

Variation in Postharvest Quality among Nordmann Fir Provenances

Ulrik Bräuner Nielsen

Danish Centre for Forest, Landscape and Planning, Hørsholm Kongevej 11, DK-2970 Hørsholm, Denmark

Gary A. Chastagner

Washington State University Research and Extension Center, Puyallup, WA 98371

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Abstract. Needle retention is an important trait when selecting for high quality Christmas trees. Nordmann fir [*Abies nordmanniana* (Stev.) Spach.] is generally considered to have good needle retention, but recent research has shown that when cut trees are allowed to dry, significant needle loss problems can develop. This has the potential to limit the use of this species in situations where trees are harvested early, shipped long distances, sold in warm weather markets and displayed for extended periods of time. A set of 39 provenances were tested to identify provenance differences in needle retention. Branches were collected in two consecutive years in October in 1999 and 2000 and November 2000. Small branch samples were cut and displayed indoors under controlled conditions and allowed to dry. Strong provenance differences in needle loss were seen for all three test dates. No significant interactions were seen among the October collections, but significant rank changes occurred from October to November. Predicted (BLUP) provenance mean values ranged between 11% and 27% for needle loss when branches were allowed to dry, averaging all three tests. Despite only one test location, the study clearly indicates that it should be possible to select for provenances with generally better needle retention characteristics.

Nordmann fir [*Abies nordmanniana* (Stev.) Spach.] is an increasingly important species that is being used for cut Christmas trees and greenery products, especially in Europe. Denmark is the leading producer of nordmann fir Christmas trees and greenery products in Europe, producing about 8 to 9 million trees and an estimated 6,000 t of bough material per year (K. Østergaard, personal communication). Although work has been done to examine the genetic variation within nordmann fir provenances for characteristics such as flushing date, growth rates, foliage quality and number of branches per whorl (Larsen et al. 1984; Løfting, 1973; Madsen 1994), few studies have been done on characteristics such as needle retention that have a direct effect on consumer satisfaction with cut Christmas tree and greenery products. Nordmann fir is generally considered to have very good postharvest moisture and needle retention characteristics, but needle loss problems are known to occur

in certain years, especially for boughs that are harvested in early October (Chastagner and Riley, 2003; Christensen and Lundqvist 1999). This needle loss is characterized as a rapid loss of green needles in response to drying.

Recently it has been shown that it is possible to use small, detached branches to screen for needle loss problems in nordmann fir (Chastagner et al. 2000). To understand the genetic and environmental conditions that contribute to variation in needle loss among nordmann fir, a series of tests were conducted with a set of Danish sources and some imported provenances from the natural range of nordmann fir. These studies were conducted during October and November in two consecutive years to also get an indication of the year-to-year variation with respect to needle loss.

Materials and Methods

During 1999 and 2000, experiments were conducted to evaluate the variation in needle retention among 39 nordmann fir provenances. Tests were conducted during October and November to track the changes in needle retention patterns that occur during the fall.

Thirty-nine (39) provenances, 6 that are direct imports from Georgia (3), Russia (1), and Turkey (2), and 33 that are Danish seed sources of generally unknown origin, were used for a 2-year experiment conducted in Fall 1999 and 2000 (Table 3). These provenances are planted at six sites in Denmark, but only trees from a site at Langesø Estate (15 km northwest of Odense) were used. The field trial at Langesø was established in Spring 1994 us-

ing transplanted 4-year-old bare-root plants in a nearly randomized complete block design with five replications of 25 trees per provenance. Each replication consisted of a 5 × 5 group of trees planted on a 1.25 × 1.25-m spacing. Weed control and fertilization were done according to commercial standards. The climatic conditions during the fall were monitored by recording the daily temperatures at Langesø in 2000 and a site near Broholm in 1999 and 2000. Data were collected using a datalogger (Multilog-5; 12V, Ninasoft I/S, Denmark) with temperature measurements every 2 h at a height of 0.2 and 2.0 m. The lowest recorded temperature (out of the 12 per date) was recorded as the daily minimum temperature.

