Growth and Survival of Bareroot and Container Plants of *Pinus sylvestris* and *Picea abies* During Eight Years in Hemiboreal Estonia

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Jäärats, A., Tullus, A. and Seemen, H. 2016. Growth and Survival of Bareroot and Container Plants of *Pinus sylvestris* and *Picea abies* During Eight Years in Hemiboreal Estonia. *Baltic Forestry* 22(2): 365-374.

Abstract

Planting is a preferred method for establishing Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) Karst.). The stock types for these species include bareroot and container plants. However, only a few long-term trials have been established to compare the performance of the different modern stock types within the large distribution range of these conifers. Our aim was to analyse how the growth and survival of *P. sylvestris* and *P. abies* was influenced by planting stock type up to eight years after planting in 12 experimental plantings established at prevailing sites for the test species in hemiboreal Estonia. Typically, container plants had better initial growth increment during the first two to three years but this difference disappeared during the latter years. The growth of *P. sylvestris* bareroot and container seedlings were similar while growth of *P. abies* container seedlings were slightly inferior compared to bareroot plants. Survival of both test species was independent of planting stock used. Overall, the similar growth performance of the two stock types suggests reforestation with container seedlings may be a preferable option, since they are produced more easily using intensive propagation methods, which will enable more convenient transportation and cause less planting stress.

Keywords: forest planting, planting stock type, Norway spruce, Scots pine.

Introduction

In conifer-dominated forests of Northern Europe, planting is the most important means for establishing a new forest generation with desired species (Nilsson et al. 2010). In 2010 the estimated area of forest plantings in Northern Europe was 29% of the harvested area (Europa Forest 2011). Containerised planting stock has been produced in Norway, Sweden and Finland since the 1960s (Rasanen 1981) and covers today about 95% of the coniferous regeneration (Nilsson et al. 2010). In the Baltic States, conifer stands are established with either container or bareroot plants in a 50:50 ratio (Jäärats et al. 2010, Klavina et al. 2013). However, the many years of experience with containerised plants in Norway, Sweden and Finland is not fully applicable to the whole of Northern Europe including the Baltic States, e.g. Estonian forests offer somewhat more fertile growing conditions (Jäärats et al. 2010, Johansson et al. 2012). Besides that, comparisons of the performance of container and bareroot seedlings have not provided consistent results, depending on the level of planting stress caused by the particular site conditions (Grossnickle and El-Kassaby 2015). For example, Hunt and McMinn (2000) and Griswold (1981) suggest an equally good or even a slightly better performance of container plants compared to bareroot plants. However, South et al. (2005) found that in longleaf pine (*Pinus palustris* Mill.), container seedlings had a 20% higher performance during the first growing season, although in the next year their mortality rate exceeded that of bareroot seedlings by 9%. By contrast, Thiffault et al. (2012) pointed out that the height growth of bareroot white spruce (*Picea glauca* (Moench) Voss) seedlings was comparable to that of container seedlings during the first eight growing seasons, although survival rate of container seedlings was 13% higher than that of bareroot seedlings.

Growth rate is often compared only in the first years following planting and there are only few long-term studies. Experiments, which compare the growth rates of different modern stock types in similar growing conditions, are scarce; rather, we have seen studies that focus on one stock type or different growing conditions (Pinto et al. 2011, Johansson et al. 2012, Heiskanen et al. 2013).

Earlier research demonstrated that a disadvantage of stands established with container plants may lie in higher incidence of a deformed root system. Root deformation may persist for at least the first 20 years (Lindström and Rune 1999, Seemen 2001). This may result in tree instability at a more mature age and increase susceptibility to windfall. Previously, stands were widely established with plants grown in paperpots (Scarrat 1990), but in recent decades the use of plastic multi-cell containers has helped improve the root form of seedlings and significantly increase the proportion of root hair in the growing substrate (Rosvall et al. 1998, Gruffmann et al. 2012). Modern container types allow and support air-pruning to promote the development of symmetric root systems with as little root deformation as possible, which aims at better future wind stability for the forest stands. Nevertheless, few long-term comparative studies have been compiled about the growth and survival of container seedlings and bareroot plants.

