Growth and reaction to drought of 43 Abies grandis provenances in a greenhouse study

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Summary

Abies grandis provenances show great variation in drought effects but also in mortality after transplanting, late frost damage, needle spots, height growth, flushing and bud-setting. Provenances from northern coastal regions showed better height growth than interior ones, but were more affected by drought as well as late frost and needle spots. A relation between hygromorphicity and susceptibility to drought and late frost became obvious.

Key words: Abies grandis, drought, resistance, mortality, height growth, flushing, bud-setting, late frost, needle spots.

Zusammenfassung

Zwischen 43 in einem Gewächshausversuch geprüften *Abies grandis*-Provenienzen bestanden große Herkunftsunterschiede bezüglich der Reaktion auf Trockenheit, der Mortalität nach dem Verpflanzen, Spätfrostschaden, Nadelflekken, Höhenwachstum sowie Austriebs- und Abschlußtermin. Herkünfte aus den nördlichen Küstengebieten zeigten besseres Höhenwachstum als Interior-Herkünfte, waren aber durch Trockenheit, Spätfrost und Nadelflecken stärker geschädigt. Offenbar reagieren hygromorphe Provenienzen empfindlicher auf Trockenheit und Spätfrost.

Introduction

Abies grandis (DOUGL.) LINDL. is a promising exotic tree species in Germany, because of its high productivity (BEUSCHEL 1968, KRAMER 1976, RÖHRIG 1978, KLEINSCHMIT and SVOLBA 1979). Its great resistance to abiotic damages and diseases is of special interest in connection with the severe fir dying of *A. alba* MILL. in Central Europe. In a greenhouse study, the reaction of *A. grandis* provenances to drought was investigated under practical conditions. Also mortality, height growth, flushing, bud-setting, and late frost damage was studied in *A. grandis* plants up to the age of 5 years. This is a report on first results.

Materials and Methods

Plant material. Fourty-three *Abies grandis* provenances of the IUFRO seed collection from 1974/76 were used (FLETCHER 1975). Geographical data are given in *Table 1.* For comparison, an autochthonous provenance of *A. alba* (Bodenmais, Bavaria, altitude 650—770 m) was also included in the study. According to FLETCHER (1975) the *A. grandis* provenances were grouped in 5 geographical regions:

- Ia : Vancouver Island (British Columbia)
- Ib : Coastal region of Washington, Oregon and California
- II : Eastern slopes and higher elevations in Cascade range north of about 44—45° N.
- III: Interior provenances (North Idaho)
- IV: Eastern slopes and higher elevations in the Cascade range south of about 44—45° N (Oregon)

The plants for this trial were part of the material which was sown in spring 1977 in outdoor seedbeds in Schmalenbeck, for the purpose of provenance trials. More detailed information on the seedling stage and results of the performance and biomass production were reported by SCHOLZ (1978) and on the nursery stage by RECK (in press).

In August 1979, a total of 120 seedlings per provenance was transplanted into 2-liter plastic pots and kept outdoors.

Drought reaction. The trial was carried out in a greenhouse under environmental conditions similar to outdoor ones. Because soaking the soil of potted plants after a longer drought period by normal watering is difficult, 9 beds, each for 230 potted plants, were prepared, which allowed controlled irrigation of the plants by flooding.

The plants were placed into these beds in April 1980 with 5 replications in each bed, each replication containing one plant per provenance randomly located.

A pilot study on drought resistance was started with 3 beds after bud-set in July 1980. One bed was watered regularly (no drought stress). The second bed was watered in intervals of about 5 weeks (medium drought stress). The third bed was kept dry from July to the beginning of October for about 3 months (strong drought stress). After that date all beds got the same treatment.

In 1981 the drought resistance study was repeated in the same way, but with 3 beds for each treatment. In both years, the number of dead plants a few weeks after finishing the water stress treatment was taken as basis for the effect of drought to the respective provenance.

Further traits. The following traits were recorded outdoors and in the greenhouse respectively.

Outdoors (120 plants per provenance) in beds, without replication: height 1979; flushing in spring 1980 (number of days between April 25, 1980, with the first flushing plants of the whole trial, and when 50% of the respective provenance had flushed); late frost damage in June 1980; mortality between August 1979 and April 1980. Greenhouse (45 plants per provenance): height 1980 and 1981; height increment 1980 and 1981; flushing; bud-setting (number of days between April 25, 1980, and the day when 96% of the plants of the respective provenance had set bud); needle spots in spring 1980.

Criterion for flushing was the date when the scales of the bud of the terminal shoot were burst and the tips of young needles were showing. The date, on which the scales of the terminal bud became brownish, was recorded as bud-set. Needle spots of unknown origin could be observed in spring 1980 on current year needles. First small yellow flecks were showing, which later turned brown and caused a needle cast.

Table 1. — Geographical data of the IUFRO provenances of *Abies grandis*.