Sample collection. Tung branches, which are slightly shaded branches growing from the underside of a main branch, were used for these studies. Each tung was a one-cross (one-whorl) branch with 1-year-old and current year needles. The tungs were harvested from main branches from the 3rd to 6th uppermost whorl of the main stem. Tungs were harvested from the 39 provenances grown at Langesø on 2 Oct. 1999 as well as 3 Oct. and 14 Nov. 2000. A single tung was harvested from 10 randomly selected trees from each replication of each provenance. They were placed into labelled plastic bags, transported back to the Danish Forest and Landscape Research Institute and stored outdoors overnight. The branches were set up in a display room the following day. The same trees were sampled in 1999 and 2000 with the exception of a few trees that were removed by the grower in 1999.

Display room. The same two indoor display rooms were used for testing in both years. The rooms were 5.5 m long × 2.85 m wide × 3.4 m high and each room was furnished with two table frames (1 × 5 m) covered with hardware cloth netting with 2.5 × 2.5-cm square grids. Fans (45 cm in diameter) with plastic convection tubing that ran the length of the bench, were mounted underneath each table to provide continuous air circulation in the room. Each replicate plot sample from the field trial was placed through the hardware cloth frame as a 10-tree row plot using the original block structure from the field. In 1999, tungs were placed in every second row, whereas, in 2000 a system of two neighbouring rows of branch samples and then an empty row was used. This resulted in a higher density of tungs in the tables and in the rooms in 2000 than in 1999.

The room temperatures were set at 20 °C and temperature and relative humidity were measured using a hygrothermograph that was calibrated with a sling psychrometer.

Measurements. Needle loss was rated on the 3rd, 7th, and 10th day after placing the tungs in the display room. The samples were gently rubbed between the fingers and the extent of needle loss was rated on a 0 to 7 scale, where 0 = no needle loss, 1 = <1%, 2 = 1% to 5%, 3 = 6% to 15%, 4 = 16% to 33%, 5 = 34% to 66%, 6 = 67% to 90%, and 7 = 91% to 100% needle loss. An average needle loss rating and the percentage of trees with a rating >1 was calculated for each replicate plot of each provenance.

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¹Geneticist; e-mail ubn@fsl.dk.

²Plant pathologist; e-mail chastag@wsu.edu.

Table 1. Mean temperatures and degree days (<17 °C) for 1999 and 2000 and the norms from 1971–90 for degree days and 1961–90 for mean temperature (Cappelen, 2000; Cappelen and Jørgensen, 2001).

Month	1999	2000	Norm
Mean temperature			
September	16.2	13.2	12.7
October	9.4	11.0	9.1
November	5.5	7.0	4.7
Degree days			
September	35	115	136
October	237	186	251
November	343	300	361

Tungs were also visually examined to determine if samples came from hybrid type trees. Hybrid type trees are considered to be a cross between nordmann fir and european silver fir (*A. alba* Miller). The hybrid types typically are characterized by shorter needles with a very flat needle orientation, as well as a grayer bark. The percentage of hybrid types was estimated only in October 1999.

The number of dry tungs were also assessed based on visual examination. Dryness was characterized by pale green, brittle needles. The percentage of dry tungs was estimated after adjustment for the number of tungs with total needle loss since the dryness of a tung with no needles could not be evaluated using this method.

Statistical analysis. Statistical analysis of needle loss was carried out on replicate plot means and the percentage of tungs with needle loss ratings >1. The percent dry needles and percent hybrid types were also analysed. The program package SAS was used for the analysis of variance using the GLM procedure (SAS 8.02, SAS Inst. Inc., Cary, N.C.).

The model used for single traits and days:

$$Y = b + P + e \quad [1]$$

where Y = observed value of plot mean for the given trait, b = fixed effect of block, P = random effect of provenance, and e = error assumed NIID. Each provenance was expected to be a random sample of the future seed crops from the given stand.

