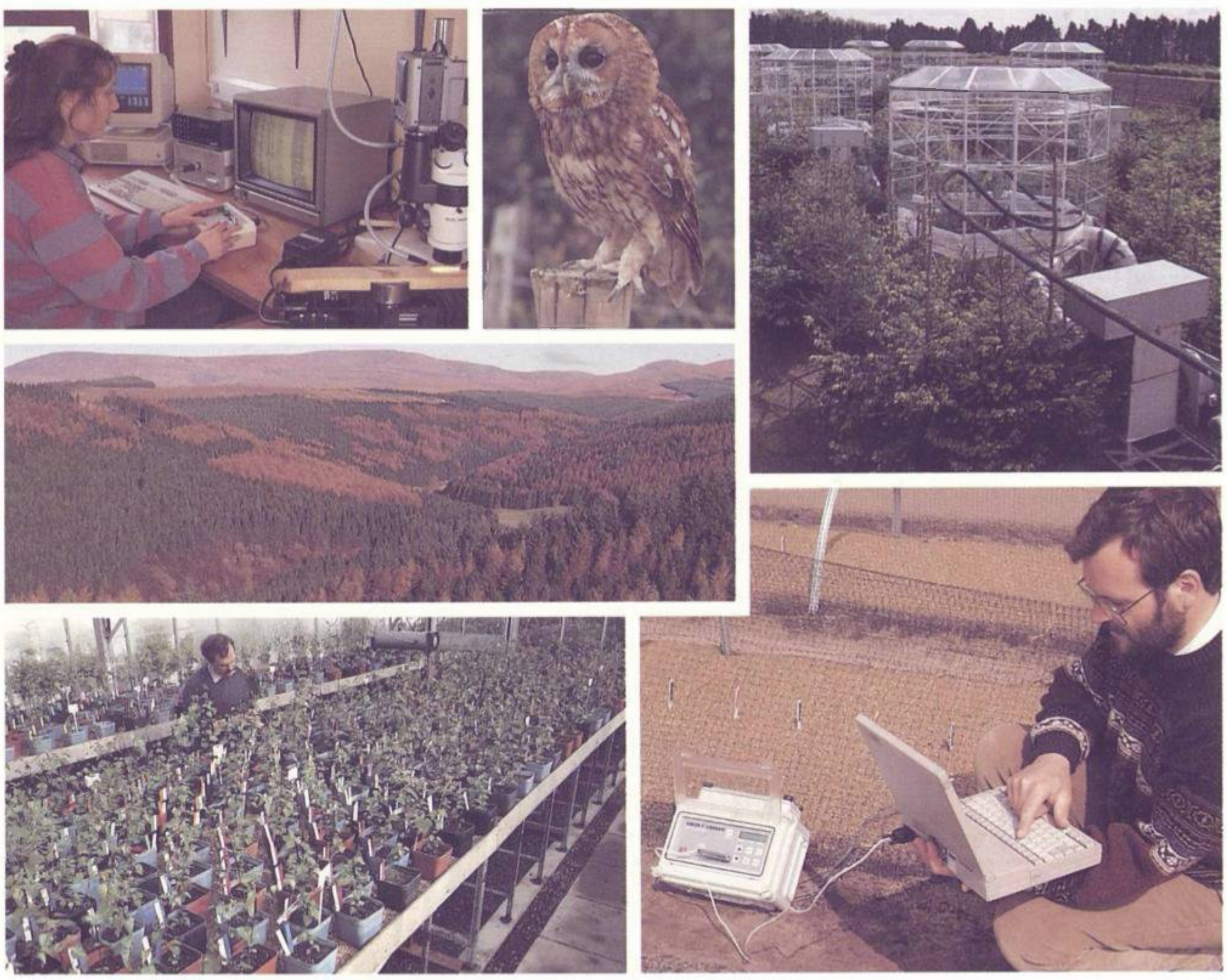
Forestry Commission

Deterioration of Fine Tree Roots During Cold Storage in Two Contrasting Winters

Helen McKay



Technical Paper 2

FORESTRY COMMISSION TECHNICAL PAPER 2

Deterioration of Fine Tree Roots During Cold Storage in Two Contrasting Winters

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FORESTRY COMMISSION, EDINBURGH

First published 1993

ISBN 0 85538 249 X
FDC 164.3 : 181.36 : 174.7 232.4127: (410)

KEYWORDS: Root systems, Physiology, Cold Storage,
Conifers, Forestry

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Abstract

Electrolyte leakage from fine roots was measured before and after 30 and 90 days cold storage. The effect of the entry date and the length of cold storage were examined during the exceptionally mild winter of 1989-90 and the more typical winter of 1990-91. In the first year, roots from 2-year-old transplants and undercuts of Sitka spruce (Queen Charlotte Islands), Douglas fir (Darrington, Washington) and Japanese larch (unknown origin) grown at Wykeham Nursery were stored at +1°C on 13 occasions between October and April. In the following year, undercuts of Sitka spruce from Alaska, Queen Charlotte Islands and Oregon, Douglas fir (Darrington), Japanese larch (unknown origin) and Scots pine (South England provenance) were stored on nine occasions between mid-November and April.

