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Variation in the rate of winter hardening of one-year-old plus-tree families of Scots pine raised in different environments

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TIIVISTELMÄ: YMPÄRISTÖTEKIJÖIDEN VAIKUTUS YKSIVUOTIAIDEN MÄNNYN PLUSPUUJÄLKELÄISTÖJEN TALVEENTUMISNOPEUTEEN

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The effects of different enviromental conditions (four outdoor localities and one greenhouse locality in northern Sweden) on cold hardening of 29 one-year-old full-sib families from plustrees of Scots pine were studied by artificial freeze testing. Plants exposed to low night temperatures during August achieved faster cold hardening than plants raised in milder localities. The family ranking for rate of winter hardening was consistent among outdoor localities if freeze testing was performed at times when plants from different localities had attained similar levels of cold hardiness. However, significant family × locality interactions were obtained when plants from the outdoor localities were freeze tested on the same occasion. Freezing damage was positively correlated with plant height but not correlated with dry matter content in the autumn. Freezing damage of greenhouse raised plus-tree families was uncorrelated with damage of plants raised outdoor. Possible implications for hardiness breeding are suggested.

Ympäristötekijöiden vaikutusta 29 yksivuotiaan männyn pluspuujälkeläistön talveentumiseen tutkittiin pakastamiskokeiden avulla. Elokuun aikana matalille yölämpötiloille altistetut taimet talveentuivat lämpimämmässä ympäristössä kasvaneita taimia nopeammin. Eri jälkeläistöjen välillä havaittiin erilaisissa ympäristöissä sama talveentumisnopeuden järjestys, kun eri kasvatusympäristöjä edustavien taimien mittausajankohta valittiin saavutetun pakkaskestävyystason mukaan. Samana ajankohtana tehdyissä mittauksissa havaittiin merkitsevä jälkeläistön ja kasvatusolosuhteiden välinen yhdysvaikutus. Pakkasvaurio korreloi positiivisesti taimien pituuden kanssa, mutta ei korreloinut kuiva-ainepitoisuuden kanssa. Kasvihuoneessa kasvatettujen taimien pakkaskestävyys ei korreloinut ulkona kasvatettujen taimien pakkaskestävyyden kanssa. Lopuksi tarkasteltiin mahdollisuuksia soveltaa tuloksia metsänjalostuksessa.

Keywords: cold acclimation, freeze testing, full-sibs, seed orchard, selection
ODC 174.7 *Pinus sylvestris* +232.13+181.2/.3+181.221.1

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1. Introduction

Good survival is the most important goal of pine reforestation in northern Sweden today. From field experiments we know that survival can be increased by southerly transfer of seeds (Eiche 1966, Stefansson and Sinko 1967, Remröd 1976, Eriksson et al. 1980). Early winter hardening, initiated by increasing night length in the summer and improved by low autumn temperatures, is one of the main factors determining survival of pine populations (Jonsson et al. 1981).

There is often a large within-stand variation in field survival of Scots pine several years after planting (Eriksson et al. 1976) and in the rate of winter hardening in freezing experiments of young seedlings (Nilsson and Eriksson 1986). Positive correlations on the family level between survival after several years in the field and the rate of winter hardening in freezing experiments of young Scots pine seedlings (Nilsson and Eriksson 1986, Nilsson and Andersson 1987) indicate that selection of Scots pine plus trees on the basis of damage following freeze testing, as used in the present Swedish breeding program of Scots pine (Andersson 1985), should have a positive effect on survival in northern localities. However, as for field experiments, the ranking of families often varies between freezing experiments if the plants have been exposed to different growth and hardening conditions before freeze testing (Nilsson and Andersson 1987). This suggests that a genotype × environment interaction effect might be involved in the early stages of winter hardening.

The main objective of the present investigation was to study the existence and importance of genotype × environment interaction effects for cold hardening of young Scots pine seedlings. Such interactions might influence the methods used in hardiness selection. Also, the consequences of selection based on damage in freezing tests on height growth and dry matter content of young Scots pine seedlings are investigated.

In wish to thank Maj-Lene Åman for most valuable technical assistance and Bengt Andersson for comments on the manuscript. The experiments were established with seeds from The Institute for Forest Improvement in Sävar. The plants in the outdoor experiments were taken care of by local weather observers of The Swedish Meteorological and Hydrological Institute (SMHI). The study was part of the project 'Breeding for hardiness in Scots pine' financed by the Swedish National Board of Forestry.