IUFRO-Nr.	Collect.	State and County	Latitude	Longitude	Altitude (m)
I a : Vancouver Island (British Columbia)					
12040	1976	Canada, Br. Columbia Salmon River, Sayward	50°20' N	125°56' W	25
12041	1976	Brit. Columbia, Oyster Bay, 23 km S of Campbell River	49°56' N	125°12' W	5
12042	1976	Brit.Col., Buckley Bay, 23 km S of Courtney	49°31' N	124°52' W	45
12043	1976	Brit.Col., Spoat Lake, 15 km W of Port Alberni	49°18' N	124°58' W	25
12044	1976	Brit.Col., Kay Road 5 km S of Parksville	49°17' N	124°16' W	50
12045	1976	Brit.Col., Yellow Point, 40 km SE of Nanaimo	49°03' N	123°46' W	30
12046	1976	Brit.Col., Mt. Provost, 4 km NW of Duncan	48°47' N	123°46' W	75
12047	1976	Brit.Col., Sooke, 4 km W of Sooke	48°22' N	123°47' W	20
I b : Coastal region of Washington, Oregon and California					
12001	1974	Washington, Buck Creek, NE of Darrington	48°16' N	121°21' W	400
12002	1974	Wash., Tulalip Ind. Res., North of Everett	48°05' N	122°16' W	30
12003	1974	Wash., Indian Creek, 5 km W of Elwa	48°04' N	123°38' W	140
12004	1974	Wash., Gardiner, 15 km E of Sequim	48°04' N	122°54' W	30
12005	1974	Wash., Bear Mountain, Louella-Blyn	47°59' N	123°02' W	825
12048	1976	Wash., Ducabush River, 10 km W of Brinnon	47°41' N	123°01' W	90
12049	1976	Wash., Shelton, 4 km SW of Shelton	47°11' N	123°07' W	40
12051	1976	Wash., Rainbow Falls Park, 12 km NE of PE ELL	46°38' N	123°15' W	125
12052	1976	Oregon, Pittsburg, 12 km N of Vernonia	45°56' N	123°10' W	255
12053	1976	Oregon, Armstrong Road, Bluell, 14 km NW of Dallas	45°01' N	123°23' W	260
12054	1976	Oregon, Alsea Falls, 30 km SW of Philomath	44°20' N	123°28' W	275
12056	1976	Oregon, Norway, 10 km SE of Coquille	43°07' N	124°09' W	60
12057	1976	Oregon, Otter Point, 8 km N of Gold Beach	42°28' N	124°28' W	45

Evaluation. Statistical analysis of data was done by analysis of variance, H-test of Kruskal and Wallis, and calculations of correlation coefficients (Spearman Rank Correlation).

Results

Mortality after transplanting

The mortality of transplanted, potted plants of *A. grandis* was recorded for the period of August 1979 to April 1980

II : Eastern slopes and higher elevations in the Cascade range north of about 44-45°N

12006	1974	Wash., Eagle Creek, 12 km NE of Leavenw.	47°41' N	120°34' W	760
12007	1974	Wash., Eagle Creek, 13 km NE of Leavenw.	47°39' N	120°30' W	1200
12008	1974	Wash., Jack Creek, 18 km NE of Cla Elum	47°20' N	120°50' W	825
12009	1974	Wash., Cougar Flats, 15 km W of Cliffdell	46°55' N	121°15' W	945
12010	1974	Wash., Rattlesnake Creek, 30 km SW of Cliffdell	46°45' N	121°06' W	1300
12011	1974	Wash., Clear Lake, N.fork of Tieton R.	46°37' N	121°20' W	945
12012	1974	Wash., Cascade Creek, 15 km NW of Trout	46°07' N	121°39' W	945
12013	1974	Oregon, Cooper Spur, 10 km S of Parkdale	45°27' N	121°39' W	1040
12014	1974	Oregon, Beaver Creek, 8 km W of Bear Springs Ranger Station	45°07' N	121°40' W	1040
12015	1974	Oregon, Sisi Butte, E of the Claskamas River	44°52' N	121°48' W	975

III : Interior provenances (north Idaho)

12023	1974	Wash., Corville NF, Chewelah	48°18' N	117°38' W	1280
12026	1974	Idaho, St. Joe Area Plummer Hill	47°17' N	116°53' W	850
12029	1974	Idaho, St Joe NF Porcupine Creek	46°56' N	116°22' W	900
12030	1974	Idaho, St. Joe Area, Moscow Mtn.	46°50' N	116°52' W	1005
12032	1974	Idaho, Clearwater Area, Alder Creek	46°43' N	115°48' W	950
12038	1974	Idaho, Clearwater, Weitas Creek, Off the North Fork of the Clearwater River	46°33' N	115°26' W	760

IV : Eastern slopes and higher elevations in the Cascade range south of about 44-45°N (Oregon)