In 1989-90, the species' tolerance to cold storage increased in the order Douglas fir < Japanese larch < Sitka spruce (Queen Charlotte Islands). This order was evident in 1990-91 too. Within Sitka spruce, the more northerly the seed origin the greater its tolerance to cold storage. Scots pine was only slightly more tolerant of cold storage than Sitka spruce of Oregon origin. Undercutting and regular wrenching had a minor effect on the ability of Japanese larch to withstand cold storage but did not have a consistent, significant effect on the tolerance of Sitka spruce or Douglas fir.

Plants were more tolerant of storage in the colder winter of 1990-91 than in the preceding milder winter. On the basis of the leakage patterns found in the two contrasting years, safe lifting dates are given for Sitka spruce (Queen Charlotte Island) and Japanese larch. Safe lifting dates for Douglas fir, Scots pine, Oregon Sitka spruce and Alaskan Sitka spruce are suggested; further research is needed to verify these dates.

Deterioration of FineTree Roots During Cold Storage in Two Contrasting Winters

Introduction

Cold storage of plants over winter is common in Scandinavia, Canada and the USA and is becoming increasingly common within the UK Forestry Commission following the recent investment in cold stores at Newton, Delamere and Wykeham. Over the winter and spring of 1988-89, approximately 10 million seedlings were stored for 3 months or longer. This represents about 30% of the conifers planted annually by the Forestry Commission.

Cold stores offer significant practical benefits to both nursery and forest managers. Firstly, plants can be lifted in late winter, when ground conditions permit, to form a bank of plants. In spring when planting conditions are suitable, nursery conditions may not allow lifting at all or plant demands may be greater than the numbers machinery or staff can lift, grade and supply. At such times cold stored plants can be dispatched. Secondly, plants stored in peak condition can be used for late spring or early summer planting at a time when plants in the nursery would have begun active root and shoot growth and when nursery managers wish to have their ground clear to begin their sowing programme. Unfortunately incorrect storage practices have been implicated in many cases of post-planting failure investigated by Forestry Commission staff during 1985-1989 (Mason and McKay, 1990).

Guidelines for storage published by Aldhous (1972) are based on outplanting trials. Those published by Tabbush (1988) are based on measurements made over a number of years of root growth potential. In both cases, prescriptions are given for 'normal' winters whereas weather conditions during recent winters have been extremely variable.

The rate of electrolyte leakage from the fine roots of several conifers has proved to be a good indicator of the condition of plants after 1 to 6 months cold storage; the greater the leakage rate the poorer the condition of the plants (McKay, 1991). The rate of electrolyte leakage from fine roots was more closely correlated to field survival than the electrolyte leakage rate from the shoots (McKay and Mason, 1991). Thus a comparison of the electrolyte leakage rate from fine roots at lifting and after storage is a measure of the deterioration of the plant during cold storage. This paper presents data on root deterioration during cold storage in two very different winters to guide nursery and forest managers in their use of cold stores.

Method

During the winters of 1989-90 and 1990-91, plants were lifted from Wykeham nursery (54° 16'N, 0° 34'W, 215 m above sea level) and sent overnight for testing at the Northern Research Station. In the first experiment, 15 transplants and 15 undercuts of Sitka spruce (SS) of Queen Charlotte Islands origin, Douglas fir (DF) of Darrington, Washington origin and Japanese larch (JL) of unknown origin were lifted at fortnightly intervals from October to April. In the second experiment, 15 undercuts of SS (Queen Charlotte Islands), DF (Darrington, Washington), JL (unknown), Scots pine (SP) of South England provenance, SS (Oregon), and SS (Alaskan) were lifted at approximately fortnightly intervals between mid-November and April.

The procedures used to assess the deterioration of the root system during storage were identical in both years. Plants were washed, rinsed and three samples of fine roots removed from each plant. Electrolyte leakage over 24 hours was measured on one sample (method is described in McKay, 1991). The other two samples were sealed in plastic bags and stored in the dark at +1°C for 30 or 90 days. At the end of the storage period electrolyte leakage was determined.

The number of hours when the air temperature fell below 5°C was read daily between September and April 1986-1991 from a biophenometer sited in a Stevenson screen at the nursery. Daily precipitation was also measured at the nursery. In both winters, the soil temperature at 10 cm depth below each species was recorded daily at 9.00 am GMT.

The effect of time and duration of storage was analysed using analysis of variance. Ranked data were used because treatment variances were not equal, even after arcsine and logarithmic transformations (in general, the variances increased with the length of storage). Unless stated otherwise, differences are described as significant if $P \leq 0.05$.

In both years, plants from the same beds as those used in the current experiments were cold stored as entire plants at intervals through winter and spring and outplanted on a second rotation site at Broxa in April (McKay and Mason, 1991; McKay *et al.*, in preparation). The relationships between root electrolyte leakage and survival obtained in these sister experiments (McKay, 1992) allow the reader to put leakage values of the current experiments into context.

Results

1989-90

Queen Charlotte Islands Sitka spruce

Initial leakage values of both plant types during October were approximately 20% (Figure la). During November and early December, initial leakage values decreased to *ca.* 18%. Initial leakage values fluctuated around this level during mid-December to mid-February before increasing gradually to *ca.* 10% by the end of March.