Estonia is located in a region of intensive forestry, where most forest management is carried out using clear-felling and clear felled areas are reforested by three different methods: planting, direct seeding and natural regeneration. Among reforestation methods, planting in suitable growing sites provides the best results in Estonia; direct seeding is only an option for Scots pine and natural regeneration is common in growing sites suitable for deciduous trees. Coniferous stands form 53% of the total stand volume in Estonia. In 2004−2013, more than 64,000 ha of forests in Estonia were reforested by planting. Norway spruce is the dominant species used for planting − 70% of the area planted in 2013 was with Norway spruce, 24% with Scots pine, and 5% with silver birch (Keskkonnaagentuur 2014). In general, the growth of Estonian forests is 12 million m^3 per year, which corresponds to 5 m^3 per hectare annually (Keskkonnaagentuur 2014).

Next to traditional open-field nurseries, the production of containerised seedlings has been strongly developed during the last two decades. Today, altogether up to 30 million plants are produced annually for domestic use in Estonia or for export, and in 2012, 51% of the produced plants were container seedlings (Keskkonnaagentuur 2014). Countries in the Nordic region have adopted the technology of growing container seedlings in order to shorten the period of plant growth, thus enabling more flexibility in responding to market needs as well as more efficiency in forest regeneration (Heiskanen et al. 2007).

In Estonia, Norway spruce, Scots pine, Silver birch, Black alder (*Alnus glutinosa* (L.) Gaertn.), and European larch (*Larix decidua* Mill.) have been produced as containerised seedlings in the last 20 years. Mainly Norway spruce and Scots pine seedlings have been grown in bareroot nurseries. The ratio of barerooted plants and container plants currently used in forest regeneration is 55% and 45%, respectively.

Long-term trials comparing the performance of bareroot and container stocks type in Northern Europe are scarce and scattered being more extensive in Scandinavia but almost absent in the Baltic region, which has different climatic and soil conditions.

The main reasons for the increase in the proportion of container plants are the longer planting period, faster production of a more uniform stock in greenhouses as well as better and more symmetric root systems and less expensive and much faster planting in the field (Idris et al. 2004, Davis et al. 2005, Luoranen et al. 2005, Vaario et al. 2009, Nilsson et al. 2010).

The aim of this study was to analyse how the growth and survival of Scots pine and Norway spruce used in forest regeneration depends on stock type (container seedlings or bareroot plants) up to eight years after planting. It was hypothesized that bareroot and containerised plants of both tree species did not differ significantly in terms of growth and survival.

Material and Methods

Study area and experimental design

The study was conducted in eight experimental plantings of Scots pine (*Pinus sylvestris* L.) and four experimental plantations of Norway spruce (*Picea abies* (L.) Karst.) with a total area of 5.6 hectares (Table 1). The experimental plantings were established during the period of 1997−2009 in various parts of Estonia representing a hemiboreal forest zone. The planting sites were selected as typical sites for the focal tree species based on forestry practice in Estonia. In each experimental planting, trees were planted in blocks consisting of two rectangular sub-plots (25 × 35 m), one sub-plot was established with bareroot and another with container plants. The number of sub-plots within one planting varied from 2–12 (Table 1).

Planted bareroot *P. abies* transplants were 3−4 years old (grown in nurseries for 2 years in transplant lines with 10 × 25 cm spacing); the age depended on whether the seedling was a 2-year-old open-field seedling (2+2) or a 1-year-old greenhouse one (1+2). Prior to planting, bareroot *P. sylvestris* seedlings had been growing on an open field for two years (2+0) and were selected from 1 m seedbeds with 25 cm between the rows. Container seedlings had been grown in containers of different sizes – Plantek 64F (volume 115 cm^3) was used for 2-year-old Norway spruce seedlings (2+0), Plantek 81F (volume 85 cm^3) was used for 1-year-old Scots pine seedlings (1+0). Container seedlings were grown in greenhouses for about 6-7 weeks after germination and then transported to growing field with trays. All planting stocks overwintered in nurseries. As a rule, bareroot plants originated from seeds collected from near-by managed stands and container plants originated from seed orchards.

All experimental plantings were established in clearfelled sites during spring. Sites were scarified with various disc trenchers, such as Donaren 190, TTS10 and Bräcke T26, which resulted in rows of scarified mineral soil planting beds. The plants were planted in the bottom of these furrows.

