DYNAMICS OF FROST RESISTANCE IN VARIOUS PROVENANCES OF *ABIES GRANDIS* LINDL.

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ABSTRACT

The frost resistance of one year old needles and shoots of *Abies grandis* (seven provenances) and *Abies alba* (one provenance) was determined using Dexter's method since early autumn till late spring (September-May). Material was collected from trees over ten year old, planted in Beskid Sądecki Range near Krynica, 800 m above sea level. In this study it was found, that in early autumn (September) *A. grandis* develops weaker frost hardiness than *Abies alba*. In the late autumn and in winter, provenances coming from region II (according to Müller), and especially provenance 12016, are equal in respect to frost hardiness of shoots and needles to *Abies alba*. Among the provenances from Müller's region I exceptional frost hardiness is displayed by provenance 12005, which is also characterized by fast growth. In spring, *Abies alba* flushes earlier than *A. grandis*, which makes it more susceptible to late frosts.

KEY WORDS: *Abies grandis* Lindl., provenances, frost resistance.

INTRODUCTION

The grand fir (*Abies grandis* Lindl.) comes from North America, where it occurs from British Columbia in the North (52° N) to San Francisco region in California (37° N). It grows from the Pacific Coast (128° W) through Cascade Mountains, through scattered stands in Blue Mountains, through mountain areas in Idaho to western slopes of Rocky Mountains in Montana (110° W) (Bellon et al. 1986, Fletcher 1986). Within this range, grand fir occupies sites from the sea level to 2200 m above sea level, with climates ranging from maritime to continental, extremal temperatures from -40°C to +40°C, and annual sum of precipitation ranging from 300 to 3000 mm (Fletcher 1986, Kleinschmit, Svolba 1979, Leibundgut 1983, Müller 1935). Such a big variety of site conditions have resulted in development of ecotypes differing in physiological traits and in site requirements (Müller 1935).

Abies grandis is characterised by a fast height growth and large volume increment. In that respect, it is better than all tree species (including *Abies alba*) native to Western and Central Europe (Günzl 1992, Kleinschmit 1986, Magnussen 1982, Rau, Weisberger 1986). Advantageous features of *A. grandis* are also: relatively small requirements in respect to water supply and soil fertility, so that it can grow also in sites which are too dry for *A. alba* (König 1995), and strong resistance to snow- and windbreaks (Rau, Weisberger 1986, Tumiewicz, Wodzicki 1990). The biology of *A. grandis* was described in detail in a separate paper (Dolnicki, Nawrot-Chorabik 1997).

Long-term investigations proved the usefulness of *A. grandis* for planting in Western and Central Europe, including Poland, provided that the right provenances are chosen. *Abies grandis* can enrich the species composition of European forests, enlarge the timber supplies, and – possibly – replace *Abies alba* in some habitats (Burzyński, Vančura 1985, Rau et al. 1991).

While introducing alien tree species to forest plantations it is necessary to predetermine their reaction to site conditions of the region of planting. The aim of this work was to investigate the frost hardiness of several provenances of *Abies grandis*, introduced within the framework of the international IUFRO program, in the climatic conditions of Beskid Sądecki range.

MATERIAL AND METHODS

The object of our study were seven provenances of *A. grandis* and one provenance of *A. alba* (Table 1). The experimental plot of the Department of Tree Breeding of Agricultural University of Kraków was established in Beskid Sądecki range near Krynica. The study area was located at elevation of 800 m above sea level, on moderately deep brown soil developed from the Carpathian flysh – namely sandstones with admixture of marl. In respect to texture, the soil was a sandy clay. According to the forest site classification system, the site represented a fertile montane broadleaf forest type. In the year 1981 in plots of size 20 x 20 m one hundred of two-year seedlings of each analysed provenance of *Abies* were

TABLE 1. Location of provenances.

