Effect of provenance on the volume increment of grand fir (*Abies grandis* Lindl.) under mountain conditions of Poland

M. Kulej[1], J. Socha[2]

[1]*Department of Forest Tree Breeding, Faculty of Forestry, Agricultural University of Cracow, Poland*
[2]*Department of Forest Mensuration, Faculty of Forestry, Agricultural University of Cracow, Poland*

ABSTRACT: The purpose of this study was to assess the volume increment diversification of selected provenances of grand fir growing under mountain conditions of Poland. The mean increment was determined on the basis of volume reached by the respective provenances when trees were 30 years old while the current increment was calculated from a difference between the volume when trees were 30 years old and the volume when they were 26 years old. It was found that the productive (increment) potential of tested grand fir partial populations is determined by the genotype (provenance). Among the tested provenances grand fir from Salmon River on Vancouver Island in Canada is characterized by the greatest productive capacity.

Keywords: genotype; planting experiment; productivity

The knowledge of genetic resources of the North American grand fir (*Abies grandis* Lindl.), an exotic species for Poland, is acquired mainly by provenance studies. Their results yield the basic information on variation of definite characters, silvicultural value, and productive capacity of individual populations, as well as on their usefulness in forestry practice. The individual selection is directly associated with the results of these experiments, since the selection of the best growing individuals from the best provenances brings the greatest genetic gain. Therefore the acquisition of basic data on the diversification of provenances of foreign forest trees species decides on the success of their introduction and acclimatization.

Grand fir has successfully been introduced into many countries including France, England, Belgium, the Netherlands, Slovakia, Czech Republic, and Germany (Hofman 1967; Lacaze 1967; Lines 1974; Nanson et al. 1986; Vančura 1990; Dong et al. 1993; Kleinschmit et al. 1995). However, great diversification of climatic and soil conditions within the natural range of grand fir, as well as the existence of geographic races (Müller 1935, 1936) or definite provenances (Kramer 1978; Kleinschmit 1986; Steinhoff 1986) makes it necessary to select partial populations of this species suitable for the given site conditions. In Poland a long-term research on grand fir started in 1976 on the initiative of IUFRO. Its aim is to determine the silvicultural usefulness of selected provenances in different regions of our country.

This paper is a part of a long-term study on genetic and silvicultural variation of grand fir conducted by the Department of Forest Tree Breeding, Faculty of Forestry, Agricultural University of Cracow. Among the results obtained so far considerable diversification of partial populations in respect of survival, growth (Kulej, Półtorak-Kądziołka 1998), frost resistance (Dolnicki, Kraj 1998), early spring growth (Sabor et al. 1999), silvicultural quality (Kulej 2003) and stem form (Socha, Kulej 2005) is of a particular interest.

The purpose of the study presented in this paper was to assess the diversification of productivity

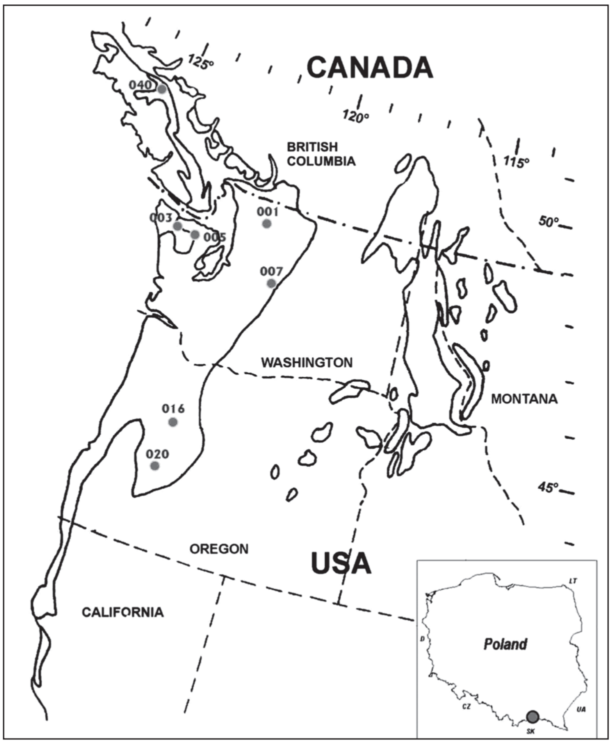

Fig. 1. Location of mother stands of tested grand fir provenances in North America and experimental area in Poland

of different grand fir provenances growing under mountain conditions of the Beskid Sądecki Mts. on the basis of mean and current annual volume increments.