12016	1974	Oregon, Santiam Summit, 31 km NW of Sisters	44°26' N	121°52' W	1400
12017	1974	Oregon, Tombstone Prairie, 14 km E of Soda	44°24' N	122°10' W	1340
12018	1974	Oregon, Big Spring, 18 km W of Bend	43°59' N	121°31' W	1500
12019	1974	Oregon, Roaring River Ridge NE of Box Canyon G.St.	43°53' N	122°01' W	1310
12055	1976	Oregon, Salt Creek, 10 km E of Oakridge	43°43' N	122°19' W	684
12020	1974	Oregon, Crescent Creek, 16 km W of Crescent	43°28' N	121°57' W	1375

Table 2. — Means of the geographical groups of *Abies grandis* provenances and of the *A. alba* provenance for various traits.

group	number of provenances	mortality after trans-planting (%)	height 81 (cm)	increment 81 (cm)	late frost (%)	needle spots (%)	dead trees after drought (%)	fresh-weight 78 (g) 1)	water content 78 (%) 1)
I a	8	42	59	21	43	79	42	3.7	64.3
I b	13	50	61	21	58	72	74	5.9	66.6
II	10	48	42	14	54	52	36	4.3	65.8
III	6	48	42	14	18	59	38	4.6	62.1
IV	6	54	38	11	39	43	28	5.7	65.4
A. alba	1	0	30	10	100	0	0	--	--

[1]) Data from SCHOLZ (1978)