For each measurement, an analysis across the tests was carried out using the following model:

$$Y = t + b(t) + P + Pxt + e \quad [2]$$

where Y = measured trait, t = fixed effect of test, b(t) = fixed effect of block within test, P = random provenance, Pxt = random provenance by test interaction, and e = error assumed NIID.

Homogeneity of variance was tested by plotting residual vs. predicted values and the UNIVARIATE procedure for testing the assumption of normally distributed errors. There were minor deviations from the assumption of normality and some lack of homogeneity was seen, but not in a manner that affected the analyses seriously.

Ecovalence, the contribution of a genotype to the total genotype × environment interaction (GE) estimated in model 2 as Pxt, was calculated for each provenance according to Wricke (1962, 1964) and interpreted as stability in an agronomic concept, i.e., small

ecovalence values are preferred, as described by Becker (1981).

Based on model 1, predicted (BLUP) values for provenance means for each test were estimated using the MIXED procedure. Provenance values were estimated as deviations from overall provenance mean. Components of variance in model 2 were estimated using the VARCOMP procedure with the REML option.

Results and Discussion

Climatic conditions

Compared to the norm for the period 1941 to 1980, the mean fall temperatures in Denmark during 1999 were very high in September and just a little above normal for October and November (Table 1). In 2000, September was about average or a little warmer, whereas, November was very warm having an average temperature 2.3 °C above normal. No frost was recorded before harvest in mid-November 2000 (Cappelen 2000, Cappelen and Jørgensen 2001).

In 2000, the daily minimum temperature at the Langesø and Broholm sites were similar (Fig. 1). Because of incomplete data due to equipment problems at Langesø in 1999, data for 1999 and 2000 from a very similar site 30 km away in Broholm was also collected.

The temperature data from the Broholm site also indicates that the fall temperatures in 2000 were much warmer than 1999, with no frosts even in November.

Needle loss

Year-to-year variation. In 1999, the overall percentage of trees with needle loss rating >1 for the 39 provenances was 27% in October. Considering the mild temperatures in 2000, the amount of needle loss in October 2000

was unexpectedly low, with an overall average of 9%. This increased across all provenances to 17% in mid-November. The effect of test is highly significant for all measured traits (Table 2).

Provenance variation. Provenances showed significant differences for all traits measured at day 7 and 10 except for the percentage of tungs with 1-year-old needle ratings >1 at day 7 (Table 2). The provenance differences were more pronounced at day 10 than at day 7 and there was a strong interaction between provenance and test date for all traits (Table 2).

For all needle loss characters, the estimated components of variance for the interaction between provenance and test were of the same magnitude or a little higher than the provenance effect alone. The percentage of branches with dry needles seems more independent of test day than the needle loss because 25% of the total random variation is due to provenance and only 9% due to interaction at day 10.

Results from the 1999 and 2000 October harvests were similar, indicated by a correlation of 0.50 ($p = 0.0012$) for the predicted needle loss values for October 1999 and October 2000, whereas, the November needle loss results in 2000 did not correlate significantly to any of the other two test dates. Looking more closely at the provenance × test date interaction by use of ecovalence showed that five provenances (137, 263, 128, 271, 262) accounted for 46% of the total interaction variance (Table 3).

Despite the interactions, there seems to be a group of provenances having 4% to 7% fewer trees with needle loss ratings >1 compared to the average on all test dates. Furthermore, there is a group of provenances having 5% to 9% more trees that are prone to have needle loss ratings >1 compared to the average group of provenances.

