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Geographic Variation of *Abies grandis*-Provenances Grown in Northwestern Germany[1])

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Summary

In 3 field trials in northwestern Germany height and diameter growth as well as mortality of 52 provenances of Grand fir (*Abies grandis* LINDL.) up to the age of 15 years were investigated. Fast growing provenances originate from the East of Vancouver Island and the Olympic Peninsula, the West of the Cascade Range and – with exceptions – from the coastal regions of Oregon. But provenances from the South of the last mentioned region show the highest plant losses and a high percentage of forked trees. In general a rather large variation within provenances was observed. The estimated correlation coefficients between height at age 15 and some geographic variables are weak. In the years after planting pronounced rank changes occurred. Height growth seems to stabilize at a plant age of about 7 or 9 years. Finally wood properties of Grand fir and the silvicultural possibilities to influence them are discussed.

Key words: Grand fir (*Abies grandis*), provenances, height and diameter growth, mortality, correlations, rank changes, wood properties and silviculture.

FDC: 232.11; 232.12; 165.5; 174.7 *Abies grandis;* (430).

Zusammenfassung

Auf 3 nordwestdeutschen Versuchsorten wurde das Höhen- und Durchmesserwachstum sowie die Mortalität von 52 Küstentannen-Provenienzen bis zum Alter von 15 Jahren untersucht. Raschwüchsige Provenienzen stammen vor allem aus folgenden Regionen: Ostseite von Vancouver Island und Olympic Peninsula, Westseite der Kaskaden und – mit Ausnahmen – Küstenregion Oregons. Herkünfte aus dem südlichen Teil der zuletzt genannten Region zeigen aber die höchsten Pflanzenausfälle und den höchsten Anteil an zwieseligen Stämmen. Innerhalb von Provenienzen ist eine ausgeprägte Differenzierung feststellbar. Die geschätzten Korrelationskoeffizienten zeigen nur schwache Zusammenhänge zwischen der Höhe im Alter von 15 Jahren und einigen geographischen Variablen. In den Jahren nach der Versuchsbegründung findet eine ausgeprägte Rangverschiebung der Provenienzmittelwerte statt. Etwa ab dem Alter von 7 oder 9 Jahren scheint sich das Höhenwachstum zu stabilisieren. Abschließend wird auf die Holzeigenschaften der Küstentanne eingegangen und die waldbaulichen Möglichkeiten einer Beeinflußung derselben diskutiert.

Introduction

Grand fir (*Abies grandis* LINDL.) was first introduced to Germany some 120 years ago (KILLIUS, 1931) and several stands have shown good to excellent growth. Some examples: HEWICKER (1988) reported on a Grand fir stand in northern Germany on poor sandy soils, where the tallest trees had at an age of 56 years a height of 33 m. DONG et al. (1990) compiled growth and yield data of a Grand fir stand mixed with Douglas fir in southern Germany. At the age of 58 years Grand fir had reached mean heights of 35.9 m and was 5 m taller than the Douglas fir. In a review leaflet on Grand fir the opinion is issued that on good sites at an age of 80 years heights of 50 m and breast height diameters of 100 cm can be expected (Anonymus, 1987).

In the natural habitat the species performs well on different types of sites (QUERENGÄSSER, 1959; HERMANN, 1981), but it does not grow well on compacted soils with stagnant water and oxygen deficiency. German investigations have revealed that on these sites Grand fir is not able to develop an appropriate tap root system (KREUTZER et al., 1988) and it is therefore not able to replace our indigenous silver fir (*Abies alba* MILL.), which has been destroyed by air pollution in several regions. Grand fir is to a limited extent used as well as Christmas tree and early returns are gained by selling branches for covering or ornamental purposes. But nevertheless a large scale planting is generally not recommended. In Schleswig-Holstein, the northernmost state in Germany, planting recommendations are limited to poor sandy soils which are influenced by ground water. These sites are too poor for Norway spruce and too cold for Douglas fir, and Scots pine may suffer from a needle cast disease (ROEHRING, 1988). In Lower Saxony 2 management goal

[1]) Dedicated to Dr. G. H. MELCHIOR on his 70th birthday.

types with Grand fir are established: a) Grand fir as the main species mixed with beech and b) Douglas fir mixed with Grand fir (OTTO, 1989). Other types are still in an experimental phase. In the southwest of Germany WEIDENBACH and SCHMIDT (1988) recommend the use of *Abies grandis* for the outplanting of holes in spruce stands which were caused by snow break or for sites which are still suited for Douglas fir, but are already rather dry. A mixture with other species, especially Douglas fir, and a comparatively short rotation time decreases the risk of early losses.

Considering the available figures on areas of older plantations (e.g. STRATMANN, 1988), Grand fir is not at the top of introduced North American conifer species in Germany. It ranks after Douglas fir, Eastern White pine and probably after Sitka spruce. But in the past decades many young plantations have been established, especially advanced plantings or underplantings. ROERING (1988) reports for Schleswig-Holstein a plantation area of Grand fir of about 1500 ha, and in the state forests the percentage has increased to 2.8%.

From the point of view of forest reproductive material moving into trade Grand fir has been considered that important, that it was included into the list of species, which are underlying the German law on forest seeds and plants from 1979. This implies that seed must be collected only from approved selected stands and the import of forest reproductive material is regulated. According to statistics, in 1993 only 10.6 ha of German Grand fir stands were approved as seed stands (Anonymus, 1993), and in the 10 years period from 1984/1985 to 1993/1994 only 98 kg seed were collected from these approved seed stands (Anonymus, 1994). On the other hand in the same period 9268 kg seed were imported into Germany from which an amount of only 450 kg was reexported. This shows clearly how much Germany depends on foreign seed sources, and underlines the importance of systematic seed source studies.

The aim of the present study was therefore to observe the performance of several *Abies grandis* seed sources in comparative field trials, in order to get indications for fast growing and well adapted provenances suited for silviculture in northwestern Germany.

Material and Methods

In older plantations the origin of seed is seldom well known and comparisons between different seed origins have so far not been possible. Therefore within the frame of IUFRO a provenance collection was carried out in 1974 and 1976 in British Columbia, Washington, Oregon, Idaho and Montana. Details are described by FLETCHER (1986). The seed was distributed by the Danish Forest Seed Centre (DANIDA), Humlebæk. An additional collection was carried out by the Bayerische Landesanstalt für forstliche Saat- und Pflanzenzucht in Oregon in 1976, whereby especially in seed zones 461 and 675 seed of elevational transects was sampled. Finally 1 sample (017-02) was furnished by the U.S. Forest Tree Seed Centre, Macon, Georgia. In total 64 samples were sown in the nursery at Grosshansdorf, North Germany, in spring 1977. SCHOLZ (1978) reported on early nursery results. Transplanting was done in 1979. 43 provenances were used for a greenhouse study, where special reference was put on the investigation of drought tolerance (SCHOLZ and STEPHAN, 1982). Further nursery results at the age of four years were published by RECK (1986).