In most of experimental plots, the heights of all trees were measured at planting and after each growing season up to the age of eight years. In five earliest trials (year of establishment ≤ 2001), measurements with consistent methodology were initiated 1, 2 or 5 years after planting. A measurement interval of 1 cm was used for 1−2-year-old plants, whereas an interval of 5 cm was used for plants with a height of more than 1 metre. In *P. sylvestris* plantings, the mean initial height of container plants varied from 5 to 15 cm and the mean height of bareroot plants ranged from 9 to 23 cm. In *P. abies* plantings, the mean initial height of container plants varied from 11 to 29 cm and the height of bareroot plants varied from 22 to 34 cm. In total, 15,399 height measurements were recorded – 69% for Scots pine and 31% for Norway spruce. Survival rate of trees was evaluated after the first and second growing seasons.

Data analysis

The aim was to compare the growth performance of trees established with two different types of planting material (bareroot or container seedlings). As the plantings had been monitored up to various ages (max. eight years), we analysed the effect of seedling type separately in each planting. The effect of seedling type on tree height was tested each year, when data was available, using the linear mixed (random intercept) model accounting for the random effect of a block. Analysis was performed with the

Table 1. Characterisation of experimental plantations

Planting identification number	Forest site type[a]	Site index, H100, m	Coordinates	Planting establishment, year	Area, ha	No. of sub-plots	Density, plants ha^{-1}	
							barerooted	containerised
P. sylvestris plantings:								
JS288-06	MT	23.6	58°12’25” N 27°19’36” E	2009	0.5	2	4000	4100
JS237-06	d-bog	17.5	58°16’22” N 27°17’59” E	2001	0.7	6	4000	4000
JS301-02	MT	23.6	58°15’17” N 27°18’30” E	2007	0.3	6	3800	3800
JS301-02B	MT	23.6	58°15’15” N 27°18’31” E	2008	0.1	6	3700	3600
QT111-12	RH	23.6	58°14’27” N 26°57’6” E	2001	0.1	2	3600	3600
RP013-07	OXRH	27.6	58°10’17” N 27°8’6” E	2006	0.9	6	4400	4000
XX151-02	OXMT	27.6	58°35’55” N 25°45’4” E	1997	0.5	12	4200	4200
SJ320-03	OXMT	27.6	58°14’47” N 24°37’32” E	2004	0.4	6	3840	3840
P. abies plantings:								
TT042-01	AE	27.6	58°24’59” N 26°35’34” E	1997	0.1	6	1800	1700
SJ177-01	d-DR	25.5	58°15’47” N 24°43’56” E	2005	0.5	8	1800	1800
PA469-13	OX	29.5	58°1’56” N 25°33’16” E	2007	0.4	6	2500	2200
JS285-15	OXMT	27.6	58°14’35” N 27°18’17” E	2000	1.1	2	2500	2200

Notes: [a] Site type according to the Estonian forest site type classification (Lõhmus, 2004) – MT: *Myrtillus*, d-bog: drained raised bog, RH: *Rhodococcon*, OXRH: *Oxalis-Rhodococcon*, OXMT: *Oxalis-Myrtillus*, AE: *Aegopodium*, d-DR: drained *Dryopteris*.

function *lmer* in package *lme4* with the R Statistics software (R Core Team 2014). In plantings, where trees were planted in one block, the general linear model was used (function *lm*). We analysed also the relative height difference between the average height of container plants and bareroot plants in the same block. In this case the abovementioned models were run as intercept-only models. The effect of stock type on survival was tested with the Student's t-test for dependent samples (survival of two stock types in each block).

Normality of model residuals was checked from residual distributions and Q-Q plots. The level of significance, α = 0.05, was used for rejecting null-hypothesis in statistical tests.