Only five provenances had >5% of their

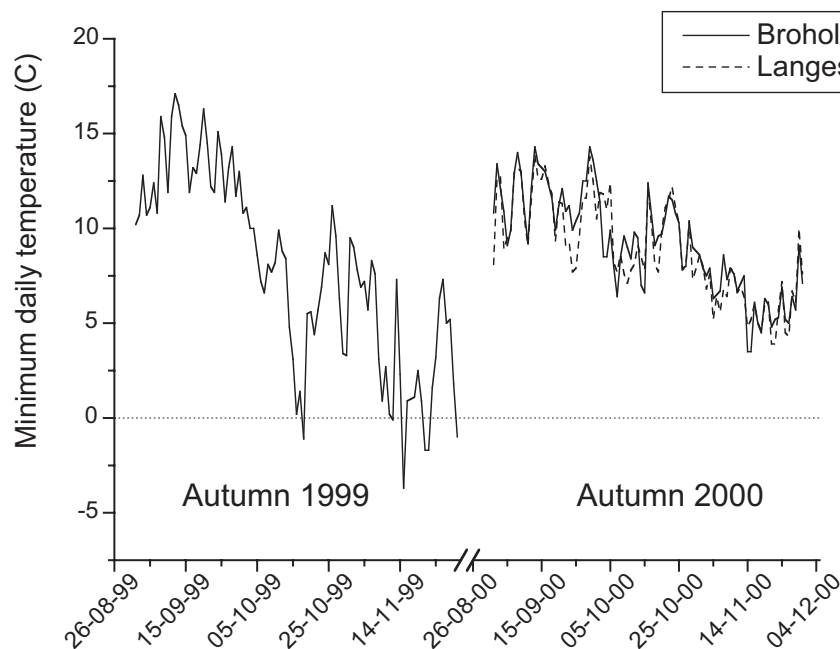


Fig. 1. Daily minimum temperatures from September to November during 1999 and 2000. Because of incomplete data due to equipment problems at Langesø in 1999, data for 1999 and 2000 from a very similar site 30 km away in Broholm is also plotted.

Table 2. Results from analysis of variance and estimated components of variance for random effects shown as total variation (Total) and the percentage contribution of provenance effect (Prov), provenance × test interaction (Prov × test) and error. Data included are from October 1999, October and November 2000. Due to very low frequencies of tungs with dry needles at day 7, the data were not suitable for an analysis of variance.

Characteristic	Provenance overall mean	ANOVA significance levels		Components of variance					
		Test	Block (test)	Prov	Prov × test	Total	Prov (%)	Prov × test (%)	Error (%)
Day 7									
Last year's needles (score)	0.57	<0.0001	0.3586	0.0308	0.0001	0.31922	6.7	14.3	79.0
Current year's needles (score)	0.73	<0.0001	0.0008	0.0035	0.0001	0.35986	10.2	13.0	76.8
Severe damaged, last year's needles (%)	11.4	<0.0001	0.1397	0.0692	0.0005	0.01363	4.8	12.3	82.9
Severe damaged, current year's needles (%)	15.5	<0.0001	<0.0001	0.0135	<0.0001	0.01692	8.6	16.1	75.3
Dry needles (%)	1.7								
Day 10									
Last year's needles (score)	0.65	<0.0001	0.0277	0.0054	0.0004	0.35992	9.2	11.7	79.1
Current year's needles (score)	0.84	<0.0001	<0.0001	0.0011	0.0003	0.41254	11.7	11.9	76.3
Severe damaged, last year's needles (%)	13.1	<0.0001	0.0088	0.0232	0.0029	0.01508	6.4	9.9	83.7
Severe damaged, current year's needles (%)	17.7	<0.0001	<0.0001	0.0041	<0.0001	0.01930	10.1	13.4	76.5
Dry needles (%)	13.6	<0.0001	<0.0001	<0.0001	0.0006	0.02014	24.8	9.4	65.8

trees with the flat needle characteristic that is indicative of hybridization with European silver fir (Table 3). Two provenances (101, 128) had a very high number of hybrid types, with averages of 38% and 30%, respectively. A group of three provenances (129, 168, 9686) had between 12% and 16% hybrid types. The two provenances having the highest number of hybrid types also had the highest needle loss ratings. The other three provenances with the next highest number of hybrid types exhibited poor to average needle retention. Based on all provenances, there is a correlation of 0.40 ($p = 0.0118$) between the percentage of trees with needle loss ratings >1 and frequency of hybrid types. Detailed results are only given for needle loss on current-year-needles (Table 3). However, predicted values across tests for 1-year-old needles correlated very well with the results for current-year-needles ($r = 0.83$, $p < 0.0001$).