Early cold storage caused significant increases in root leakage after storage for 30 and 90 days indicating a deterioration in plant quality. Both plant types became more tolerant of cold storage as the date when they were placed in storage was delayed. By mid-November, leakage rates before and after 30 days' storage were not significantly different. Leakage rates after 90 days' storage were greater than initial rates for a further month but by mid-December pre- and post-storage rates were not significantly different. In general, mid-winter levels of tolerance were maintained until late March. Undercuts had lower leakage rates than transplants before and after 30 days' storage but values after 90 days' storage were similar.

Douglas fir

Initial leakage values from Douglas fir were higher throughout the experimental period than from Sitka spruce or Japanese larch (Figure lb). In October, initial leakage values were 30-35%. During November and early December, initial leakage values decreased to 17-18%. There were minor fluctuations around this level until mid-February when initial leakage began to increase gradually reaching a level of 20% by the end of March.

Leakage rates from fine roots which had been cold stored for 90 days were very high for all storage dates between October and the end of March. Leakage rates following 30 days' storage in October were also high (>60%) but decreased during November and December to 32%. Rates of electrolyte leakage rose again in plants stored in January before falling back to levels of 25 to 30% in plants stored in mid-February to the end of March.

Japanese larch

There was a decrease in initial leakage values from Japanese larch from *ca.* 22% in mid-October to *ca.* 11% in mid-December (Figure 1c). This level was maintained until mid-March when there was an increase to 15%.

Storage for 90 days at any time between October and April resulted in greater leakage than 30 days' storage. Leakage rates following storage fell during October and November. Least damage occurred to samples stored in December. Mid-winter initial leakage values were maintained until March yet storage for 30 and 90 days beginning from mid-January onwards increased leakage rates. Under-cutting in July and regular wrenching of larch during the following 3 months reduced leakage rates, particularly following storage.

1990-91

Sitka spruce of Queen Charlotte Islands provenance

In mid-November and early April, initial leakage values were 12% (Figure 2a). In the intervening months, initial leakage values decreased slightly reaching a minimum of 9% in early January. The greatest increase occurred in late March.

Plants stored in mid-November had greater leakage rates after 30 and 90 days' storage than before storage. As the time of lifting was delayed, the damage caused by storage decreased; by mid-December there was no significant damage after 30 or 90 days storage. Thereafter, there was little or no damage to roots stored throughout winter up to the latest storage date (April 1).

Douglas fir

The initial leakage values were lower than in 1989-90. Initial leakage values decreased gradually from *ca.* 21% during mid-November to mid-December to *ca.* 12% by the end of February through to mid-March (Figure 2b). In late March, the initial leakage values increased sharply.

After 30 days' storage, leakage values fell until mid-January when they were similar to pre-storage values. On the last two lifting dates, leakage values before and after 30 days were also close but on the intervening date, 25 February, there was a marked increase in leakage rates following 30 days' storage. After storage for 90 days' leakage rates were high (*ca.*40%) irrespective of the date of storage. The general pattern of leakage values after 90 days' storage with month of storage was generally similar to that after 30 days' storage.

Japanese larch

There was a gradual decline in the initial leakage values from 16% in November to 9% in March followed by a slight increase at the end of March (Figure 2c). During November and December, pre- and post-storage leakage rates were similar. Leakage rates of JL after both 30 and 90 days' storage increased slightly when plants were stored during early January, and dramatically when plants were stored after the end of February.

Sitka spruce of Oregon provenance

Sitka spruce of Oregon seed origin had initial leakage values which fell from 14% in November to 9% in late February before rising again in March (Figure 2d).

Storage for 90 days caused greater damage throughout the year than 30 days' storage. Leakage values following cold storage fell as lifting was delayed until mid-November. Thereafter the values before and after 30 days' storage were similar. Following 90 days' storage beginning from mid-December until late February, leakage values fluctuated around the 15% level. Storage for 90 days beginning in March resulted in much greater leakage rates than their initial values.

Sitka spruce of Alaska provenance

Sitka spruce of Alaskan seed origin had the lowest initial leakage values which fell from 11% in November to 8% by the end of January (Figure 2e). Initial leakage values increased slightly in late March to 11%. The

