Will Climate Change Affect the Optimal Choice of *Pinus sylvestris* Provenances?

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Provenance experiments with *Pinus sylvestris* (L.) were evaluated in Sweden north of latitude 60°N. Survival and yield were determined as functions of temperature sum of the site and latitudinal origin of the provenance. Altitudinal origin was of negligible importance. The effects of latitudinal transfer were influenced by temperature sum at the growing site. At the harshest situated sites southward transfer longer than 3° was optimal for survival and yield, whereas transfer effects in a mild climate were weak. Climatic warming would reduce demands of hardiness. However, moderate differences in productivity are expected between formerly optimal seed sources and the ones adapted to changed climatic conditions. Since mortality usually was low in plantations older than 20 years or higher than 2 m, established stands are expected to be robust against adverse effects of climate change.

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1 Introduction

During next rotation global temperatures are expected to raise due to effects of CO_2 and other "greenhouse gases" (e.g. Gates 1993, Houghton et al. 1995). Even if global temperature increases, there could be a cooling trend in northern Scandinavia because of weakening of atmospheric and oceanic circulation (Washington and Meehl 1989).

Provenance trials are used to model effects of climate change (Beuker 1994a, Mátyás 1994, Schmidtling 1994). A problem when studying provenance performance over a severity gradient is that climate factors are confounded. Most prominently, photoperiod usually differs between harsh and mild sites since temperature conditions are strongly influenced by latitude. To distinguish effects of temperature, photoperiod and other climatic factors, a dense matrix of sites and provenances is needed. In northern Sweden the amount of provenance experiments with *Pinus sylvestris* (L.) is substantial. There are differently harsh sites situated on the same latitude. This increases the opportunities to isolate impacts of temperature sum. Based on Swedish provenance data, Persson and Beuker (1997) developed functions showing that the growth of *Pinus sylvestris* increased more with increased annual temperature sum when effects of southward provenance transfer were eliminated. Annual growth over rotation increased linearly with increased temperature sum over a wide range in temperature sum. Even though provenances respond positively to improved temperature climate, they may not utilise the growth conditions well and grow optimally. Several studies have shown that the effects of using transferred provenances depends on the severity of the site (Remröd 1976, Ericsson 1988, Persson and Ståhl 1990).

The objectives of the present paper was to predict the effects of provenance transfer under the influence of climate chance. The limitations of the models used were evaluated. The study is based on data and functions presented by Persson and Ståhl (1993) and Persson (1994).

2 Materials and Methods

The core of the experimental data used is derived from a provenance series with *Pinus sylvestris* which was planted in 1953–1954 (the Eiche series). This very well-documented and intensively studied series has generated data which have been used for developing functions for provenance variation in survival, growth and wood properties (e.g. Eriksson et al. 1980, Ståhl 1988, Ståhl et al. 1990, Persson and Ståhl 1990,1993). The series consists of incomplete Latin squares experiments of 7 or 14 provenances planted in 1.25 m and 2.0 m spacings. The provenances originated from Scandinavia outside the most maritime region. Some provenances were common to several trials.

To make survival data represent different planting years and silvicultural practices, eight different experimental series were analysed, one of them being the Eiche series. Besides provenance experiments, provenances planted in seed orchard tests and progeny tests were analysed. Also *Pinus sylvestris* provenances planted in *P. contorta* provenance experiments were used. The experiments, altogether 88, were established between 1950 and 1979. The number of provenances per trial was 3–21 (Persson 1994). In addition, another set of 52 planting experiments were used to verify that survival in the eight experimental series was at a representative level. The location of experiments studied are shown in Fig. 1.

To make survival in experiments of different age comparable, survival at 2.5 m mean height was determined. Then climatic mortality has almost ceased, while competition between trees is low and stands are not yet thinned. “Yield” for 2.0 m initial spacings was calculated from stem volume at 29 years after planting in the Eiche series and survival at 2.5 m mean height in the eight series studied. In the mildest parts of northern Sweden this means an over-estimation of yield 29 years after planting, since the number of remaining stems is lower than at 2.5 m mean height.

