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CAN FIELD MORTALITY OF LODGEPOLE PINE (*PINUS CONTORTA* VAR. *LATIFOLIA*) FAMILIES BE PREDICTED BASED ON EARLY FREEZING TEST RESULTS?

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ABSTRACT

Individuals from 119 half-sib family seed lots of lodgepole pine (*Pinus contorta* Dougl. *ex* Loud. var. *latifolia* Engelm.) collected in the Yukon territory were freeze tested for frost tolerance classification as one-year-old seedlings during the autumn frost hardening period. Hardening was induced artificially by manipulating temperature and photoperiodic conditions in a greenhouse. Members of the same families were also planted as one-year-old seedlings on three sites in northern Sweden and assessed at 13–14 years of age. The correlation between field survival and freezing test damage (pooled $r = 0.164$) was weaker than that frequently obtained for Scots pine (*Pinus sylvestris* L.). The assessment of family performances separately by source stand did not add significant information regarding correlation structures.

Key words: early freezing test, field mortality, half-sib families, hardiness, harsh climate, introduced exotic species, *Pinus contorta, Pinus sylvestris.*

INTRODUCTION

During recent years, it has become increasingly common to use early freezing tests for autumn frost hardiness assessment to forecast Scots pine (*Pinus sylvestris* L.) field survival. North Swedish seed orchard harvests are regularly tested, so that their distribution for use in reforestation among sites with severe climates can be optimized. Correlations between freezing test results and field survival are generally significant, and their magnitude tends to increase with the harshness of the climate at the studied site (ANDERSSON, 1986). Many of the correlations reported have been far above 0.5 (NILSSON & ERIKSSON, 1986; ANDERSSON, 1986; NILSSON & ANDERSSON, 1987; NILSSON *et al.*, 1991; ANDERSSON, 1992a).

For lodgepole pine (*Pinus contorta* Dougl. *ex* Loud. var. *latifolia* Engelm.), which is an introduced species in Europe, studies based on the same material tested in both early freezing tests and field experiments are lacking. However, many studies of frost tolerance have been carried out by means of artificial freezing tests (*e.g.* JONSSON *et al.* 1986; REHFELDT 1980, 1989), and strong associations have been obtained between test results and the variation in field hardiness that is a consequence of large-scale provenance variation (*e.g.* JONSSON *et al.*, 1981; LINDGREN & NILSSON 1992).

In this work we measured correlations between field mortality and damage obtained in early freezing tests with lodgepole pine half-sib families from one provenance region grown from samples of the same seed lots.

MATERIAL AND METHODS

The investigated lodgepole pine progenies were introduced from western Canada to Sweden during the 1970's as open-pollinated seed from 119 plus-trees, mainly within a larger cooperative forest industry collection project described by ERICSSON (1993). The mother trees had been selected from stands to the north of 63 °N in the Mayo area of the Yukon territory which is the northernmost region containing extensive stands of lodgepole pine. The collected half-sib families comprise 119 of the 155 plus-tree progenies intended for utilization in northernmost Sweden. Most families (108) were collected from nine selected stands where 12 mother trees were chosen in each. The remaining 11 families were progenies from individually selected trees (Fig. 1).

Freezing test

Samples from the 119 family seed lots were raised in a greenhouse until they were about equal in size to one-year-old greenhouse-grown seedlings. During the greenhouse period, from December 8, 1982 to April 1983, the seedlings were kept in multi-pot styrofoam containers using a seven-plant row-plot design with six germination week, the seedlings were exposed to a 20h