MATERIAL AND METHODS

Seven provenances of grand fir (*Abies grandis* Lindl.) were investigated. During their selection for the experiment the diversification of climatic conditions in the natural range of grand fir was taken into account based on the regions distinguished by Müller (1935, 1936) and also on the altitude. Mother stands of the analyzed provenances were growing in a height interval from 25 m to 1,400 m above the sea level (Table 1). Their location is illustrated in Fig. 1.

The experimental area is situated at an altitude of 700–720 m a.s.l. (i.e. in the middle part of the lower mountain zone) in the Wojkowa Forest Section of the Krynica Experimental Forest located in the Carpathian Forest Region. It is situated at a site of the mountain forest type. The tested provenances were planted under the system of random blocks in four replications (28 plots, 20 × 20 m each). A detailed description of this area may be found in the earlier publication (Kulej, Półtorak-Kądziołka 1998).

This study is based on the results of measurements of diameter at breast height (dbh) and height (H) of trees of the investigated grand fir provenances. The measurement of dbh included the entire study material, while the height measurement included 10 trees selected at random on each plot.

The values of dbh and H were measured when trees were 26 and 30 years old (i.e. at the beginning and at the end of increment period). In total, dbh of 1,663 trees and height of 282 trees were measured. At the end of increment period the dbh of the measured trees ranged from 1.7 to 32.0 cm and their height from 1.6 to 18.1 m (Table 2). To determine the mean volume increment of the tested grand fir provenances the volume of individual trees at 30 years of age was calculated.

Table 1. Data on mother stands where the seed of analyzed grand fir provenances was collected (Kamiński 1982)

Number of provenance acc. to IUFRO	Name of provenance	Location of mother stands				
		region, country, locality	latitude N	longitude W	altitude (m)	region acc. to Müller
12040	Salmon River	British Columbia Canada Sayward	50°20′	125°56′	25	I
12003	Indian Creek	Washington, USA 5 km W of Elwha	48°04′	123°38′	140	I
12001	Buck Creek	Washington, USA NE of Darrington	48°15′	121°21′	400	I
12005	Bear Mountain	Washington, USA Louella-Blyn	47°5′	123°02′	825	I
12007	Eagle Creek	Washington, USA 13 km NE of Lavanworth	47°39′	123°30′	1,200	II
12020	Crescend Creek	Oregon, USA 16 km of Crescend	43°28′	121°57′	1,375	II
12016	Santiam Summit	Oregon, USA 13 km of Sisters	44°26′	121°52′	1,400	II

Table 2. Biometrical characteristics of tested grand fir provenances in the experimental area of Krynica Experimental Station

Provenance	Diameter at breast height (cm)			Height (m)			Volume ($m/^3$ ha)			Mean annual increment (m^3/ha/year)			Current annual increment (m^3/ha/year)		
	mean	min	max	mean	min	max	mean	min	max	mean	min	max	mean	min	max
040	15.09	2.7	31.6	12.2	4.1	16.9	192	153	212	6.39	5.1	7.1	16.36	14.3	18.7
003	13.74	1.7	28.2	9.7	1.6	14.6	179	132	233	5.97	4.4	7.8	14.97	11.5	18.5
001	14.09	1.7	29.4	10.1	2.0	18.1	149	119	170	4.97	4.0	5.7	12.97	10.9	14.7
005	15.84	3.6	32.0	11.5	5.5	14.8	173	111	232	5.77	3.7	7.7	13.55	8.8	18.3
007	14.51	1.8	31.0	10.8	2.0	16.5	169	133	189	5.63	4.4	6.3	15.51	12.4	19.1
016	14.04	1.8	29.1	8.9	2.4	13.8	111	89	137	3.69	3.0	4.6	10.90	8.9	14.8
020	14.43	1.9	25.4	9.2	3.5	12.9	58	37	85	1.94	1.2	2.8	5.18	2.3	8.3
Total	14.52	1.7	32.0	10.4	1.6	18.1	147	37	233	4.91	1.2	7.8	12.78	2.3	19.1