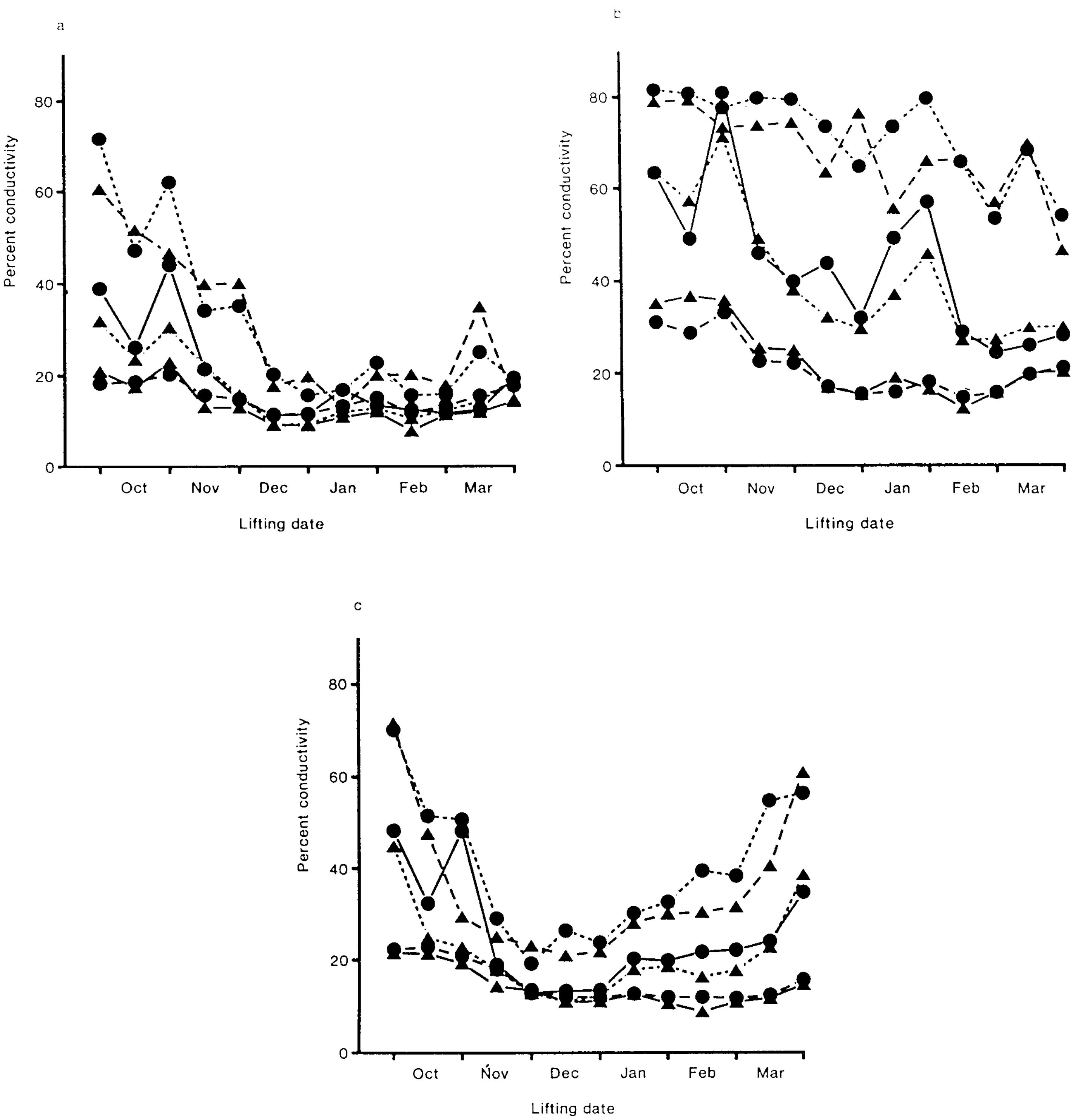


Figure 1. Electrolyte leakage rates from fine roots before (———) and after cold storage for 30 (– – – –) and 90 (-------) days in 1989-90. (a) Sitka spruce, (b) Douglas fir, (c) Japanese larch. Undercuts (▲) and transplants (●).

values following storage were not significantly different from the pre-storage values for all dates of storage between November and April.

Scots pine

The initial leakage rates (Figure 2f) fell from 14% in November to 9% in mid-January. This level was maintained until the end of February. Thereafter values increased slightly.

Storage for 90 days resulted in greater leakage than 30 days' storage throughout the winter of 1990-91. For both storage durations, leakage values after storage decreased as the storage time was delayed from November until the end of January. There was a slight increase in leakage from plants which had been put into cold storage for 90 days in February and early March while plants stored in late March had high post-storage leakage rates.

Meteorological data

The mean monthly air and soil (30 cm) temperature and rainfall recorded in September to March at High Mowthorpe (175 m asl, 54° 01'N, 0° 38'N), 5 km from Wykeham nursery, in 1989 and 1990 are given in Table 1. 1989-90 was exceptionally warm (for example the spring of 1990 was the warmest in central England since 1945) whereas 1990-91 was more typical of the long term average.

The numbers of hours when the air temperature at Wykeham nursery fell below 5°C in winters 1986-91 are shown in Figure 3. The chill hours in the two winters were broadly similar until the end of December after which chill hours accumulated more slowly in 1989-90 than in 1990-91.

Figure 4a illustrates the differences in the temperature of the rooting zone in the two years. Soil temperatures in 1989-90 were approximately 2°C warmer between late December and late February than in 1990-91. Though the temperature difference was smaller, there was also a tendency for the winter of 1989-90 to be warmer during the five previous weeks. Thus soil temperatures were generally higher in 1989-90 than in 1990-91 for the majority of the winter. The pattern of precipitation can be considered in three periods. During the central period (mid-December to mid-February) the winter of 1989-90 was on the whole wetter than in 1990-91 (Figure 4b). However during the periods November to mid-December and mid-February to late March it was drier in 1989-90 than in 1990-91.

