

Increasing Survival and Growth of Scots Pine Seedlings with Selection Based on Autumn Coloration

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This study evaluates the possibility of using autumn coloration of young Scots pine (*Pinus sylvestris* L.) seedlings as an indicator of adaptation to harsh climate conditions. One-year old seedlings from natural stands with different origins and seed orchards were classified as “red/reddish” and “green” based on the needle color after artificially increased night length in nursery and then measured after 14 years in field trials. In almost all the studied groups seedlings classified as “red/reddish” had significantly higher survival rate than seedlings classified as “green”. The survival of “red/reddish” was 14.2% higher than “green” among natural stand seed material and 56.2% among seed orchard material. During the study period the survival difference between “red/reddish” and “green” seedlings tended to increase. The seedling color had limited connection with the height growth, even though the trees classified as “red/reddish” were slightly taller than those classified as “green”. However, the total productivity over all field trials, described here as a heightsum, of “red/reddish” trees was 15% higher than productivity of “green” trees from natural stand material, and 61% higher than those from seed orchard material. It seems that controlled selection based on autumn color can be utilized within seed crops of different types with the aim to increase the adaptability of seed material to different environmental conditions.

Keywords adaptation, field trials, harsh conditions, needles, nursery, *Pinus sylvestris*, selection

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1 Introduction

Scots pine (*Pinus sylvestris* L.) has the widest range of all pine species (Mirov 1967), being one of the most abundant and economically important forest tree species especially in northern Europe. It is the subject of extensive breeding and seed orchard programs in Scandinavia (Danell 1991, Haapanen and Mikola 2008). Currently, tree breeding is gaining new interest, partly as a result of the new challenges arising from the threat of global warming. Typically selected Scots pine trees are multiplied by grafting, and seed orchards are established to provide seeds for commercial reforestation. The extremely long time span from establishment of the progeny trials to the last harvest of the bred trees is one of the main challenges in selection. Thus, the breeder should be able to claim that the selections based on the 10–15 year field trials, made on the past conditions, will also provide benefits in the future conditions. The extremely long process of breeding may be aided by some short-term methods in a nursery, greenhouse or phytotron to facilitate the selection of the material for field studies. For example, short-term methods may help in the selection of the most adaptive material for sites with changing environmental conditions. The studied traits which may be beneficial in selection include, growth rhythm (Dietrichson 1969), hardiness to frost or drought (Nilsson and Eriksson 1986, Andersson 1992), and the effect of pollen origin on the adaptation of seedlings (Aho and Pulkkinen 1993). Autumn coloration could also be a marker to be used in the selection of seedlings.

Autumn coloration is a phenomenon where plants undergo a change in leaf coloration due to low temperatures (Gerhold 1959) and long nights (Wettstein-Westerheim and Grüll 1954). However, the ecophysiological role of autumn coloration of needles is rather unclear (Toivonen et al. 1991). Most of the results indicate that the emergence of purple or red color during autumns is related to the increase of frost hardiness of the seedlings (Langlet 1942, Dietrichson 1970, Johnson et al. 1981, Toivonen et al. 1991). The red/reddish color of conifer seedlings has often been noted to be more common and stronger in more northern origins or provenances (Wright

et al. 1966, Dietrichson 1970, Toivonen et al. 1991). The substantial gene flow from differently adapted environments to the pine seed orchards (Pakkanen and Pulkkinen 1991, Parantainen and Pulkkinen 2003, Almqvist and Pulkkinen 2005) or to natural northern pine populations (Varis et al. 2009) may also affect the autumn coloration, thus color may provide the possibility to identify seedlings from different adaptation regimes.

In this study our hypothesis was that the red or purplish color of needles in autumn is connected with the better survival of individual seedlings in severe climatic conditions. In addition, if this is proven, we examine the possibilities to use this autumn coloration as a simple tool to improve the adaptation of Scots pine. Specifically we address two questions: 1) is there any connection between autumn coloration of one-year-old pine seedlings and the later survival of these seedlings? 2) Can we utilize this possible connection to improve the survival and growth of pines in northern areas?

