specifically, the objective of the current study is to evaluate the effects of several different scarification practices to leave surface soil (replacing, screening and plowing) on the early establishment of *B. maximowicziana* seedlings. With consideration of the ability of this species to create buried seeds, it is expected that this species is positively affected by these practices. However, because the alternation of the soil environment, in particular the water conditions in relation to the intensity of soil disturbance, vary according to the practice adopted, we expect that there would be a variation in the early establishment of the species among these practices.

Materials and Methods

Study site and treatments

This study was carried out in the Teshio Experimental Forest of Hokkaido University in Hokkaido, northern Japan. Mean annual temperature and precipitation are respectively 5°C and 1000mm, with the maximum snow depth is over 200cm. The forest is largely dominated by a mixed conifer-broadleaf stand [consisting mainly of *Picea jezonensis* Carr., *Abies sachalinensis* (Fr. Scham.) Masters, *Querucus crispula* Blume. and *Betula* species], with secondary *Betula* stands as an occasional associate.

Soil scarification has been widely conducted for non-wooded sites dominated by dwarf bamboos (*Sasa* species), and has resulted in establishment of *Betula* stands in many cases in northern Japan (Umeki 2003). In this study, this practice was conducted in large canopy openings created in a 39-year-old mature secondary stand (total basal area 2.6 m^2 ha^{-1}). This stand was established following soil scarification in 1974, and consisted of *B. ermanii* Cham. (62.5% of the basal area), *B. maximowicziana* (24.2%) and *B. platyphylla var. japonica* (Miq.) Hara (6.6%). The understory was densely and exclusively covered with dwarf bamboo, *Sasa kurilensis* (Rupr.) Makino et Shibata, and there were few tree seedlings. Four experimental plots, each with an area of 250 m^2 (25 × 10 m), were established in the center of the canopy openings. The four plots were located within the range of several hundred meters on a gentle ridge (slope inclination < 5°). In each of these plots, four different practices of soil scarification (Fig. 1) were conducted during the summer of 2013.

(1) Scarifying: It is a standard treatment in which a power shovel (Hitachi Construction Machinery Co. Ltd, HITACHI ZX130L-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) Replacing: It is an alternative practice which can retain more surface soil at the site (Aoyama et al. 2009). The surface soil with understory vegetation was removed from the site using a power shovel, similar to the scarifying process; however, the soil was subsequently replaced using a power shovel after a certain period. The site was left for duration of 4 weeks in this case to prevent recolonization of dwarf bamboos from root stocks (Aoyama et al. 2009).

(3) Screening: It is an additional alternative practice to retain the surface soil (Sato 1998). The understory vegetation was removed by clamping using the bucket of the power shovel, in which the entire plant is removed, including the root system. As much soil as possible is shaken off the root debris so as to retain the soil at the site.

(4) Plowing: It is a practice that involved removal of the above-ground part of the understory vegetation with disturbance to surface soil. All the understory plants, mostly *S. kurilensis*, were cut by using a machinery grass cutter, and were carried out from the area. The blade of the cutter was inserted to soil to cut

bamboo stems as close to the ground as possible. The resultant surface condition was mostly consisted of plowed soil.

After completing these practices, we established two quadrats (1 × 1 m) for each treatment in each plot. For evaluating germination from buried seeds, these quadrats were covered with meshed-cloth to exclude dispersed seeds until the beginning of the next growing season. We note that a record of seed-fall in nearby natural forests showed that an abundant crop of *B. maximowicziana* occurred 2 years before the treatment (Teshio Experimental Forest. unpublished), indicating that there were sufficient buried seeds in surface soil (Osumi and Sakurai 1997).

Field survey

We censused seedlings of *B. maximowicziana* immediately after the treatment, at the end of the first growing season (2013), and at the beginning and the end of the second growing season (2014). The seedlings were tagged and individual heights were measured with confirmation of their survival at the time of each investigation. The other plant species were also recorded in terms of individual stem density during the last census. We noted that it was difficult to identify species of many seedlings among the three *Betula* species immediately after germination. Therefore, we tentatively classified these seedlings by their morphological characteristics and achieved identification after species characteristics became clear. The individuals that died earlier were identified according to the early characteristics.