From March 31 to April 30, 1981, 4 field trials and a non experimental planting were established. The provenances used in the still existing trials are listed in *table 1.* They begin in the North with Vancouver Island and are then arranged in ascending order of the seed zones established by the Western Forest Tree Seed Council. This means that first the coastal, then the western mountainous regions of the Cascades and then the eastern and interior provenances are listed. In column 2 a code for the frequently used ecogeographic zones was inserted. The 9 zones are (from FLETCHER and SAMUEL, 1990):

- I Northern Washington (west of the Cascades) and the Olympic Peninsula
- II Eastern slopes of Cascades in Washington and northern Oregon
- III Eastern Washington and northern Idaho
- IV Crest of the Cascades in Oregon
- V Eastern Oregon and southern Idaho (not represented in our samples)
- VI (Higher) western slopes of Cascades in Oregon
- VII Vancouver Island, British Columbia
- VIII East of Coast Range in Oregon
- IX Coastal areas in southern Oregon

Table 1. – List of *Abies grandis* provenances. After Vancouver Island the provenances are listed in ascending order of seed zone numbers. The last 3 columns indicate the allocation of provenances to field tests.

Seed zone	Eco. zone	Prov. no.	State	County	Location	Latitude N	Longitude W	Elevation (m)	No. in test	Field exp. Ta 6	Ta 8	Ta 10
1020	VII	12040	BC	Vanc.Is.	Salmon River	50°20'	125°56'	25	1	x		
1020	VII	12041	BC	Vanc.Is.	Oyster Bay	49°56'	125°12'	5	2		x	x
1020	VII	12042	BC	Vanc.Is.	Buckley Bay	49°31'	124°52'	45	3	x		x
1020	VII	12043	BC	Vanc.Is.	Spoat Lake	49°18'	124°58'	25	4			x
1020	VII	12044	Bc	Vanc.Is.	Kay Road	49°17'	124°16'	50	5		x	
1020	VII	12045	BC	Vanc.Is.	Yellow Point	49°03'	123°46'	30	6			x
1020	VII	12047	BC	Vanc.Is.	Sooke	48°22'	123°47'	20	8	x		
052	VIII	12052	OR	Columbia	Pittsburg	45°56'	123°10'	255	17	x		
061	VIII	12054	OR	Lincoln	Alsea Falls	44°20'	123°28'	275	22		x	x
072	IX	C-0.5	OR	Coos	unknown	43°00'	124°00'	0-152	26	x		
072	IX	12056	OR	Coos	Norway	43°07'	124°09'	60	27	x		
081	IX	12057	OR	Curry	Otter Point	42°28'	124°28'	45	28		x	x
221	I	12003	WA	Clallam	Indian Creek	48°04'	123°38'	140	9			x
221	I	12003	WA	Clallam	Indian Creek	48°04'	123°38'	140	10		x	
221	I	12004	WA	Clallam	Gardiner	48°04'	122°54'	30	11	x		
222	I	12048	WA	Jefferson	Ducabush River	47°41'	123°01'	90	14	x		
231	I	12049	WA	Mason	Shelton	47°11'	123°07'	40	15	x		
240	I	12051	WA	Lewis	Rainbow Falls Park	46°38'	123°15'	125	16			x
251	VIII	12053	OR	Polk	Armstrong R. Bluell	45°01'	123°23'	260	18	x		x
251	VIII	C-1.5	OR	Yamhill	Willamina	45°10'	123°30'	304-456	19	x		x
252	VIII	C-1.0	OR	Benton	Philomath/Drain	44°30'	123°30'	152-304	20	x		
252	VIII	C-1.5	OR	Benton	Philomath/Drain	44°30'	123°30'	304-456	21	x		
262	VIII	C-2.0	OR	Lane	South Willamette V.	44°00'	123°25'	456-608	23	x		
262	VIII	C-3.0	OR	Lane	South Willamette V.	44°00'	123°25'	760-902	24	x		
403	I	12001	WA	Snohomish	Buck Creek	48°16'	121°21'	400	29		x	
430	II	12011	WA	Lewis	Clear Lake	46°37'	121°20'	945	48		x	x
452	VI	12015	OR	Clackamas	Sisi Butte	44°52'	121°48'	975	31		x	
461	VI	C-1.0	OR	Linn	Santiam River	44°45'	122°30'	152-304	32	x		
461	VI	C-1.5	OR	Linn	Santiam River	44°45'	122°30'	304-456	33	x	x	
461	VI	C-2.0	OR	Linn	Santiam River	44°45'	122°30'	456-608	34	x		
461	VI	C-2.5	OR	Linn	Santiam River	44°45'	122°30'	608-760	35	x		
461	VI	C-3.0	OR	Linn	Santiam River	44°45'	122°30'	760-912	36	x		
462	VI	12017	OR	Linn	Tombstone Prairie	44°24'	122°10'	1340	38		x	
471	VI	C-2.0	OR	Lane	Upper Mohawk R.	44°15'	122°45'	450-600	39	x	x	
473	IV	12016	OR	Lane	Santiam Summit	44°26'	121°52'	1400	37		x	
473	IV	12019	OR	Lane	Roaring River Ridge	43°53'	122°01'	1310	40		x	x
481	VI	C-1.0	OR	Lane	Cottage Grove	43°45'	123°00'	152-304	25	x		
482	VI	12055	OR	Lane	Salt Creek	43°43'	122°19'	684	41			x
501	VI	12021	OR	Jackson	Whiskey Creek	42°56'	122°23'	1160	42			x
622	II	12006	WA	Chelan	Eagle Creek	47°41'	120°34'	760	43			x
652	II	12012	WA	Skamania	Cascade Creek	46°07'	121°39'	945	30		x	x
661	II	12013	OR	Hood River	Cooper Spur	45°27'	121°39'	1040	50			x
671	II	12014	OR	Wasco	Beaver Creek	45°07'	121°40'	1040	51		x	x
675	IV	C-2.5	OR	Jefferson	Santiam Pass	44°30'	121°40'	600-750	52	x		
675	IV	C-3.0	OR	Jefferson	Santiam Pass	44°30'	121°40'	750-900	53	x		
675	IV	12018	OR	Deschutes	Big Spring	43°59'	121°31'	1500	55			x
675	IV	C-3.5	OR	Jefferson	Santiam Pass	44°30'	121°40'	900-1050	56		x	x
675	IV	C-4.0	OR	Jefferson	Santiam Pass	44°30'	121°40'	1050-1200	57		x	x
681	IV	12020	OR	Klamath	Crescent Creek	43°28'	121°57'	1375	58			x
812	III	12023	WA	Stevens	Colville NF	48°18'	117°38'	1280	59		x	x
–	III	12026	ID	Benewah	Plummer Hill	47°17'	116°53'	850	60		x	
–	III	017-02	ID	Kootenai	unknown	48°24'	116°48'	1372	63			x
–	III	12038	ID	Clearwater	Weitas Creek	46°33'	115°26'	760	66		x	