2 Material and Methods

We investigated the effect of autumn coloration based selection using seedlings originating from different natural stands, commercial seed orchard crops from different years, and seedlings collected from open pollinated seed orchard trees. Natural stand seeds were collected from nine stands located from northernmost to central Finland (Table 1). Seeds of commercial seed orchard crops were collected from the northern seed orchard in three different years. Seeds from the northern seed orchard trees were from 12 different trees and were collected in one year (Table 1), thus the total number of different seed lots (entries) was 24.

Seeds were sown in spring 1991 in TAL-410 plant boxes (growth media M6-peat, with N:K:P ratio 16:4:17 and calcium level of 2 kg/m³) located in a plastic house with partly open ceilings. The seeds were sown into 10 replications, three boxes/entry/replication, with the boxes being randomized within the replication. All material was raised in the same place during one growing season, with similar growing conditions by using normal nursery irrigations and no extra fertilization during nursery growth period. These nursery actions

Table 1. Locations, temperature sums (long term average) and seed years of used Scots pine seeds.

Type of seed	Origin	Latitude	Longitude	TEMP SUMS (degree days)	Seed year
Natural stand	Inari	68°55'	26°40'	640	1965
	Inari	68°34'	27°45'	720	1985
	Salla	67°34'	29°10'	660	1985
	Kittilä	67°22'	25°07'	760	1988
	Kemijärvi	65°48'	27°04'	870	1988
	Rovaniemi	66°55'	25°35'	820	1988
	Kuhmo	63°55'	30°05'	960	1988
	Vuolijoki	64°03'	27°14'	1020	1988
Seed orchard 141	Jämsä	62°01'	24°48'	1120	1988
	Commercial crop	62°12' ¹	25°21' ¹	841 ²	1987
	Commercial crop	62°12' ¹	25°21' ¹	841 ²	1989
Seed orchard 141	Commercial crop	62°12' ¹	25°21' ¹	841 ²	1990
	12 trees, open pollinated	62°12' ¹	25°21' ¹	841 ²	1990

¹ location of seed orchard. ² mean origin of seed orchard trees.

Table 2. Basic information of the field trials.

Subtrial	Established	Location	Latitude	Longitude	Altitude (m)	Temperature sum (degree days)
1441/02	1992	Kittilä	67°38'	25°32'	210	739
1441/03	1992	Ivalo	68°45'	28°11'	145	716
1441/04	1992	Kemijävi	67°30'	27°42'	230	732

were carried out in the Finnish Forest and Park Service's nursery in Imari, Rovaniemi (66°29'N, 25°35'E, with long term average temperature sum of 870 degree days)

In order to accelerate the process of winter adaptation with emphasized autumn coloration development, we increased the night length in the greenhouse from the beginning of August by one hour per week for three weeks until each night lasted 12 hours. The classification of individual seedlings to "red/reddish" or to "green" was started when all entries had at least a moderate number of red/reddish seedlings. During the third and fourth week of September the seedlings were classified into groups of "red/reddish" and "green" within every 24 entries. Thus after classification the number of "red/reddish" entries was 24 and "green" entries were also 24.

Three measured subtrials were established in appropriate Scots pine forests in harsh northern Finnish conditions in June 1992 (Table 2). Each of the three subtrials was divided into four replications (blocks) with 48 randomly located row plots (5×5 seedlings), thus the total number of seedlings planted per subtrial was 4800 (4×48×25),

and altogether 14 400 in the whole trial. The only actions in the field trials were the removal of weeds and naturally generated birch and pine seedlings to minimize uncontrolled competition.

The seedlings were measured during the autumn of the years 1997, 2000 and 2002. The final measurements were carried out during autumn 2006, when trees had been in the field for 14 years. The southernmost natural stand (Jämsä) and one of the seed orchard clones were omitted from the growth analyses due to low survival rates (about 1% survival for seedlings selected as "red/reddish" and close to 0% survival for seedlings selected as "green" after 14 years in the field trials). Based on the individual height measurements we calculated heightsums (living tree height sum per plot), survival percentage and mean height per plot of the "red/reddish" and "green" seedlings within each of the included entries. The effects of sorting (red/reddish and green), e.g. selection group, origin of seed and location of subtrial on the survival and height were analysed using ANOVA. With survival we employed arcsine transformation. Statistical analyses were made using SYSTAT-statistical package, Version 13.