2. Material and methods

2.1 Full-sib families

Twentynine one-year-old full-sib families of 20 randomly selected parent clones of *Pinus sylvestris* (L.) from the clonal seed orchard 10, Östteg, in Umeå (Fig. 1) were examined for frost hardiness, height growth and dry matter content in five short-time experiments in the summer of 1986. All parent clones in the seed orchard were plus-trees selected for height and quality in mature stands between latitude 64°04'–66°01'N and altitude 290–500 m in the interior of northern Sweden (Table 1, Fig. 1). The 29 families used for freezing tests (Table 2) were obtained from surplus seeds of a mating program performed in the Östteg seed orchard by the Institute for Forest Improvment, Sävar, in 1971–72. The number of families per clone in the freezing tests varied between two and four.

Table 1. Identification (ID) and geographical origin of parent clones of families used in the study. The degrees of latitudes and longitudes are presented as decimal figures.

IC	LAT (°N)	LONG (°E)	ALT (m)	IC	LAT (°N)	LONG (°E)	ALT (m)
AC1001	64.68	18.96	300	AC1065	64.92	18.03	290
AC1011	64.83	18.78	345	AC2004	65.67	17.45	380
AC1013	64.97	18.41	300	AC2011	65.67	17.45	370
AC1015	64.78	18.55	340	AC2021	65.32	17.66	340
AC1017	64.82	18.63	300	AC2022	65.33	18.03	345
AC1019	64.23	16.28	320	AC2026	65.13	18.53	370
AC1020	65.28	16.75	450	AC2050	64.02	16.18	500
AC1021	65.08	17.65	370	AC2057	65.42	17.55	340
AC1022	65.28	16.75	450	AC2097	64.07	18.43	300
AC1025	64.88	17.66	300	AC3023	64.72	19.50	380

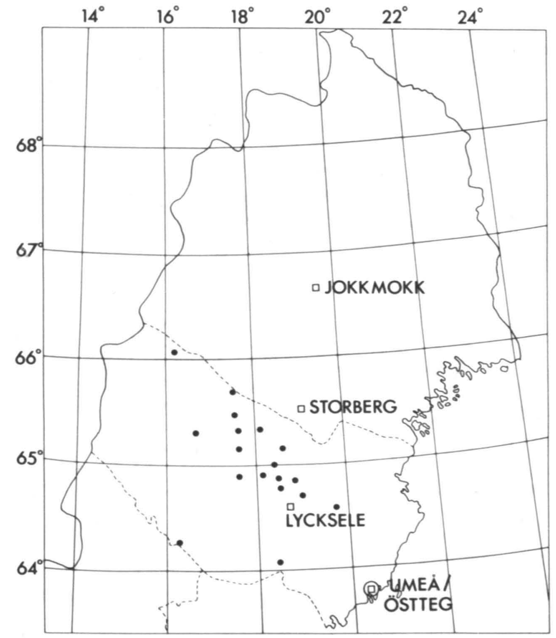

Fig. 1. Origins of the 20 parent clones (●), localizations of the Östteg seed orchard (○) and the experimental localities (□) of Umeå, Lycksele, Storberg and Jokkmokk.

Experimental	locality	Latitude,°N	Longitude,°E	Altitude, m
Jokkmokk-OD	outdoor	66°38'	19°39'	260
Storberg-OD	outdoor	65°30'	18°57'	450
Lycksele-OD	outdoor	64°35'	18°39'	235
Umeå-OD	outdoor	63°49'	20°17'	15
Umeå-GH	greenhouse	"	"	"

2.2 Progeny experiments

Sowing of 150 seeds per family was done in May 13–14 1986, in fifty styrofoam boxes (Cp II) filled with peat. In every box, which held 84 pots, 28 families were replicated three times by complete randomization of the single-plant plots. During germination and the first weeks of growth the plants were cultivated in a greenhouse in Umeå with day/night temperatures of approximately 22°/15° C and natural light conditions. On June 25 the fifty plant boxes were divided into five experimental groups of ten. Each group was then transferred to one of five experimental localities (Fig. 1).

The OD (outdoor) experimental material at Lycksele, Storberg and Jokkmokk were located at meterological stations of SMHI (The Swedish Meterological and Hydrological Institute). Here temperature recordings were made less than 10 meters from the plants and approximately one meter above plant level. For the Umeå-OD locality SMHI temperatures were recorded 5 km from the plants. However, the difference in temperature between the Umeå-OD locality and the SMHI station was rarely larger than 1°C.

The night temperatures in August and early September were much higher at the Umeå-GH (greenhouse) locality (approximately +15°C before September 5 and +5°C thereafter) than at the OD localities (Fig. 2). No supplementary light was used in the greenhouse.

Table 2. Mating scheme. Mother and father clones of the 29 full-sib families from the Östteg seed orchard studied.