To compare provenance variation in different experiments, performance of provenance was related to local provenances. In spite of existence of true local provenances in the Eiche series, local-provenance values were estimated separately for each trial (the intercept when performance was set as function of latitudinal and altitudinal transfer). The variation of local-provenance performance was determined as function of site temperature sum. “Transfer effects” were expressed as provenance performance minus local provenance performance. For more details see Persson and Ståhl (1993) or Persson (1994).

The following functions were used:

$$\text{logit } S_0 = -75.69 - 0.009617 \text{ tsum} + 12.53 \ln \text{tsum}, \quad R^2 = 0.42 \tag{I}$$

$$\Delta\text{logit } S = 0.01510 - 1.406\,\Delta\text{lat} - 0.1458\,\Delta\text{lat}^2 + 0.001115 \text{ tsum}\,\Delta\text{lat} + 0.000105 \text{ tsum}\,\Delta\text{lat}^2, \quad R^2 = 0.67 \tag{II}$$

$$\text{Volst}_0 = -63.68 + 0.1369 \text{ tsum}, \quad R^2 = 0{,}66 \tag{III}$$

$$\Delta\text{Volst} = 0.008009 + 3.114\ 10^{-6} \text{ tsum}^2\,\Delta\text{lat} - 0.000402 \text{ tsum}\,\Delta\text{lat}^2, \quad R^2 = 0{,}29 \tag{IV}$$

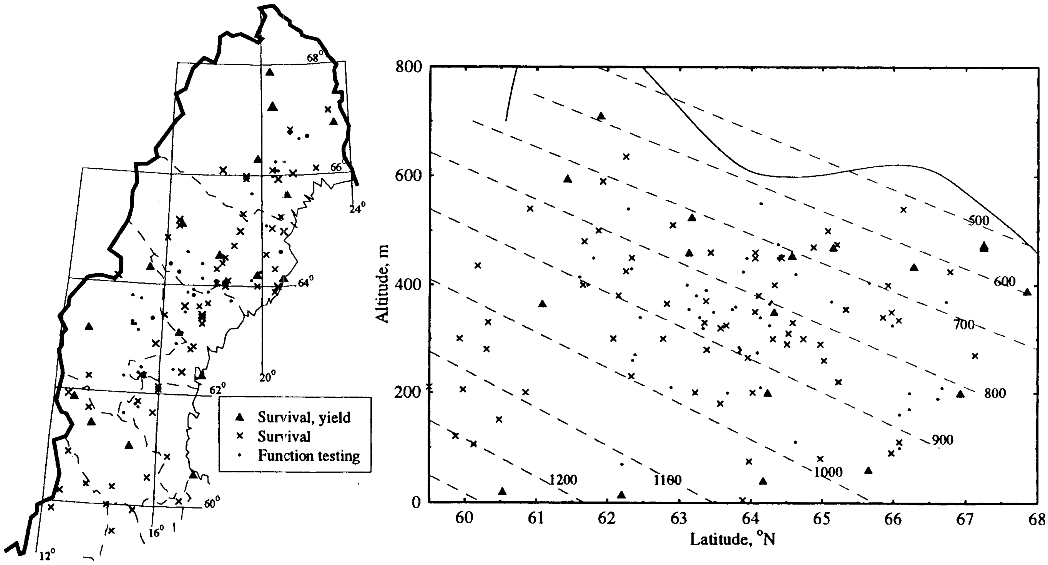

Fig. 1. Trials studied in northern Sweden. Growth was studied in 18 provenance trials, survival in 88 trials. Representativity of survival was checked in 52 other trials. To the right the trials are shown relative to latitude and altitude. Temperature sum in degree days above +5 °C is shown with broken lines, and the tree limit is shown as a solid, curved line.

where

S_0 and $Volst_0$
= survival (%) and volume per stem (dm^3 o.b.) of local provenances,

logit S_0
= $\ln (S_0/(100 - S_0))$,

Δlogit S
= $\ln [S_{prov}(100 - S_0)/(S_0(100 - S_{prov}))]$,

ΔVolst
= $Volst_{prov} - Volst_0$,

S_{prov} and $Volst_{prov}$
= survival (%) and volume per stem (dm^3 o.b.) of a provenance,

tsum
= temperature sum (degree-days above +5 °C calculated according to Odin et al. [1983]),

Δlat
= latitudinal transfer (decimal degrees, positive value refers to northward transfer).