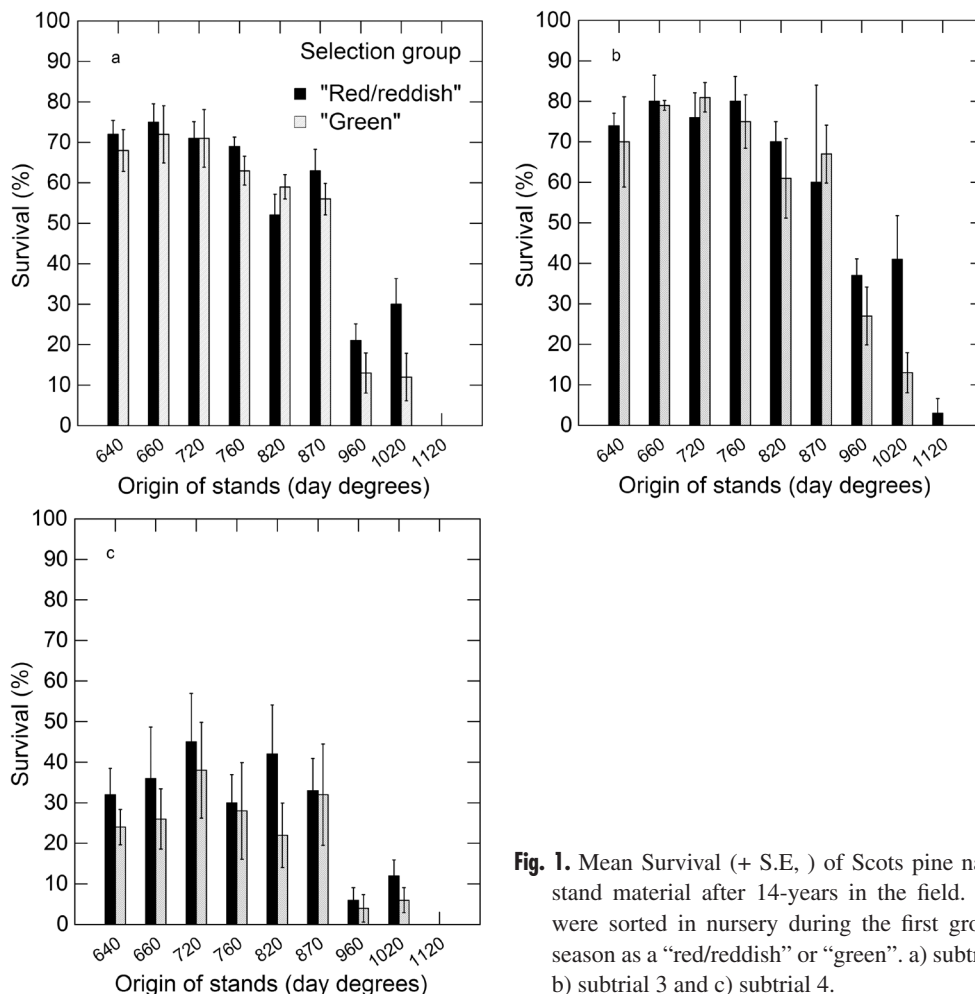


Fig. 1. Mean Survival (+ S.E.) of Scots pine natural stand material after 14-years in the field. Trees were sorted in nursery during the first growing season as a “red/reddish” or “green”. a) subtrial 2, b) subtrial 3 and c) subtrial 4.

3 Results

3.1 Natural Stand Material

The mean survival of natural stand seedlings classified as “red/reddish” was 50.8% (SE±2.7, N=96), height 263.7 cm (SE±2.4, N=1220) and heightsum 33.51 meters/plot (SE±3.15, N=24) after 14 years in the field experiments. The respective values of pines classified as “green” were survival 44.5% (SE±2.8, N=96), (Fig. 1), height 262.6 cm (SE±2.5, N=1067) and heightsum 29.19 meters (SE±3.56, N=24).