Table 3. Dependence of the mean and current volume increment of grand fir on provenance and replication

Effect	Mean annual increment					Current annual increment				
	SS	DF	MS	*F*	*P*	SS	DF	MS	*F*	*P*
Free term	674.84	1	674.84	1,285.79	< 0.0001	4,571.49	1	4,571.49	1,231.23	< 0.0001
Provenance	59.45	6	9.91	18.88	< 0.0001	348.00	6	58.00	15.62	< 0.0001
Replication	15.77	3	5.26	10.01	0.0004	93.30	3	31.10	8.38	0.0011
Error	9.45	18	0.52			66.83	18	3.71		

The stem form of trees of partial grand fir populations in the experimental area in Krynica considerably varied (Socha, Kulej 2005). For this reason during the earlier investigations the separate empirical equations for stem volume determination were elaborated for two regions of provenances. To calculate the stem volume (v) of trees from region I equation (1) and from region II equation (2) were used (Kulej, Socha 2005).

$$v = 0.00006799 \times h^{1.2124} \times (h - 1.3)^{-0.2739} \times (d^2)^{0.9038} + \varepsilon \quad (1)$$

where: v – stem volume,
h – height of a tree,
d – diameter at breast height,
ε – random error.

$$v = 0.00002057 \times h^{3.6625} \times (h - 1.3)^{-2.2695} \times (d^2)^{0.8921} + \varepsilon \quad (2)$$

To determine the volume of all trees and height of only about 20% of them height curves were used which were constructed for the respective provenances on the basis of the Näslund equation (Bruchwald, Wróblewski 1994) according to equation (3).

$$h = \left(\frac{d}{b_0 + b_1 \times d}\right)^2 + 1.3 \quad (3)$$

where: h – height of a tree,
d – diameter at breast height,
b_0, b_1 – equation parameters.

After adding the volumes of trees on the plots and dividing the result by the time period of their formation the mean annual volume increment (I_{mij}) of individual provenances (i) in replications (j) was obtained (equation 4).

$$I_{mij} = \frac{\sum_{k=1}^{n} v_{kij}}{w \times A} \quad (4)$$

where: I_{mij} – mean annual volume increment of provenance (i) in replication (j),

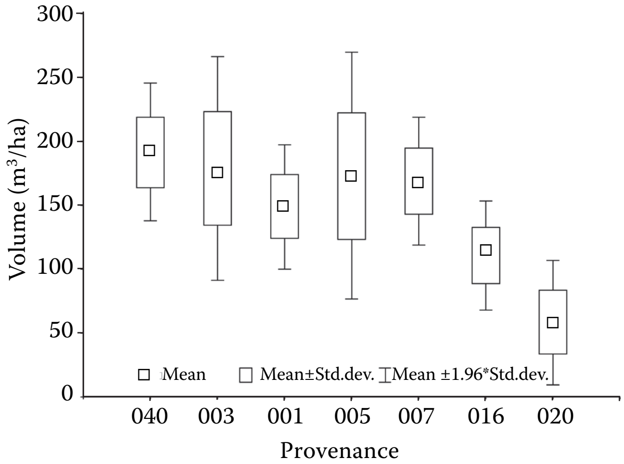

Fig. 2. Mean volume per ha of individual provenances of *Abies grandis*

v_{kij} – volume of tree No. k,
n – number of trees in replication,
w – age,
A – plot size (0.04 ha).

Current increment (I_{cij}) for individual plots was calculated by subtracting the volume of trees at 26 years of age from the volume at 30 years of age (equation 5):

$$I_{cij} = \frac{\sum_{k=1}^{n} v_{kij30} - v_{kij26}}{4 \times A} \quad (5)$$

where: I_{cij} – current annual volume increment of provenance (i) in replication (j) (m³/ha),
v_{kij30} – volume of tree No. k at 30,
v_{kij26} – volume of tree No. k at 26,
n – number of trees in replication.