Functions I and II were given by Persson (1994) and functions III and IV by Persson and Ståhl (1993).

Yield of local provenances (Y_0) and transfer effects on yield (DY) were calculated in m^3 ha^{-1} according to:

$$Y_0 = 0.025\ S_0\ Volst_0$$
$$DY = 0.025\ (S_{prov} - S_0)\ DVolst_0\ .$$

3 Results and Discussion

3.1 Response of Provenances to Different Temperature Climates

Both survival and yield of local provenances increased with increasing temperature sum (Fig. 2). The most rapid increase in survival was between 600–900 d.d., above which further increase is limited. As stem volume increased linearly with temperature sum, yield responded to higher temperature also in mild areas. The residual distributions for survival and stem volume did not follow any latitudinal or altitudinal trend. Thus, geographically distant sites with similar temperature sums seem to be equally harsh to *P.*

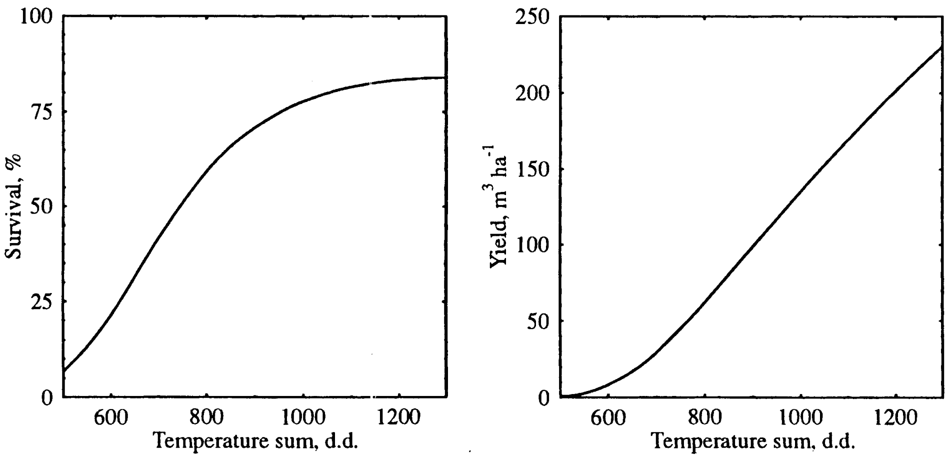

Fig. 2. Survival and yield of local provenances relative to temperature sum. Yield was calculated for 2 m spacing from stem volumes 30 years after planting and survival at 2.5 m height.

sylvestris, which shows that temperature sum reflects temperature conditions important to pine performance. For survival, the greatest residual variation was found in the interval where response to temperature sum was greatest (600–900 d.d.). Causes to residual deviation could be that temperature sum was estimated, not recorded at the individual sites, that calamities with random but drastic effects have occurred, or that factors other than temperature have influenced. Survival and yield of Scots pine in severe climate is demonstrated to be lowest on flat grounds or in north-facing slopes (Poso and Kujala 1973, Kullman 1981, Persson 1994).

The effect of using transferred provenances was predominately determined by length of latitudinal transfer. The altitudinal origin of a provenance transfer had no obvious influence on hardiness. Temperature sums vary much with altitude (Morén and Perttu 1994), but this has not resulted in any clear genetic differentiation. However, when comparing latitudinal transfer effects in different climate there was variation that could be attributed to temperature sum of the sites. As shown in Fig. 3, survival could be raised substantially at a site with 600 d.d. if a southwardly transferred provenance was used. At sites with 1200 d.d., provenance transfer had small influence on survival. Yield was not possible to improve much at 1200 d.d., compared with the local provenance, but long southward transfer reduced yield substantially. At 600 d.d. southward transfer was positive to yield: 2–3° of southward transfer resulted almost twice the yield of local provenances, although the increase in absolute terms was limited. In severe climate, yield was greatly determined by survival, whereas stem growth was of most important in mild areas.