In addition, we measured soil conditions within the vicinity of each quadrat. The measurements were carried out after non-rainy weather lasted several days during the summer of the first growing season (2014). We suppose these measurements can represent the soil condition of the study site, because their trends were consistent with those observed in the preliminary (immediately after the treatment in 2013) and the subsequent (summer of 2015) measurements. Soil hardness was measured with a tester (Fujiwara Scientific Co.Ltd, Yamanaka's Soil Hardness tester) at nine points randomly selected in each quadrat, and the mean values was used as a representative measure of hardness in each quadrat. Soil samples were also collected systematically at a depth of 0-10cm (three repetitions for each quadrat) using on auger (196.25cm^3). The mean values of the three repetitions were used for the analysis (six samples per treatment in a plot). We carefully removed roots, stones and large bulks using the sieve (2-mm mesh), and weighted the sample before and after drying (105 °C, 24 h) to determine water contents. The extracts of collected samples, obtained using 2N KCl, were measured to determine NH_4 and NO_3 using an analyzer (BL-TEC, AACS-4), and total NH_4 and NO_3 was regarded as the amount of inorganic nitrogen.

Analysis

The emergence of *B. maximowicziana* from buried seeds was evaluated by the number of seedlings observed in the covered (i.e., seed dispersal limited) quadrats at the beginning of the second growing season. The growth potential of *B. maximowicziana* was evaluated by height-class distribution of seedlings at the last census. The number of seedlings and stems of major regenerated plant species recorded at the last census was also subjected. For comparison among treatments, the statistical differences was tested using a generalized liner mixed model (GLMM) in which the plot was considered as a random effect. We assumed a Gaussian distribution with an identity-link function for the soil conditions, and a Poisson distribution with a log-link function for the densities of seedlings.

We found that there was considerable variation in soil conditions among the plots (Table 1) despite they were located on a same gentle ridge topography. Therefore, we conducted an additional analysis that explicitly examined the effects of soil factors on the emergence of *B. maximowicziana*. The soil hardness, soil water content, and their interaction were used as predictor variables. There was no multi-collinearity among soil hardness and soil water content (the variance inflation factors for soil hardness and soil water content were both 1.27). We again used a GLMM in which the treatment and plot were used as random effects. We assumed a Poisson distribution with a log-link function for the analysis. R 3.1.2 was used (R Development Core Team 2017) for the analyses.

Results

Soil conditions

Soil conditions were significantly influenced by the treatments (Table 1). The standard scarification showed the highest soil hardness (6.5 ± 1.3kg cm^{-2}), followed by the plowing and the screening, whereas the soil hardness of the replacing showed an exceedingly low value (1.5 ± 0.3kg cm^{-2}). On the other hand, the standard scarifying process resulted in significantly lower soil nutrients (17.5 ± 1.7mg kg^{-1}) than that of the other three treatments. There was no significant difference in soil water contents among the treatments, although the maximum and minimum values were observed respectively in replacing and scarifying treatment (43.2 and 23.5%).

Regeneration

The emergence of *B. maximowicziana* seedlings originating from buried seeds was 50 stems m^{-2} on an average. The replacing and plowing treatments resulted in significantly richer emergence (78.5 ± 76.8 and 65.8 ± 98.9 stems m^{-2}, respectively; Fig. 2), whereas the screening treatment resulted in the lowest emergence (24.3 ± 16.5 stems m^{-2}). The results of the GLMM suggested that the emergence was influenced by soil hardness, soil water content, and their quadratic interaction (Table 2). The soil water contents generally had a considerable positive effect, and the most abundant emergence was estimated to have occurred in the case of higher soil water content with lower soil hardness (Fig. 3). The height-class distributions demonstrated that *B. maximowicziana* seedlings were more abundant in the replacing treatment in all the height classes (Fig. 4). In particular, number of seedlings with a height >30cm (8.9 ± 5.7 stems m^{-2}) was approximately more than four to eight fold greater than that of the other treatments.