In the third column follows a code for the seed origins (provenance number). The code of the IUFRO-provenances begins with 120, whereas the code of the Bavarian collection begins originally with a C followed by the seed zone number and a specification for the altitudinal zone. The seedzone number was omitted in column 3 since it is already stated in column 1, but the code is used in complete form in some tables and graphs. For the C-provenances geographic longitude and latitude were estimated from the location specification. In total 7 samples originate from British Columbia (BC), 10 from Washington (WA), 32 from Oregon (OR) and 3 from Idaho (ID).

In the last 3 columns of *table 1* the allocation of provenances to the field tests is indicated. Unfortunately there was not enough material available to plant all provenances at all locations. Planting was carried out in spring 1981 with 2+2, i.e. 4 years old plants. The numbers 9 and 10 in the field tests are the same provenance (12003). In *table 2* the main data of the field trials are summarized.

Table 2. – Main information on the *Abies grandis* test sites and designs.

Trial	Ta 6	Ta 8	Ta 10	Ta 11
Location	Rantzau	Kroeppelshagen	Luetetsburg	Reepsholt
Geogr. latitude N	53°53'	53°29'	53°36'	53°29'
Geogr. longitude E	9°50'	10°20'	7°16'	7°51'
Elevation [m]	30	50	1	6
No. of provenances	24	20	24	48
Design	rand. blocks	rand. blocks	rand. blocks	rand. blocks
No. of replications	4	2	4	4
Plotsize	48	36	30	16
Plotshape	6 x 8	6 x 6	5 x 6	4 x 4
Spacing	2 x 2 m	2 x 1.5 m	2 x 2 m	2 x 2 m
Remarks	50 years old larch between plot rows. Replants in 1983	Mixed with wild growing trees and shrubs	Trenches between plot rows. Grass and *Rubus* growth	Aerea was flooded, plants died. Experim. was abandoned

In addition to the nursery and greenhouse experiments several traits were recorded in the field trails. MIRBACH (1990) made a detailed study on flushing, height growth and needle damage in the trail at Rantzau (Ta 6). The present paper concentrates mainly on height and diameter growth and mortality up to an age of 15 years. Height and diameter were measured at the plant ages listed in *table 3*.

Table 3. – Plant ages when height and diameter were measured.

Trial	Ta 6	Ta 8	Ta 10
Height	4, 9, 11, 13, 15	4, 7, 10, 11, 15	4, 7, 9, 11, 15 (2 r.)
Diameter	15	15	15

Statistical evaluation was done with the help of the SAS software package (SAS, 1985). First basic statistics were looked at, like variation within provenances, absolute and relative provenance means and plant losses. Then analyses of variance were run and pairwise comparisons of differences of provenance means were made, applying TUKEY's honestly significant difference (*hsd*) procedure (STEEL and TORRIE, 1960). Furthermore correlation coefficients between several variables were estimated. Finally means of and variation within seed zones (extremes and quartiles) were plotted in the manner of a boxplot.

Results

Development of mean heights and plant losses, coefficients of variation

The development of the experimental means for height growth and the development of plant losses are shown in *figure 1*. At age 15 plant losses were at 28% for the trial Ta 6 and between 32% and 34% in the trail Ta 10 (height was at age 15 measured only in 2 replications and several trees were still smaller than breast height). In trial Ta 8 mortality has arrived at 45%. Mean heights are at the age of 15 years in 2 trials at 5 m and in 1 at 3 m. It can be seen that after a rather slow growth after planting, height growth increases rapidly in the following years.

In the trials Ta 6 and Ta 10 the overall coefficient of variation is around 35%, whereas in Ta 8 it reaches 45% for height growth at age 15, what is very high. This is partly due to the competition of wild shrub and tree vegetation in this location, which suppresses a part of the Grand fir trees. The experiment is therefore only of reduced value. Furthermore it must be remembered that in this location only 2 replications were planted. With regard to individual provenances a high variation coefficient indicates a high differentiation in tree growth within the same plot or provenance, respectively. In the 2 better experiments many trees have passed 8 m and some are taller than 10 m at the age of 15 years. The coefficients of variation for the diameter are yet greater than those for height growth (mean c.v. in Ta 6: 45%, in Ta 8: 72% and in Ta 10: 42%).

Mean heights of and variation within seed zones

For all seed zones a boxplot was made seperately for the trials Ta 6 and Ta 10 (*Figure 2*). These plots should give a first impression about the mean and the variation between and within seed zones. But since in most cases the seed zone is represented only by one provenance per field trial, in these cases the variation within individual provenances is shown. The upper and the lower horizontal line of the box include half of the trees (medium range), the dotted vertical lines above and

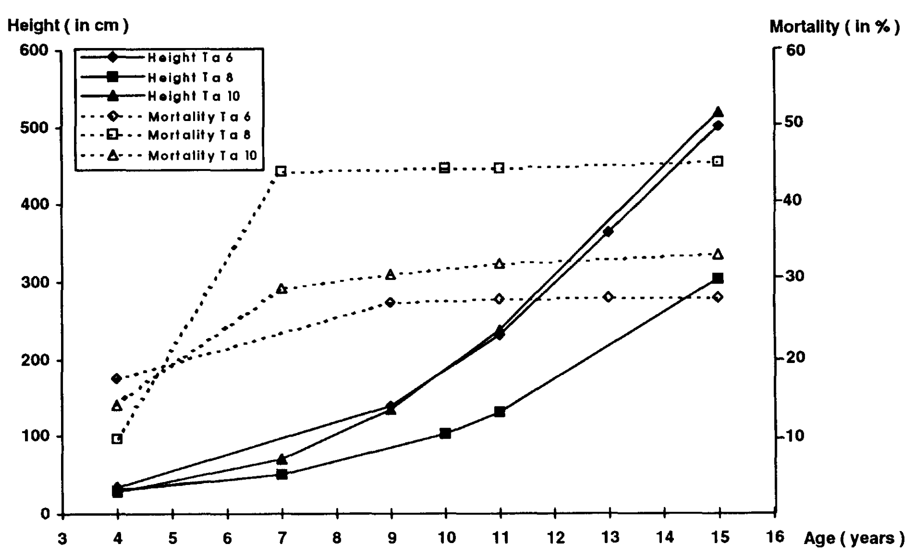

Figure 1. – Development of overall mean heights (solid lines) and mortality (dotted lines) in the field trials Ta 6, Ta 8 and Ta 10.