The effect of the provenance (genotype) and the replication (environment) on the mean and current annual volume increments of grand fir was determined on the basis of the analysis of variance following Bartlett's test of variance homogeneity. Statistical analysis was done using STATISTICA (Version 7.1), statistical software package (StatSoft Inc. 2007).

Table 4. Comparison of volume increments of tested grand fir provenances using the analysis of variance

Variable	Test of variance homogeneity			Analysis of variance							
	DF	Chi-square	P	SS model	DF model	MS model	SS error	DF error	MS errors	F	P
Mean annual increment	6	1.5763	0.2033	21	6	3.5392	2.7648	21	0.1317	27	< 0.00001
Current annual increment	6	2.2957	0.0733	21	6	3.4754	3.1476	21	0.1499	23	< 0.00001

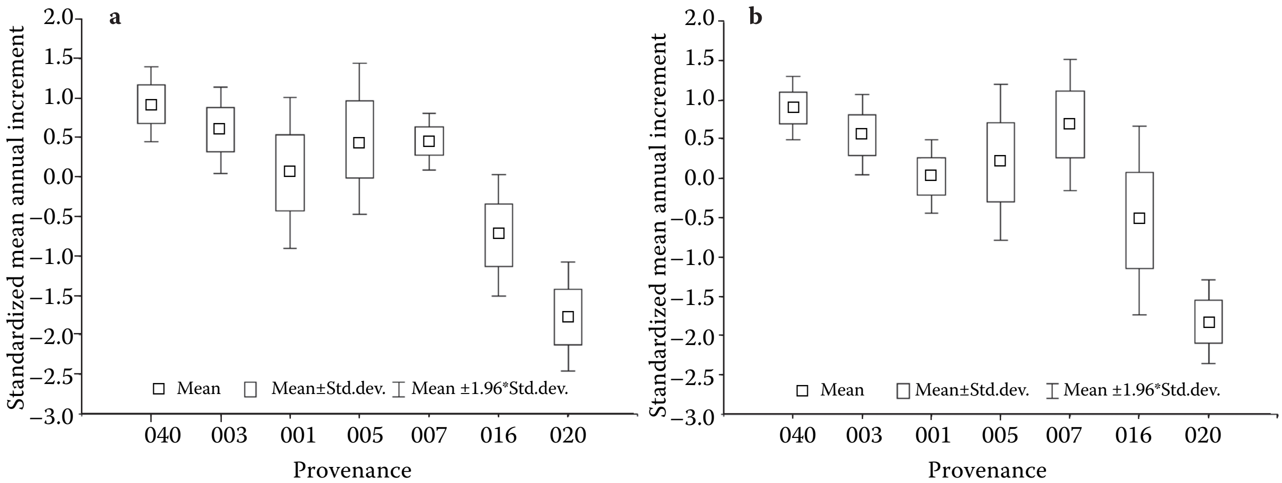

Fig. 3. Standardized volume increment of tested grand fir provenances (a – mean annual increment, b – current annual increment)

RESULTS

The mean volume per ha of 30-years-old grand fir of tested provenances varied from 58 m^3 (provenance 020) to 192 m^3 (provenance 040) (Fig. 2). The mean annual volume increment of grand fir of the respective provenances was considerably diversified and varied from 1.94 m^3/ha/year (provenance 020) to 6.39 m^3/ha/year (provenance 040) (Table 2). The current annual volume increment was much higher, ranging from 5.18 m^3/ha/year (provenance 020) to 16.36 m^3/ha/year (provenance 040) (Table 2).

It was found on the basis of the two-factor analysis of variance that the mean and current annual increment depends on the provenance as well as on the replication (Table 3). To eliminate the effect of the replication the standardization of the values of mean increment within a given replication was used according to equation (6).

$$I_{sij} = \frac{I_{ij} - I_j}{\delta_{Ij}} \qquad (6)$$

where: I_{sij} – standardized value of volume increment of provenance (i) in replication (j),
I_{ij} – volume increment of provenance (i) in replication (j),
I_j – mean volume increment in replication (j),
δ_{Ij} – standard deviation of volume increment in replication (j).