	FATHER									
	AC 1065	AC 2021	AC 1017	AC 2011	AC 1011	AC 1015	AC 1013	AC 2026	AC 1021	AC 2050
MOTHER										
AC2050	1									
AC2057	2	4								
AC1001	3	5	7							
AC1025		6	8		13					
AC1020			9	10		17				
AC2022				12	15	18	20			
AC2097					14	16				
AC3023				11		29	19	22		
AC2004							21	23	25	
AC1022								24	26	
AC1019									27	28

The fertilization regime was the same for all localities (Fig. 2). However, the prerequisites for growth and cold hardening varied among localities with respect to factors such as temperature (Fig. 2), photoperiod and light intensity. The total natural precipitation in July and August varied between 120 and 135 mm for the outdoor localities. Manual irrigation was done when necessary to avoid dessication.

On August 27 all outdoor plantboxes were brought back to the OD locality of Umeå for freeze testing and other observations. The initial freezing test (1st test) of 4 plantboxes (12 plants/family) per OD locality was carried out the following night. Another 4 plantboxes per locality were freeze tested on later occasions (2nd tests, c.f. Table 3) determined on the basis of damage obtained after the first freezing test.

The freezing tests were performed by moving the plantboxes to a special freezing chamber where the plants were exposed to a gradual decrease of temperature at a rate of 3.5°C/hour from +10°C to –11°C during an artificial 16 hours night. After three hours at –11°C the temperature was gradually raised at the same rate to the initial value of +10°C. Six hours later the plants were moved to a greenhouse with 20/10°C day/night temperatures.

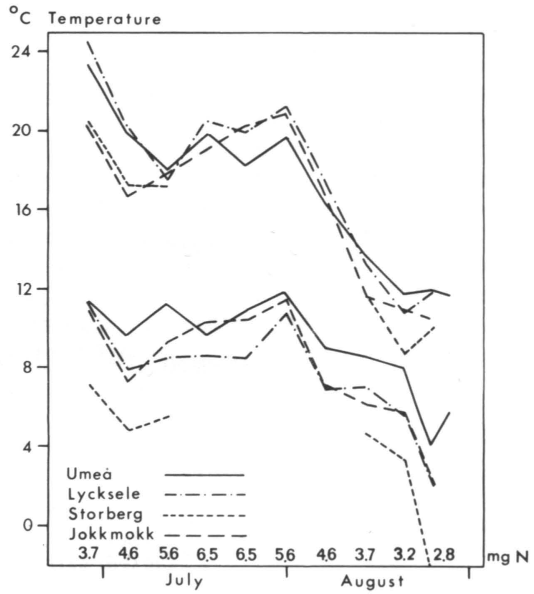

Fig. 2. Weekly emount of nitrogen per plant (numbers on horisontal axis). Weekly average of daily maximum and minimum temperatures (vertical axis) at the four outdoor localities.

2.3 Assessments

Freezing damage: Two weeks after freeze testing the visual damage (discoloration of needles and stem) of every plant was assessed

Table 3. Average damage score of families (ID) in 10 freezing tests of plants grown at five localities (OD = outdoor localities, GH = green house) and frozen on different occasions. Below mean damage scores for all families tested. Localities with different letters following the mean damage scores for August 27 differ significantly, (t-test, α=0.01). The freezing temperature on August 30 was –15°C, in all other cases –11°C.