With regard to the other plant species, as similar to *B. maximowicziana*, *B. platyphylla var*. *japonica* was significantly denser in the replacing treatment(57.8 ± 42.7 stems m^{-2}, Fig. 5) and scarcer in the screening treatment (20.3 ± 23.3 stems m^{-2}, Fig. 5). In contrast, there was no significant difference among the treatments for *Phellodendron amurense* Rupr. A shrub (*Rubus idaeus* L. var. aculeatissimus Regel et Tiling) and a forb (*Eupatorium chanense* L. subsp. sachalinense (F.Schmidt) Kitam. Ex Murata) showed richer density in the three treatments in which surface soil was retained. The dwarf bamboo *Sasa kurilensis*, which had exclusively dominated before the scarification, was significantly denser in the plowing treatment.

Discussion

Effects of soil retention on seedling emergence

We found that the efficiencies of the treatments in which surface soil was retained were clearly condition-dependent; the effects on the early demography of *B. maximowicziana* were sometimes not apparent or even negative in the present study. We observed a large seed-fall event of the species 2 years before the treatment (Teshio Experimental Forest, unpublished). With regard to the extended life-span of the buried seeds of this species (more than half of the buried seeds were able to germinate even after 6 years; Osumi and Sakurai 1997), it can be expected that there was a large quantity of buried seeds in the soil at the time of the treatment (Yamazaki et al. in prep). It has been reported that a standard scarification treatment using a rake dozer removed approximately 10 cm of surface soil (Yoshida et al. 2005), which is the depth within which most of the available buried seeds are distributed (Godefroid et al. 2006; Zobel et al. 2007; Sakai et al. 2010). Hence, a positive effect of the treatments with surface soil retention has been regarded as an obvious precondition for the management of species with buried seeds. Goto et al. (2007) reported that many seedlings of *B. maximowicziana*, as well as other species producing buried seeds, such as *Phellodendron amurense* and *Aralia elata*, germinated following scarification with the retaining of surface soil. In addition, Sato (1998) observed similar effects of such treatments on *P. amurense*.

However, as shown in the present study, the effect of the treatment with retaining surface soil is not necessarily positive; the abundance of seedling emergence of *B. maximowicziana* in the screening treatment was significantly lower than that of the standard scarification treatment (Fig. 2). This strongly indicates that the potential to utilize buried seeds is subjected to certain limitations, depending on the conditions induced by the treatments.

Significance of soil conditions

We suppose that the difference in soil properties, induced differently by each scarification treatment, would be important as the limiting factor. Many previous studies have suggested that, in scarification sites, soil desiccation as a result of exposure to direct radiation (Wetzel and Burgess 2001) is a major negative factor on early establishment of seedlings (Fleming et al. 1994; Madsen 1995; Resco de Dios et al. 2005; Yoshida et al. 2005); this would be significant also for *B. maximowicziana*, which has vulnerability to water stress (Tabata 1964; Yamazaki et al. in prep). In the current study we did not find significant differences in the mean water content of the soil (≤10 cm depth) among the treatments (Table 1). However, we suspect there may be a difference in water retention capacity, if we consider only the shallower part of the soil, which correspond to the rooting depth of the first-year seedlings. In fact, our subsequent investigation (Yamazaki et al. in prep) demonstrated that the replacing showed significantly higher soil water content of the shallow surface layer (0-2.5 cm depth) than screening treatment. We confirmed that some extent of cultivation induced by these surface soil retentions resulted in higher porosity of surface soil, which generally has a potential to decrease water retention capacity (McNabb and Startsev 2001; Ares et al. 2005; Siegel-Issem et al. 2005). We therefore suspect soil desiccation might be less remarkable in the replacing than in the screening; the replacing produces a relatively heterogeneous surface condition with considerable root debris in the soil, which might contribute to partial maintenance of water retention capacity in the sites (Yamazaki et al. in prep). We need further investigations regarding detailed structures and processes in surface soil associated with the treatments.