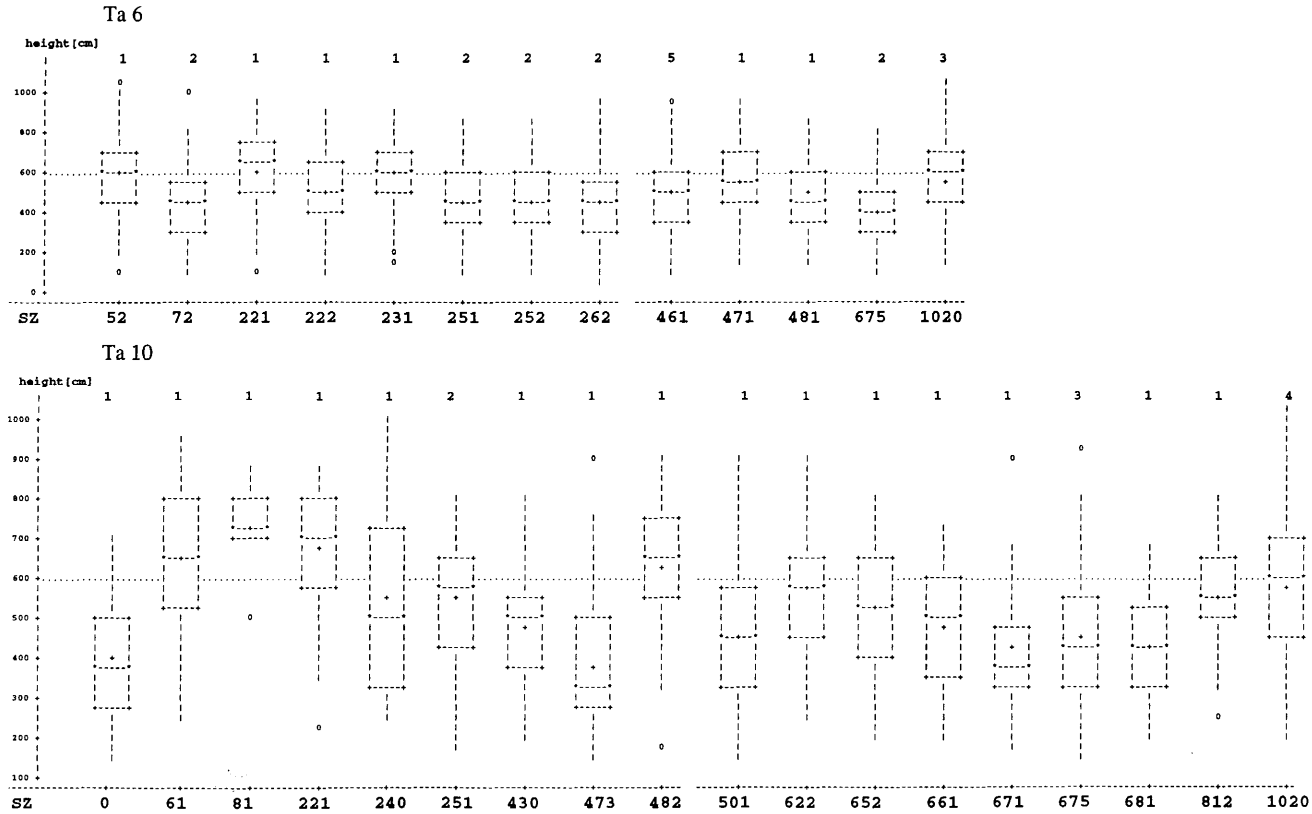

Figure 2. – Boxplots showing mean heights and variation parameters arranged by seed zones (SZ) in the trials Ta 6 and Ta 10. Seed zone 0 is Idaho. The number above each boxplot is the number of provenances in this zone. The upper and lower horizontal lines are the 75% and 25% percentile, respectively. The line in the middle of each boxplot is the median and the plus sign (+) the arithmetic mean.

below the box show the range of the tallest and smallest quarter of trees, respectively. Zeros (0) stand for extreme small or tall trees. The actual number of provenances per zone is noted above each boxplot. For technical reasons the plots are arranged in ascending seed zone number. This means that Vancouver Island (1020) is now on the right hand of the horizontal axis, and on the left, under seed zone number 0 (Ta 10 only) the provenances from Idaho, which is not included in the seed zone system, are summarized. To facilitate the assessment of seed zones or provenances, respectively, a horizontal line was drawn arbitrarily at the height of 6 m. If the mean of an individual boxplot is located on or above this limit, the zone/provenance is considered as outstanding. These are the coastal zones 052, 061 and 081 of Oregon (without 072), 221, and 231 (eastern part of the Olympic Peninsula), 482 (western slopes of Cascades in Oregon) and 1020 (Vancouver Island). The provenance 12051, Rainbow Falls Park, from zone 240 is the most variable one, and it can be seen, that at least one third of the trees are taller than 6 m. This is true also for the provenance Upper Mohawk River of zone 471, which performs well both in trial Ta 6 and Ta 8. On the lower ranks are the provenances from Idaho and the High and Eastern Cascades.

Mean heights and plant losses of individual provenances

In addition to the boxplots, mean heights and plant losses are compiled for each provenance in *table 4*. The table is sorted like *table 1* by seed zones beginning with Vancouver Island in the north (1020), followed by the coastal zones which code begins with a 0, and then continuing to the east or the mountainous regions. The experimental means are given in centimeters in the last line, but the individual provenance means are given in percentages of the particular experimental mean in order to facilitate the comparison between provenances of different field trials. Overall plant losses were already presented in *figure 1*. In *table 4* the mortality for each provenance is listed. Remarkable are the high plant losses for the coastal provenances of southern Oregon (seed zones 072 and 082). For these provenances also the percentages of forked trees in trial Ta 10 are very high (more than 30%).

