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Growth and development of Polish provenances of *Picea abies* in the IUFRO 1972 experiment

Abstract: The paper presents the results of research on the genetic variability in the growth characteristics and plasticity of Polish provenances of Norway spruce, tested on thirty plots established in Europe and Canada in the IUFRO 1972 provenance experiment. Special consideration was devoted to the plots in Poland, especially in Knyszyn. The variability in the growth and quality characteristics of the provenances, found at experiment level, is high (within 6.099 standard deviation units). At provenance level, it ranges between 4.674 for Kartuzy and 2.192 for Rycerka Zwardoń. This indicates that the performance of the provenances depends much on environmental conditions. Although no provenance can be considered adaptable to any conditions that may occur in the cultivation of spruce, the Istebna Bukowiec and Zwierzyniec Lubelski provenances, having a very high breeding value and high plasticity, may be recommended for a wider use in reforestation.

Additional key words: Norway spruce, provenance variability, plasticity

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Introduction

Since the 1950s, the Department of Genetics and Physiology of Woody Plants (up to 1994, the Department of Seed and Selection), Forest Research Institute, Warsaw, has conducted studies on the variability in the growth and quality characteristics of Norway spruce (*Picea abies* (L.) Karst.) populations.

Initially, the Department was entrusted by the US Department of Agriculture with doing research into the quality and productivity of Polish spruce populations in mature stands. The results of the research completed in 1968 were published in the report "Population studies of Norway spruce in Poland" (Tyszkiewicz 1968a, b; Tyszkiewicz et al. 1969). The permanent experimental plots set up within the framework of this research were used to collect seeds for establishing a parallel experiment on the variation in Norway spruce populations.

The greater is the number of experimental plots and the more varied are the conditions in which the populations are tested, the more precise is the evaluation of their growth characteristics and plasticity. Based on these assumptions, a large-scale experiment with Polish spruce provenances was started with the aim of investigating their genetic variability and determining plasticity, i.e. adaptability to different environmental conditions. The parental populations used in the provenance experiment were Norway spruce stands growing on permanent measurement and observation plots mentioned above (Tyszkiewicz 1968a). The location of the stands from which seeds for the experiment were collected in 1965/66 and 1971/72 is shown in Fig. 1, and some basic data about the stands are presented in Table 1. The detailed data about seed collection, sowing efficiency, and seedling growth have been provided in an earlier report (Kocięcki 1980a).

In 1972, twenty one foreign research institutes from 20 countries and four Polish universities and institutes were invited by the Forest Research Institute in Warsaw to participate in the provenance experi-

Fig. 1. Location of Norway spruce provenances for IUFRO 1972 experiment

Table 1. Characterisation of provenances tested in IUFRO 1972 international provenance experiment with Norway spruce

Prov. No.	Forest district	Forest range	Compartment	Geographical coordinates		Altitude (m)	Tree age (years)
				latitude	longitude		
1	Zwierzyniec Biał.	Pogorzelce	281 Ba	52°48’	23°47’	160	98
2	Zwierzyniec Biał.	Krzyże	449 Ca	52°42’	23°46’	180	84
3	Wigry	Krzywe	144 b	54°03’	23°03’	170	100
4	Przerwanki	Zawady	66 b	54°10’	22°05’	180	82
5	Borki	Sarnianka	141 a	54°06’	22°04’	180	71
6	Nowe Ramuki	Przykop	128 d	53°41’	20°34’	160	100
8	Międzygórze	Wodospad	81 a	50°13’	16°45’	580	102
9	Stronie Śląskie	Kletno	200 b	50°14’	16°50’	820	123
10	Wisła	Malinka	89 c	49°38’	18°58’	710	112
11	Istebna	Bukowiec	149 h	49°34’	18°53’	630	121
12	Istebna	Zapowiedź	115 f	49°32’	18°57’	600	107
13	Rycerka	Zwardoń	68 d	49°31’	19°01’	620	89
14	Rycerka	Praszywka	125 c	49°29’	19°00’	700	93
15	Rycerka	Praszywka	125 c	49°29’	19°00’	950	91
16	Orawa	Stańcowa	40 c	49°34’	19°33’	1050	108
17	Witów	ur. Chotarz	125 f	49°13’	19°48’	1420	152
18	Tarnawa	Sokolniki	130 a	49°05’	22°52’	750	79
19	Zwierzyniec Lub.	Obrocz	119 f	50°34’	22°58’	260	69
20	Bliżyn	Świnia G.	134 f	51°04’	20°41’	310	75
21	Kartuzy	Kosowo	67 d	54°23’	10°08’	200	90

ment with Norway spruce. Seventeen institutions from 13 countries and the four Polish institutions accepted the proposal (Kocięcki 1980a).