The survival difference between groups “red/reddish” and “green” was highest among the

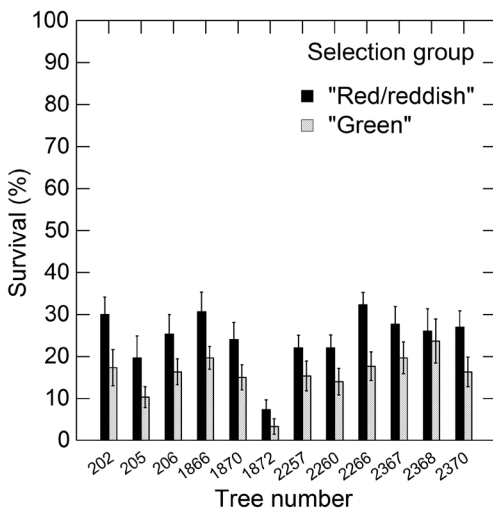
southernmost origins. The difference was also high in the subtrial where the survival was, on average, the lowest (Fig. 1). The survival difference between groups “red/reddish” and “green” increased from 7.3% for five-year old up to 14.2% for 14-year old trees. Color, origin of the tested stand, subtrial, and origin*subtrial interaction, significantly explained the variation in survival after 14 years in the field conditions. The height of the seedlings were significantly explained by origin of the stand and subtrial together with interaction between selection groups and origins (Table 3).

Table 3. The effect of nursery sorting by autumn coloration (selection group), origin of material and the subtrial on the survival and height of the Scots pine seedlings from natural stands after 14 years in the field.

Source	D.f.	Survival MS	p	D.f.	Height MS	p
Selection group	1	0.183	0.004	1	26.3	0.897
Origin of material	8	1.561	0.000	7	3725.4	0.025
Subtrial	2	2.797	0.000	2	56275.0	0.000
Selection group*Origin	8	0.017	0.599	7	4309.5	0.010
Selection group*Subtrial	2	0.002	0.926	2	703.8	0.639
Origin*Subtrial	16	0.090	0.000	14	1003.7	0.827
Selection group*Origin*Subtrial	16	0.013	0.868	14	1395.2	0.570
Error	160	0.022		138	1566.4	

Table 4. The effect of nursery sorting by autumn coloration (selection group), seedyear and the subtrial on the survival and height of the Scots pine seedlings from commercial seed orchard seed after 14 years in the field.

Source	D.f.	Survival MS	p	D.f.	Height MS	p
Selection group	1	0.222	0.000	1	208.9	0.748
Seedyear	2	0.003	0.799	2	5184.4	0.085
Subtrial	2	0.400	0.000	2	66452.1	0.000
Selection group*Seedyear	2	0.001	0.909	2	2596.5	0.590
Selection group*Subtrial	2	0.038	0.061	2	73.3	0.964
Seedyear*Subtrial	4	0.016	0.296	4	2596.5	0.284
Selection group*Seedyear*Subtrial	4	0.008	0.657	4	3045.4	0.210
Error	54	0.013		49	2001.2	

**Fig. 2.** Mean survival (+ S.E.) of Scots pine seed orchard material after 14-years in the field. Trees were sorted in nursery during the first growing season as a “red/reddish” or “green”.

3.2 Seed Orchard Seedlings

On average the mean survival of seed orchard seedlings classified as “red/reddish” was 25.3% (SE±1.9, N=180), the mean height was 292.4 cm (SE±2.7, N=1137), and heightsum 18.47 meters/plot (SE±1.26, N=45) after 14 years in the field experiments. The values of seed orchard seedlings selected as “green” were: survival 16.2% (SE±1.4, N=180) (Fig. 2), height 284.6 cm (SE±3.4, N=727) and heightsum 11.49 meters (SE±0.89, N=45). The survival difference between trees classified as “red/reddish” and “green” increased from 26.9% for five-year old up to 56.2% for 14-year old trees.