Results

Height growth
Scots pine

In three *P. sylvestris* plantings, the mean initial height of container plants was significantly higher and in two plantings significantly shorter than bareroot plants (Figure 1). After the first two to three growing seasons, the height of container seedlings was from 5 to 20 cm greater than that of bareroot seedlings, while in relative terms the difference could be 50% or more (Figure 1). Generally, the height after the second growing season was not related to initial height in *P. sylvestris* of both stock types (Figures 2a and 2b). However, the lowest height increment of bareroot plants during the first two years (13 cm) was observed in the planting SJ320-03, where their initial height had been the highest (23 cm). During the latter growing seasons, the difference between plant types generally became less evident. An exception was in planting XX151-02 where container seedlings were the shortest (5 cm) at planting and their difference from bareroot seedlings increased during the eight-year study period. Based on aggregated data from all plantings and study years, the average height development curves of *P. sylvestris* from both stock types coincided (Figure 3).

Most of the plantings were growing on sites of medium fertility for *P. sylvestris*, representing dry and fresh boreal forests (*Rhodococcum*, *Myrtillus* and *Oxalis-Myrtillus* forest site types); as an exception, JS237-06 represented poor conditions of a drained peatland forest (Table 1). Although the height growth of the trees after eight years was the slowest in this planting, the site conditions were not reflected in the mean height difference between the two stock types, which was comparable to other plantings (the lowest pair of growth curves on Figure. 3a).

Norway spruce

In two *P. abies* plantings, where initial height had been measured, container plants were initially significantly shorter than bareroot plants. After the first two to three growing seasons, the discrepancy disappeared in two plantings while in one planting container plants remained significantly shorter (Figure 1). Afterwards (between the ages of four to eight) a slower growth of container plants was observed in two plantings, especially in TT042-01. In this plantings also the initial height of container plants was the lowest (Figure 3). Generally, the height after the second growing season was significantly positively correlated with the initial height of *P. abies* of both stock types (Figures 2a and 2b). Based on aggregated data from all plantings and study years, the average height develop-

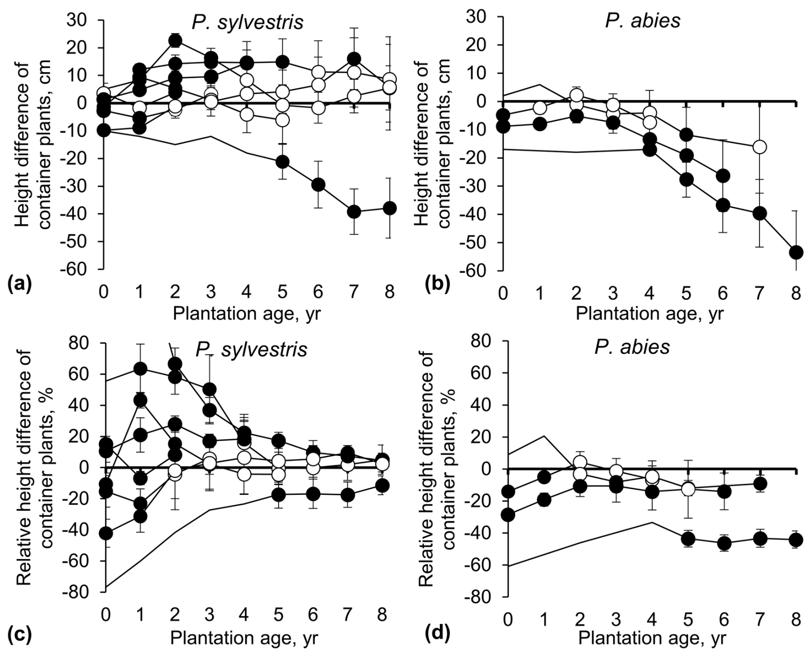

Figure 1. Total (a, b) and relative (c, d) height difference between container plants and bareroot plants (used as reference) in the studied plantings of *P. sylvestris* (a, c) and *P. abies* (b, d). Annual mean differences are shown as filled circles when the difference was statistically significant ($p < 0.05$), as empty circles when no difference was detected or with no marker when only mean height data was available; error bars indicate 95% confidence intervals for the mean difference

ment of *P. abies* container plants never exceeded that of bareroot plants and the height difference increased gradually during the first eight growing seasons (Figure 3).

Most of the plantings were growing on highly fertile sites for *P. abies*, representing fresh boreal and boreonemoral forests (*Aegopodium*, *Oxalis* and *Oxalis-Myrtillus* forest site types); as an exception, planting SJ177-01 represented somewhat poorer conditions of drained paludified forests (drained *Dryopteris* forest site type) (Table 1). Nevertheless, in this planting the growth rate of trees was very good and the height difference between the two stock types was comparable to that observed in other plantings.