Analyses of variance were run for all traits and pairwise tests of all differences between mean heights at age 15 (TUKEY's *hsd*-test) were carried out. The results are summarized in *table 5* for trail Ta 6 and in *table 6* for trail Ta 10. The first column gives the ranking of the provenances. The shaded area of a specific line shows which provenance means are significantly different from the provenance which code is given in the left hand column of the tables. The test results can be used in an other way as well: They show which provenances are not significantly different from the provenance at rank 1 (top provenances) and which provenances are not significantly different from that with the lowest rank (bottom provenances). In *table 4* the top and the bottom group were marked in that manner that the percentage numbers of the top provenances were typed bold and the cells were shaded with 25% intensity, whereas the figures of the most slowly growing provenances were italicized and the cells were only shaded weakly. In experiment Ta 8 the top and bottom ranges are overlapping. Therefore this kind of grouping could not be applied, and the results of TUKEY's test are not presented. But the relative figures of height growth are included in *table 4* to have some supplementary information. In addition to the results described in connection with the boxplots it can clearly be seen that the most slowly growing provenances originate from east of the Cascade ridge of Oregon (seed zones beginning with a 6).

Table 4. – Mean heights, plant losses and forked trees in % at age 15 in the field trials Ta 6, Ta 8, and Ta 10. In the last line means for height are given in cm which were put 100% for each trial. Intensively shaded cells with bold typed percentages indicate the fastest growing provenances, weakly shaded cells with italicized figures slowly growing ones. See also *Table 5* and *Table 6*.

Seed zone	Prov. no.	State	Location	Mean height Ta 6	Mean height Ta 8	Mean height Ta 10	Mortality Ta 6	Mortality Ta 8	Mortality Ta 10	Forks Ta 6
1020	12040	B.C.	Salmon River	**126**	-	-	19	-	-	8
1020	12041	B.C.	Oyster Bay	-	109	**134**	-	47	32	-
1020	12042	B.C.	Buckley Bay	98	-	102	21	-	19	11
1020	12043	B.C.	Spoat Lake	-	-	104	-	-	28	-
1020	12044	B.C.	Kay Road	-	111	-	-	40	-	-
1020	12045	B.C.	Yellow Point	-	-	**107**	-	-	56	-
1020	12047	B.C.	Sooke	**119**	-	-	35	-	-	13
052	12052	Oreg.	Pittsburg	**118**	-	-	17	-	-	5
061	12054	Oreg.	Alsea Falls	-	104	**125**	-	33	17	-
072	C-0.5	Oreg.	unknown	93	-	-	40	-	-	35
072	12056	Oreg.	Norway	*87*	-	-	56	-	-	33
081	12057	Oreg.	Otter Point	-	143	**140**	-	53	71	-
221	12003	Wash.	Indian Creek	-	-	**128**	-	-	54	-
221	12003	Wash.	Indian Creek	-	112	-	-	79	-	-
221	12004	Wash.	Gardiner	**122**	-	-	24	-	-	8
222	12048	Wash.	Ducabush River	103	-	-	21	-	-	8
231	12049	Wash.	Shelton	**115**	-	-	27	-	-	4
240	12051	Wash.	Rainbow Falls Park	-	-	106	-	-	21	-
251	12053	Oreg.	Armstrong R. Bluell	*86*	-	*94*	33	-	23	8
251	C-1.5	Oreg.	Willamina	100	-	**117**	21	-	35	5
252	C-1.0	Oreg.	Philomath/Drain	94	-	-	25	-	-	13
252	C-1.5	Oreg.	Philomath/Drain	94	-	-	25	-	-	8
262	C-2.0	Oreg.	South Willamette V.	*82*	-	-	23	-	-	12
262	C-3.0	Oreg.	South Willamette V.	95	-	-	29	-	-	15
403	12001	Wash.	Buck Creek	-	108	-	-	85	-	-
430	12011	Wash.	Clear Lake	-	80	*91*	-	39	25	-
452	12015	Oreg.	Sisi Butte	-	108	-	-	60	-	-
461	C-1.0	Oreg.	Santiam River	99	-	-	24	-	-	8
461	C-1.5	Oreg.	Santiam River	93	101	-	25	39	-	12
461	C-2.0	Oreg.	Santiam River	100	-	-	35	-	-	10
461	C-2.5	Oreg.	Santiam River	98	-	-	27	-	-	8
461	C-3.0	Oreg.	Santiam River	100	-	-	34	-	-	9
462	12017	Oreg.	Tombstone Prairie	-	79	-	-	24	-	-
471	C-2.0	Oreg.	Upper Mohawk R.	110	129	-	27	42	-	11
473	12016	Oreg.	Santiam Summit	-	109	-	-	42	-	-
473	12019	Oreg.	Roaring River Ridge	-	85	*74*	-	31	25	-
481	C-1.0	Oreg.	Cottage Grove	96	-	-	29	-	-	10
482	12055	Oreg.	Salt Creek	-	-	**122**	-	-	16	-
501	12021	Oreg.	Whiskey Creek	-	-	*88*	-	-	23	-
622	12006	Wash.	Eagle Creek	-	-	**108**	-	-	74	-
652	12012	Wash.	Cascade Creek	-	102	99	-	40	24	-
661	12013	Oreg.	Cooper Spur	-	-	*93*	-	-	30	-
671	12014	Oreg.	Beaver Creek	-	104	*79*	-	47	23	-
675	C-2.5	Oreg.	Santiam Pass	*86*	-	-	24	-	-	7
675	C-3.0	Oreg.	Santiam Pass	*77*	-	-	25	-	-	15
675	12018	Oreg.	Big Spring	-	-	*85*	-	-	31	-
675	C-3.5	Oreg.	Santiam Pass	-	93	*87*	-	43	32	-
675	C-4.0	Oreg.	Santiam Pass	-	74	*91*	-	33	27	-
681	12020	Oreg.	Crescent Creek	-	-	*82*	-	-	46	-
812	12023	Wash.	Colville NF	-	97	**107**	-	25	19	-
-	12026	Idaho	Plummer Hill	-	94	-	-	42	-	-
-	017-02	Idaho	Kootenai	-	-	*74*	-	-	30	-
-	12038	Idaho	Weitas Creek	-	97	-	-	67	-	-
Experimental mean (height in cm)				500,9	304,9	520,9	28	45	32	11

Finally the main results are shown in *figure 3* as well. The map was taken from FLETCHER (1986) and slightly modified. Originally all locations of the IUFRO-provenances were indicated by black triangles (▲). In order to include the results given in *table 4* the triangles were replaced by black circles with a white plus sign for the provenances at the top and a black circle with a white minus sign for the provenances at the bottom. The provenance group between top and bottom was left unchanged. In this way the geographic variation with some regional grouping can be observed at one glance, but some results have to be commented again in the discussion. Not all seed sources drawn on the map are included in our field tests. Especially eastern Oregon, northern Idaho and Montana is represented only by the IUFRO provenances 12026 and 12038. The provenance locations of the Bavarian collection and the location of the seed lot sent by Macon were not drawn into the map.