The current study site was located on gentle ridge topography (see Material and Methods), which indicates a relatively dry site condition. This may strengthen the result of the current study that the retaining surface soil was not necessarily effective. In actual fact, the result of the GLMM demonstrated a negative effect of soil hardness (i.e. lower compaction, induced by the replacement treatments) on seedling emergence, which was particularly apparent under a higher water content condition (Fig. 3). We suppose that this may again result from the high vulnerability of *B. maximowicziana* to water stress. In contrast, the established densities of the other plant species, *Rubus idaeus* and *Eupatorium chinense*, were simply higher in the two soil-retention treatments (Fig. 5). These two species are known to adapt to relatively dry-site conditions (Saito et al. 2016) and produce buried seeds (cf. Zobel et al. 2007; Sakai et al. 2010). We suppose that the species characteristics of vulnerability to water stress resulted in the different patterns evident between these two species and *B. maximowicziana*. This may be supported by the results showing that *Phellodendron amurense* which is adapted to a relatively moist condition in comparison with *B. maximowicziana* (Saito et al. 2016), has showed no significant differences in density among the treatments (Fig. 5). We note that a similar result has been observed in a scarification site in northern America in which a *Rubus* species increased by the treatment, regardless of the soil water environment, whereas *Betula alleghaniensis* was subjected to germination restrictions by water stress (Prévost et al. 2010).

The retention of surface soil produced richer nitrogen content (Table 1). In spite of this, at the end of the second growing season, the retention did not result in greater density of large seedlings of *B. maximowicziana* expect for the replacement treatment (Fig. 4). We suppose the positive effect of the soil fertility was canceled by competition with other plants. The vigorous regeneration recorded for shrubs and/or forb species is naturally a concern for forestry management (Yoshida et al. 2005), and the competitive interaction among plant species would be also an issue requiring further examination. The current study focused on the regeneration pattern during the earliest development stage; thus, we did not explicitly test the effect of the competition because vegetation coverage was still generally sparse in the plots. However, we suspect that the recovery of *Sasa kurilensis* in the plowing treatment (Fig. 5) may have exceptionally influenced the growth of *B. maximowicziana*; the treatment left the rhizome of *S. kurilensis* intact and resulted in vigorous recovery in the plots. This may partly result in the lower seedling density of *B. maximowicziana* observed in the plowing treatment despite its greater seedling density at the emergent stage (Fig. 2, 5)

Implications for management

The current study clarified that the scarification treatments in which surface soil is retained can be evaluated to be positive or negative according to the site conditions and physiological characteristics of the target tree species. In previous studies, the treatment in which surface soil was retained was simply regarded to increase the number of seedlings from buried seeds (Sato 1997; Sugita et al. 2006; Goto and Tuda 2007). However, as also shown in many studies, the area subjected to soil scarification often produces desiccate surface conditions because of exposure to direct radiation (Wetzel and Burgess 2001), and this might be strengthened depending on way of the retention of surface soil. Therefore, the creation of a soil structure that can maintain a certain amount of water content should also be added as a required condition, particularly when a tree species demanding a wet condition such like *B. maximowicziana* is targeted. We can recommend the replacing treatment, but the detailed elucidations of soil structures induced by different treatments are necessary to test the emerged hypothesis.

In addition, it should also be noted that retaining the surface soil can induce a significant increase in competitive vegetation (Yoshida et al. 2005). As shown in the present study, the numbers of seedlings of several shrub and forb species were clearly abundant in the treatments in which surface soil was retained (Fig. 5). Although *B. maximowicziana* have a fast growth rate, it is also reported to be highly vulnerable to competition with neighbors (Ohno et al. 2010). Hence, a condition in which a light-demanding pioneer shrub and forb species is able to grow abundantly should be avoided. For developing sustainable forest management that incorporates scarification practice, further investigation to grasp the appropriate location for each treatment, with or without retaining surface soil, is required.