It should be noted that some of the other nordmann fir provenances that had low frequencies of hybrid types (<5%) were direct imports from its natural distribution area where European silver fir does not occur. Therefore, it is likely that not all of the flat needle characteristics on the tungs were the result of hybridization.

Dry branches. The percentage of tung branches with dry needles on day 10 ranged from 6% to 37% (Table 3). Provenance 137, Svenstrup Bastbjerg dept. 130, had a very high number of dry branches. Three provenances, including the two poorest ones, contributed more than 30 percent to the provenance by test interaction.

Needle retention is an important trait when selecting for high quality Christmas trees. Nordmann fir is generally considered to have good needle retention, but recent research has shown that when cut trees are allowed to dry, significant needle loss problems can develop (Chastagner and Riley, 2003). This has the potential to limit the use of this species in situations where trees are harvested early, shipped long distances, sold in warm weather markets and displayed for extended periods of time. Although drying may not be as important an issue in European markets, where

trees tend to be displayed indoors for a limited number of days, in North American markets where trees are often set up in homes after the Thanksgiving holiday in late November, many studies have shown that one of the major concerns consumers have regarding the use of cut Christmas trees is needle loss. Needle loss problems can also adversely affect the quality of nordmann fir boughs when they are allowed to dry (Christensen and Lundqvist, 1999).

During our studies, branches with >1% needle loss were considered to be unacceptable. Under normal growth conditions and standard fertilization regime, the total dry needle weight of a two-meter tall nordmann fir is about 2,000 g. An individual needle weighs about 0.01 g (M. Ingerslev, personal communication). This means that a standard-size 2-m-tall tree will have about 200,000 needles. Therefore, needle loss of 1% equals 2,000 needles. If needle loss is evenly distributed between needle age classes, it may not affect the visual quality of the tree, but from the point of view of the consumer, who is expecting little to no needle loss, 2,000 needles on the living-room floor is probably above an acceptable level. With some of the provenances, needle loss ratings were >1 after only 3 d.

Nordmann fir can readily hybridise with European silver fir. Two methods, visual evaluations, similar to those used in this study, and the analysis of phenolic compounds in the needles have been used to identify hybrids between these two species (Hansen and Nielsen, 2001). In other postharvest studies, European silver fir has exhibited very poor needle retention (Chastagner and Riley, 2000) and probably explains why none of the provenances in this study that had the highest percentage of hybrid types had good needle retention. Although there were some tungs from direct import provenances such as Borshomi, which were recorded as hybrid types, it is much more likely that true hybrids occur in Danish provenances that sometimes are planted in close proximity to stands of European silver fir. However, there is a large variation in needle structure within stands, and presumably, a few nonhybrids were misidentified as hybrid types within provenances originating from the

natural distribution of Nordmanns fir like the Borshomi provenance (4%).

It is well documented that the physiological changes that occur during the fall can have a significant effect on the postharvest quality of cut Christmas trees and bough material. For instance, fraser fir, which is normally considered to have excellent moisture and needle retention, can have significant needle retention problems if there are relatively warm conditions before harvest (Mitcham-Butler et al. 1988). By conducting some of our tests in October, we were trying to increase the likelihood of needle loss problems in an effort to identify provenances that would have minimal needle loss when weather conditions before harvest were unseasonably warm, such as they were in November 2000.

It is presumed that the large differences in the climatic conditions during 1999 and 2000 caused the very different pattern in the needle loss in October compared to November. Christensen and Lundqvist (1999) have shown that needle loss on nordmann fir diminished almost linearly from early to late fall in 1 year. In 2 other years, the trend for diminished needle loss was seen, but needle loss level fluctuated depending on the temperature 7 to 11 d before harvest of test branches.