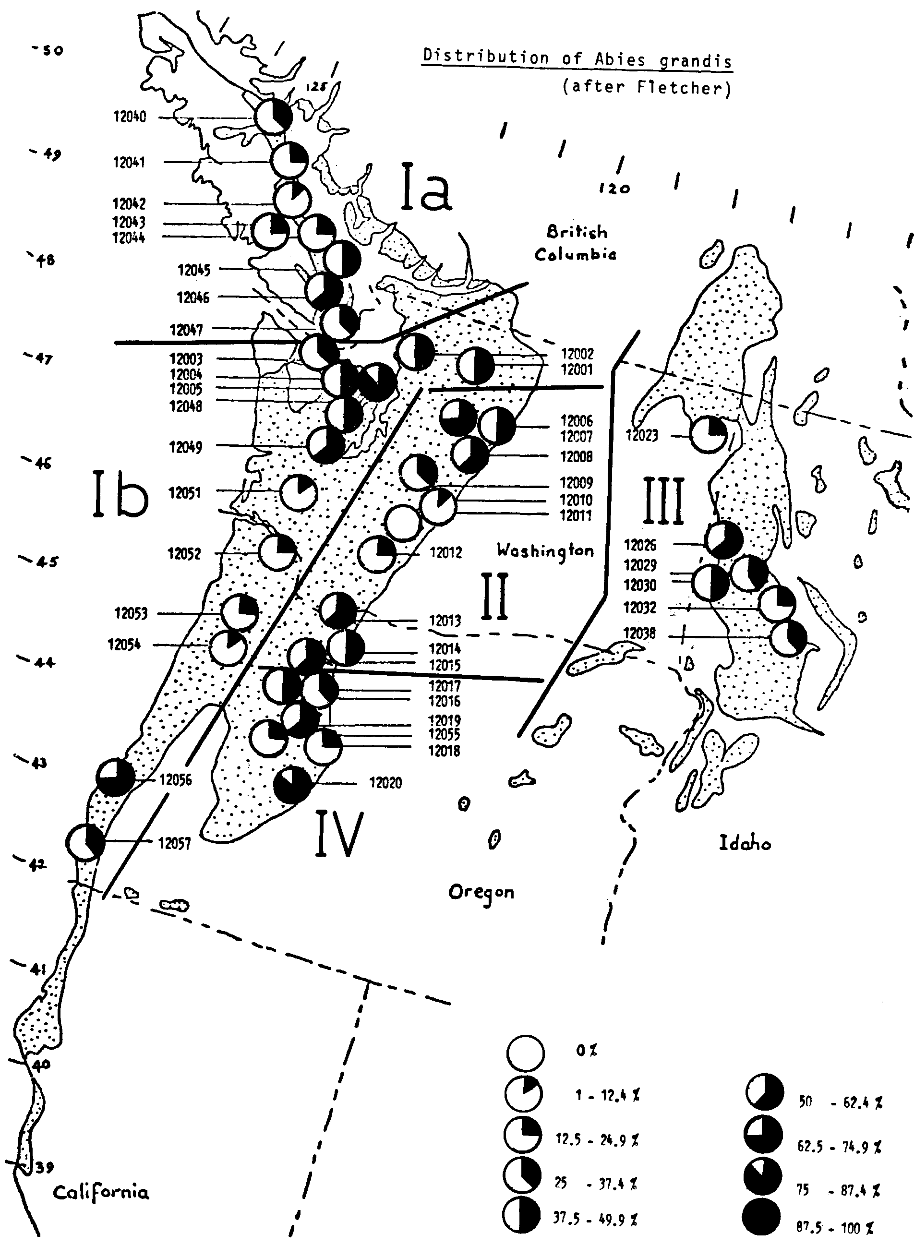

Figure 1. — Mortality after transplanting 1979/1980

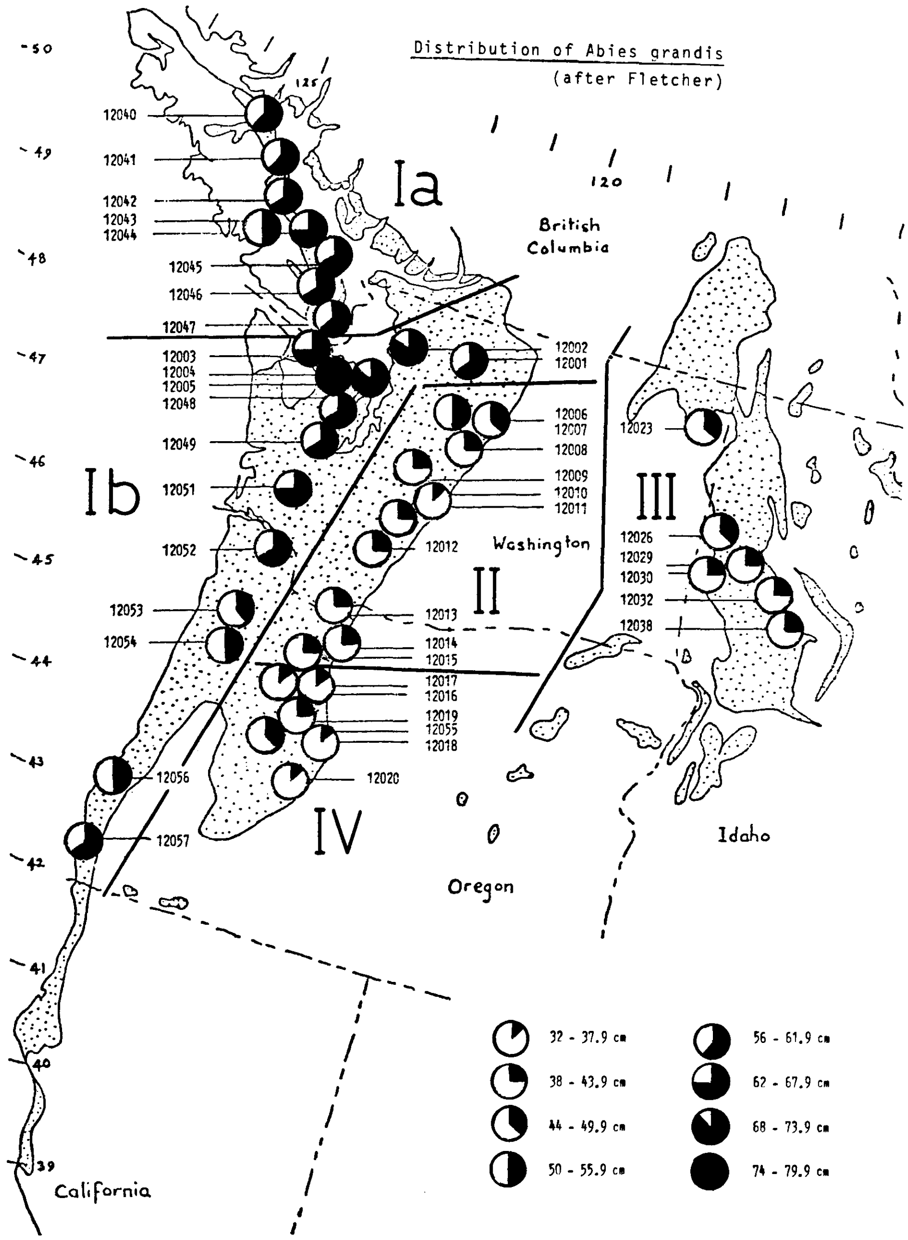

Figure 2. — Height 1981

Table 3. — Analysis of variance for height growth 1981 with respect to geographical groups and provenances of *Abies grandis.*

source of variation	df	F - value	variance component (%)
between groups	4	32.3 ***	68.6
between provenances	38	8.5 ***	16.2
rest	258	--	15.2

*** $p \leq 0.01$

in outdoor beds, because it is well known that *A. alba* reacts sensitively to transplantation. On the whole, the mortality was also rather high in *A. grandis.* Great provenance differences were observed with a range between 2.7% (no. 12011, Clear Lake, Wash.) and 96.2% (no. 12004, Gardiner, Wash.). There is variation between geographical regions, with Vancouver Island showing lowest mean mortality *(Table 2)*; but great variability existed mainly within the geographical regions *(Figure 1)*.