Provenance number IUFRO	Provenance	Müller's regions	Geographic		Elevation above sea level [m]
			latitude [°N]	longitude [°N]	
12040	Salmon River, Sayward, Vancouver Island, British Columbia, Canada	I	50°20'	125°56'	15
12001	Buck Creek, NE of Darrington, Washington USA, west slopes of Cascade Mts.	I	48°16'	121°21'	400
12003	Indian Creek, 5 km W of Elwha Washington USA, Olympic Peninsula	I	48°04'	123°38'	140
12005	Bear Mountain, Louella-Blyn Washington USA	I	47°59'	123°02'	825
12007	Eagle Creek, 13 km NE of Leavenworth, Washington USA, east slopes of Cascade Mts.	II	47°39'	120°30'	1200
12016	Santaim Summit, 31 km NW Sisters, Oregon USA, east slopes of Cascade Mts.	II	44°26'	121°52'	1400
12020	Crescent Creek, 16 km W Crescent, Oregon USA, east slopes of Cascade Mts.	II	43°28'	121°57'	1375

planted. The method of randomized block with three replicates was employed. A detailed description of the plots was given in a paper by Kulej and Żuchowska (1994).

In autumn in each of the plots two groups of trees were permanently marked. Each of these groups consisted of 5 typical trees. Since September till the middle of May from third or fourth whorl of each tree the one-year old shoots with needles were collected for analysis. Samples from five trees were pooled, because it was the level of frost hardness, and not its variation, that was the topic of this study. For each provenance analyses were conducted on 30 trees (3 plots x 2 groups x 5 trees). For the study of frost resistance the method of Dexter (Dexter et al. 1932) was employed. Cut shoots, in plastic bags, were put into foamed polystyrene boxes and frozen in freezer room; the temperature was lowered at the rate of three degrees per one hour. The temperature of freezing was maintained for 24 hours, and then the material was defrosted at the temperature of 0°C. In the beginning of autumn the temperatures of freezing were: -8.5°C, -16°C and -22°C, in late autumn and winter -22°C and -33°C, and in spring -10°C and -22°C. After defrosting, portions of 1 g of fresh intact needles and - separately - 1 g of fresh shoots chopped into pieces 7 mm long were blended with 20 g of double distilled water per each gram of plant material. Test-tubes were put into vacuum chamber at the negative pressure of 0.1 MPa to allow water to penetrate the intercellular spaces. After 24 hours the electrolytic conductivity of the solution was determined, then the plant material was killed by exposing to the temperature of 100°C during 1 hour. The solution was supplemented with water to the former volume, and after next 24 hours the electrolytic conductivity was measured again. The same procedure was repeated with the unfrozen material to determine the so-called "background electrolytic conductivity".

The frost resistance of plant material was expressed as the "index of injury" (Flint et al. 1967) calculated on the basis of the rate of diffusion of electrolytes from the frozen plant tissues related to the rate of diffusion of electrolytes from the tissues killed by high temperature. The index included the correction which should account for the "background diffusion" from the unfrozen samples. The "index of injury" was

expressed in percent of the amount of electrolytes, which could not diffuse from the unfrozen material, taken as 100%. The detailed explanation of the method was provided in the recent work of the authors (Dolnicki, Kraj 1996). In the tables values of the "index of injury" were given both in percent and in angular values (ϕ), on which the statistical analysis was conducted. Letters denote the homogeneous groups.

Additionally, before the spring freezing (May 18th), development of terminal buds was estimated and their fresh weight was determined.