Survival

Survival of *P. sylvestris* and *P. abies* varied between 43–98% and 63–99%, respectively, after the first year, and between 52–97% and 21–92%, respectively, after the second year (Table 2). Thus, survival was higher in *P. abies* plantings although it dropped slightly faster by the second year compared to *P. sylvestris* (Figure 4, Table 2).

In both *P. sylvestris* and *P. abies* plantings, tree survival after the first two growing seasons was not affected by stock type (Figure 4, Table 2).

In three *P. sylvestris* plantings with the lowest survival, significant damage by the large pine weevil (*Hylobius abietis*) was observed. In those plantings ca. 50% of damaged plants eventually died while the remaining 50% survived although their growth was suppressed.

Survival of bareroot *P. sylvestris* after the second year was negatively affected by the initial height of seedlings, while survival of *P. sylvestris* container plants as well as survival of *P. abies* from both stock types was not significantly affected by initial height (Figures 5a and 5b). Even in the study block, where *P. sylvestris* container plants had the lowest initial height (5 cm), their survival was relatively high (80%). At the same time, the height of *P. abies* after the second year was positively correlated with the initial height in both stock types while no such relationship was detected in the case of *P. sylvestris,* whose heights had equalized (Figures 2a and 2b).

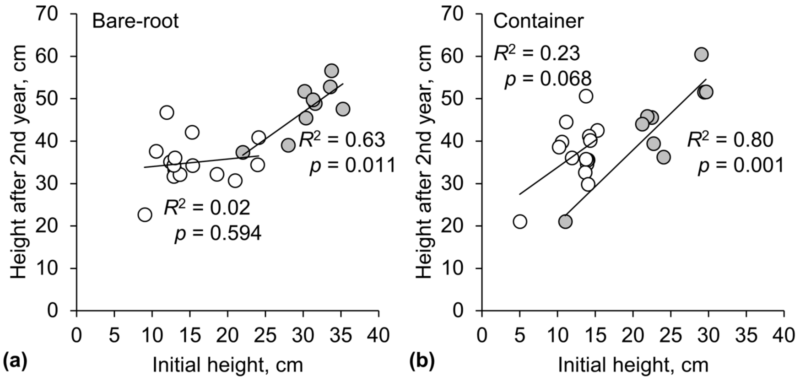

Figure 2. Linear effect of initial plant height on height after the second year of bareroot (a) and container (b) *P. sylvestris* (empty circles) and *P. abies* (filled circles) plants (sub-plot-level data)

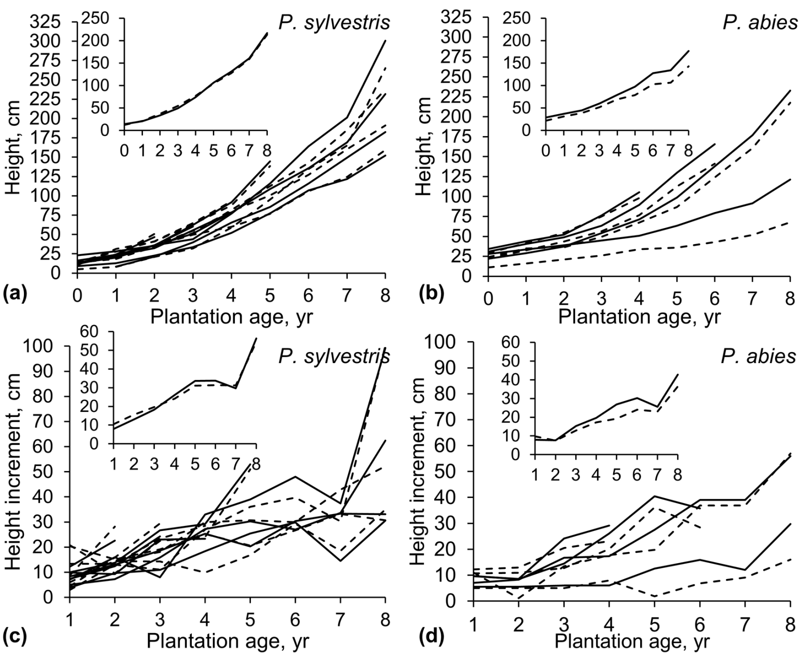

Figure 3. Development of average tree height (a, b) and current-year height increment (c, d) of bareroot (solid lines) and container (dashed lines) seedlings in the studied plantings of *P. sylvestris* (n = 8) (a, c) and *P. abies* (n = 4) (b, d); inset figures show the average values for all plantings