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Table 1. Soil conditions in the four scarification treatments. The averages and the standard deviations (in parentheses) are shown

Table 2. The result of the generalized liner mixed model explaining the emergence of *B. maximowicziana* seedlings originated from buried seeds. The treatments and plots were considered as random factors. The coefficients and p values (in parentheses) are shown

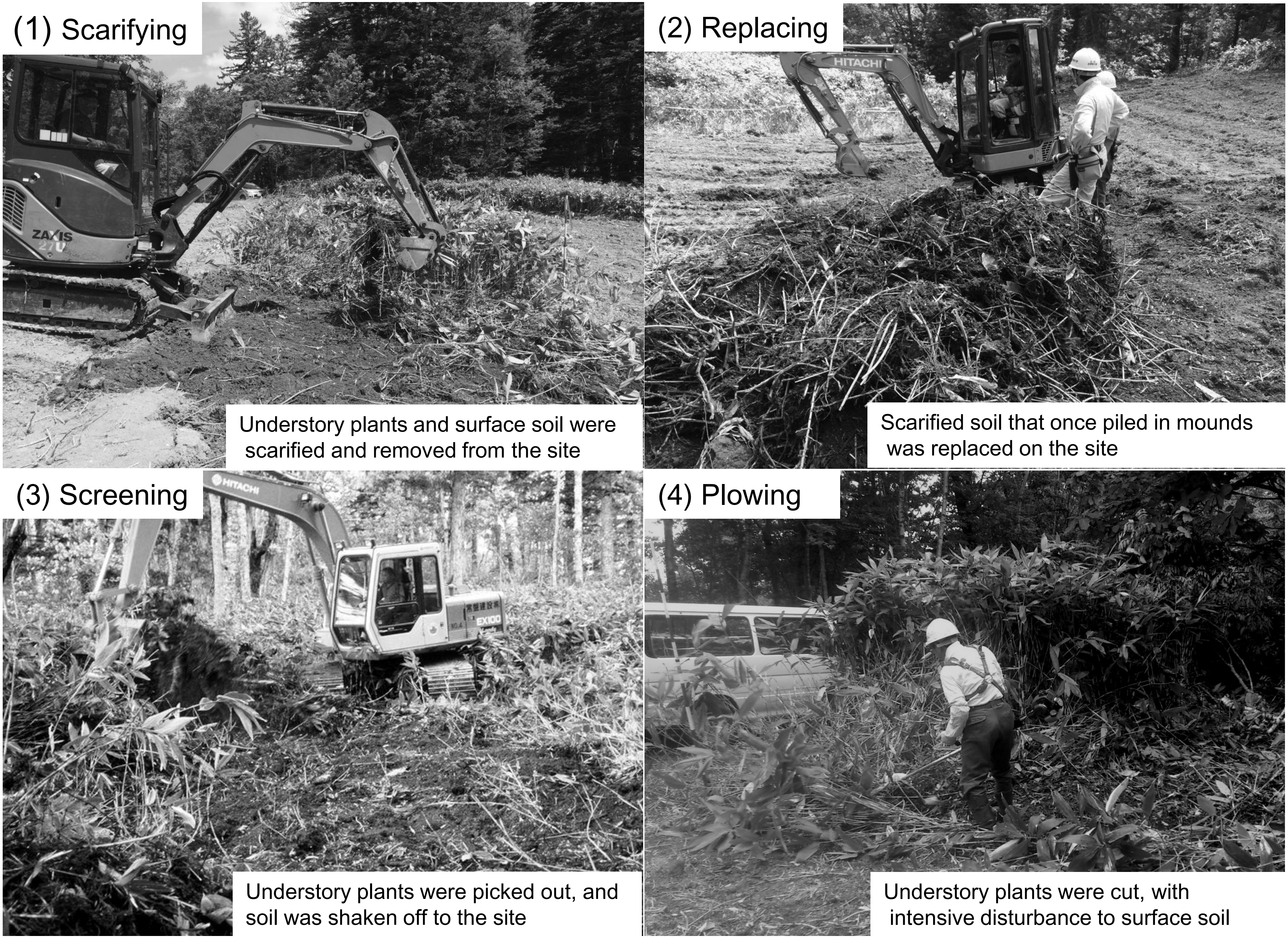
Figure 1. The four scarification treatments applied in this study. See details in Materials and Methods