Freezing occasion:			1st occasion 27/8	27/8	27/8	27/8	12/9	2nd occasion 7/9	1/9	30/8	5/9	17/9
			LOCALITY					LOCALITY				
ID	Mother	Father	Umeå OD	Lyck. OD	Stor. OD	Jokk. OD	Umeå GH	Umeå OD	Lyck. OD	Stor. OD	Jokk. OD	Umeå GH
1	2050	1065	2.7	1.3	.7	4.0	3.2	1.8	2.2	2.8	1.0	1.6
2	2057	1065	3.7	2.2	1.2	3.8	2.7	1.7	2.3	2.9	1.5	1.8
3	1001	1065	4.0	2.8	.9	4.0	3.0	2.7	1.9	3.3	2.7	1.2
4	2057	1021	4.0	3.0	1.1	4.2	3.1	1.4	2.0	2.9	2.0	2.1
5	1001	1021	3.4	3.2	1.2	3.8	3.2	2.4	2.7	3.7	2.7	1.1
6	1025	1021	3.8	3.4	1.4	4.2	4.2	1.8	2.3	3.2	2.7	2.6
7	1001	1017	3.6	3.0	.9	4.1	4.0	2.0	2.3	3.3	2.2	1.6
8	1025	1017	3.8	2.9	1.1	4.3	4.7	2.3	2.6	2.8	2.6	2.9
9	1020	1017	3.3	2.4	1.5	3.1	4.1	1.3	2.0	2.4	1.2	2.0
10	1020	2011	2.5	2.2	1.1	3.7	2.8	1.1	1.6	2.2	1.1	1.5
11	3023	2011	4.2	3.3	1.2	4.2	4.1	1.6	2.7	3.1	2.2	1.8
12	2022	2011	3.6	1.8	1.2	4.0	3.8	1.5	1.4	2.7	1.4	1.9
13	1025	1011	3.5	3.8	1.8	4.6	4.1	1.8	3.2	3.8	2.8	1.8
14	2097	1011	4.3	3.8	2.2	4.5	3.7	3.2	3.7	4.1	3.5	1.2
15	2022	1011	3.7	2.8	1.8	4.2	3.5	1.9	2.1	3.6	2.2	1.7
16	2097	1015	4.5	2.9	1.9	4.4	3.5	2.3	3.1	4.0	3.4	1.7
17	1020	1015	3.3				2.8	1.4				1.3
18	2022	1015	3.3	2.2	1.2	4.0	3.4	1.6	2.1	3.0	2.2	1.4
19	3023	1013	4.1	3.9	1.7	4.2	4.0	2.7	2.7	3.7	3.0	1.8
20	2022	1013	4.2	2.2	1.4	4.1	3.1	1.2	1.6	3.0	1.5	1.2
21	2004	1013	4.6	3.3	1.4	4.4	3.2	1.7	2.8	3.3	2.8	1.2
22	3023	2026	4.4	3.1	1.4	4.4	4.2	2.2	3.2	3.7	2.5	2.3
23	2004	2026	4.1	3.2	1.3	4.3	3.2	2.3	2.8	3.9	2.9	1.7
24	1022	2026	4.4	3.2	1.2	4.1	4.1	3.1	2.4	3.3	2,8	1.4
25	2004	1021	4.5	3.8	2.2	4.3	4.0	2.8	3.5	4.0	3.1	1.9
26	1022	1021	4.5	3.5	1.9	4.1	4.2	2.1	3.1	3.7	3.1	1.8
27	1019	1021	4.6	3.8	2.1	4.1	3.5	3.4	3.3	3.9	3.2	2.2
28	1019	2050	4.3	3.8	1.8	4.1	3.3	2.9	3.1	3.9	2.6	1.1
29	3023	1015		2.3	1.2	4.4			2.2	3.9	2.3	
		Mean	3.89A	2.97B	1.43C	4.13A	3.59	2.07	2.53	3.36	2.40	1.72
		St.dev.	0.56	0.68	0.41	0.30	0.52	0.63	0.60	0.51	0.71	0.45

on a six-graded scale, from 0 = undamaged plant to 5 = dead plant (Nilsson and Eriksson 1986).

Plant height: Height of 12 plants/family was measured on August 28 from the base of the lowest needle to the top of the plant.

Dry matter content: The dry matter content (per cent dry weight of fresh weight) was individually measured on September 17 in the top two centimeters of five plants per family which had not been exposed to freeze testing.

2.4 Statistical analysis

In the statistical analyses, freezing damage was treated as a normally distributed quantitative variable. This means that the significance levels of damage must be considered approximative. The analyses of freezing damage were mainly based on original score values. In some cases suplementary analyses of standardized variables (family mean =0 and variance =1 within blocks) were used to eliminate differences in variation within and between blocks and localities.

Two models of analysis of variance were used to evaluate the effects of growth locality, family and their interaction on the observed plant characteristics. Model 1 was used for unstandardized damage (three plants per family in every block) and height data, model 2 for dry matter content and standardized (within blocks) freezing damage.

$$Y_{ijkl} = m + L_i + F_j + (LxF)_{ij} + B_{k(i)} + e_{ijkl} \quad \text{model 1)}$$

and

$$Y_{ijk} = m + L_i + F_j + (LxF)_{ij} + e_{ijl} \quad \text{(model 2)}$$

where m = total mean
L_i = effect of locality i
F_j = effect of family j
$(LxF)_{ij}$ = interaction of locality i with family j
$B_{k(i)}$ = effect of block k in locality i
e_{ijl}, e_{ijkl} = Residual effects

Pairwise comparisons between materials were tested by the ordinary t-test method. Product-moment correlation coefficients were used to determine relationships between plant characters.

3. Results and discussion

3.1 Freezing damage

3.1.1 Variation among localities

Twelve plants per family from each of the four OD localities were freeze tested on August 27 (1st test) immediately after the plants had been returned to Umeå. Significant differences in damage following freeze testing were found for all pairwise comparisons of localities except the Umeå-Jokkmokk comparison (Table 3). This indicates that the level of cold acclimation attained in late August was influenced by one or more environmental factors that varied among outdoor localities.