RESULTS

During the early autumn (September 27th) needles of *Abies alba* (at all temperatures of freezing - Table 2) and the one-year old shoots (frozen to -16°C and to -22°C - Table 3) displayed higher frost resistance than needles and shoots of *Abies grandis*. Among the provenances of *A. grandis* the greatest variability in respect to the index of injury was obtained in early autumn after freezing to -22°C. In four provenances representing the Müller's region I (which includes the areas on the Pacific Coast and in western slopes of the Cascades) the freezing injury of shoots and needles was significantly more severe than in provenances representing the region II (eastern slopes of the Cascade Mountains). When freezing was conducted in the middle of October, the frost hardness of shoots was higher (the index of injury at temperatures of -16°C and -22°C declined from 37% and 46% to 22% and 27%, respectively) (Table 3). The frost hardness of needles in the middle of October was similar to that ascertained in the early autumn (Table 2). In October the largest variability of analysed material in respect to degree of needle injuries was obtained after freezing to -16°C; provenances from region I had the needle index of injury in the range from 60 to 64%, while the provenances from the region II - similarly as *Abies alba* - between 10% and 20% (the only exception was the provenance 12020, where the index amounted to 37% - Table 2). Similar figures were obtained for frost resistance of shoots, where again the provenance 12020 was inferior in respect to frost hardness to other provenances of region II,

TABLE 2. Damage index of needles in one-year old shoots in different provenances of *Abies grandis* and *Abies alba* related to time and temperature of freezing.

A.

Provenance Number IUFRO	Freezing date													
	September 27						October 16				November 30			
	Freezing temperature													
	−8.5°C		−16°C		−22°C		−16°C		−22°C		−22°C		−33°C	
	%	Φ	%	Φ	%	F	%	Φ	%	Φ	%	Φ	%	Φ
12040	4.3	10.0 b	36.3	36.9 bc	57.8	49.6 d	59.9	51.0 c	46.7	42.9 cde	5.7	13.6 d	8.8	15.5 cd
12001	7.8	14.9 b	24.6	29.8 bc	53.4	46.6 cd	60.0	50.9 c	58.2	49.8 de	2.3	7.2 bc	5.4	10.6 bc
12003	7.9	15.9 b	48.3	44.4 c	70.2	57.3 d	60.0	51.1 c	65.5	54.3 e	4.4	11.0 cd	14.7	20.8 d
12005	4.0	9.4 b	43.2	41.5 bc	55.4	48.1 d	63.9	54.4 c	37.6	35.4 bc	1.6	2.3 ab	9.6	15.7 cd
12007	6.8	14.7 b	13.8	21.5 b	20.0	25.4 b	19.9	25.4 a	22.9	28.0 ab	2.6	8.3 cd	2.2	7.8 bc
12016	7.7	15.3 b	31.2	33.5 bc	33.8	35.8 bc	16.4	22.2 a	19.0	23.8 ab	1.0	0.8 a	−1.3	−5.0 a
12020	5.5	12.5 b	24.0	25.8 bc	20.0	25.3 b	37.0	37.3 b	44.6	41.2 cd	2.0	7.6 bc	10.6	15.7 cd
<i>A. alba</i>	−0.2	−1.1 a	5.6	10.8 a	5.0	10.3 a	14.4	17.3 a	17.2	18.9 a	−0.4	−2.0 a	1.1	3.3 b
Average	5.5	11.5	28.4	30.5	39.4	37.4	41.4	38.7	39.0	36.8	2.4	6.1	7.4	10.5
LSD P = 0.95		7.58		20.16		10.81		9.51		11.66		5.56		8.3

B.

Provenance Number IUFRO	Freezing date											
	December 7			April 20				May 18				
	Freezing temperature											
	−22°C		−33°C		−22°C		−33°C		−10°C		−22°C	
	%		%	Φ	%	Φ	%	Φ	%	Φ	%	Φ
12040	at	19.3	24.1 c	11.9	19.6 a	30.4	33.3 cd	0.9	1.2 ab	21.3	27.5 ab	
12001	the	30.0	32.3 d	19.6	24.7 ab	34.9	36.2 e	12.6	20.2 d	42.3	40.7 e	
12003		21.2	26.9 cd	21.1	27.2 bcd	36.4	37.0 e	8.3	16.2 cd	32.8	34.8 cde	
12005	back	18.0	23.3 c	15.3	20.7 ab	27.2	31.4 cd	4.7	8.5 abc	41.6	40.4 e	
12007		16.0	20.6 bc	29.3	32.8 d	31.7	34.0 de	6.3	12.7 bcd	27.3	31.2 abc	
12016	ground	8.0	13.6 ab	13.4	21.1 ab	16.6	23.9 b	−0.4	−2.2 a	17.8	25.5 a	
12020		17.7	22.4 c	14.1	21.9 ab	25.0	29.9 c	3.3	3.3 abc	29.0	32.4 bcd	
<i>A. alba</i>	level	7.7	11.1 a	25.1	29.7 c	12.4	20.3 a	0.9	0.5 a	38.0	38.2 de	
Average	0.0	17.2	21.8	18.7	24.7	26.8	30.8	4.6	7.9	31.5	33.8	
LSD P = 0.95			8.42		7.05		3.55		11.60		6.51	