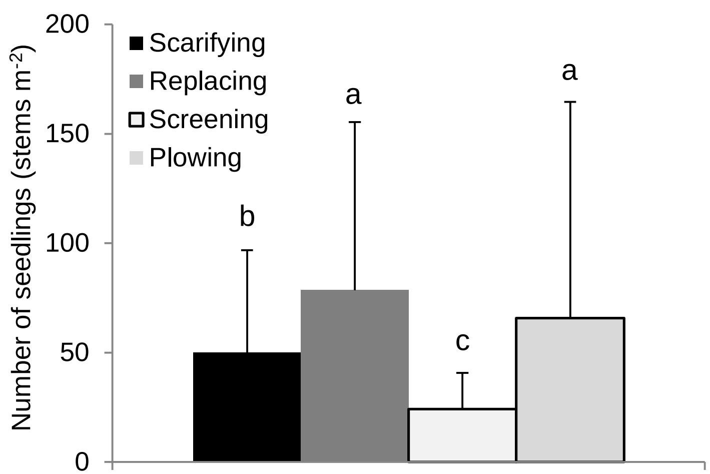
Figure 2. The mean emergence of *B. maximowicziana* seedlings originated from buried seeds. Bars indicate standard deviation. Different letters indicate significant difference among the treatments

Figure 3. The effect of soil conditions on the emergence of *B. maximowicziana* seedlings originated from buried seeds, based on the result of the generalized linear mixed model (Table. 2). High (45%) and low (25%) water contents, which are respectively represent upper and lower limits of the observed values

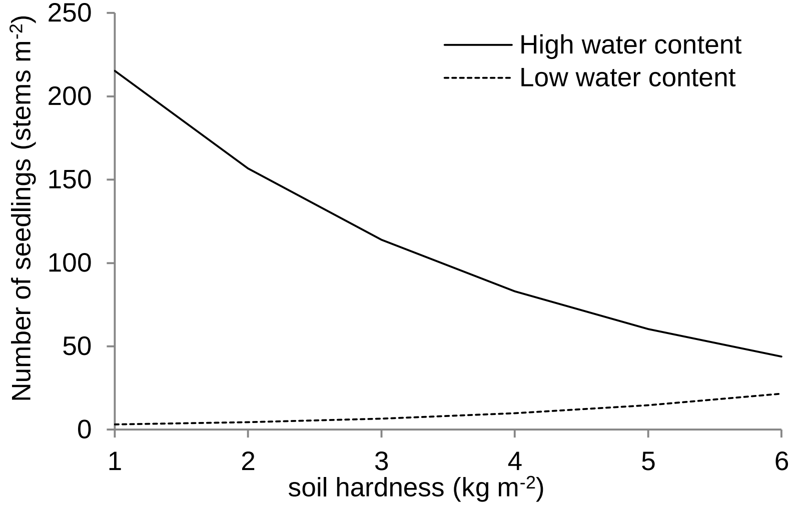
Figure 4. The size frequency distribution of *B. maximowicziana*. seedlings in the four scarification treatments at the end of the second growing season

Figure 5. The number of seedlings or stems established in the four scarification treatments at the end of the second growing season. Bars indicate standard deviation. Different letters indicate significant difference among the treatments; N.S. : not significant