The data from October harvests showed no provenance by year interaction. However, including November 2000 in the analysis created a strong interaction and also rank changes between provenances. Christensen and Lundqvist (1999) further showed that single trees respond with different patterns through the autumn, and that needle loss on some of the needle shedding trees was fluctuating more than for a group of nonshedding trees. It is likely that some of the rank changes from October to November in the 2000 study is related to different response patterns to climatic or other season related factors.

This provenance study was only conducted on one site. A limited provenance × site interaction study involving five provenances, three sites and two harvest dates, indicated provenance rank can change among sites and time (Nielsen and Chastagner, unpublished data). Although additional studies are

Table 3. Predicted Day 10 current-year-needle loss values and frequency of dry needles for each provenance and test. Values are given as frequencies and deviation from mean. All = average value across all three test dates and Oct. = average values of Tests 1 and 2. Test 1 = harvest 2 Oct. 1999, Test 2 = harvest 3 Oct. 2000 and Test 3 = harvest 14 Nov. 2000. Hybrid types were measured in Test 1 only.

No.	Provenance	Needle loss current year							Hybrids		Dry needles					
		Average					Ecov.		%	Average					Ecov.	
		All	test 1	test 2	test 3	FREQ	Oct.	%		test 1	All	test 1	test 2	test 3	Oct.	%
131	Boller Ussinggård annekts dept.239d	-0.07	-0.11	-0.02	-0.08	3.00	-0.06	3	-1.3	-0.08	-0.13	-0.01	-0.09	-0.07	4	
142	Farum Sønderskov dept.650e (1989)	-0.07	-0.11	-0.04	-0.05	3.00	-0.07	2	0.5	-0.04	-0.10	0.00	-0.04	-0.05	3	
1142	Middelfart Batteri (late flushing)	-0.06	-0.07	0.00	-0.10	3.00	-0.04	3	-3.1	-0.07	-0.13	-0.01	-0.08	-0.07	4	
313	Russia, Arkyz, Stavropol, district Zelenckuk	-0.05	-0.04	-0.01	-0.11	3.00	-0.03	2	-3.1	-0.03	-0.01	0.00	-0.07	0.00	1	
230	Svenstrup Grønholt Lodde dept.278	-0.04	-0.07	-0.02	-0.04	3.00	-0.04	1	-3.1	0.01	0.04	-0.01	0.02	0.01	1	
130	Boller Ussinggård annekts dept.235e	-0.04	-0.06	0.01	-0.05	3.00	-0.03	2	-3.1	-0.03	-0.07	-0.01	-0.02	-0.04	1	
231	Ryegård dept.18g	-0.03	0.00	-0.02	-0.07	3.00	-0.01	1	-3.1	-0.08	-0.14	-0.01	-0.08	-0.08	4	
178	Georgia, Ambrolauri Tlugi	-0.03	0.02	-0.01	-0.08	3.00	0.00	2	-3.1	0.04	0.09	-0.01	0.05	0.04	3	
94	Vallø Storskov dept.274	-0.02	-0.05	-0.03	0.01	3.00	-0.04	1	-3.1	-0.06	-0.08	-0.01	-0.08	-0.05	2	
233	Sorø Sønderskov Vindelbro dept.824	-0.02	-0.04	-0.02	-0.01	3.00	-0.03	0	-3.1	-0.03	-0.05	-0.01	-0.04	-0.03	0	
136	Uggerby dept.775a (1989)	-0.02	-0.03	-0.03	-0.01	3.00	-0.03	0	-1.3	0.00	-0.04	-0.01	0.05	-0.03	2	
138	Ryegaard dept.8c	-0.02	-0.03	-0.02	0.00	3.00	-0.02	0	-3.1	-0.08	-0.13	-0.01	-0.08	-0.07	4	