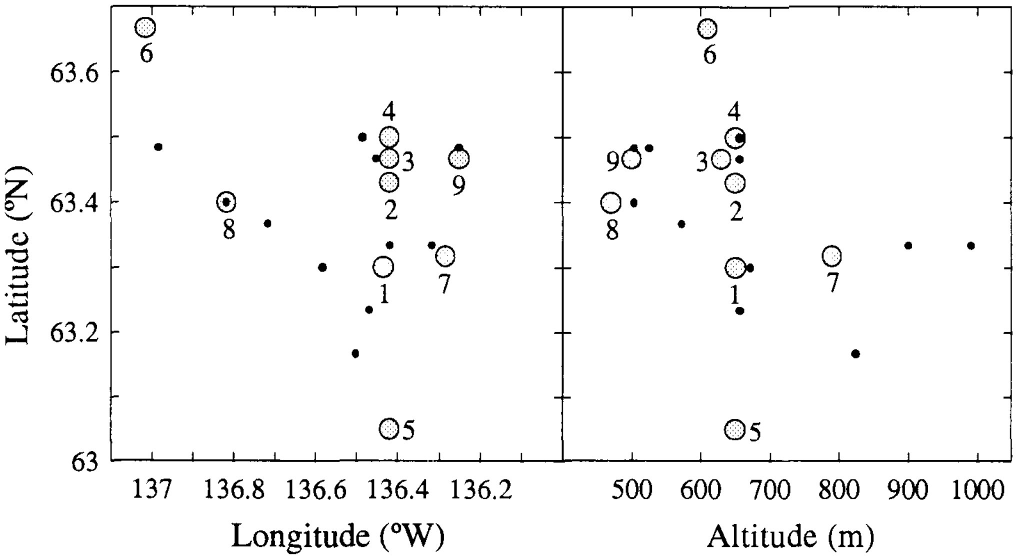

Figure 1. Origins of the selected mother trees. Circles = origins of the stands, in each of which 12 trees were selected (stand numbers indicated). Dots = origins of the individually selected trees.

photoperiod with 20/15 °C day/night temperatures for two months, representing the growing period. Next, an autumn conditioning program was introduced in order to initiate winter acclimation. This involved a decrease in day/night temperatures to 15/5 °C, and daylength was successively shortened by one hour per week. By the last week of March, nights were 11 h long.

From April 1 onwards, one replication at a time was taken for freeze testing at about one-week intervals. The cooling rate was 4 °C per hour, during which time the seedlings were kept in darkness. Before initiating thawing, at a similar rate, the minimum temperature, –10 °C for the first four and –15 °C for the last two replications, was maintained for 2 h. To quantify damage, the seedlings were visually judged regarding discoloration of buds and needles and assigned to one of seven classes, after a recovery period of at least two weeks. Test conditions and damage assessment followed ANDERSSON (1992b).

In this study, the frequencies of seedlings in the three lowest damage classes (undamaged or slightly damaged) were used in order to obtain the best resolution. Previously, the two first freeze-tested replications were excluded from analysis owing to an overall extremely high degree of damage and, consequently, small degree of differentiation.

Field tests

The collected half-sib seed-lots were used in various progeny trials planted from 1979 through 1981 throughout northern Sweden. The 119 families presented here were planted in 1981 on three field testing sites. The planting design was 10-tree row-plots, randomized within five replications (for details see ERICSSON, 1993). The survival data utilized in this study were collected at 13 or 14 years of age in 1992 (site nos. 362 and 364) and 1993 (no. 363) for genetic evaluation. In general, yearly tree mortality rates show a substantial decline at around this age (Table 1, Fig. 2.).

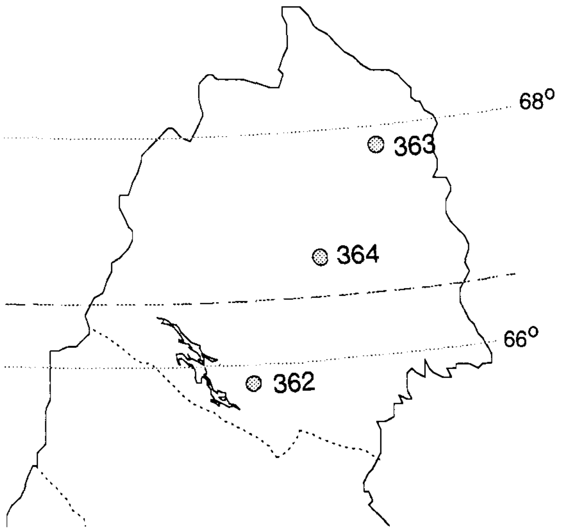

Figure 2. Field test sites in northern Sweden. Broken line = Arctic circle.