TABLE 3. Damage index of shoots in different provenances of *Abies grandis* and *Abies alba* related to time and temperature of freezing.

A.

Provenance Number IUFRO	Freezing date													
	September 27						October 16				November 30			
	Freezing temperature													
	−8.5°C		−16°C		−22°C		−16°C		−22°C		−22°C		−33°C	
	%	Φ	%	Φ	%	F	%	Φ	%	Φ	%	Φ	%	Φ
12040	9.5	15.2 a	39.4	38.6 b	52.8	46.8 cd	17.7	24.8 bc	26.9	31.0 cd	3.2	8.3 bc	6.2	10.3 cde
12001	11.9	19.3 ab	55.3	48.7 e	51.4	45.8 cd	19.0	23.8 cd	25.4	29.0 cd	7.5	15.8 d	13.1	20.5 e
12003	18.0	24.9 bc	53.8	47.2 c	60.3	51.0 d	25.8	30.3 c	30.2	32.7 d	5.2	10.4 cd	12.4	18.2 d
12005	12.4	18.3 ab	39.0	38.5 bc	53.6	47.0 cd	10.1	14.9 a	21.3	26.8 bcd	0	0 a	4.6	8.2 bcd
12007	26.3	29.8 c	35.1	35.7 b	43.2	41.0 bc	13.9	21.3 ab	18.6	25.1 abc	1.3	3.1 abc	1.2	2.8 abc
12016	10.1	17.1 ab	28.1	31.1 b	49.9	45.0 cd	12.4	19.5 ab	14.9	20.1 ab	1.2	2.4 ab	−1.0	−3.2 a
12020	16.3	23.2 abc	34.8	35.9 b	36.7	36.5 b	26.8	30.5 c	29.6	32.1 cd	9.8	17.8 d	14.1	19.2 e
<i>A. alba</i>	13.7	20.1 ab	10.4	13.4 a	22.0	27.3 a	13.8	21.5 ab	12.0	18.7 a	1.2	2.1 ab	−0.7	−1.3 ab
Average	14.8	21.0	37.0	36.1	46.2	42.6	17.4	23.3	22.4	26.9	2.9	4.6	6.2	9.3
LSD P = 0.95		8.79		10.63		7.51		6.72		7.26		7.52		10.11

B.

Provenance Number IUFRO	Freezing date												
	December 7			April 20						May 18			
	Freezing temperature												
	−22°C		−33°C		−22°C		−33°C		−10°C		−22°C		
	%		%	Φ	%	Φ	%	Φ	%	Φ	%	Φ	
12040	at	12.6	16.3	31.5	32.9	b	41.3	39.8	ab	26.1	30.5	90.9	72.4
12001	the	13.3	20.6	30.6	32.6	b	46.2	42.6	bc	34.3	35.9	93.3	75.0
12003		12.0	15.3	44.0	36.8	b	55.6	48.2	cd	49.4	44.6	87.0	68.9
12005	back	7.8	11.1	10.1	9.0	a	29.2	32.1	a	29.7	33.0	96.2	78.6
12007		15.8	21.1	28.7	31.3	b	62.3	52.4	d	26.9	31.2	91.9	73.3
12016	ground	6.5	12.0	23.4	24.8	ab	30.4	31.8	a	30.4	33.0	87.1	69.0
12020		12.6	18.9	47.4	41.4	b	28.6	32.1	a	18.2	25.3	88.4	66.7
<i>A. alba</i>	level	9.9	15.3	29.4	26.3	b	32.9	34.2	ab	36.4	37.0	88.4	70.0
Average	0.0	11.3	16.3	30.6	29.4		40.8	39.2		31.4	33.8	89.9	71.1
LSD P = 0.95			not significant		17.27			8.98			not significant		