Increasing night length in summer, which covaries with latitude, is considered one of the main factors influencing the initiation of winter hardening in trees (e.g. Weiser 1970). However, in the present investigation no relationship was found between latitude of the growth locality and rate of cold acclimation measured by damage of plants after freeze testing (Fig. 3). Instead, the variation in cold acclimation between plants grown at different localities was probably mainly in response to the variation in night temperatures among localities (c.f. Weiser 1970, Rosvall-Åhnebrink 1985). Plants with the least damage were raised at Storberg, where the lowest minimum temperatures during the later part of August were found (Fig. 4, no temperatures were assessed at Storberg before August 11). The plants from Storberg were also on the average smaller (Fig. 3) and considerably more autumn-colored than plants from other OD localities. The ranking of the Umeå, Lycksele and Jokkmokk localities for freezing damage also conforms with the low night temperature hypothesis (Figs. 3 and 4).

A small number of plants from the GH locality were freeze tested at the same time as the outdoor plants on August 27 and September 1. They all died as a result of considerably later cold hardening than the outdoor plants. The freezing tests carried out in the middle of September show that the greenhouse plants reached the –11°C level of cold hardiness approximately two weeks later than the outdoor grown plants from the same geographical location (Table 3). The late hardening of the greenhouse plants was probably a consequence of the high night temperatures during the hardening period in the greenhouse mentioned earlier.

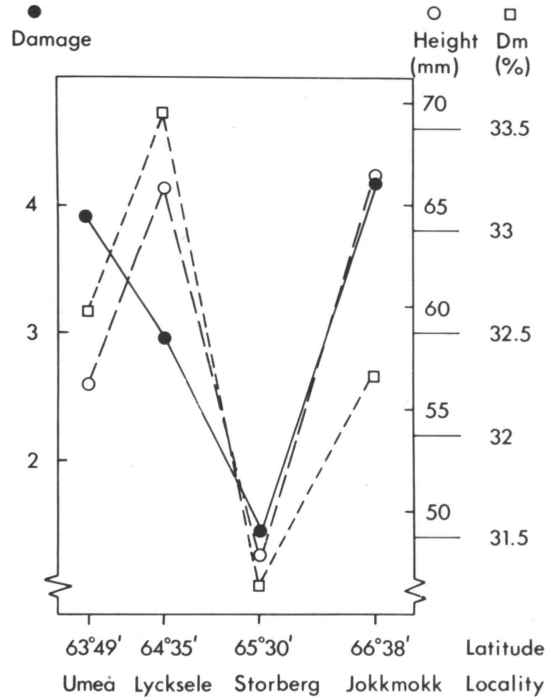

Fig. 3. Average damage score on August 27, plant height on August 28 and dry matter content (Dm) on September 17 of plants raised at the four outdoor localities.

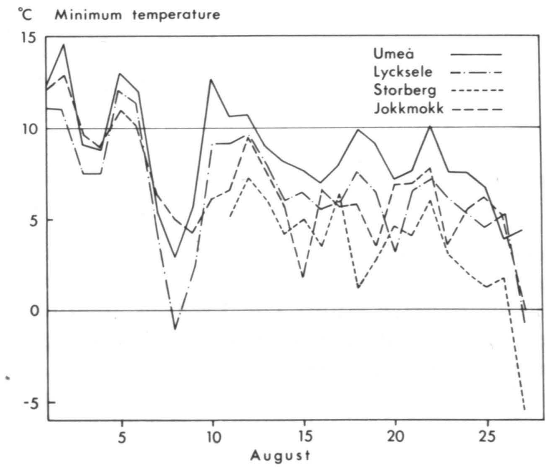

Fig. 4. Daily minimun temperatures at the four outdoor localities during the hardening period from August 1 until freeze testing on August 27.

3.1.2 Variation among families

The locality effect was by far the most important source of variation in damage following freeze testing on August 27 (1st test) as mentioned above. However, highly significant effects on freezing damage were also obtained from family and locality × family interaction, both when analysing original (Table 4) and standardised data. Four plant Boxes from each of the OD localities were later frozen on different occasions (2nd tests), selected on the basis of damage after the first test to obtain approximately equal levels of damage in the four OD materials (Fig. 5). Also these second tests showed significant family effects but no locality × family interaction was found (Table 4).

Table 4. Mean squares and estimated variance components $E(\sigma^2)$ obtained from analyses of variance of freezing damage observed for plants raised at four outdoor localities (Umeå, Lycksele, Storberg and Jokkmokk).

Source	df	1st test (Aug 27) Mean sq	$E(\sigma^2)$	2nd tests (various occasions from Aug 30 to September 7 Mean sq.	$E\sigma^2)$
Locality, L	3	161.11***	1.480	30.479***	0.274
Family, F	26	2.657***	0.154	5.113***	0.300
LxF	78	0.510***	0.079	0.367^{ns}	0.013
Block w L	12	0.977***	0.029	0.793**	0.018
Error	312	0.195	0.195	0.314	0.314

Significances of effects: *** = significant at α = 0.001, ** = significant at α = 0,01, ns = not significant at α = 0.05.

L fixed, i.e. σ^2_L is not a variance component. F and B random.