To represent field survival at the family level, breeding values for family members were used (ERICSSON & DANELL 1995). Through BLUP evaluation, physical blocking and variance structures were simultaneously considered for the estimated tree vitality trait. The estimation was based on a tree vigour classification with dead trees included. To facilitate interpretation,

Table 1. Field progeny trials established in 1981 and investigated in 1992 and 1993.

Test site		Geographical situation		Overall mean values	
No.	Name	Latitude (N)	Altitude (m)	Height (cm)	Survival (%)
362	Mader	65° 48'	500	215	66
363	Pirttivaara	67° 49'	374	266	42
364	Radnelombele	66° 54'	375	261	61

Table 2. Correlations between early freezing test results (percent seedlings undamaged or with only slight damage) and breeding values for field survival evaluated at 13 or 14 years of age. All 119 families included.

Correlation coefficients between	Survival on site			
	362	363	364	362–364[1]
Freezing test results	0.119 °	0.173 *	0.109 °	0.167 *
Survival on site 362		0.536 ***	0.509 ***	0.834 ***
363			0.525 ***	0.870 ***
364				0.759 ***

Null hypothesis that correlation ≤ 0: ° – accepted, * – rejected at the 5 % level, *** – rejected at the 0.01 % level. [1] – pooled data

the normalized breeding values were transformed into predicted survival rates given an average reference level reflecting a representative, real situation. Here, 60% survival was chosen as an adequate comparison level considering the test site mean survivals.

The expected average mortality of local Scots pine calculated as a 'Severity index' according to ERIKSSON *et al.* (1980) was estimated to be about 80 % on sites 362 and 363, and 75 % on site 364.

Comparisons

Ordinary Pearson correlation coefficients were calculated between family percentages of undamaged /slightly damaged seedlings in freezing tests and breeding values for predicted field survival on the different sites. Also, correlations between predicted survival rates on different sites were computed. Correlations and graphic relationships between freezing test and survival data were assembled in greater detail by source stands and test sites.

The calculated correlations are not true estimates of genetic correlations but rather describe actual relationships between measurements, in accordance with most other studies referred to in this paper.

RESULTS

Correlations between family survival rates on different sites were highly significant, indicating that the experimental conditions were fairly normal (Table 2). Overall correlations between freezing test damage and field survival were nonsignificant in most cases. However, survival rates on the harshest locality, 363 Pirttivaara, correlated slightly better with freezing damage compared with survival on the other sites.

To detect specific differences between test sites or particular families originating from different stands, relationships between freezing test results and survival rates are shown, by stand and test site, in Fig. 3. However, the different regression slopes and correlation coefficients can be fully explained by random variation, except the case where all families were included, as indicated in the first row of Table 2.

DISCUSSION

The correlations obtained between early freezing-test results and actual field survival were weaker than most other such correlations obtained for Scots pine (*e.g.* ANDERSSON 1992a). One reason for the weaker values could be that the particular freezing-test carried out did not reflect the character of lodgepole pine hardiness very well. There are, however, many examples of covariation between results from similar freezing-tests and large-scale variation in provenance, thus indirectly reflecting genetic variability caused by adaptation to varying environments, including differentiation with respect to autumn dormancy onset and winter cold acclimation (JONSSON 1981, 1986; REHFELDT 1980, 1989). The reason for the poor correlation with field