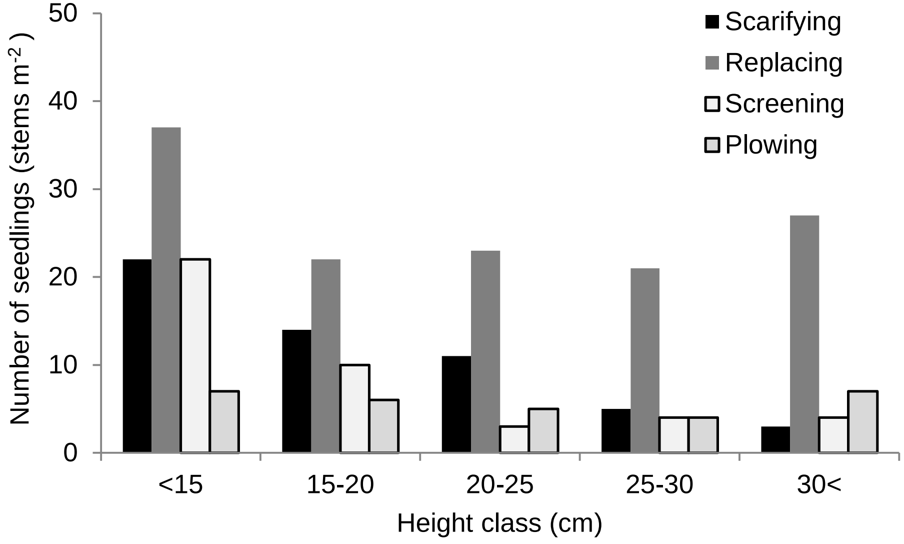

(1) Scarifying
Understory plants and surface soil were scarified and removed from the site
(2) Replacing
Scarified soil that once piled in mounds was replaced on the site
(3) Screening
Understory plants were picked out, and soil was shaken off to the site
(4) Plowing
Understory plants were cut, with intensive disturbance to surface soil



Number of seedlings (stems m-2)
200
150
100
50
0
Scarifying
Replacing
Screening
Plowing
b
a
c
a



Number of seedlings (stems m-2)
250
200
150
100
50
0
High water content
Low water content
1
2
3
4
5
6
soil hardness (kg m-2)


Number of seedlings (stems m-2)
50
40
30
20
10
0
Scarifying
Replacing
Screening
Plowing
<15
15-20
20-25
25-30
30<
Height class (cm)