Height growth

The provenance means of plant height after the season 1981 (at age 5 years) are shown in *Figure 2.* The average height growth of the provenances varied between 77 cm (no. 12004, Gardiner, Wash.) and 32 cm (no. 12020, Crescent Creek, Oregon). In general, good growers are from Vancouver Island and the coastal range of Washington *(Fig. 2)*. Correlations, as known in other species too, between height growth and 1000 seed weight ($r_S = -0.69^{***}$), germination percent ($r_S = 0.43^{**}$), number of cotyledons ($r_S = -0.51^{**}$) were found for *A. grandis* too.

There are clear and significant differences between the geographical regions *(Table 2)* as demonstrated by an analysis of variance *(Table 3)*. 69% of the total variance can be explained by these regional differences.

Flushing and bud-setting

For flushing and bud-setting, three dates are plotted in *Figure 3:* (a) flushing of the first plant in the provenance, (b) 50% of the plants in the respective provenance had flushed, and (c) 96% of the plants of the respective provenance had set bud. There are significant differences (for flushing $p \leq 0.01$; for bud-setting $p \leq 0.5$) between geographical regions. Provenances of Vancouver Island were earliest to start flushing and to set buds, and interior provenances from Idaho were the latest *(Figure 3)*. Some geographical regions show remarkable variation of flushing between provenances, such as Vancouver Island and the coastal region of Washington.

In contrast, region II (eastern slopes of the Cascades), however, reacts rather homogeneously. The provenances no. 12056 (Norway, Oregon) and no. 12020 (Crescent Creek, Oregon), which belong to the most southern provenances of the whole collection, had an extraordinary long growing season in 1980.

Flushing in the greenhouse was significantly correlated with flushing of outdoor plants of the respective provenance ($r_S = 0.56^{***}$).

Late frost damage

The damage by late frost in spring 1980 had remarkable influence on many of the provenances in outdoor beds, ranging from 95.5% damaged plants in no. 12051 (Rain Bow Falls Park, Wash.) to no damaged plant in no. 12026 (St.