Correlations

Correlations were estimated between height (h) and diameter (d) measurements at various plant ages and between height at age 15 and the geographic variables elevation, latitude and longitude. The results are shown in *table 7.* All coefficients are statistically significant ($\alpha \leq 0.05$), but it can be seen that the correlations for height between age 4 and age 15 are not yet very high. On the other hand correlations between height and diameter at age 15 are high (0.91 and 0.89), which is to be expected. Therefore a column for diameter growth of individual provenances was omitted in *table 4.* The correlations between the height growth at age 15 and the geographic variables are very weak. If all regions are taken together a slight tendency can be detected that seed sources from lower elevations grow better than those from higher elevations. The positive correlation with the latitude explaines in an other way the good growth of the Vancouver Island and Washington provenances compared to those of Oregon. The positive correlation with longitude reflects the fact that the faster growing provenances originate from west of the Cascade crest. Longitude and elevation are significantly negatively correlated.

Table 5. – Differences between provenance means for height at age 15 in cm in field trial Ta 6. The first column gives the ranking of the provenances. The shaded areas show which provenances are according to TUKEY's *hsd*-test significantly different from the provenance in the left hand column of the same line.

Prov. no.	120 04	120 47	120 52	120 49	C-471 -2.0	120 48	C-251 -1.5	C-461 -2.0	C-461 -3.0	C-461 -1.0	C-461 -2.5	120 42	C-481 -1.0	C-262 -3.0	C-252 -1.5	C-252 -1.0	C-072 -0.5	C-461 -1.5	120 56	120 53	C-675 -2.5	C-262 -2.0	C-675 -3.0
120 40	21	37	43	54	**80**	**114**	**132**	**133**	**134**	**137**	**139**	**141**	**153**	**155**	**164**	**164**	**166**	**167**	**195**	**200**	**204**	**221**	**247**
120 04		16	21	33	59	**93**	**111**	**112**	**112**	**115**	**118**	**119**	**131**	**134**	**142**	**143**	**144**	**146**	**174**	**178**	**182**	**200**	**225**
120 47			5	17	43	**77**	**95**	**96**	**97**	**100**	**102**	**104**	**116**	**118**	**127**	**127**	**129**	**130**	**158**	**163**	**167**	**184**	**210**
120 52				12	38	**72**	**90**	**91**	**91**	**94**	**97**	**98**	**110**	**113**	**121**	**122**	**123**	**125**	**153**	**157**	**161**	**179**	**204**
120 49					26	60	**78**	**79**	**80**	**82**	**85**	**86**	**98**	**101**	**109**	**110**	**111**	**113**	**141**	**145**	**149**	**167**	**192**
C-471-2.0						34	52	53	54	57	59	60	**73**	**75**	**84**	**84**	**86**	**87**	**115**	**120**	**124**	**141**	**167**
120 48							18	19	20	23	25	26	38	41	49	50	51	53	81	**85**	**89**	**107**	**132**
C-251-1.5								1	2	4	7	8	20	23	31	32	33	35	63	67	**71**	**89**	**114**
C-461-2.0									1	4	6	7	20	22	31	31	33	34	62	67	71	**88**	**114**
C-461-3.0										3	5	7	19	21	30	30	32	33	61	66	70	**87**	**113**
C-461-1.0											2	4	16	18	27	27	29	31	58	63	67	**85**	**110**
C-461-2.5												1	13	16	25	25	26	28	56	60	64	**82**	**107**
120 42													12	15	23	23	25	27	55	59	63	**81**	**106**
C-481-1.0														3	11	11	13	15	43	47	51	69	**94**
C-262-3.0															9	9	10	12	40	44	48	66	**91**
C-252-1.5																0	2	4	31	36	40	58	**83**
C-252-1.0																	2	3	31	36	40	57	**83**
C-072-0.5																		2	30	34	38	56	**81**
C-461-1.5																			28	32	36	54	**79**
120 56																				5	8	26	51
120 53																					4	22	47
C-675-2.5																						18	43
C-262-2.0																							25
C-675-3.0																							

Table 6. – Differences between provenance means for height at age 15 in cm in field trial Ta 10. The first column gives the ranking of the provenances. The shaded areas show which provenances are according to TUKEY's *hsd*-test significantly different from the provenance in the left hand column of the same line.

Prov. no.	120 41	120 03	120 54	120 55	C-251 -1.5	120 06	120 45	120 23	120 51	120 43	120 42	120 12	120 53	120 13	120 11	C-675 -4.0	120 21	C-675 -3.5	120 18	120 20	120 14	017-02	120 19
120 57	31	63	77	92	118	164	170	172	178	188	197	214	241	243	255	256	268	274	284	302	316	341	344
120 41		32	46	61	88	134	139	141	147	157	166	183	210	212	224	225	238	243	253	271	285	310	313
120 03			14	29	55	101	107	108	115	125	133	151	178	179	192	193	205	211	221	238	253	278	280
120 54				15	42	88	93	95	101	111	120	137	164	166	178	179	192	197	207	225	239	264	267
120 55					26	72	78	80	86	96	105	122	149	151	163	164	176	182	192	209	224	249	252
C-251-1.5						46	52	53	60	70	78	95	123	124	137	137	150	156	166	183	198	223	225
120 06							6	7	14	23	32	49	77	78	91	91	104	110	120	137	151	176	179
120 45								1	8	18	26	44	71	72	85	85	98	104	114	131	146	171	173
120 23									6	16	25	42	69	71	83	84	97	103	113	130	144	169	172
120 51										10	19	36	63	65	77	78	90	96	106	124	138	163	166
120 43											9	26	53	55	67	68	81	86	96	114	128	153	156
120 42												17	44	46	58	59	72	77	88	105	119	144	147
120 12													27	29	41	42	55	60	70	88	102	127	130
120 53														2	14	15	27	33	43	61	75	100	103
120 13															12	13	26	31	42	59	73	98	101
120 11																1	13	19	29	47	61	86	89
C-675-4.0																	13	18	29	46	60	85	88
120 21																		6	16	33	48	73	75
C-675-3.5																			10	27	42	67	70
120 18																				17	32	57	59
120 20																					14	39	42
120 14																						25	28
017-02																							3
120 19																							