134	Tversted dept.599a	-0.01	-0.04	-0.02	0.02	3.00	-0.03	1	-3.1	0.01	0.05	-0.01	0.01	0.02	1	
262	Georgia, Djava Tskhinvalskij region	-0.01	-0.09	0.00	0.05	3.00	-0.04	6	-3.1	-0.01	0.00	-0.01	-0.02	0.00	0	
132	Boller Lystrup dept.208f	-0.01	-0.02	-0.02	0.00	3.00	-0.02	0	-3.1	-0.04	-0.08	0.00	-0.03	-0.04	2	
11587	Tversted dept.623a (1987)	-0.01	0.01	0.00	-0.04	3.00	0.00	1	-3.1	0.04	0.09	0.01	0.02	0.05	2	
139	Sorø Harrested dept.962e	-0.01	-0.05	-0.02	0.05	3.00	-0.04	3	-1.3	0.00	0.00	0.00	-0.01	0.00	0	
135	Tversted dept.623a (1989)	-0.01	0.05	-0.03	-0.04	3.00	0.01	4	-1.3	-0.01	0.00	-0.01	-0.01	0.00	0	
129	Boller Kærskov dept.205b	0.00	-0.01	-0.01	0.01	3.00	-0.01	0	11.0	-0.07	-0.11	0.00	-0.09	-0.06	4	
137	Svenstrup Bastebjerg dept.130	0.00	0.00	0.08	-0.10	3.00	0.04	13	-3.1	0.23	0.34	0.12	0.22	0.23	12	
124	Gråsten Frøslev plgt. dept.640b	0.00	-0.04	0.01	0.03	3.00	-0.02	2	-3.1	-0.04	-0.07	-0.01	-0.05	-0.04	1	
126	Boller Klokkeal dept.64a	0.00	0.04	-0.01	-0.02	3.00	0.01	2	0.5	-0.04	-0.04	-0.01	-0.07	-0.03	1	
140	Sorø Sønderskov Vindelbro dept.772e	0.00	-0.01	0.02	-0.01	3.00	0.01	1	-1.3	0.01	0.03	-0.01	0.01	0.01	1	
128	Boller Kærskov dept.203g	0.00	0.08	0.01	-0.08	3.00	0.05	8	23.3	0.05	0.09	0.01	0.05	0.05	2	
11486	Langesø dept.36 (1986)	0.01	-0.01	-0.01	0.03	3.00	-0.01	1	-3.1	0.00	0.05	0.01	-0.07	0.03	4	
143	Farum Sønderskov dept.654a	0.01	0.02	0.00	0.01	3.00	0.01	0	-3.1	-0.02	-0.02	0.00	-0.04	-0.01	0	
234	Sorø Bodal-Lårup dept.117	0.01	0.03	0.04	-0.04	3.00	0.03	3	-3.1	0.03	0.03	0.03	0.02	0.03	0	
133	Boller Lystrup dept.209a	0.01	0.00	-0.04	0.07	3.00	-0.02	4	-3.1	-0.01	0.02	-0.01	-0.05	0.00	1	
179	Georgia, Borshomi	0.01	-0.01	-0.02	0.06	3.00	-0.01	2	0.5	0.07	0.08	0.00	0.12	0.04	4	
263	Georgia, Sjovi Onskij region	0.02	0.12	0.01	-0.07	3.00	0.06	11	-3.1	0.07	0.17	0.01	0.03	0.09	7	
271	Turkey, Trabzon Torul Saricdagi	0.03	-0.05	0.02	0.12	3.00	-0.02	8	-3.1	0.01	0.00	-0.01	0.03	0.00	1	
165	Langesø dept.6	0.03	0.03	0.02	0.05	3.00	0.02	0	-3.1	-0.04	-0.02	0.00	-0.11	-0.01	4	
125	Østre Palsgård Toftekov dept.160	0.03	0.03	0.00	0.08	3.00	0.01	2	-3.1	0.06	0.09	0.00	0.08	0.05	3	
168	Langesø dept.20	0.05	0.08	0.03	0.02	3.00	0.06	2	9.3	0.01	-0.04	-0.01	0.08	-0.03	4	
177	Turkey, Artvin Ortaköy	0.05	0.08	0.04	0.02	3.00	0.06	2	-3.1	0.07	0.07	0.05	0.08	0.06	0	
166	Langesø dept.88	0.05	0.08	0.02	0.05	3.00	0.05	2	0.5	0.01	0.03	-0.01	0.01	0.01	1	
1141	Middelfart Batteri (ordinary)	0.05	0.10	0.02	0.04	3.00	0.06	2	-3.1	-0.02	-0.04	-0.01	-0.02	-0.03	0	
101	Rathlousdal Tornsbjerg dept.650	0.08	0.05	0.02	0.15	3.00	0.04	3	30.4	0.03	-0.04	-0.01	0.15	-0.03	12	
9686	Falster dept.74b (1986)	0.09	0.11	0.04	0.14	3.00	0.07	1	7.5	0.07	0.06	0.00	0.13	0.03	5	
Average values (frequencies)		0.18	0.27	0.09	0.17		0.18		3.5%	0.14	0.22	0.02	0.17	0.12		