Impact of different winter climates

The effect of the different climate can be seen by comparing Figures 1 and 2 for SS, DF and JL. In general, the differences between years in initial leakage rate of the three species were negligible or small and inconsistent. The only apparent trend was for lower initial values in March 1991 than in March 1990.

The post-storage leakage values from the fine roots of all three species were higher in the mild winter of 1989-90 than in 1990-91. In the case of SS, this was especially true for roots stored for 90 days. Hence in 1990-91, there was no deterioration following 90 days' storage beginning in mid-December to late February whereas the leakage rates following 90 days' storage commencing on similar dates the previous year were greater than the initial levels. For DF, leakage rates after both 30 and 90 days' storage were noticeably lower in 1990-91 with the result that there were occasions in 1990-91 when leakage rates after 30 days' storage were similar to initial values. In 1989-90, there was always a significant increase in leakage rates from DF after 30 days' storage. In the case of JL, 30 days' storage was possible with little or no increase from mid-November 1990 until late February 1991 whereas in the previous winter this was only possible up to late December.

Discussion

Sitka spruce had the greatest tolerance to cold storage of the species examined. Stock were stored for 30 days with no damage from late November in both years. In the more typical winter of 1990-91, 90 days' storage caused no root damage after late November and even in the unusually warm winter of 1989-90 the level of damage was acceptable after mid-December. Even in the exceptionally mild winter, QSS from Wykeham could be stored with little or no damage for 90 days, beginning as late as early April. This suggests that QSS cold stored in early April should be in an acceptable physiological condition to plant up to early July. In both years, there was a rise in leakage rate following storage for 90 days from mid-March. The reason for this is not clear. Therefore the cautious safe lifting dates for 90 days' storage of Sitka spruce of Queen Charlotte Islands origin are from mid-December to late February. In cold winters, the safe lifting dates can be brought forward by 2 weeks and extended for 4 weeks at the end of the season.

There are clear differences between northerly and southerly seed origins of SS. In typical winters, Alaskan Sitka spruce could be cold stored for at least 90 days on any date from mid-November until early April whereas early storage (mid-November) for 90 days resulted in root damage to QSS. Oregon SS was damaged, even in cold winters, by storage for 90 days especially when stored in November and late March.

Douglas fir was the least tolerant of the species tested. In mild winters, 90 days' storage at any time of the year caused severe damage to the root system. The root leakage value after 90 days' storage meaned over all storage dates was 70%. In previous experiments, DF with root leakage values of this level had 0% survival on a typical, second-rotation site when planted by research staff in April within 48 hours of leaving the cold store (McKay and Mason, 1991). In the colder winter of 1990-91, the mean leakage value afte 90 days' storage was 39% which is equivalent, in the experiment described above, to only 60% survival. Storage for 1 month