TABLE 4. Development of buds of *Abies grandis* and *Abies alba* (May 18th).

Provenance	Visual estimation*	Fresh mass of bud [mg]
12040	2.4	52
12001	2.4	49
12003	2.8	58
12005	2.4	50
12007	3.2	60
12016	2.4	56
12020	2.2	49
<i>Abies alba</i>	4.4	155

* 1 – bud swelling

2 – bud obviously prolonged

3 – break of bud scale cover, needles visible

4 – the first prolongation of bud, needles close together at tip

5 – developed bud, needles begin to spread.

while the provenance 12005 (region I) was characterised by a good frost hardness (Table 3).

Freezing conducted after November 30th revealed very strong increase in frost resistance in all provenances of *Abies grandis* and *A. alba*, so that even after freezing to the temperature of -33°C the index of injury for shoots and needles amounted only slightly above 10%. However, even in that case the variability among provenances was substantial. The slightest injury of shoots and needles (at the level comparable with

Abies alba) was recorded for the provenance 12016 of *A. grandis*, while strongest injuries occurred in all provenances from region I and in the provenance 12020 from region II. Similar results were obtained for freezing conducted in December.

To sum up, one can say that in Beskid Sądecki during autumn and winter the provenances of *Abies grandis* from eastern slopes of the Cascade Mountains (especially the provenance 12016) almost match *Abies alba* in respect to frost resistance (the only exception is the provenance 12020), while the provenances from region I are less resistant (among them only the provenance 12005 displays a higher frost hardness).

In spring (April 20, and especially May 18) a significant reduction in frost resistance of shoots was ascertained (Table 3), while the decline in frost resistance of needles was less pronounced (Table 2). In spring the ranking of provenances in respect to frost hardness has changed, meaning that there was no correlation between frost resistance in autumn and in spring. Needles of *Abies alba*, frozen to -22°C , were injured even more than needles of most provenances of *A. grandis*.

In spring trees of all provenances of *Abies grandis* started vegetation and developed buds earlier than *Abies grandis* (Table 4).

In Table 5 given are correlation coefficients (r) between the freezing injury index, representing the current frost resistance of needles and shoots of *A. grandis*, and geographic location of the area of the origin of the given provenance. In autumn (September 27th) after freezing in temperature of -22°C a significant correlation was found between the latitude of locality, from which the seeds were collected, and frost resistance of needles and shoots. This relationship was apparent also in needles analysed in October and in November, and in shoots analysed in May. The relationship between the altitude of the natural range of the given provenance and frost resistance of its needles and shoots, ascertained in September, was observed in needles during the entire autumn, winter and early spring.

TABLE 5. Values of coefficient "r" between freezing injury index in provenances of *Abies grandis* and various tree attributes:

Attribute	Frozen material	September 27		October 16		November 30	December 7	April 20	May 18
		-16°C	-22°C	-16°C	-22°C	-22°C	-33°C	-33°C	-22°C
I. Location of provenances									
1. Latitude $^{\circ}\text{N}$	needles	0.368	0.753 ^a	0.726 ^b	0.457	0.724 ^b	0.509	0.638	0.259
	stems	0.550	0.683 ^b	-0.150	0.216	-0.184	-0.188	0.375	0.647
2. Elevation	needles	-0.526	-0.879 ^a	-0.812 ^a	-0.756 ^a	-0.751 ^b	-0.618	-0.703 ^b	-0.237
	stems	-0.745 ^a	-0.746 ^a	-0.244	-0.524			0.366	-0.303
II. Present height of trees (from the work by Kulej 1994)	needles	0.551	0.609	0.564	0.233	0.563	0.048	0.484	0.286
	stems	0.198	0.430	-0.157	0.132		0.072	0.234	0.398
III. Height increment in 1992 (from the work by Kulej 1994)	needles	0.495	0.670 ^b	0.702 ^b	0.284	0.578	0.309	0.501	0.371
	stems	0.368	0.669 ^b						0.758 ^a