The elimination of the effect of the replication permitted to carry out the one-way analysis of variance which was used to find out whether there are differences between average values of the standardized volume increment of individual provenances (Table 4). The data in Table 5 show that in mean increment as well as in current volume increment the variances in the respective provenances were homogeneous. The probability level found on the basis of the analysis of variance showed that the tested hypothesis about the equality of averages of mean and current volume increments of individual provenances should be rejected. Thus, the provenance (genotype) significantly affected the mean and current volume increments of the analyzed grand

Table 5. Comparison of the mean values of standardized mean volume increment of individual grand fir provenances using Tukey's test

Provenance	Standardized mean volume increment	Homogeneous groups			
		1	2	3	4
020	–1.767	****			
016	–0.737		****		
001	0.052		****	****	
007	0.455			****	****
005	0.482			****	****
003	0.597			****	****
040	0.919				****

****homogeneous groups at α = 0.05

Table 6. Comparison of the mean values of standardized current volume increment of individual grand fir provenances using Tukey's test

Provenance	Standardized mean volume increment	Homogeneous groups		
		1	2	3
020	–1.822	****		
016	–0.533		****	
001	0.025		****	****
005	0.202		****	****
003	0.554			****
007	0.679			****
040	0.895			****

****homogeneous groups at α = 0.05

fir partial populations. The groups of provenances statistically homogeneous in respect of analyzed characters distinguished on the basis of Tukey's test are shown in Tables 5 and 6.

As regards the mean volume increment the analyzed provenances may be divided into four homogeneous groups (Table 5). The first includes grand fir from Crescend Creek characterized by the smallest mean volume increment, smaller by –1.77 of standard deviation than the general average (Fig. 3a). Grand fir of provenance 016 from Santiam Summit and 001 from Buck Creek showed a relatively small increment, smaller by 0.74 and 0.05 of standard deviation, respectively, than the averages for the entire study material. The third group includes partial populations 001, 007, 005, and 003, i.e. from western and eastern slopes of the Cascade Range in Washington. Decidedly the greatest mean volume increment, greater by 0.92 of standard deviation than the general average, was reached by grand fir from Salmon River (040) in British Columbia.

The analyzed provenances may be divided into three homogeneous groups according to current annual increment (Table 6). The first, characterized by the smallest increment (smaller by 1.82 of standard deviation than the general average), comprises provenance 020. The increments close to the average one were found for provenances 001 and 005. Provenances characterized by the greatest current increment include grand fir from Indian Creek (003) and Eagle Creek (007) in Washington and Salmon River (040) from British Columbia (Fig. 3b).

DISCUSSION

The results of this study aimed at the provenance variation of mean and current volume increments of grand fir confirmed that its productive capacity under mountain conditions of Poland was determined by the provenance (genotype) in the first place. The location of its mother stands, i.e. the altitude and latitude, also has a considerable effect on grand fir growth. In general, the mean and current annual volume increments of the analyzed grand fir provenances decrease with an increase in the altitude. In the case of mean increment the provenances from Bear Mountain (005) and Eagle Creek (007), and in the case of current increment the provenances from Indian Creek (003) and Eagle Creek (007) are exceptions in this respect. As far as the latitude is concerned, grand fir of provenance 040 from Salmon River in British Columbia, the northernmost one (latitude 50°20´), is characterized by the greatest increment, while the provenances from Santiam Summit (016) and Crescend Creek (020) from eastern slopes of the Cascade Range, the southernmost ones, are characterized by the smallest increment. The medium increments were found in grand fir populations originating from latitudes ranging from 47°9´ to 48°15´

The mean annual volume increment of 30-years-old grand fir of tested provenances varied from 1.94 m^3/ha to 6.39 m^3/ha. In comparison with silver fir (*Abies alba*), for which the mean annual volume increment in Poland under site class I reaches about 4.2 m^3/ha (Schwappach 1943), the tested provenances of grand fir generally showed a greater volume increment. Only in provenances 016 and 020 the mean volume increment was smaller and was equal to the increment of European fir growing on sites of classes II and III.