The low or absent effects of altitudinal transfer shows that any genetic differentiation between highland and lowland has not occurred in northern Sweden. The reason for this is probably low altitudinal amplitude in combination with an intense gene flow which counteracts the selective forces (cf. Levin 1988).

3.2 Effects of Climatic Change

The temperature conditions during establishment of the experiments, from 1950s and ahead, were colder than in the previous decades, but substantially warmer than in the previous centuries (Eriksson 1982). Occasional periods of severe weather have caused great mortality (Eiche 1966).

As survival and yield of local provenances increased with temperature sum (Fig. 2), climatic warming could be expected to have a generally

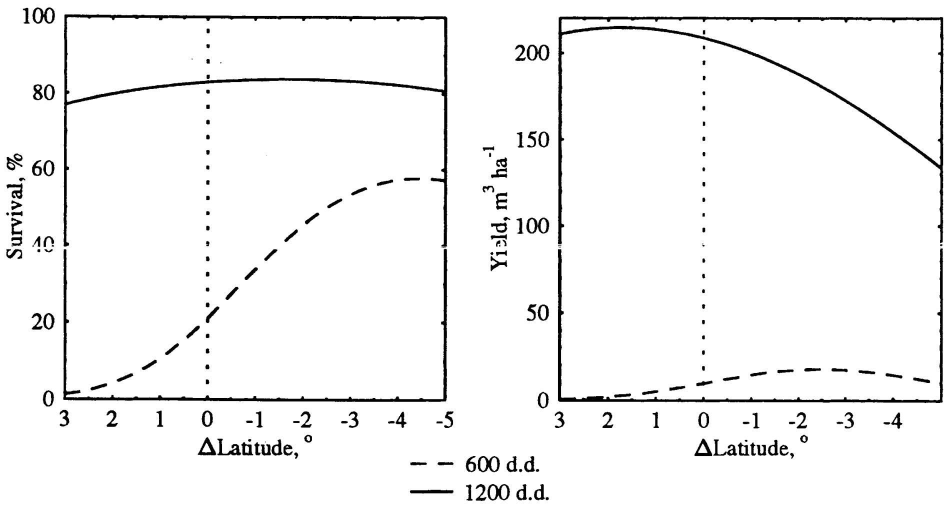

Fig. 3. Effect on survival (left) and yield (right) of latitudinal transfer of provenances at sites with 600 d.d. and 1200 d.d. temperature sums. ΔLatitude expresses latitudinal transfer to the plantations. Negative values of ΔLatitude means southward transfer.

positive effect. The same trends were shown in an analysis of provenances in the Eiche series replicated at sites with different temperature sums, where effects of photoperiod were eliminated (Persson and Beuker 1997). Other studies have also predicted that global warming would increase production and raise the tree limit (Kellomäki et al. 1988, Junttila and Nilsen 1993, Beuker 1994a). 1 °C warmer temperature during growing season has been predicted to increase general plant productivity by about 10 % (Grace 1988).

Trees well adapted to the climatic conditions prevalent at the time of planting could, as effect of climatic change, perform less optimal as mature and possibly risk mortality. The sharp difference between cold and warm sites in the effects of latitudinal transfer points in that direction (Fig. 3). Fig. 4 shows the estimated optimal latitudinal transfer depending on temperature sum. The ranges of transfers where the expected survival and yield are above 95 % and 90 % of the optimal ones are also shown. According to Fig. 4, the optimal transfer for survival and yield at a site with 700 d.d. would be 4.5° and 2.2° southward, respectively. If temperature changes to 1200 d.d. such transfers would still be expected to give more than 90 % of the optimal survival and yield. The figure indicates that climatic cooling could have a more dramatic effect.