The year of the collection of seed orchard seeds does not explain either the survival variation or height variation of the trees after 14 years in the field. Color and subtrial significantly affected the survival variation, but height variation was explained only by subtrial (Table 4).

The most pronounced differences in survival were among open pollinated seed orchard tree

Table 5. The effect of nursery sorting by autumn coloration (selection group), tree and the subtrial on the survival and height of the Scots pine seedlings from open pollinated seed orchard trees after 14 years in the field.

Source	D.f.	Survival MS	p	D.f.	Height MS	p
Selection group	1	0.598	0.000	1	3972.7	0.186
Tree	11	0.081	0.000	10	10012.32	0.000
Subtrial	2	1.014	0.000	2	130994.7	0.000
Selection group*Tree	11	0.008	0.472	10	3627.4	0.106
Selection group*Subtrial	2	0.020	0.078	2	8770.1	0.022
Tree*Subtrial	22	0.020	0.000	20	4830.0	0.004
Selection Group*Tree*Subtrial	22	0.008	0.405	20	3469.2	0.072
Error	216	0.008		180	2249.1	

progenies (Fig. 2). On average survival difference between color groups “red/reddish” and “green” was 8.8%-units, and after 14 years in the field trials survival of “red/reddish” trees was 90.3% higher than “green” ones. Survival variation was explained by color, tree and subtrial together with tree*subtrial interaction. The respective height variation was explained by tree, subtrial and color*subtrial and tree*subtrial interactions (Table 5).

4 Discussion

This is a study of the effect of color-based selection with subsequent long lasting survival monitoring in field trials. As far as we know, such a study has never been reported before, since the most focus has been given to color difference depending on the seed source with no further investigation of performance after such selection. In addition, the selection was done within the entries and not as in related experiments where the adaptation of the origins or seed crops has been the main focus (e.g. Andersson 1992, Pulkkinen 1995).

It is quite evident that the color of seedlings during their first autumn is connected to the survival of the trees during the 14-year period in the field trials. The connection between color and height growth was not clearly evident, although some seedlings in certain conditions had positive connection with “red/reddish” color (see interactions in Table 3). However, total production (described here as heightsum) was higher among

trees classified as “red/reddish” than among those classified as “green”. This is true with all tested groups: stand material harvested from natural stands, commercial seed orchard groups from different years, and seed orchard clonal seed (open pollinated families).

The connection between autumn coloration and frost damage at the population level has been noticed by Dietrichson (1970) and Johnson et al. (1981). According to Nielsen and Roulund (1996) with clonal Sitka spruces (*Picea sitchensis* (Bong.) (Carr.)) the connection was not clear, however the high frequency of autumn colored cuttings per clone indicates a slower growth rhythm. It may expose these clones to frosts and weed competition due to the small size of the cuttings (Nielsen and Roulund 1996). In controlled greenhouse experiments “red/reddish” and “green” one-year-old pines seem to have a different frost hardening development rhythm even within the full-sib families (Leppänen, Aulis, pers. comm. 2010). Toivonen et al. (1991) suggest that even though the red coloration and increased frost hardiness correlates, the development of autumn coloration is not suitable for an indirect method of frost hardiness estimation, because the timing of coloration varied due to different fertilization treatments. According to Vollenweider and Günthardt-Goerg (2005) leaf or needle symptoms can be used as stress indicators if the key adaptation mechanisms for particular stresses are well known. However, when considering the possible practical implications it is important to evaluate not only the basic processes like mechanism of autumn coloration and the connection of autumn coloration with frost hardiness, but also the mate-

rial and methods and the goals, i.e. higher survival and total growth together.