a – significant at $P = 0.95$; b – significant at $P = 0.90$.

DISCUSSION

Our investigations demonstrated the usefulness of the Dexter's method for determining frost hardiness in species and provenances of *Abies*. While determining the degree of freezing injuries in trees it is indispensable – according to the recommendations of Flint et al. (1967) and Pearce (1985) – to take into consideration the amount of electrolytes washed out of the unfrozen tissues ("background diffusion"). Differences between the values of injury index (I_i), calculated according to Flint et al. (1967), taking into account the "background diffusion", and the relative value of diffusion (RC) (Dexter et al. 1932) are the greater the weaker the freezing injury. This problem was described in detail (on the basis of results obtained in this study) in the earlier work by the authors (Dolnicki, Kraj 1996).

In our investigations "background diffusion" in *A. grandis* and *A. alba* amounted in needles 11%, and in chopped shoots 30% of the total amount of electrolytes. Similar figures had been obtained by other authors, like: Arronsson and Eliasson (1970) 15% for needles of *Pinus sylvestris*, Edwards et al. (1990) 5% for needles of *Pinus taeda*, Salaj (1988) around 10% for needles of *Abies alba* and *Picea abies*. For chopped shoots the values obtained by other authors had amounted to 20-30% in *Pinus radiata* (Green, Warrington 1978), *Pseudotsuga menziesii* (Driessche 1969). Substantial differences in "background diffusion" between needles and shoots can be explained by the fact, that at preparing needles for analysis the injured surface is relatively small (needles are only detached from the shoot), while chopping shoots into pieces several mm long causes injuries to many cells, including the conducting vessels.

In our research "background diffusion" of needles and shoots of *A. grandis* and *A. alba* was not subjected to any substantial changes from early autumn to late spring, which suggests the absence of injuries caused by frosts occurring in natural conditions of Beskid Sądecki range during our study. This allows us to estimate the real frost hardiness of the analysed plants on the basis of results obtained after freezing in freezer room.

Significant differences were found between provenances of *A. grandis* (Tables 2, 3) in the level and seasonal dynamics of changes in frost resistance. In autumn and winter provenances from the Müller's region II (i.e. provenances 12040, 12001, 12003, 12005) were mainly inferior in respect to frost hardiness in comparison with provenances from region II (12007, 12026, 12020). This can be explained by the different climates in the regions of origin of those provenances, and by the long-lasting selection pressure, shaping their genetically determined physiological traits, among others frost hardiness. Region I, which includes Vancouver Island (Canada), Pacific Coast, Olympic peninsula, Bear Mountain and western slopes of Cascade Mountains (USA), is characterised by a maritime type of climate, with high precipitation, lack of summer heat and lack of severe frosts in winter (minimal temperatures -18°C , -25°C). This kind of climate is conducive for the growth and development of *A. grandis* (Bellon et al. 1986, Fowells 1965). Provenances coming from that region display a genetically determined medium level of frost hardiness and high growth potential. On the contrary, in region II, situated in eastern slopes of the Cascade Mountains in Washington and Oregon the climate is more severe (annual sum of precipitation 500-700 mm, most of it in winter, winter frosts down to -34°C) (Fletcher 1986, Kleinschmit, Svolba 1979). According to the data from the literature, provenances from the re-

gion II tolerate the harsh winter conditions better than provenances from region I. This was found among others in USA (Steinhoff 1986), in Germany (Kleinschmit 1986, Kleinschmit, Svolba 1979, Larsen, Ruetz 1980, Rau, Weisgerber 1986), in Austria (Günzl 1992), in France (Lacaze, Tomassone 1967), in Czech Republic and in Slovakia (Burzyński, Vančura 1985, Šika, Vančura 1987), in Poland (Bellon et al. 1986). Investigations conducted in the laboratory (Larsen 1978) proved that provenances from the Müller's region I harden slowly, while they dehardens faster, than the provenances from region II.