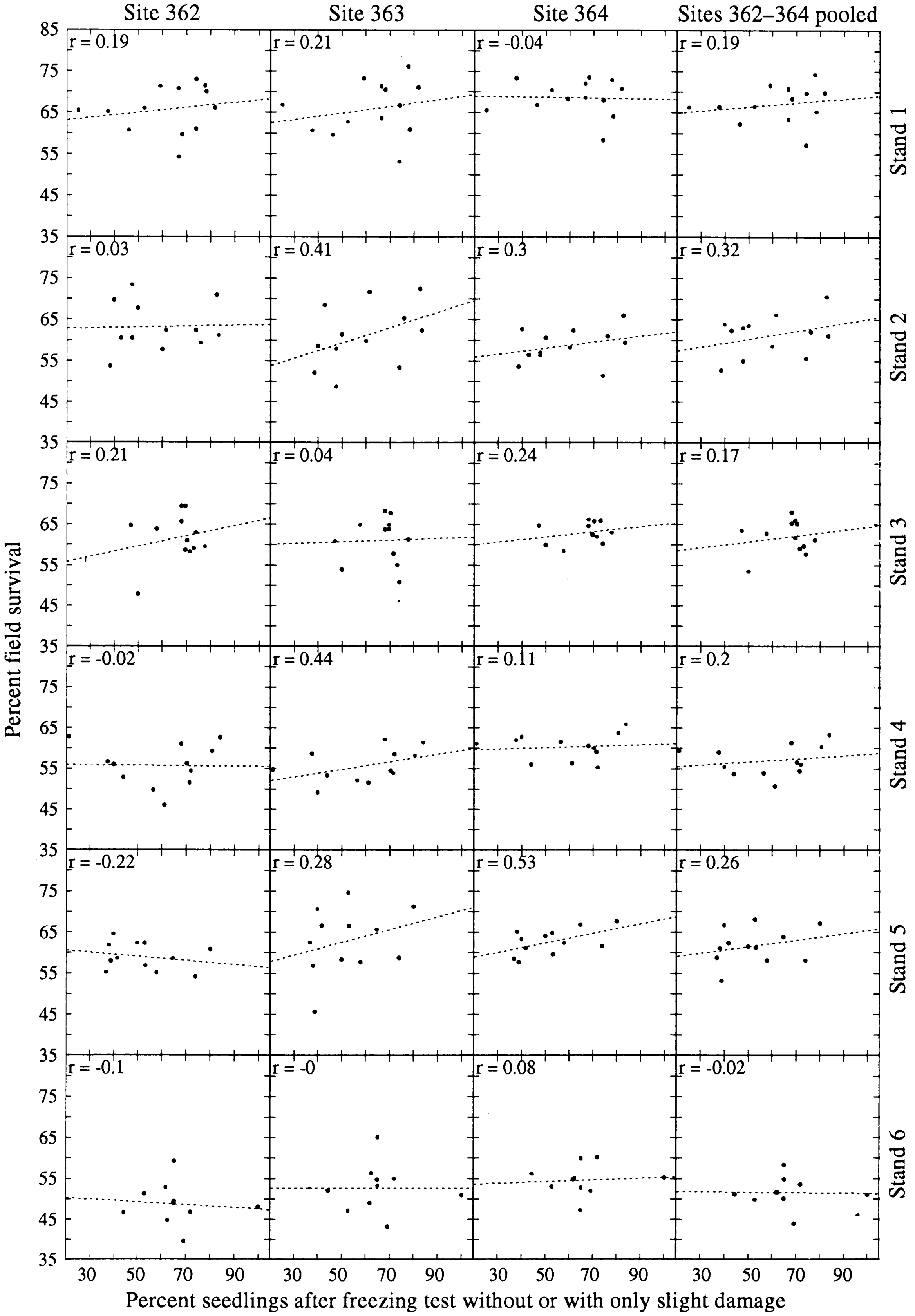

Figure 3 Relationship between freezing test results and field survival. The field survival rates arefamily member breeding values expressing predictions for an environment where 60% average survival is assumed.