Table 5. Correlation coefficients (r) for damage between pairs of freezing experiments. Calculations were based on 27–28 families.

Freezing day Locality	0827 Umeå OD	0827 Lyck OD	1st tests 0827 Stor OD	0827 Jokk OD	0912 Umeå GH	0907 Umeå OD	0901 Lyck OD	2nd tests 0830 Stor OD	0905 Jokk OD	0916 Umeå GH
Umeå–OD		.67	.55	.52	.33	.56	.58	.64	.73	.07
Lycksele–OD			.66	.44	.40	.65	.78	.69	.84	.07
Storberg–OD				.30	.25	.47	.70	.65	.63	.02
Jokkmokk–OD					.25	.35	.54	.64	.65	.09
Umeå–GH						.25	.59	.36	.17	.59
Umeå–OD							.68	.74	.74	–.04
Lycksele–OD								.70	.54	.08
Storberg–OD									.85	–.16
Jokkmokk–OD										.03
Mean damage	3.89	2.97	1.43	4.13	3.59	2.07	2.53	3.36	2.40	1.72
Stand.dev.	0.56	0.68	0.41	0.30	0.52	0.63	0.60	0.51	0.71	0.45

The correlation coefficient r is significant (two-tailed) at $\alpha = 0.001$ if $|r| > 0.59$, at $\alpha = 0.01$ if $|r| > 0.48$, at $\alpha = 0.05$ if $|r| > 0.37$.

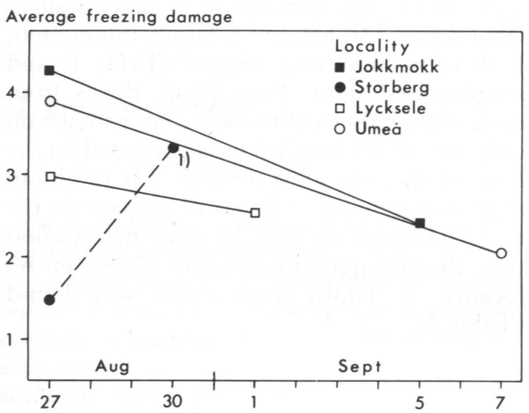

Fig. 5. Average damage following freeze testing on different occasions for plants raised at the four outdoor localities. [1] The freezing temperature for the Jokkmokk plants on August 30 was –15°C compared to –11°C in the other freezing experiments.

The correlations in damage between pairwise OD localities on the first freezing occasion were generally lower ($0.30 < r < 0.67$) than correlations between freezing occasions for plants within outdoor locality ($0.56 < r < 0.78$) (Table 5). The highest within-locality correlation was found between the two Lycksele freezing tests which were frozen at a time interval of only five days, both resulting in average family damage close to the mid-point of the damage scale. The Lycksele freezing results were also best correlated with damage at the other localities (Table 5).

The results from the outdoor-grown plants indicate that 1st year family ranking for cold hardening in a freezing test is more affected by the date of freeze testing, i.e. the general level of cold hardiness at the time of testing, than by the growth conditions prior to freeze testing. This does not necessarily mean that a family × time-of-freezing interaction for rate of cold acclimation exists. It can also be a statistical effect due to smaller resolution between families when the damage scores tend to be close to either end of the damage scale. However, if a family × time-of-freezing interaction exists, freeze testing in order to obtain a better basis for hardiness selection should be carreid out on various occasions during the cold hardening process.

The correlation for family damage between the two GH freezing tests was r=0.59 (Table 5). However, damage from the GH tests were less correlated ($-0.16 < r < 0.40$) with damage from the OD tests than was previously found in an investigation of full-sib families from another Swedish seed orchard (Nilsson and Andersson 1987).

Part of the explanation may be that the

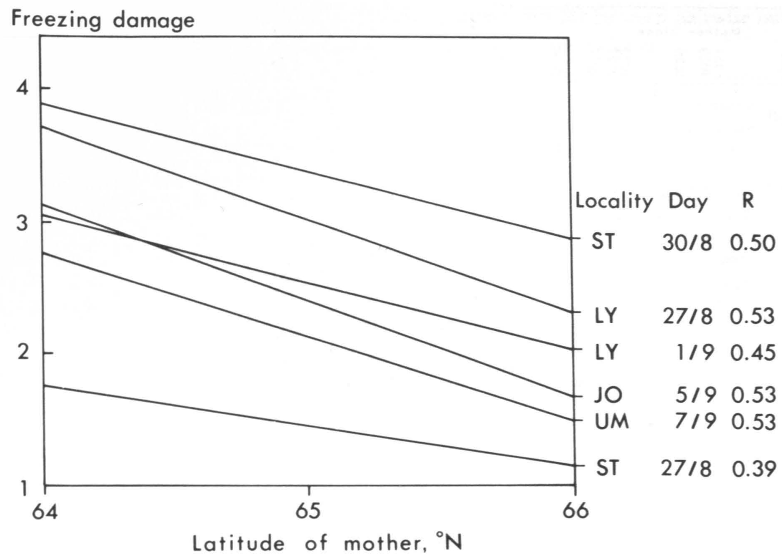

Fig. 6. Regression for freezing damage of outdoor grown plants on the latitude of origin of the mother clones. Only significant (p<0.05) regressions are shown.