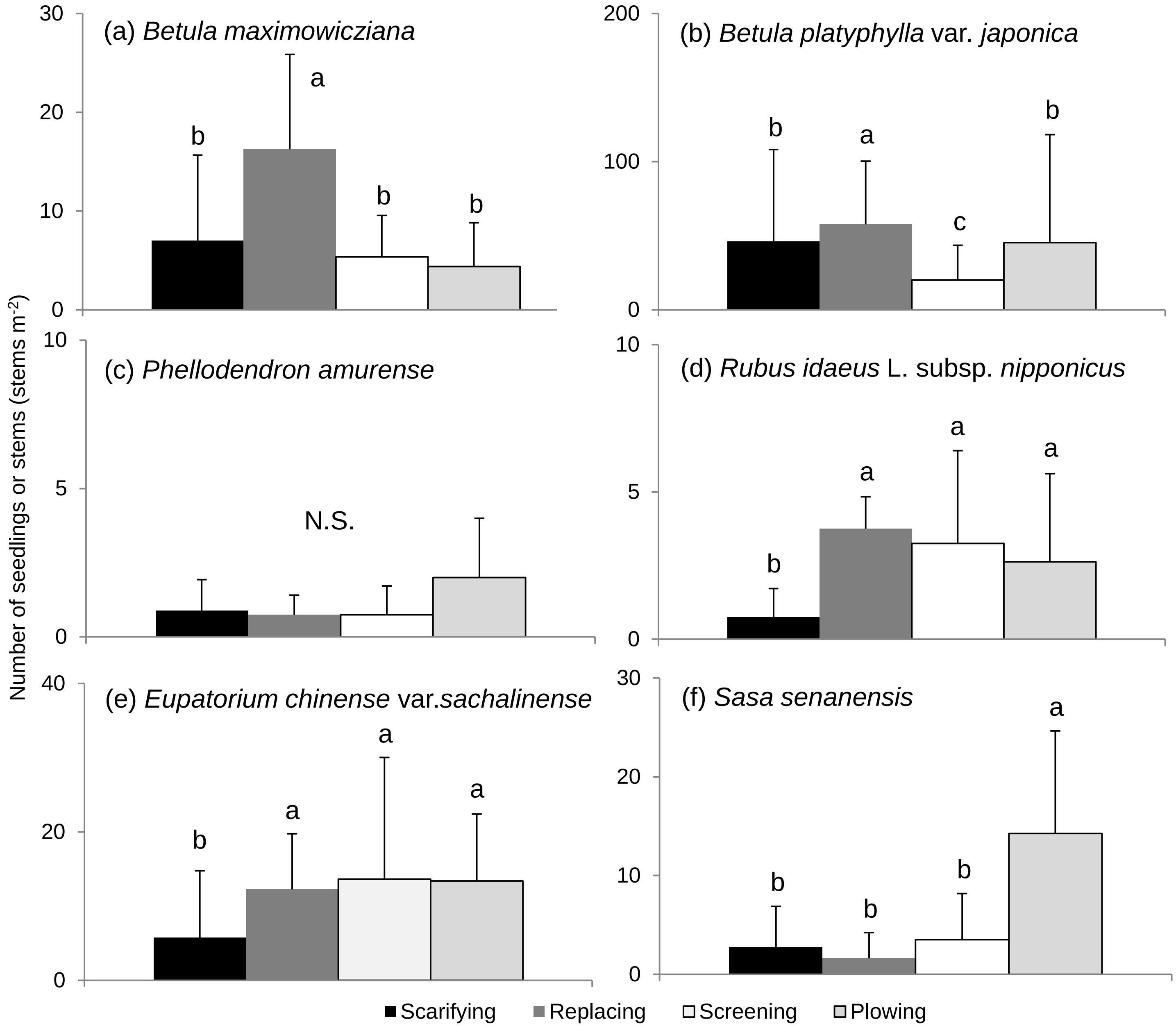

Number of seedlings or stems (stems m-2)
(a) Betula maximowicziana
30
20
10
0
b
a
b
b
(b) Betula platyphylla var. japonica
200
100
0
b
a
c
b
(c) Phellodendron amurense
10
5
0
N.S.
(d) Rubus idaeus L. subsp. nipponicus
10
5
0
b
a
a
a
(e) Eupatorium chinense var.sachalinense
40
20
0
b
a
a
a
(f) Sasa senanensis
30
20
10
0
b
b
b
a
Scarifying
Replacing
Screening
Plowing

Table.1 Soil conditions in the four scarification treatments. The averages and the standard deviations (in parentheses) are shown

	Treatment							
	Scarifying		Replacing		Screening		Plowing	
Hardness (kg cm^{-2})	6.5	(1.3) [a]	1.5	(0.3) [d]	2.5	(0.5) [c]	4.2	(0.5) [b]
Nitrogen content (mg kg^{-1})	17.5	(1.7) [b]	43.0	(17.5) [a]	38.4	(8.3) [a]	41.5	(6.5) [a]
Water content (%)	33.1	(5.0) [a]	35.6	(4.1) [a]	34.4	(3.5) [a]	35.6	(3.1) [a]

Different letters indicate significant difference among the treatments.

Table.2 The result of the generalized liner mixed model explaining the emergence of *B. maximowicziana* seedlings originated from buried seeds. The treatments and plots were considered as random factors. The coefficients and p values (in parentheses) are shown

Soil hardness	1.27	(<0.01)
Soil water content	24.80	(<0.01)
hardness × water content	-3.54	(<0.01)
Intercept	-5.47	(<0.01)
AIC	352.57	
Random effect		
Variance	0.7	
Std. Dev.	0.84	