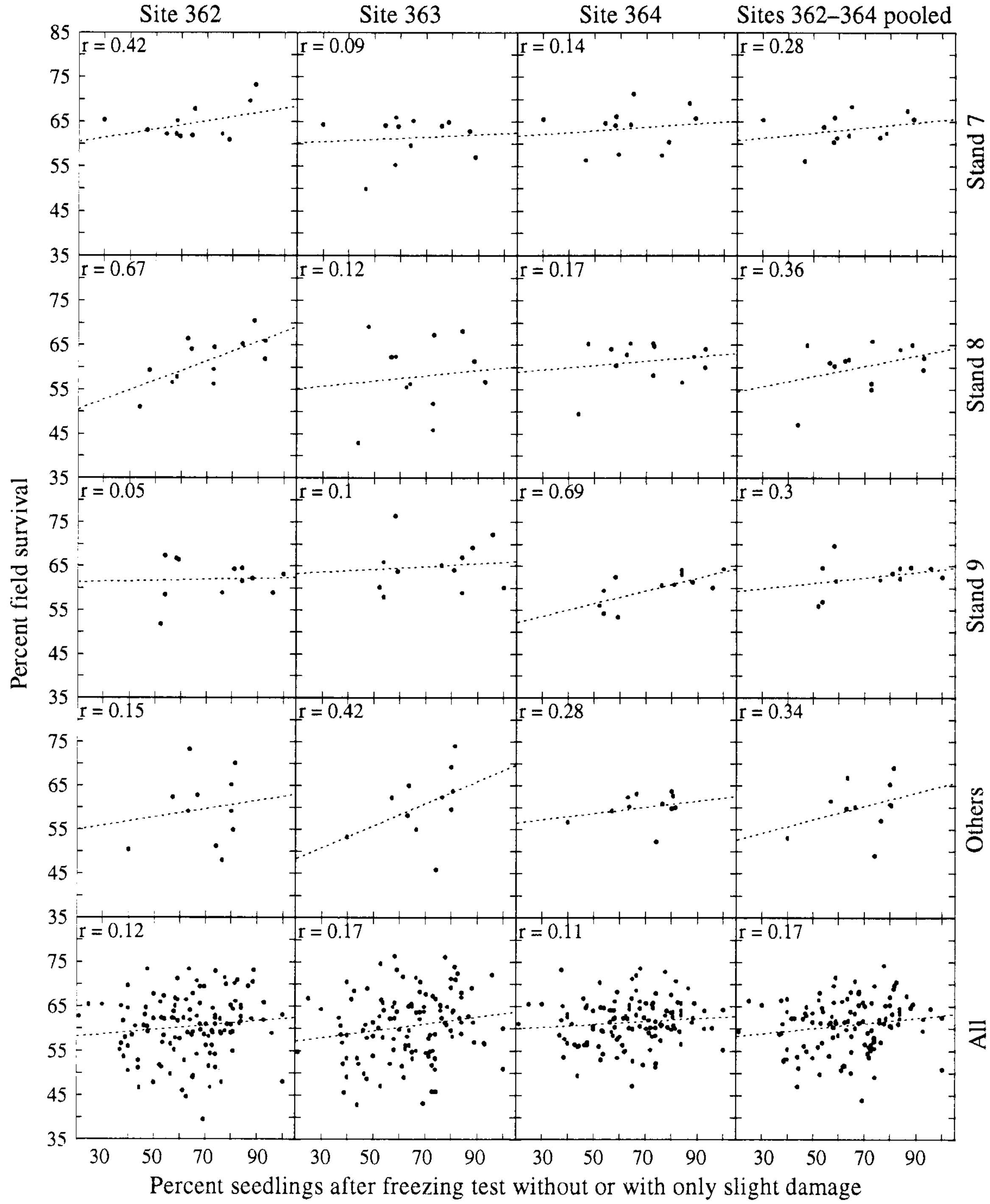

Figure 3, (continued).

survival obtained in the present study may well be that the provenance source area (Fig. 1) was too small to supply enough genetic variability in cold acclimation rate and/or field survival.