needed, this means that it is important to be cautious when trying to use the results from a single site to predict how much needle loss a given provenance will have when grown at another site.

The tendency for dry branches to develop after 10 d seems to be more provenance dependent than needle loss. Dry shoots may also be related to other traits, such as size, which is provenance dependent (Madsen 1994). One of the problems with the dry shoot data is that there is an autocorrelation between dry branches and needle loss due to the fact that branches which have shed all their needles will never be recorded as dry, because dry is a needle characteristic. Partial needle loss is also likely to reduce the rate of moisture loss and thus affect this rating.

Based on the results of the tests with the 39 provenances, it is clear that growers should avoid provenances that have a high percentage of hybrid type trees, even if some of these have other desirable characteristics, because of the high level of needle loss associated with these

provenances. Madsen and Christensen (1994) evaluated the same 39 provenances in the nursery just before field establishment. The top eight ranking provenances from the nursery evaluation for flat needle structure includes the five most pronounced hybrid types in this experiment. This suggests that it may be possible to rough hybrid types in the nursery, but the identification of hybrids in the nursery is more difficult. Although, all of the provenances included in these tests exhibited some degree of needle loss, these tests also indicated that there is a relatively large amount of provenance variation with respect to needle loss, even at low needle loss levels. This means that growers can significantly improve the postharvest quality of their product by choosing certain provenances.

Given the level of variation in needle loss between some provenances (Table 3), it should be possible to predict which provenances are likely to shed. There also appear to be some very stable provenances. If the main criteria for selecting a provenance is low needle loss (Table

3) followed by a below average tendency to develop dry needles, the top three provenances in this study would be 142, 131, and 313 followed by 130, 231, and 94. Another provenance, number 230, is omitted because it has a fairly high number of dry branches. Although 1142 is among the top 25% of provenances for needle retention, it should not be considered because it represents a selected harvest of late-flushing individuals from the stand, while the standard harvest from the same stand (1141) had the third poorest needle retention in the study—quite a difference for the same stand. The better needle retention of the late-flushing selected individuals appears to be related to fewer hybrid types and would be expected because hybrids tends to flush earlier. Such relatively large differences within a single stand due to harvesting selected trees could indicate a strong genetic component for needle loss, which also is indicated by progeny testing (Nielsen and Chastagner, unpublished data).

While additional studies are clearly needed to obtain a better understanding of the factors

contributing to the possible provenance x site interaction and the apparent influence climatic variation has on needle loss, these studies still indicate that there were stable performing provenances among the 39 tested. This indicates that it should be possible to select for provenances with generally better needle retention characteristics, although several other traits also have to be considered for growing high quality Christmas trees. Among the Danish sources—of mostly unknown original origin—that were included in these tests, needle retention varied from very good to very poor. Overall, the Turkish sources tended to have lower needle loss problems than some of the Danish sources, but given the limited number of sources of Russian and Georgian material included in our tests, it was not possible to determine if there were geographic patterns associated with needle retention.

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