In comparison with the results of research carried out in North America, according to which the mean annual increment of grand fir is from 8 to 13 m^3/ha in Idaho (Stage 1969) and from 6 to 10 m^3/ha in Montana (Pfister et al. 1977), the mean increment of grand fir growing under mountain conditions of Poland was relatively low. However, the high values of the current increment found recently may suggest that the mean increment of the analyzed grand fir provenances will reach the level recorded in its natural range with an increase in age.

The values of the current annual volume increment of the tested grand fir populations are close to the values recorded for 40-years-old trees of this species growing on fertile soils in England, i.e. from 18 to 20 m^3/ha/year (Aldhous, Low 1974). Among the provenances tested during the present study grand fir from Salmon River and Eagle Creek showed the considerably highest increments, i.e. 16.36 m^3/ha/year and 15.51 m^3/ha/year, respectively. On the other hand, the productivity of grand fir from Santiam Summit and Crescend Creek in Oregon was considerably lower, i.e. 10.90 m^3/ha/year and 5.18 m^3/ha/year, respectively. Comparison between the mean and current volume increments of the tested grand fir populations pointed to an increase in the dynamics of current increment of provenance 007 (Eagle Creek). This provenance ranked at a much higher position in respect of the current annual increment than in respect of the mean increment, and this indicates an increase in growth dynamics in the recent period of time.

The results of this study showed the high productive capacity of tested grand fir partial populations under mountain conditions of Poland. Their volume increment depends mainly on the provenance (genotype). At the present stage of research grand fir from Salmon River on Vancouver Island in Canada is characterized by the greatest productive capacity. Grand fir of the provenances from Region I of its natural occurrence (according to Müller 1935, 1936) is characterized by markedly more favourable growth features than that of the provenances from Region II. Therefore, when introducing grand fir on a larger scale, the proper choice of provenances should be made in order to ensure its successful introduction and acclimatization.

References

ALDHOUS J.R., LOW A.J., 1974. The potential of western hemlock, western red cedar, grand fir, and noble fir in Britain. Forestry Commission Bulletin, 49. London, Her Majesty's Stationary Office.

BRUCHWALD A., WRÓBLEWSKI L., 1994. Uniform height curves for Norway spruce stands. Folia Forestalia Polonica, *36*: 43–47.

DOLNICKI A., KRAJ W., 1998. Dynamics of frost resistance in various provenances of *Abies grandis* Lindl. Acta Societatic Botanicorum Poloniae, *7*: 51–61.

DONG P., ROEDER A., ADAM H., 1993. Zum Wachstum der grossen Küstentanne in Rheinland-Pfalz. Forst- und Holzwirtschaft, *48*: 86–90.

HOFMAN J., 1967. K historii a rozšíření jedle obrovské v Československu. Rocznik Dendrologiczny, *21*: 115–127.

KAMIŃSKI K., 1982. Wzrost i wydajność siewek jodły olbrzymiej (*Abies grandis* Lindl.) różnych pochodzeń w tunelach foliowych. Sylwan, No. 8: 11–20.

KLEINSCHMIT J., 1986. Nursery results of the *Abies grandis* Lindl. provenance experiment in northern Germany. Forestry Commission Research, *139*: 39–58.

KLEINSCHMIT J., SVOLBA J., RAU H.M., WEISGERBER H., 1995. The IUFRO *Abies grandis* provenance experiment in Germany. Results at Age 18/19. Joint Meeting the IUFRO Working Parties, Limognes.

KRAMER W., 1978. Zur Entwicklung verschiedener Herkünfte von *Abies grandis*. Forst- und Holzwirtschaft, *4*: 100–110.

KULEJ M., 2003. Jakość hodowlana jodły olbrzymiej w warunkach górskich Polski na przykładzie powierzchni badawczej w Leśnym Zakładzie Doświadczalnym w Krynicy. Zeszyty Naukowe AR w Krakowie, *398*: 75–88.