temperature prerequisites for early cold hardening in the greenhouse (cold nights during late summer) were better fulfilled in that study and therefore in better agreement with the outdoor hardening conditions. Therefore, it is likely that freezing damage can show significant locality × family interaction effects if the environmental conditions (e.g. occurrance of cold nights) during the hardening period vary considerably among growth localities.

3.1.3 Variation among parent clones

The maximun difference of two degrees latitude in origin between the parent clones (one degree latitude for mid-parents) was large enough to reveal significantly negative correlations between freezing damage of the offspring in the OD environments and the latitude of parents (Fig. 6). This is in agreement with results from the Domsjöänget seed orchard reported by Nilsson and Andersson (1987). The latitude of the mother clone was better correlated with freezing damage than was the latitude of the father clone (Fig. 7). Some clones produced families with early (AC1020, AC2011, AC2022) or late hardening (AC 1001, AC1011, AC1019, AC1021, AC2097) irrespective of mating partner (Fig. 7). The smaller variation in damage found between families with a common mother (Fig. 7a) compared to families with a common father (Fig. 7b) indicates that the maternal influence on winter hardening of young Scots pine seedlings is larger than the paternal influence. However, the explanation can also be that the fathers make up a genetically more homogenous population due to a smaller geographical variation in origin compared to the mother clones.

3.2 Height growth and dry matter content

Height growth of plants that were freeze tested on the second occasions was not fully completed when measured on August 29. The height varied significantly, both between OD localities and between families (Fig. 3, Table 6). Because no locality × family interaction was found and the correlations between pair-

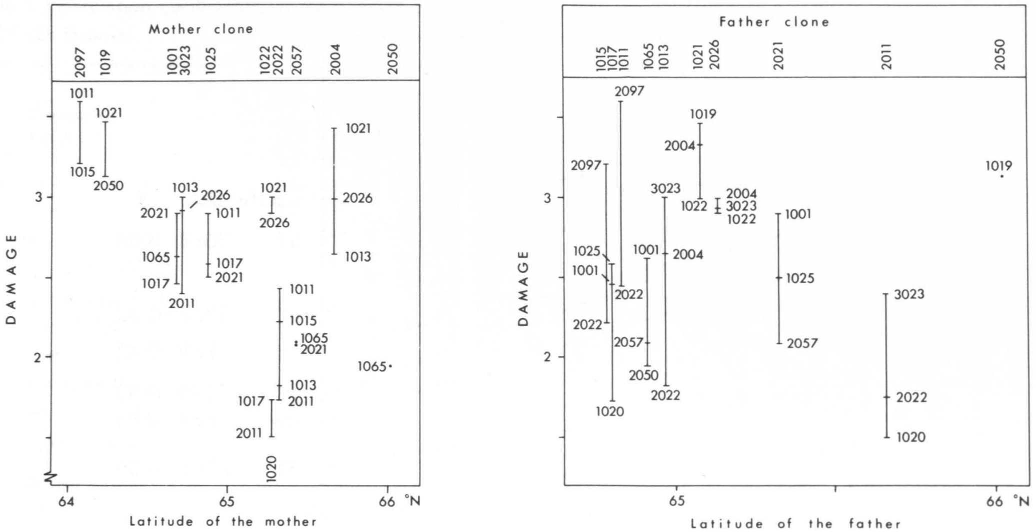

Fig. 7. Relationship between the latitude of origin of the mother (a) or father (b) and freezing damage of their offspring. The vertical and horizontal numbers in the figures refer to the identification of parent clones. The marks on the vertical bars, connecting families with a common parent, show the freezing damage (mean damage in the four 2nd occasion freezing tests of OD plants) of families. Example. In figure 7a the mean damage score of the offspring from mother AC1019 and father AC1021 is 3.47.

wise OD localities were high (Table 7) the family ranking for growth rate can be considered unaffected by growth locality.

No clinal covariation was found between plant height and latitude of the growth locality (Fig. 3). The Storberg locality, that produced the earliest hardening plants, also produced the slowest growing ones. A positive correlations on the family level was obtained between plant height and damage ($0.35 < r < 0.48$) for every outdoor locality (Table 8). Plant height was positively correlated with the altitude of parent origin (Table 7).