The highest survival of *P. sylvestris* plants after the second year was observed in plantings XX151-02, JS288-06 and RP013-7 (the average value of both stock types ranging from 76 to 81%), which represent the most fertile sites for pine within our study (Table 1). As an exception, survival was low in planting SJ320-03 (39%) representing also a fertile site, but with high pine weevil damage. The lowest survival (38%) was observed in planting JS237-06 on a poor drained peat forest site, where also pine weevil damage had occurred. All *P. abies* plantings represented highly fertile sites for spruce, thus no reliable conclusions about the interaction between site fertility and survival of different stock types can be drawn.

Table 2 Mean and range of survival (%) after the first and second growing seasons by tree species and stock type (based on sub-plot-level data)

Tree species	Stock type	First growing season			Second growing season		
		Mean	*SE*	*Min-Max*	Mean	*SE*	*Min-Max*
P. abies	Bareroot	89	3.8	70−98	74	5.1	58−88
P. abies	Container	89	5.1	63−99	71	7.9	52−97
P. sylvestris	Bareroot	71	4.6	43−98	61	4.9	36−92
P. sylvestris	Container	72	4.6	43−95	58	5.1	21−92

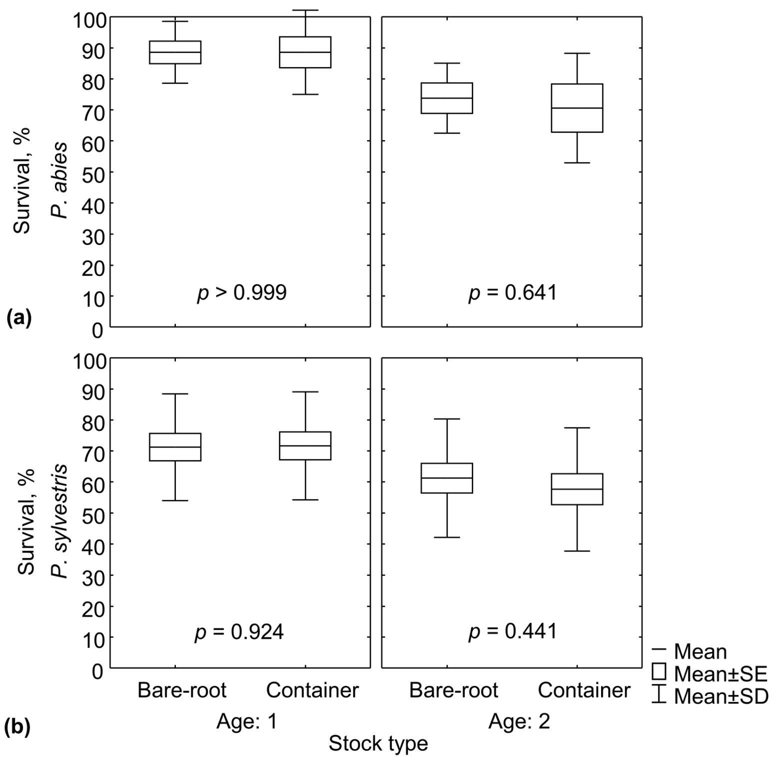

Figure 4. Box plots of mean survival after the first and second growing seasons of *P. abies* (a) and *P. sylvestris* (b) plants representing two stock types, *p*-values are based on a *t*-test