In Beskid Sądecki, among the provenances from Müller's region I the provenance 12005 stands out because of its relatively good frost hardiness of needles and one-year shoots in autumn and in winter (Tables 2, 3). This provenance comes from Bear Mountain, from a relatively high (for that region) elevation of 825 m above sea level (Table 1). This confirms the results obtained earlier by Rau and Weisgerber (1986); according to them, this provenance in Hessen lignifies earlier and is more frost resistant than the form 12003 from the Olympic Peninsula and form 12040 from the Vancouver Island. Larsen and Ruetz (1980), while investigating the dynamics of frost resistance in one-year seedlings of *A. grandis* in autumn and in winter, had found a higher (by 1° to 2°C) frost resistance in provenance 12005 in comparison with 12001.

Among the provenances from region II tested in Beskid Sądecki, the best frost resistance of needles and shoots in autumn and in early winter, in general at the level of *A. alba*, was observed in provenance 12016, while the lowest frost resistance (at the level comparable with provenances from the region I) in provenance 12020 (Table 2, 3). Both provenances come from the eastern slopes of the Cascade Mountains in Oregon, from similar elevations around 1400 m above sea level. The only difference is that the natural range of distribution of provenance 12020 is situated about 1° more to the south. Differences in frost resistance can be considered a specific reaction of the one-year shoots of these trees to the conditions of Beskid Sądecki; according to Bellon et al. (1986) young seedlings of the provenance 12016 in Rogów (central Poland) were subjected to more severe frost injuries than seedlings of the provenance 12020. Also Rau and Weisgerber (1986) observed lower frost resistance in four-year old seedlings of provenance 12016 in comparison with provenance 12020.

In *A. grandis* during early spring (measured on April 20th) the process of losing frost hardiness was faster in needles than in shoots, but later on (measured on May 18th), after the budbreak and flush of new needles, the frost resistance of shoots declined rapidly, so that after freezing in temperature -22°C they died almost completely, while the needles exposed to the same temperature were injured only in 30% (Tables 2, 3). The reason for these differences is – probably – the fact, that during flushing period shoots absorb a lot of water and they lose big amounts of assimilates.

Investigations proved the dependence between geographic latitude and elevation above sea level of places from which seeds of *Abies grandis* were collected, and frost resistance of needles and buds of young tree planted in Beskid Sądecki (Table 5).

These results confirm data from the literature. Steinhoff (1986) in his investigations conducted in the severe climate of Idaho found an increase in freezing injuries of needles at moving southward from the place of origin of seeds; the rate of this increase amounted to 6% with each degree of latitude. In the study by Kleinschmit (1986) the correlation coefficient

between the altitude of origin and frost resistance amounted to 0.85, while in the research by Larsen and Ruetz (1980) the correlation coefficient ranged from 0.63 (for winter frost resistance) to 0.95 (for resistance to late spring frosts).

Investigations in Beskid Sądecki range (Table 5) did not yield any significant relationship between tree height in *Abies grandis* (taken from the work of Kulej and Żuchowska 1994) and the freezing injury index, while in autumn (freezing in temperature -22°C on September 27th and in temperature -16°C on October 16th) a statistically significant relationship ($r = 0.670$ and $r = 0.700$) was found between the length of annual increment and frost resistance in shoots (Table 4). Also Kleinschmit (1986) and Steinhoff (1986) ascertained the significant relationship between frost hardiness and rate of height growth in *A. grandis*. Trees with a prolonged period of intense growth have – in comparison with slower growing ones – less time for shoot lignification and accumulation of defensive compounds, as well as for the structure changing of cell membranes. There is a vast literature concerning this topic.