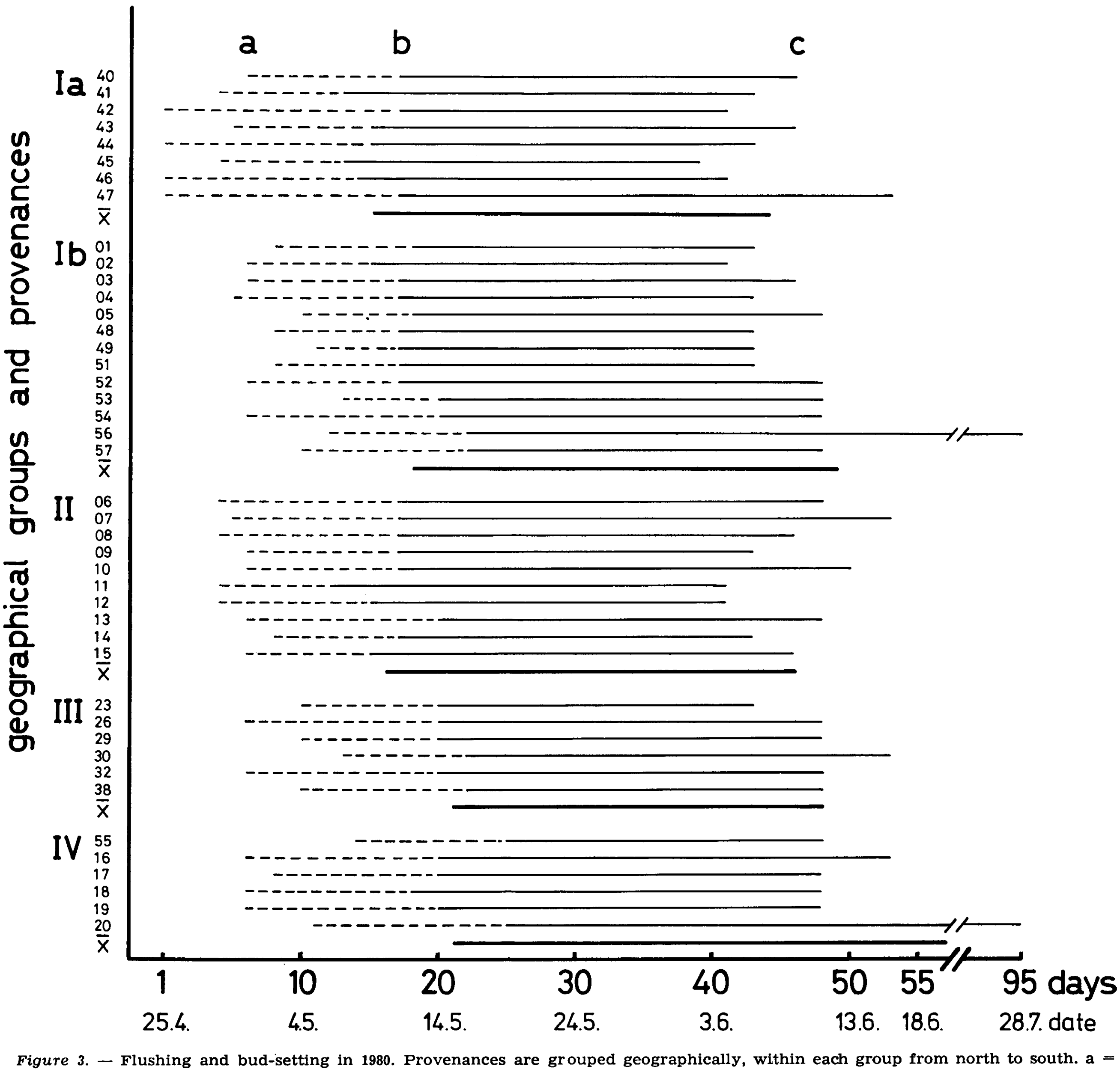

Figure 3. — Flushing and bud-setting in 1980. Provenances are grouped geographically, within each group from north to south. a = flushing of the first plant; b = 50% of the respective provenance had flushed; c = 96% of the respective provenance had set bud.

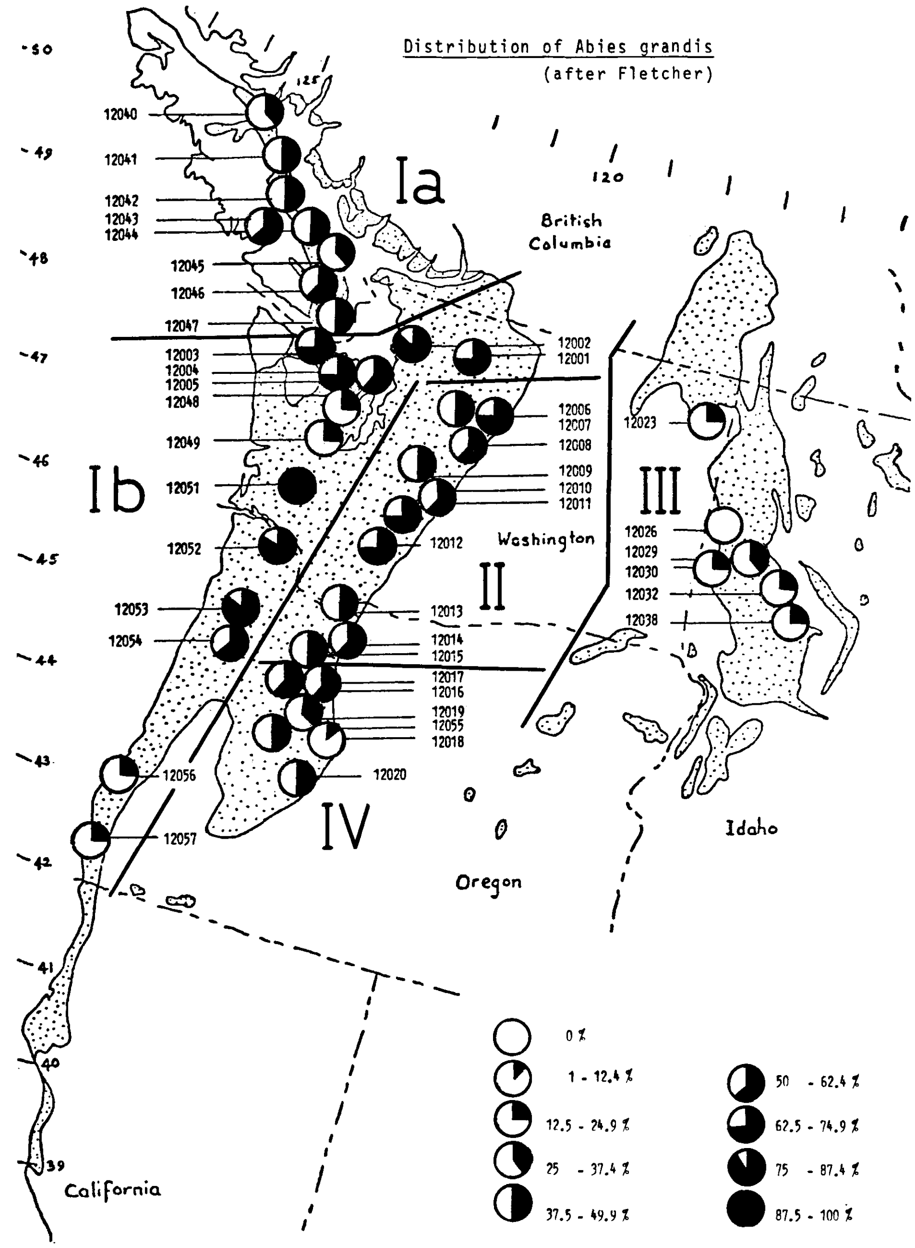

Figure 4. — Late frost damage in spring 1980

Joe Area, Idaho). Regional differences were significant at $p \leq 0.5$. Interior provenances from Idaho were generally less affected than provenances from other regions *(Figure 4)*. For group means see also *Table 2*.