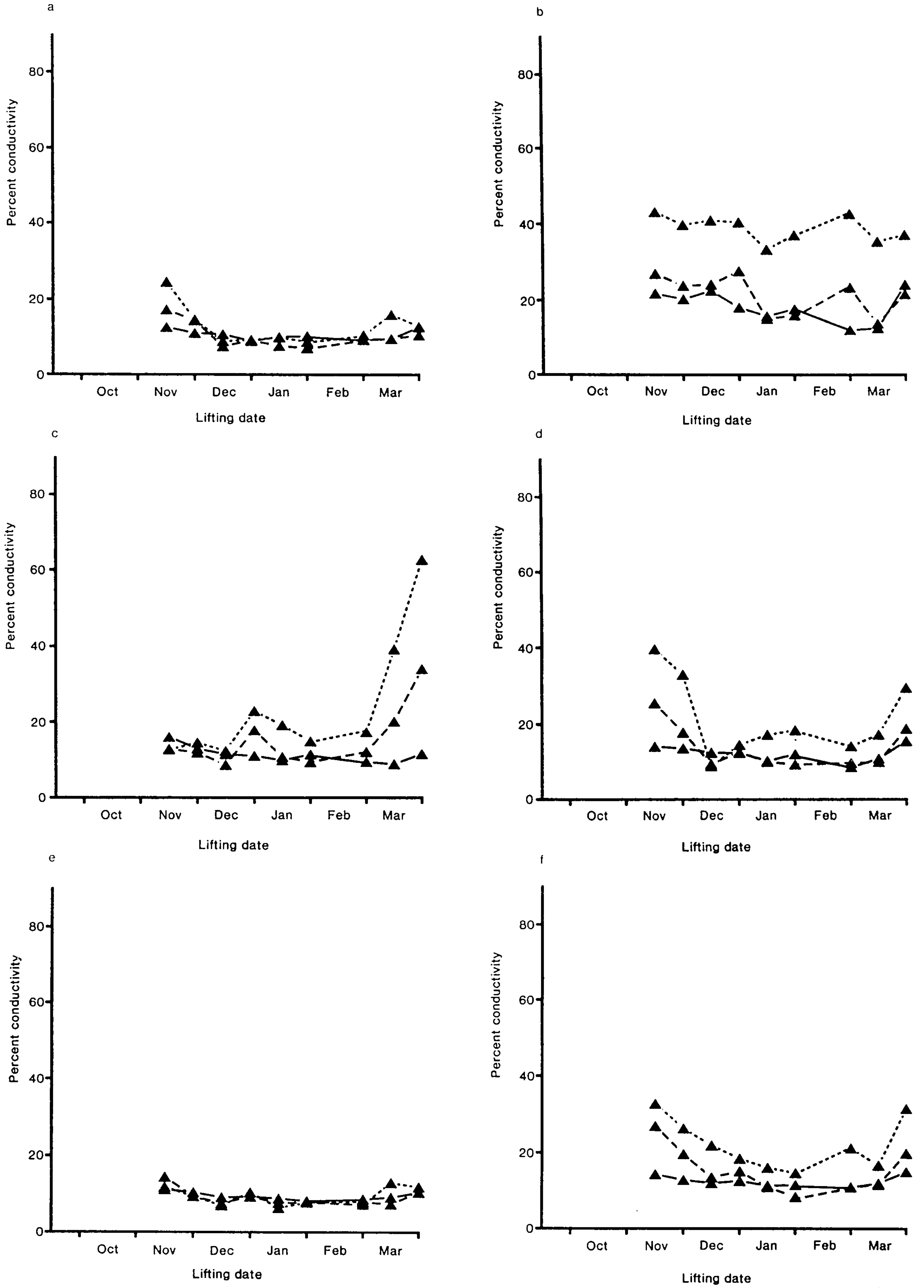


Figure 2. Electrolyte leakage rates from fine roots before (———) and after cold storage for 30 (– – – –) and 90 (-------) days in 1990-1991: undercuts of Sitka spruce of Queen Charlotte Island (a), Oregon (d) and Alaskan (e) origin, Douglas fir (b), Japanese larch (c) and Scots pine (f).

Table 1 Summary meteorological data at High Mowthorpe

Year	Record		Month Sept	Oct	Nov	Dec	Jan	Feb	March
1989-90	Air temperature:	mean(°C)	13.6	10.4	5.8	3.7	5.1	5.5	6.9
		mean deviation (°C) from 1951-81 average	+1.1	+0.9	+0.6	+0.4	+3.0	+3.3	+2.8
	Soil temperature:	mean at 30 cm depth (°C)	13.6	10.8	7.0	4.6	4.8	4.8	5.9
	Precipitation:	total (mm)	20	57	39	75	75	68	17
		percent of 30-year average	33	87	49	100	107	116	32
1990-91	Air temperature:	mean (°C)	11.9	10.9	5.9	3.6	1.9	0.8	6.6
		mean deviation (°C) from 1951-81 average	- 0.6	+1.4	+0.7	+0.3	- 0.2	-1.4	+2.5
	Soil temperature:	mean at 30 cm depth (°C)	13.3	10.8	6.8	4.0	2.2	-	5.9
	Precipitation:	total (mm)	41	74	65	102	58	87	51
		percent of 30-year average	67	112	82	136	104	147	94