One can further speculate that specific adaptation to conditions along the borders of the species' distribution area, from which the present study material was obtained, resulted in low variability. It is unlikely, however, that such an effect would be large enough to be discernible. Conifers, which are wind pollinated, tend to express a lower than expected degree of local adaptation since in the absence of a geographic barrier,

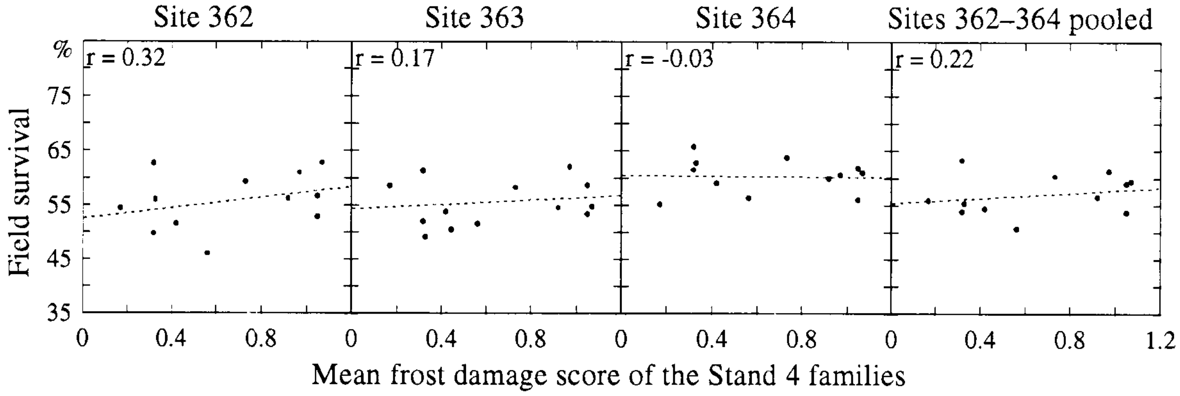

Figure 4. Relationship between freezing test results obtained by JONSSON *et al.* (1986) and field survival in the present investigation (cf. Fig. 3).

pollen flow exists between distant populations (PERRY 1978; EPPERSON & ALLARD 1989). The strong correlations between survival on different sites also disallows any speculation regarding exclusively random sources of variation as far as field survival is concerned. Furthermore, genetic parameters estimated for lodgepole and Scots pines for traits related to survival are of similar magnitude (ERICSSON *et al.* 1994).

Low correlations between early freezing-test results and field survival suggest that autumn hardening in the field in lodgepole pine is a rapid and uniform process, hence resulting in less pronounced population and family differences compared with Scots pine. REHFELDT (1989) speculated that "acclimation in an extremely short time" could occur. In cases where autumn hardening occurs rapidly, variation in hardening rate should have little influence on overall hardiness and survival, thus explaining low correlations with freezing tests where differences are amplified by artificial means. A rapid and fairly invariable winter acclimation process of lodgepole pine could also partly explain why this species is better able to tolerate unfavourable climatic conditions compared with Scots pine (ERICSSON 1993).

One should further keep in mind that growing lodgepole pine so far to the north, where the light climate is so different compared with conditions in the areas of Canada from which the trees originated, could have unforeseen consequences.

Seed samples from the families of stand 4 ('Rusty Creek C') were also freeze-tested by JONSSON *et al.* (1986) after cultivation and autumn preconditioning in climatic chambers. Among simultaneously tested populations, the resolution turned out to be acceptable only for a latitude 57° population. The 'stand 4 population' from 63.5° sustained too little damage to allow for good differentiation between entries. However, it can be seen in Fig. 4 that the relationships between freezing test results and actual survival rates are about equal to those obtained in our study.

To forecast hardiness differences between lodgepole pine families or populations from within a limited provenance area, more investigations regarding the relationship between field survival and early freezing-test results will be needed.

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