KULEJ M., PÓŁTORAK-KĄDZIOŁKA A., 1998. Jodła olbrzymia (*Abies grandis* Lindl.) w warunkach górskich Polski na przykładzie powierzchni doświadczalnej w LZD Krynica. Sylwan, No. 1: 39–53.

KULEJ M., SOCHA J., 2005. Estimation of productivity of selected provenances of grand fir in the provenance experiment in the Krynica Experimental Forest (Southern Poland). Electronic Journal of Polish Agricultural University, *8* (4).

LACAZE J.F., 1967. Les choix des provenances d'*Abies grandis*. Prémirés conclusions sur stade pépiniére. Revue Forestière Française, *19*: 613–624.

LINES R., 1974. A preliminary provenances trial with grand fir (*Abies grandis* Lindl.) Scottish Forestry, *28*: 85–98.

MÜLLER K., 1935. *Abies Grandis* und ihre Klimarassen. Mitteilungen der Deutschen Dendrologischen Gesellschaft, No. 47: 54–123.

MÜLLER K., 1936. *Abies Grandis* und ihre Klimarassen. Mitteilungen der Deutschen Dendrologischen Gesellschaft, No. 44: 82–132.

NANSON A., DE JAMBLINNE DE MEUX A. GATHY P., 1986. Provenance experiments on *Abies grandis* in Belgium. Forestry Commission Research, *139*: 11–21.

PFISTER R.D., KOWALCHIK B.L., ARNO S.F., PRESBY R.C., 1977. Forest habitat types of Montana. USDA Forestry Service General Technical Report INT-34.

SABOR J., SKRZYSZEWSKA K., KULEJ M., BANACH J., 1999. Rola obserwacji fenologicznych w genetyce populacyjnej drzew leśnych In: Konferencja naukowa Klimatyczne uwarunkowania życia lasu. Zakopane, Drukrol S. C.: 105–115.

SCHWAPPACH A., 1943. Ertragstafeln der wichtigeren Holzarten. Prag, Druckerei Merkur: 66–73.

SOCHA J., KULEJ M., 2005. Provenience-depending variability of the stem form of *Abies grandis* under mountain conditions of Beskid Sądecki (southern Poland). Canadian Journal of Forest Research, *35*: 2539–2552.

STAGE A.R., 1969. Computing procedures for grand fir site evaluation and productivity estimation. USDA Forestry Service Research Note INT-98.

StatSoft, Inc., 2007. STATISTICA (data analysis software system), version 7.1. www.statsoft.com.

STEINHOF R., 1986. Nursery performance of grand fir provenance collections in North Idaho. Forestry Commission Research, *139*: 145–151.

VANČURA K., 1990. Provenienční pokus s jedlí obrovskou série IUFRO ve věku 13 let. Práce Výzkumného ústavu lesního hospodářství a myslivosti, *75*: 47–66.

Received for publication November 9, 2007
Accepted after corrections November 30, 2007

Vliv provenience na objemový přírůst jedle obrovské (*Abies grandis* Lindl.) v horských podmínkách Polska

ABSTRAKT: Cílem studie je hodnocení rozdílů objemového přírůstu u vybraných proveniencí jedle obrovské pěstované v horských růstových podmínkách Polska. Průměrný přírůst byl stanoven na základě objemu stromů vybraných proveniencí ve věku 30 let. Běžný přírůst je vypočítán z rozdílu mezi objemem stromů ve stáří 30 a 26 let. Bylo zjištěno, že produkční možnosti (přírůst) testovaných populací jedle obrovské jsou dány genotypem (proveniencí). Z testovaných proveniencí vykazovala nejvyšší produkční kapacitu jedle ze Salmon River na ostrově Vancouver v Kanadě.

Klíčová slova: genotyp; výsadbový pokus; produkce

Corresponding author:

Dr. Jaroslav Socha, Agricultural University of Cracow, Faculty of Forestry, Department of Forest Mensuration, Al. 29 Listopada 46, 31 425 Cracow, Poland
tel.: + 48 12 662 5011, fax: + 48 12 411 9715, e-mail: rlsocha@cyf-kr.edu.pl