Late frost occurred between May 21 and 23, 1980, when most of the plants of all provenances had already flushed. Weak correlation existed between frost damage and flushing outdoors ($r_S = -0.39$*), suggesting that early flushing provenances were damaged heavier.

There were significant correlations between late frost damage and percental water content of 1-year old seedlings (Scholz 1978) with $r_S = 0.5$**, and also with plant-height 1979 ($r_S = 0.42$**). Thus, more hygromorphic and higher plants seemed to be more affected.

Needle spots

In spring 1980, which was a very humid one, a yellowing of current year needles, with subsequent needle cast of unknown origin, was observed on the plants in the greenhouse, as well as on outdoor plants of the same age, but also on older trees in the surrounding of Schmalenbeck. The provenances in the trial showed remarkable differences in percentage of plants with needle spots, ranging from 93.3% (no. 12044, Kay Road, Vancouver Island) to 20% (no. 12011, Clear Lake, Wash.; no. 12018, Big Spring, Oregon). There were also clear and significant ($p \leq 0.01$) regional group differences *(Table 2)*. The northern coastal provenances were much more affected than the interior ones. Higher plants were more affected than smaller plants ($r_S = 0.77$**).

Reaction to drought

Under the influence of drought (no watering between July and beginning of October) in the most affected provenances, all plants died; in other provenances all plants survived *(Fig. 5)*. Medium water stress, however, did not show clear differences.

The results of the pilot study in 1980, as well as the trial in 1981, show that provenances from the eastern slopes and higher elevations in the Cascade range of Oregon (geographical group IV) had low drought effects ($p \leq 0.1$). Provenances from the eastern slopes and higher elevations in the Cascade range of Washington (geographical group II), from Idaho (group III), and from Vancouver Island (group Ia) showed medium drought effects. In contrast, coastal provenances from Washington and Oregon (geographical group Ib) showed highest effects *(Table 2)*.

The drought effect on the 43 provenances was tested for correlations with other traits such as geographical data, seed characters, biomass characters in seedling stage, and characters of resistance as well as height in 1981. The respective correlation coefficients are listed in *Table 4*. There are no significant correlations with longitude and latitude. But drought effects were negatively correlated with altitude and seed characters, such as weight of 1 000 seeds and number of cotyledons, showing that provenances from higher elevations with higher seed weight and larger number of cotyledons were less affected. Characters of biomass production in seedling stage, however, show significant positive correlations, the correlation between drought effects and total fresh weight being mainly due to the fresh weight of the shoot. There was no correlation between drought effects and mortality after transplanting, suggesting that drought was not the main reason for mortality after transplanting. Occurrence of needle spots and frost damage were positively correlated to drought effects, and so was, corresponding to biomass production in the seedling stage, plant height of 5 year old plants.

Performance of the Abies alba provenance

In this study, only one *A. alba* provenance was used for comparison. Therefore the results cannot be generalized but show great differences to *A. grandis* provenances *(Table 2)*. Height was comparably low. It is of interest that there was no mortality after transplanting during the