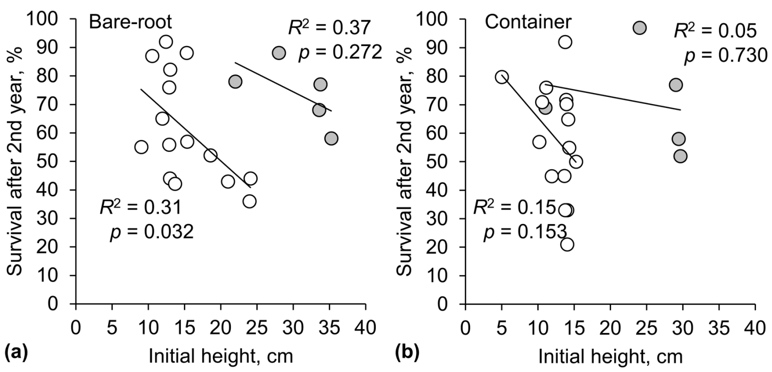

Figure 5. Linear effect of initial plant height on survival after the second year of bareroot (a) and container (b) *P. sylvestris* (empty circles) and *P. abies* (filled circles) plants (sub-plot-level data)

Discussion

The main aim of this study was to analyse whether significant differences occur between bareroot and container *P. sylvestris* and *P. abies* plants in terms of height growth and survival. Overall, we did not detect any major differences in performance. In the case of *P. sylvestris* the growth and survival of the two stock types did not differ significantly. Thus we agree with some earlier studies reporting no difference between bareroot and container plants (Griswold 1981, Rasanen 1981, Hunt and McMinn 2000). Other studies report better performance of container plants, this is usually related to their better stress resistance, while in non-stressful conditions both stock types can have comparable field performance (Grossnickle and El-Kassaby 2015). Various technologies are applied in the production of container plants, and containers of different size as well as substrates with different component ratios are used (Williams and Strope 2002, Thiffault et al. 2014). In our study, containers of the same type were used for each tree species. It is often stated that container plants demonstrate better growth and survival (Nilsson and Ördlander 1995, Grossnickle et al. 2000). Bareroot plants can be more sensitive to poor plant handling (root drying and excessive root clipping), which was avoided in the establishment of the experimental plots for our study.

In the case of *P. abies*, however, we detected a negative although not a considerably big height difference between container plants and bareroot stock. Thus, in the case of *P. abies* we cannot completely accept nor reject the hypothesis. Further surveys of these stands will show whether this effect is increasing with time also after the first eight years. Generally, the roots of *P. abies* are considered to be weaker than the roots of *P. sylvestris* in terms of root rot damage, wind damage and resistance to water-logging. Some earlier studies have shown root deformations of container stock at an older age, although in our study the type of containers should have avoided this. However, root deformations have been observed mostly in *P. sylvestris* (Linström and Rune 1999, Rune 2003).

The better initial growth acceleration of *P. sylvestris* container plants during the first two to three years is in accordance with other studies with conifers (South et al. 2005, Davis and Jacobs 2005) and is probably caused by less stressful planting compared to bareroot plants, which are more prone to root injuries and desiccation. Container plants are less sensitive to damage caused during transportation and planting (Stjernberg 1997, Rikala 2002, Singleton 2011). Better initial growth of container plants is ensured by the growing substrate, which protects the roots from any possible injuries and drying during transportation and planting. In contrast, bareroot plants first have to restore the functioning of their root hairs in order to ensure sufficient intake of minerals and water after having been planted in a clear-cut area (Nilsson and Örlander 1999). As a consequence, the height growth of these plants decreases in the first and second growing season (Hallman et al. 1978). In *P. abies* container plants never exceeded bareroot plants in height; however, usually container plants were initially smaller than bareroot plants and this difference diminished during the first two to three years before they started to slightly increase again at an older age.

After the third growing season, differences between the height growth of both stock types of *P. sylvestris* became less marked, which is in accordance with many earlier results indicating that notable differences between the heights of stands established with different planting stock disappeared 3−5 years after planting (e.g. review by Nilsson et al. 2010).

In contrast to Sluder (1979), who found larger seedlings demonstrated a faster growth, better performance and greater resistance to various physical factors (ground vegetation, game, insects), our results suggest that despite the smaller initial height of container plants, their survival in the second growing season was almost equal to that of bareroot plants. However, a difference was detected between spruce and pine seedlings: the height growth of spruce plants of both stock types during two years after planting correlated positively with the initial height of the plants, while no reliable correlation was evident between the growth rate and initial height of pine seedlings, although smaller bareroot pine seedlings showed better survival. Similarly, also Metsämuuronen et al. (1978) and Sluder (1979) found good results with Scots pine container plants with a small initial height (3−6 cm). Some studies have also shown that the initial height of plants affects future height growth for at least the first 13−15 years following planting (Sluder 1979, Kiiskila 2004, Hytönen and Julhä 2008).