Finally rank changes between planting age and age 15 were investigated. They are presented in *figure 4* and confirm the impression obtained from the correlation coefficients. From age 7 or 9, respectively a stabilization can be observed, with a few exceptions. Severe rank changes downwards (15 or more ranks) occurred in trail Ta 6 with the provenances Norway (12056), Philomath/Drain (C-252-1.0), C-072-0.5 and Santiam River (C-461-1.5). These 4 provenances originate all from Oregon west of Cascade ridge and ranked at age 4 at the top. A remarkable improvement occurred with the provenances Gardiner (12004), Pittsburg (12052) and Salmon River (12040), which ascended 18, 15 and 13 ranks, respectively. In trail Ta 10 rank changes were not so drastic. Remarkable is only Eagle Creek (12006), which improved its rank from 24 to 7.

Discussion

It is well known, that Grand fir is sensitive to dry or too wet conditions after planting, which may result in a high mortality. This was the reason why experiment Ta 11 had to be abandonned. The area had been flooded after rainfalls in the spring of the planting year. The experimental area Ta 8 seems as well to contain some wet patches, and wild grown shrubs and trees had not been removed appropriately. These facts have been considered in the evaluation. Nevertheless a rather good consistency in the results can be observed in the remaining experiments when the same provenance was planted in 2 locations.

Plant losses were not analysed statistically, because they could have been influenced by several factors, like irregular competition of weeds, or in the trial Ta 6 (Rantzau) as well by the attack of the beetle *Hylobius abietis*. Nevertheless it is remarkable that the plant losses of the provenances from southern coastal Oregon (zones 072 and 081) are the highest. This is in agreement with the observations of RAU et al. (1990). Therefore it is probable that the high mortality is due to the provenance and not to other factors like drying of roots during

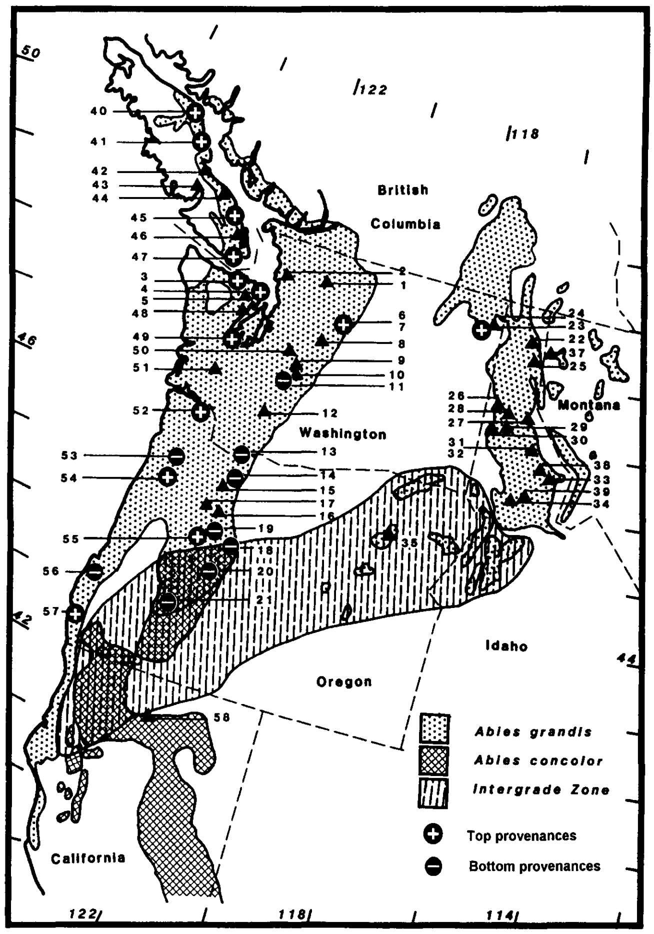

Figure 3. – Map of natural distribution range of *Abies grandis* and *A. concolor* and locations of provenances of the IUFRO collections 1974 and 1976. The map was taken from FLETCHER (1986) and has been slightly modified. Further explanations see text.

Table 7. – Correlation coefficients between a) tree heights at different ages and diameter at age 15, and b) height at age 15 and geographic variables.

Ta 6

	h 9	h 11	h 13	h 15	d 15
h 4	.50	.42	.40	.37	.39
h 9		.93	.90	.86	.85
h 11			.96	.93	.90
h 13				.97	.92
h15					.91

	Elev.	Lat.	Long.
h 15	-.19	.24	.14

Ta 10

	h 7	h 9	h 11	h 15	d 15
h 4	.62	.60	.53	.46	.42
h 7		.91	.83	.72	.72
h 9			.93	.83	.84
h 11				.91	.90
h 15					.89

	Elev.	Lat.	Long.
h 15	-.35	.14	.24

transport or planting. SCHOLZ and STEPHAN (1982) observed a rather high mortality in the provenance Norway (12056), but not in the provenance Otter Point (12057) after the seedlings were transplanted into pots. The same study revealed that these provenances were rather late flushing ones, and 12057 (together with 12020) were the latest in bud setting. In 1980 those provenances showed the lowest degree of late frost damage of the coastal provenances. MIRBACH (1990) on the other hand, who made intensive studies in the trial Ta 6 in 1989, classified the 2 provenances from zone 072 as early flushing ones. In 1989 late frosts occurred between April 27 and May 3. Later in summer MIRBACH observed to a varying extent brown spots on the needles which could not directly be classified as frost damage. Again the 2 provenances 12056 and 12057 showed the highest percentage of damaged needles. Later it was found out that these spots are caused by the fungus *Kabatina sp.* (PEHL and BUTIN, 1993).

Concerning mean height growth, the regions east of Vancouver Island, east of the Olympic Peninsula and the northern coastal zones of Oregon can be regarded as outstanding. But differences between these zones were not found to be as pronounced as reported by RAU et al. (1990) for other field trails in Germany, where the mean of all Puget Trough provenances is above that of all other regions. This may be due to a somewhat different sample and to different conditions at the test locations. Inland provenances were – with some exceptions – below the average especially those from the crest and east of the Cascade Range and those from Idaho (ecogeographic zones IV, II, and III, respectively).