Some questions could be raised against using the transfer functions to predict effects of climatic change. Firstly, the functions used are based on data from trees younger than 30 years and the variation in transfer effects is not valid for the whole rotation. The importance of survival could be expected to decrease after stands are closed. However, previous studies have shown that early recorded provenance differences are sustainable over the rotation (Persson 1975, Marklund 1981). When annual mean production over rotation was forecast using data from the Eiche series and developmental functions for height and basal area (Hägglund 1974, Persson 1992), the pattern was similar to yield at 29 years but the optimum was wider (Persson and Ståhl 1993).

Secondly, one prerequisite for using the functions to predict effects of future climatic changes is that all climatic conditions found at a certain temperature sum resemble those that will arise in other areas with the same temperature sum after climatic change. Partly this is true, since processes like evaporation and mineralization depend on temperature (Bonan and Van Cleve 1992). However, scenarios show that future temperature cli-

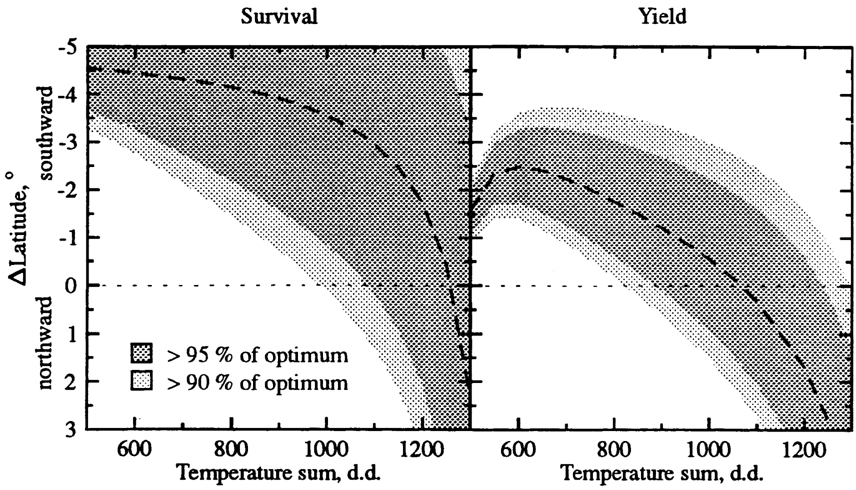

Fig. 4. Optimal latitudinal transfer at to sites with various temperature sums for survival and yield. The gridded intervals show performance higher than 95 % and 90 %, respectively, of optimum.

mates are not likely to resemble the present temperature conditions at a milder site (Hänninen 1996). Winter temperatures are expected to be more affected than summer temperatures (e.g. Jaeger 1988). Thereby, weather-induced injuries due to early dehardening followed by freezing could increase (Cannell and Smith 1986, Kellomäki et al. 1988, Hänninen 1991). Warm anticyclonic weather prior to snow melting is very harmful (e.g. Stefansson and Sinko 1967, Kullman 1981), even though *Pinus sylvestris* is not as sensitive to frost during active growth as species like *Picea abies* (Christersson 1971) Damage due to late spring frosts may also increase (Murray et al. 1989). The risk is greatest for northern provenances since their shoot elongation starts early (Beuker 1994b). Increased diurnal and periodic fluctuations in temperature (Gates et al. 1990) would also raise the level of climatic stress (Christersson and Sandstedt 1978). Besides increase in greenhouse gases and temperature, climate is expected to be more maritime with increased precipitation and frequency of storms (Kellomäki et al. 1988, Mitchell et al. 1990). This could lead to increased risk for water logging since the humidity is high in northern Sweden (Eriksson and Odin 1990).

As stated by Eriksson (1998), Scots pine is a species with high phenotypic stability. Trees are able to cope with a great diversity of climatic stresses during their lifetime. Once 2 m height is passed, mortality is low (Persson and Ståhl 1993) and the capacity to buffer against climate deterioration is high (Kullman 1987). Thus, the conditions the seedlings face at the time of planting are the ones that determines their survival most. Seed sources should be chosen to get a high enough survival in the climate that could be forecast the next 20 years, which is perhaps easier to foresee than climate in final part of rotation. During rotation maladapted trees could be removed at thinning. The variation within seed sources is great. Unless the initial selection is too hard there are good opportunities to alter the properties of the stand successively.

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