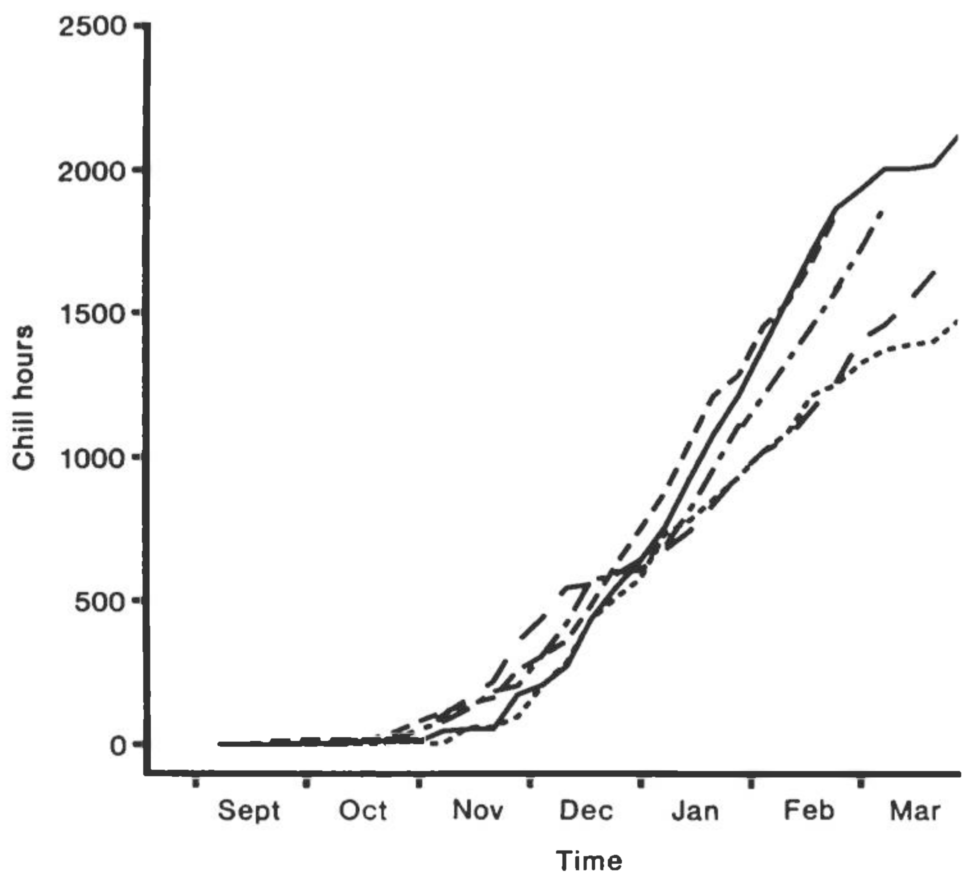


Figure 3. The accumulated chill hours < 5°C at Wykeham nursery in 1986-87 (-------), 1987-88 (–·–·–·–), 1988-89 (—— ——), 1989-90 (··············) and 1990-91 (————).

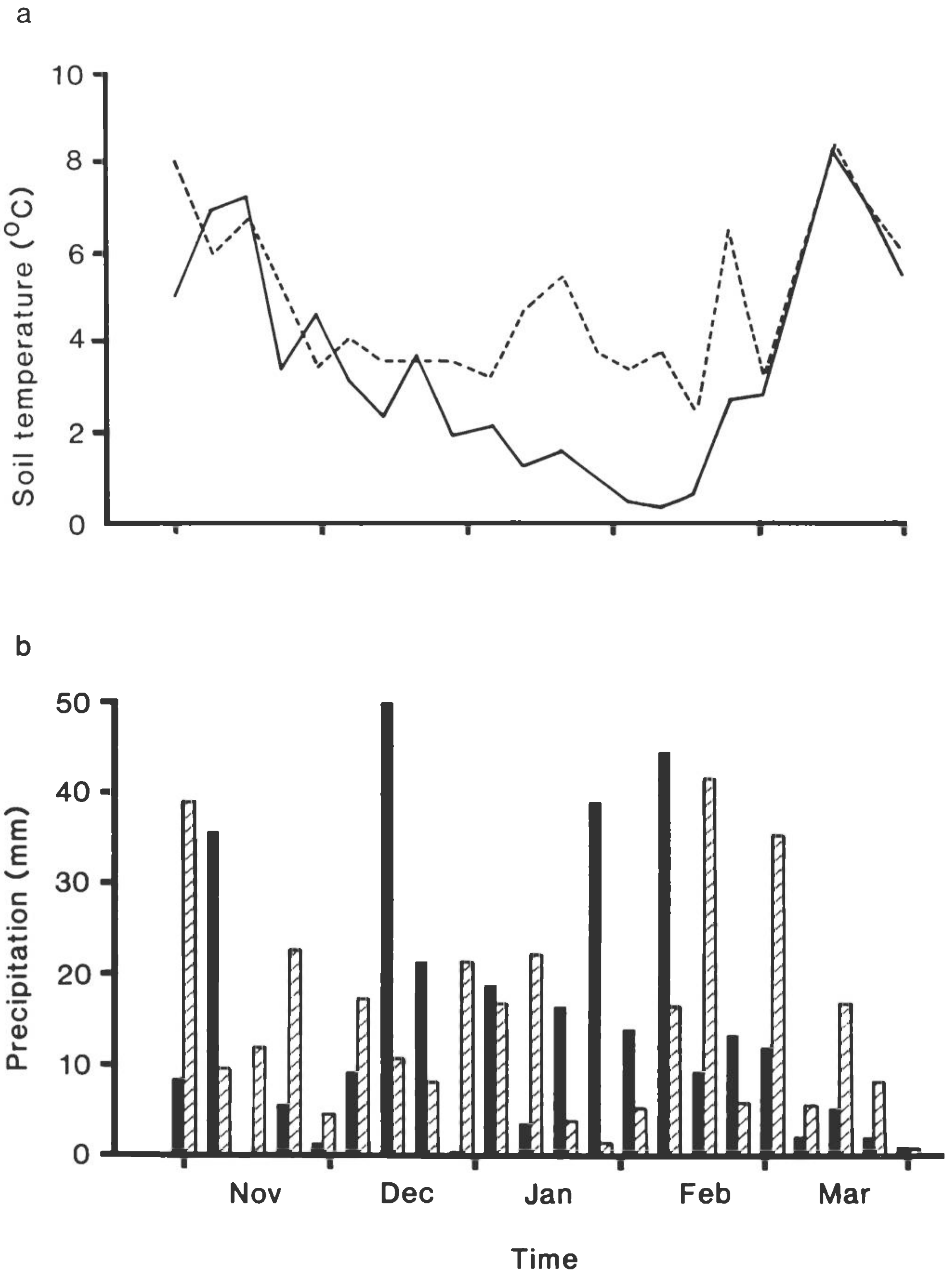


Figure 4. Meteorological data at Wykeham nursery. (a) mean weekly soil temperature at 10 cm depth under Sitka spruce, Douglas fir, and Japanese larch in 1989-90 (--------) and Sitka spruce , Douglas fir, and Japanese larch in 1990-91 (————); (b) total weekly precipitation in 1989-90 (solid bars) and 1990-91 (hatched bars).

without root deterioration was possible in 1990-91 in January, whereas in the previous year 1 month's storage caused significant damage at all storage dates. Based on this information it is suggested that in mild winters, i.e. when the mean weekly soil temperature at 10 cm depth does not fall below 3.5°C for two consecutive weeks, Douglas fir should not be cold stored, except perhaps for brief periods of less than 1 week. In cold winters, i.e. when soil temperatures at 10 cm depth fall below 2°C, Douglas fir can be cold stored for up to 30 days in mid to late January.