Frost hardening is an important adaptive mechanism, ensuring the survival of pines in cold conditions during the wintertime. However, frost hardening is only one of the processes connected with survival of the trees. Our results were clear regarding any open pollinated stand or seed orchard or even open pollinated families of Scots pine: seedlings with red or reddish color obtained during the first growing year in a nursery had significantly higher survival rate compared with seedlings with the same origin but green in color. The autumn coloration and frost hardiness tests (like Toivonen et al. 1991) have been commonly carried out with young, one-year-old seedlings. However, the long testing time is essential with trees having substantially long life spans. According to Eiche (1966), in northern conditions, Scots pine seedlings have two high mortality phases; the first one is during the early years when the seedlings are still covered with snow and the second one is after the trees have reached the level of snow cover. In northern Finland the highest mean snow level is between 50 and 75 cm (Jylhä et al. 2009), our experimental trees overcame that level 6–7 years before the final measurements. It is also evident that frost hardiness development can correlate with field survival only when the testing sites have severe enough conditions to reduce the survival (Persson et al. 2010).

From the selection point of view it is important that there is substantial gene flow in wind pollinated dominating tree species, like Scots pine and Norway spruce. If some proportion of the gene flow comes from areas with different adaptation regimes, it may provide a necessary genetic variation for the efficient utilization of autumn coloration. The “red/reddish” autumn coloration in young conifer seedlings is more common in seedlings of northern origins than in southern ones (Stoekler and Rudolf 1956, Dietrichson 1970, Canavera 1975, Toivonen et al. 1991). Moreover, the autumn coloration has been noticed to be connected to a decrease in the chlorophyll content of the needles, which is dependent not only on the latitudinal origin of the seedlings but also on altitude (Linder 1972). In the northern natural stands of Scots pine (Pulkkinen and Rantio-Lehtimäki 1995, Varis et al. 2009) and

even more in the Scots pine seed orchards (Harju and Muona 1989, Pakkanen et al. 1991, Pakkanen and Pulkkinen 1991, Almqvist and Pulkkinen 2005) the gene flow from the outside populations is evident. The dominating direction of winds and air currents in northern Europe during the flowering period of Scots pines is most commonly from the south (Lockwood 2009, Suomen Tuuliatlas 2010). The probability of more southern pollination of Scots pine trees increases when the seed orchard is in more southern location compared to the clonal origins of the trees (Parantainen and Pulkkinen 2003, Pulkkinen et al. 2009). The fairly low survival level of both the seed orchard crops and open pollinated seed orchard trees noticed in this study can be explained by the high level of background pollination during the years when the seed used in this study was pollinated (Pakkanen and Pulkkinen 1991, Pakkanen et al. 1991). The average survival rate of local material might also be rather low in climatically harsh areas (Eriksson et al. 1980), thus the ratio between the survival of seed orchard seedlings and that of local seedlings is also important for reforestation purposes and not merely the survival of the seed orchard material itself. According to our results, seeds from fairly young seed orchard trees, even after selection, are perhaps not the best material for the harshest areas. The same observation has already been made by Rousi (1983) and Pulkkinen et al. (1995). The growth of those seedlings seems to be slightly better, but due to lower survival the total productivity (here described as heightsum) of seedlings from relatively young seed orchards was, on average, lower than the productivity of local natural stand material.

The development of autumn coloration in conifers is driven by low temperatures (Gerhold 1959) and long nights (Linder 1972). Thus by decreasing the temperatures and increasing the night length it may be possible to enhance the development of autumn coloration and carry out more efficient selection than in this experiment where only the night lengths were shortened. In addition, the growing conditions should be suitable. The appropriate use of fertilizers is essential, because e.g. nitrogen deficiency can promote needle coloration (Toivonen et al. 1991). Suitable amount of watering is also important, because overwatering and root hypoxica can reduce the

amount of needle chlorophyll (Sudachkova et al. 2009), thus promoting needle coloration. The climate change may raise the need for more efficient use of different seed sources. According to Jylhä et al. (2009) climate change may be so rapid that even the seed crops produced by present seed orchards may in the future demand some kind of evaluations and sorting. According to Eriksson et al. (1980) Scots pine transfers in latitudinal and altitudinal directions can be used to obtain a specific degree of survival. Thus by efficient selection it may be possible to increase the adaptation levels of the seed material and increase the survival and productivity of the cultivated stands. That may be done not only by selecting the hardy material but also by sorting within the seed crops the less hardy material for less demanding growth conditions.

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