Research in Beskid Sądecki range proved, that only in early autumn (September) all provenances of *A. grandis* were significantly inferior to *A. alba* in respect to frost hardiness of needles and shoots (Tables 2, 3). In late autumn and in winter (October-December) provenances from Müller's region II, and especially the provenance 12016 (the only exception being provenance 12020) attained the level of frost hardiness comparable with *A. alba*. On the other hand, in spring (especially in May) the process of losing frost hardiness was much faster in *A. alba* than in *A. grandis* (Tables 2, 3), probably due to the earlier budbreak (Table 4).

As shown by the research of Magnussen (1982) provenances of *A. grandis*, and in particular the ones from Müller's region II, develop frost hardiness in autumn much more slowly than *A. alba*, while in spring they are usually less sensitive to late frosts, because they start flushing later (Leibundgut 1983). Magnussen (1982) obtained a significant correlation ($r = -0.97$) between the degree of development of buds and frost resistance in different forms of *A. grandis* and *A. alba*.

Data from the literature indicate, that in western and central Europe *A. grandis* winters over quite well, even during the seedling stage, in nurseries located underneath the canopy or in close proximity of a sheltering forest stand (Bellon et al. 1986). According to Magnussen (1986) in western Norway (the vicinity of Bergen) the mortality of seedlings in nurseries ranged – depending on provenance – from 0 to 17%, and no signs of mortality due to freezing were recorded. Older trees of *A. grandis*, especially coming from the Müller's region II, usually winter over quite well (Jaworski, Majerczyk 1975, Tumiowicz 1979, Tumiowicz, Wodzicki 1990, Vančura 1986, Zajaczkowski 1975). Only after exceptionally severe winters apparent freezing injuries were noted; for example, after the winter 1972/73 in eastern part of Germany many individuals of *A. grandis* died (Eisenreich 1984).

To summarize, we conclude that our research documented the adequate level of frost resistance in provenances of *A. grandis* from the IUFRO collection (in particular the provenance 12016) and their usefulness (this refers especially to fast growing provenance 12005) for planting in Beskid Sądecki range.

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DYNAMIKA MROZOODPORNOŚCI PROWENIENCJI JODŁY OLBRZYMIEJ (*ABIES GRANDIS* LINDL.)

STRESZCZENIE

Od wczesnej jesieni do późnej wiosny (IX-V) metodą Dextera oznaczano mrozoodporność jednorocznych igieł i pędów kilkunastoletnich drzew siedmiu proveniencji *Abies grandis* i jednej *Abies alba* rosnących w ściśłym doświadczeniu nad Krynica w Beskidzie Sądeckim (Polska Południowa) na wysokości 800 m. Stwierdzono, że wczesną jesienią (wrzesień) *Abies grandis* hartuje się słabiej aniżeli *Abies alba*. W późniejszym okresie jesieni i w zimie proveniencje z drugiego rejonu wg Müllera (zwłaszcza 12016) dorównują *Abies alba* mrozoodpornością igieł i pędów. Wśród proveniencji z I rejonu wg Müllera pod względem mrozoodporności dodatnio wyróżnia się 12005, która charakteryzuje się przy tym bardzo dobrym wzrostem. Na wiosnę drzewa *Abies alba* rozwijają się wcześniej niż *Abies grandis*, co ujemnie wpływa na ich odporność na spóźnione przymrozki. Badania wykazały, że *Abies grandis* może być uprawiana w Beskidzie Sądeckim, przy czym najlepsza wydaje się proveniencja 12005 łącząca szybki wzrost z odpowiednią mrozoodpornością.

SŁOWA KLUCZOWE: *Abies grandis* Lindl., proveniencje, mrozoodporność.