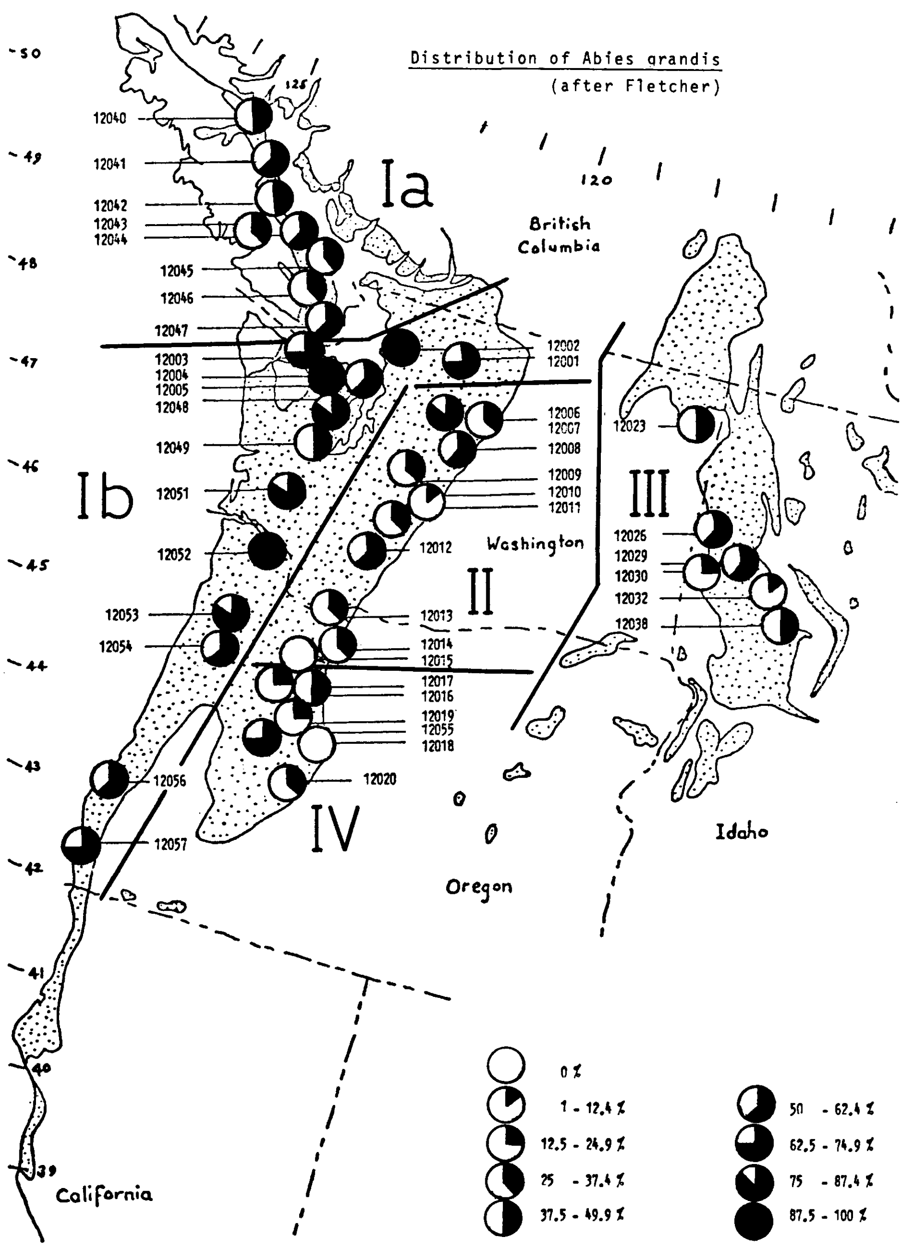

Figure 5. — Dead trees after drought 1981

Table 4. — Correlations between percentage of dead plants after drought and geographical data, seed characters, and characters of plants in the seedling stage and in the age of 5 years.

geographical data			seed characters 1)		
longitude	latitude	altitude	weight of 1000 seeds g	germination %	cotyledons $\bar{x}$ of 20 plants
n.s.	n.s.	-0.54***	-0.42**	n.s.	-0.37*

characters in seedling stage 1977 1)				
root collar diameter	shoot length	total fresh weight	fresh weight root	fresh weight shoot
n.s.	0.71***	0.44**	n.s.	0.57***

characters of plants in 1981			
mortality after transpl.	needle spots	frost-damage	height 1981
n.s.	0.55***	0.43**	0.67***

1) Data see Scholz 1978 * $p \leq 0.5$; ** $p \leq 0.1$; *** $p \leq 0.01$; n.s. = not significant

period August 1979 to April 1980. Flushing and bud-setting was much earlier than in *A. grandis.* But 100% of the plants were severely affected by late frost. The *A. alba* plants did not show any needle spot symptoms, and only weak drought effect in 1980, none in the 1981 greenhouse study.

Also of great interest was the observation of the different preference of *A. grandis* and *A. alba* by rabbits. Nearly 50% of outdoor plants of *A. alba* were damaged in spring 1980 by rabbits, none of *A. grandis.*

Conclusion

Although it is too early for a generalized assessment of the results of this greenhouse study, some conclusions can be drawn. Height growth of the 5-year old *A. grandis* plants and height increment in 1981 was best in provenances from the coastal regions of Washington and Vancouver Island. This is in agreement with results of KLEINSCHMIT (1978), FRIEDRICH (1981), and in Hesse (ANONYM 1981). Southern and interior provenances are of less interest in this respect. Flushing and bud-setting start earlier in coastal provenances. Thus they are more endangered by late frost. With respect to drought resistance, hygromorphic provenances seem to be more affected. That is in good accordance with results of LARSEN *et al.* (1981), who showed that coastal provenances, and particularly those from lower elevations, were more susceptible to drought than provenances from the Cascades and higher elevations. Provenances from Vancouver Island were not studied by LARSEN *et al.* (1981). They also seem to have a higher drought resistance under the conditions reported above. Of interest are the geographical differences between provenances regarding the appearance of needle spots.

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