The response of Japanese larch to cold storage differs from that of both Sitka spruce and Douglas fir. In both cold and mild winters, Japanese larch was most tolerant of cold storage in December and was very sensitive to cold storage in March. The extent of damage caused by 30 and 90 days' storage was considerably greater in the mild winter of 1989-90 than in the more typical winter of 1990-91. For example, in 1989-90, the root leakage after 90 days' storage beginning in mid-January to early March was approximately 30%. This is equivalent to approximately 65% survival (McKay, 1992). In 1990-91, the mean leakage value after 90 days' storage beginning at the same times of year was approximately 17% – equivalent to 90% survival. The safest lifting dates for 90 days' storage of Japanese larch are therefore mid-November to late December. In cold winters, the lifting season can be extended until late February but cold storage of Japanese larch must not continue into March.

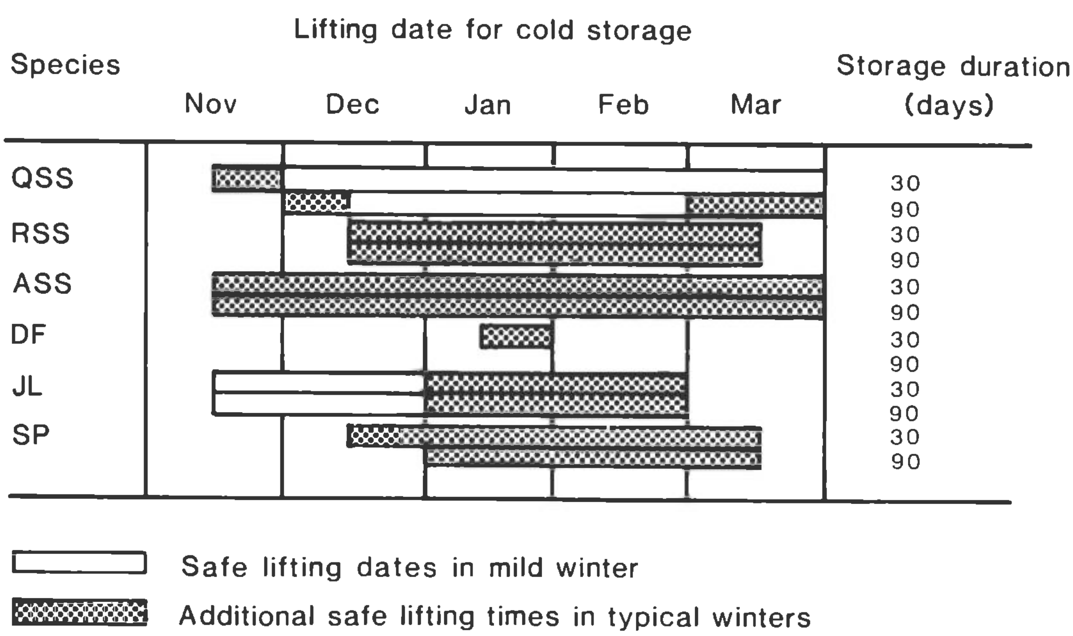
Scots pine was relatively intolerant of cold storage. Fine roots could not withstand cold storage for 30 days until mid-December and 90 days' storage caused damage at all times of year. Least damage during 3 months' storage occurred when plants were stored in early January to mid-March. Recommendations can be made for typical winters only: Scots pine can be stored for 1 month from mid-December to mid-March and for 90 days' from early January to mid-March.

The results presented here show that fine root electrolyte leakage is a useful way of detecting the deterioration of conifers during cold storage and by comparing the extent of deterioration during a range of winters it is possible to develop storage programmes. Electrolyte leakage from fine roots can also be used quickly to check the condition of plants in cold storage. However, nursery managers should ideally have rapid tests which are good indicators of cold storage tolerance to assess the physiological condition of their stock at regular intervals through the winter before the plants are lifted for cold storage. Research to provide these tests continues.

Summary

There were major differences between species and provenances of Sitka spruce in the ability to withstand cold storage. Undercutting and wrenching had minor benefits to the cold storage tolerance of Japanese larch and to a lesser extent Sitka spruce. The level of damage sustained during cold storage was much greater in the warmer winter of 1988-89. The recommended dates for cold storage at 1°C suggested by this work are summarised in Table 2.

Table 2 Recommended lifting dates for cold storage of Sitka spruce, Douglas fir, Japanese larch and Scots pine



Key:

QSS Sitka spruce of Queen Charlotte Islands provenance
ASS Sitka spruce of Alaska provenance
JL Japanese larch
RSS Sitka spruce of Oregon provenance
DF Douglas fir of Darrington, Washington
SP Scots pine

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