This is what normally would be expected when altitude and vegetation period of the original locations are taken into consideration in comparison to lowland provenances and lowland test sites. But for plantation sites with more severe conditions probably other than lowland provenances should be taken into consideration as well. As exceptions, the provenances Eagle Creek (12006) with a rather high mortality and Colville National Forest (12023) from the northeastern corner of Washington must be mentioned. Additionally the provenance Salt Creek (12055) seems not to fit into the geographic clustering as shown in *figure 3.* But this seed source comes from the western watershed of the Cascades.

Provenance x location interaction could not be investigated with our field trails. But the IUFRO-provenances are planted in several countries and on a variety of sites. FLETCHER and SAMUEL (1990) noted some origin x site interaction in Britain. Fast growing provenances (especially from ecogeographical zone I) grew comparatively better on better sites, but the authors considered the interaction as relatively unimportant if only better quality sites are used for Grand fir plantings. In Germany silvicultural considerations are somewhat different, as was outlined in the introductory chapter. The problem of interaction was studied as well by KLEINSCHMIT et al. (1995) for

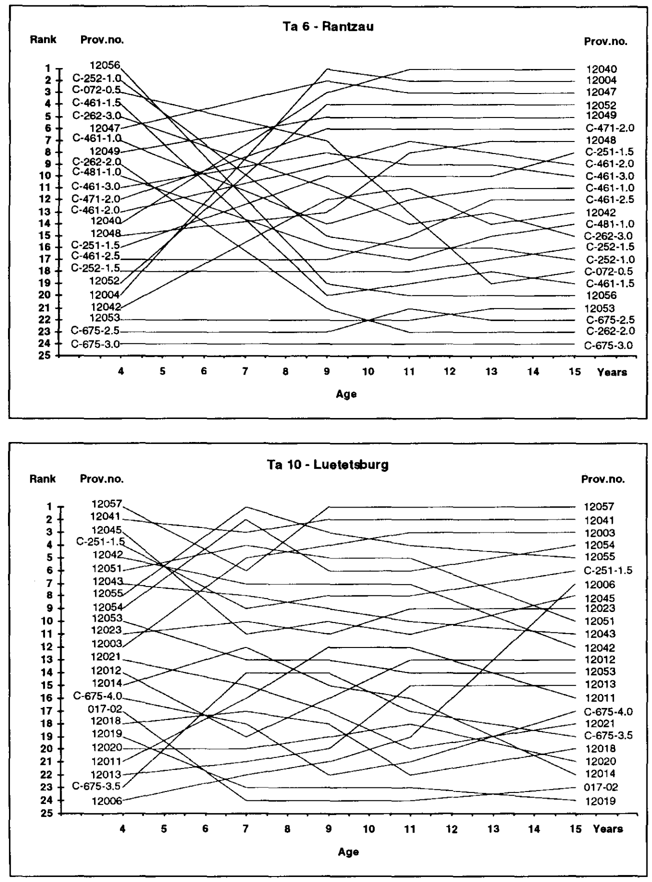

Figure 4. – Rank changes of mean heights in the field trials Ta 6 and Ta 10 between the ages of 4 and 15 years.

several German test sites. The authors considered Bear Mountain (12005) and Salmon River (12040), which reached rank 1 and 2 for height growth in their trails as very stable provenances, whereas Rainbow Falls (12051) at rank 3 was the most unstable one. They concluded that there exist no significant correlations between height growth and the stability parameters they investigated.

Correlation coefficients have revealed a small overall relationship between height growth and altitude ($r=-0.19$ and -0.35). But this observation is not confirmed when the 2 specific cases, the 2 altitudinal transects in seed zones 461 and 675, Santiam River and Santiam Pass are looked at. Neither a decreasing height growth nor a trend in mortality can be observed with increasing altitude of the seed source. As is to be expected, correlations between height and diameter are high ($r=0.91$ and 0.89). Therefore diameter growth of individual provenances was not included in *table 4.*

Considering variation within plots it has already been mentioned that the coefficients of variation are somewhat greater for diameter than for height growth. This might partly be influenced by the fact that trees which have, due to a higher mortality in the plot, more space available, grow comparatively more in diameter than in height. This could also have an influence on the correlation and lead to a small reduction of the coefficient. But it is also possible that different provenances have different stem forms.

The rank changes of provenance means between the ages of 4 and 15 years were studied by estimating correlation coefficients (*Table 7*) and by presenting them graphically (*Figure 4*). The observation of pronounced rank changes leads to the conclusion, that provenance selection for height growth is probably not very efficient in the nursery. A more reliable basis for selection seems to be given earliest at or after age 7 or 9.

For the assessment of the planting value of an introduced species in forestry some knowledge of its wood properties is necessary. The high volume production of adapted populations of Grand fir is well known. The wood is light and soft and does not possess a high strength. Durability also is short. A study on wood properties of several stems of a 42 years old stand in northwestern Germany was carried out by SCHWAB and STRATMANN (1983). They found differences in several traits as compared to silver fir and Norway spruce, but they were not statistically significant. Therefore they concluded that a common processing of the 2 fir species should be possible. Differences to Norway spruce exist if the drying behavior and the permeability of the wood are considered. Grand fir wood is suited for all purposes where the requirements to strenght are not too high.

RIEBEL (1994) investigated wood properties of Grand fir grown in southwestern Germany and compared them as well with those of Norway spruce and silver fir. The material sampled from these 2 species originated from trees which were twice as old as the Grand fir trees. Tests of clear pieces revealed that several parameters were 10% to 33% below those of Norway spruce and silver fir. But swelling and shrinking properties were better. However ring width in Grand fir was twice that of the other 2 species, and wood quality improves with increasing age since the ring with decreases. Considering basic wood properties, the author considered ring width as an uncertain, but density of the absolutely dry wood and the proportion of late wood as good predictors for elastomechanic properties. Besides the pure tests of clear test pieces also lumber tests were carried out, which revealed that Grand fir wood can be considered suited as construction wood. A higher wood quality is to be expected from slower than from very fast growing stands. In order to achieve an improvement in quality and value an early pruning is recommended (STRATMANN, 1988; RIEBEL, 1994).

The investigations on wood properties have shown that it is meaningfull to influence wood properties by silvicultural measures. If Grand fir is planted on dryer sites or under other conditions which reduce early growth (shelter, stand holes) annual ring width will also be reduced and wood properties improved. A similar effect can be achieved by artificial pruning. The branches can be sold for covering or ornamental purposes.

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