The performance of pine plants of different stock type was very different among experimental plantings and was presumably dependent on the conditions prevailing in clear-cuts, reflecting both the weather in different years and damage caused by the pine weevil. Survival was not affected by stock type but was negatively affected by the initial height in *P. sylvestris* bareroot plants. Apparently bigger bareroot stock was more sensitive to possible drought or other sources of stress during the planting year. The growth of trees is directly dependent on the soil water level as optimal moisture content in the soil is extremely important (Kozlowski 1999). The growing substrate may provide sufficient moisture for seedlings (Rikala 2002, Singleton 2011), which is why container plants are more resistant to possible extreme conditions, including draught (Boyer 1989).

Damage by pine weevil was observed in some plantings. However, it affected both stock types and did not influence the comparison between them. It has been previously found that since bareroot plants have a larger root collar diameter at planting compared to container plants, they may also be more resistant to damage caused by the pine weevil (Nilsson et al. 2010). Based on the results of this research, we cannot draw specific conclusions on the advantages of the performance of bareroot plants with respect to weevil damage because the latter was detected both in container and bareroot plants.

The provision of favourable site conditions is essential for ensuring successful establishment, however, specific conditions and factors limiting growth – e.g. ground vegetation, pine weevils – often become significant from the point of view of seedlings performance in a clear-cut area (Löf et al. 2005, Pitkänen et al. 2008, Ostry et al. 2010, Nordlander et al. 2011).

Although the experimental sites were chosen as typical sites for *P. sylvestris* and *P. abies* regeneration in Estonia, some variation existed in soil fertility. However, we could not detect any interaction between site quality and planting stock type. Good performance and height growth of forest establishments are dependent on many factors, primarily on plant quality and suitable growing conditions (Johansson 1996, Ekö et al. 2008, Jäärats et al. 2010). Moreover, successful forest regeneration requires soil scarification (Nilsson et al. 2006, Heiskanen et al. 2007, Nilsson et al. 2010, Lehtosalo et al. 2010, Johansson et al. 2013). Soil scarification was performed in all studied plots, which ensured equal initial growing conditions. Future development of planted trees is significantly influenced also by weed control (Wang et al. 2000, Götmark et al. 2005, Saksa and Miina. 2007, Sharama et al. 2010). Moderately moist fertile soils encourage intense competition between ground vegetation, the brush layer, naturally regenerated undesirable broad-leaved tree species and planted trees (Sarvaš 2003, Götmark et al. 2005, Nilsson et al. 2010). Based on visual observation, a single experimental plot (TT042-01) with such properties was included in this study, where it was found that new abundant ground vegetation in a clear-cut area led to a decrease in the spruce height growth. Some literature sources also suggest that the use of bareroot planting stock in clear-cuts with abundant ground vegetation and thickened soil gives the desired result compared to container plants (Kiiskila 1998). Ground vegetation also affects Norway spruce the most in the second year after planting (Nilsson et al. 2010).

Conclusions

This research confirmed that the growth and survival of Scots pine bareroot and container seedlings are similar, which suggests that container seedlings should be preferred as planting stock, since it is produced more easily by the intensive method, it enables more convenient transportation and planting is less sensitive to planting stress.

When using bareroot pine plants, the ones with a smaller initial height have better quality since their survival rate is higher but their growth rate is similar to that of plants with a bigger initial height.

The survival of Norway spruce bareroot transplants and container seedlings is similar and the height growth is only slightly lower in container seedlings; therefore, further research is required to determine how much this affects stand productivity in the long term.

The survival of spruce plants is not dependent on the initial height, although height growth is more rapid in plants with a bigger initial height.

Acknowledgments

This study was supported by the Environmental Investment Centre (project 8-2/T7034MIMI) and by the Estonian Ministry of Education and Research (Institutional Research Funding grants IUT21-4 and IUT34-9).

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Received 08 December 2015
Accepted 30 September 2016