The dry matter content in mid-September varied significantly both between OD localities (Fig. 3) and families (table 6) and was lowest for the Storberg plants, which had achieved the best hardening three weeks earlier. The poor correspondence between cold hardiness and dry matter content at the four OD localities might be a combined effect of transfer to the south and to milder weather conditions resulting in dehardening of the Storberg plants during the three week period in Umeå preceeding dry matter assessment.

Nonsignificant locality × family interaction and positive correlations between pairwise OD localities ($0.40 < r < 0.62$) indicate that the ranking of families for dry matter content was little affected by environment at the growth localities. The family dry matter content was uncorrelated with the geographical origin (latitude and altitude) of parents and with freezing damage and plant height in all tests of outdoor grown plants (Table 8).

Table 6. Variance component estimates $E(\sigma^2)$ from analyses of variance of height and dry matter content (DM).

Source	df	$E(\sigma^2)$ Height	$E(\sigma^2)$ Dry matter
Locality, L	3	73.5***	0.90***
Family, F	26	51.6***	0.37***
L × F	78	0 ns	0.02 ns
Block, B	12	3.48**	
Residual	312	55.3	2.04 (df=378)

Models: $Height_{ijkl} = m+L_i+F_j+L \times F_{ij}+B_{k(i)}+2_{ijkl}$
$DM_{ijk} \times m+L_i+F_j+L \times F_{ij}+e_{ijk}$

L fixed, i.e. σ^2_L is not a variance component. F and B random.

Table 7. Correlation coefficients (r) for height and dry matter content (n=28) between pairwise outdoor localities. Correlations between plant height and mean altitudinal origin of the parent clones.

OD-Locality	Height OD-Locality Umeå	Lyck	Stor	Jokk	Dry matter OD-Locality Umeå	Lyck	Stor	Jokk
Umeå		.77	.85	.82		.47	.50	.58
Lycksele			.84	.84			.54	.62
Storberg				.84				.40
Parent altitude	.45	.30	.42	.36				
Variable mean	56.2	65.9	48.3	66.3	32.6	33.6	31.3	32.3
Stand.dev.	7.96	8.45	6.95	7.84	1.05	0.94	0.87	1.18

Significance levels for r are given in Table 5.

Table 8. Pairwise correlation coefficients (r) between damage following the 2 nd freezing tests, height and dry matter content (DM) within outdoor localities. The calculations were made on 28 family means.

	Outdoor locality: Umeå Height	Umeå DM	Lycksele Height	Lycksele DM	Storberg Height	Storberg DM	Jokkmokk Height	Jokkmokk DM
Damage	.45	−.25	.47	−.13	.35	−.03	.48	−.25
Height		−.22		−.04		.03		.02

Approximate significance levels are given in Table 5.

4. Conclusions

There is a significant variation in the rate of 1st year cold hardening between full-sib families of growth selected Scots pine clones from northern Sweden. Even though the latitudinal range of parents is not more than 2 degrees, a northern origin positively affects the rate of winter hardening of the offspring. This confirms the importance of a northern clone origin in selection and breeding of Scots pine for early winter hardening.

The rate of cold hardening was strongly controlled by weather conditions during the growth and hardening periods. Slow winter hardening, that might become fatal in critical years, occurred when the plants were not exposed to low night temperatures in late summer and autumn.

Positive correlations between freezing damage of the one-year-old outdoor-grown plants and mortality of the same families in 10–20 year-old field trials have been reported earlier (Nilsson and Eriksson 1986 and Nilsson and Andersson 1987). the locality × family interction effect in rate of cold hardening of one-year-old plants was small in the present study although the plants were grown at geograpically distant outdoor localities with different photoperiods and weather conditions. Unless physiological after-effects (c.f. Björnstad 1981) have strongly influenced the results, the study indicates that early selection for rapid winter hardening on the basis of damage in freezing tests can be used in a breeding strategy for localities where early winter hardening is an important trait for tree survival. However, the family ranking for freezing damage of the slowly hardening greenhouse plants did not agree with the ranking of the outdoor-grown families. Therefore, material selected for early cold hardening under relatively normal outdoor conditions are not necessarily the best also for weather situations similar to the high autumn night temperatures found in the greenhouse. In breeding Scots pine for adaptation to both normal and extreme weather situation it is, therefore, recommended that progenies in the freezing tests are grown under various climatic conditions, including those that do not promote early cold hardening.

The low correlation between freezing test results and dry matter content, which are both commonly used as indications of cold hardiness, illustrates the complexity of cold hardening in forest trees. Careful studies, over time, on covariations between freezing damage, dry matter content and other hardiness related characters in Scots pine families from relatively small areas are needed as a basis for early selection. Further studies on correlations between early testing (e.g. freeze testing and dry matter content) and field survival several years after planting must be performed to supply breeders with information needed to optimize breeding efforts for northern localities.

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