The experiment was approved by the International Union of Forest Research Organisations and considered as the IUFRO 1972 provenance experiment.

The present paper synthesises the research results from the IUFRO 1972 series plots, gathered by the Department of Genetics and Physiology of Woody Plants, Forest Research Institute, Warsaw, before the year 2006.

Material and methods

Experimental plots

Within the framework of the IUFRO 1972 experiment, six experimental plots with Polish provenances of Norway spruce were established in Poland: two plots, in Knyszyn and Istebna (of which only Knyszyn has survived; the Istebna plot was destroyed by fire in 1981) – by the Forest Research Institute (FRI); two plots close to each other in Głuchów – by the Warsaw Agricultural University; one plot in Siemianice – by the Forestry Department, Agricultural University in Poznań; and one plot in Kórnik – by the Institute of Dendrology of the Polish Academy of Sciences.

The Knyszyn plot, managed by Forest Research Institute in Warsaw, was set up on a mixed fresh coniferous forest site using a randomised block design in four replications (Kocięcki 1980b).

Apart from the seeds gathered in the stands characterised in Table 1, also seeds from the previously selected late-flushing spruces growing in the Białowieża and Borecka Primeval Forests (represented by the letters Ppn in Table 2) and the Silesian Beskid Mts. (represented by Ppd in Table 2), collected together with the Department of Forest Tree Breeding in Nancy (presently in Orlean), were sown in Knyszyn.

Three-year-old seedlings were planted at 1.65 × 1.45 m spacing. Each plot was planted with 169 seedlings. The progeny of the late-flushing spruces from the northern and southern subranges (78 trees) were planted on one-half of the plot area. The total area of the experiment covered 3.75 ha.

So far, only one thinning was done on the Knyszyn plot (in 1999) with the aim of creating appropriate

Table 2. Growth of Norway spruce provenances on experimental plot in Knyszyn

	Provenance	Height (m)	DBH (cm)	Volume of single tree (m^3)	Stand volume ($m^3\ ha^{-1}$)	Stem straight-ness	Crown length	Vitality
11	Zwierzyniec-Pogorz.	12.8	13.7	0.149	181.30	3.48	3.31	3.31
12	Zwierzyniec-Krzyże	14.2	13.9	0.161	233.58	3.31	2.95	3.25
13	Wigry	15.7	14.4	0.177	138.93	3.30	2.52	3.22
14	Przerwanki	13.5	12.9	0.135	194.65	3.36	3.03	3.32
15	Borki	13.8	13.1	0.141	253.09	3.46	3.02	3.36
16	Nowe Ramuki	13.9	15.1	0.187	190.74	3.40	3.29	3.33
18	Międzygórze	11.9	13.0	0.147	269.78	3.57	2.99	3.33
19	Stronie Śląskie	10.3	12.1	0.110	223.83	3.55	3.21	3.39
10	Wisła	12.0	12.7	0.133	264.63	3.67	2.94	3.32
11	Istebna-Bukowiec	12.4	13.8	0.164	270.56	3.58	3.09	3.21
12	Istebna-Zapowiedź	12.3	13.8	0.158	246.63	3.61	3.00	3.24
13	Rycerka-Zwardoń	11.3	12.3	0.117	226.44	3.49	2.96	3.23
14	Rycerka-Praszywka 700 m	12.0	12.5	0.121	229.13	3.61	3.02	3.21
15	Rycerka-Praszywka 950 m	11.5	12.9	0.131	222.39	3.72	3.09	3.25
16	Orawa	11.1	11.7	0.106	222.66	3.63	2.92	3.39
17	Witów	9.3	11.0	0.085	120.50	3.58	3.34	3.26
18	Tarnawa	11.9	12.3	0.117	211.88	3.57	2.88	3.26
19	Zwierzyniec Lub.	14.0	13.6	0.149	259.08	3.34	2.50	2.76
20	Bliżyn	13.4	12.4	0.126	243.45	3.36	2.94	2.98
21	Kartuzy	8.6	10.8	0.088	151.98	3.47	3.29	3.15
	Ppd	12.6	13.0	0.143	264.07	3.48	2.82	2.82
	Ppn	11.3	11.3	0.101	166.38	3.38	2.92	2.68
	Mean	**12.2**	**12.7**	**0.131**	**217.53**	**3.51**	**3.04**	**3.23**

Ppd – late-flushing provenances from Wisła, Istebna and Rycerka area
Ppn – late-flushing provenances from northeastern subrange

growth conditions and unifying the number of trees between replications.

The detailed description of the environmental conditions, preparatory works, and plot establishment, as well as the measurement and observation results obtained in the previous stages of the experiment can be found in the FRI reports and other publications (Kocięcki 1980b; Kocięcki et al. 1990; Matras 1993, 1996a, b, 1998, 2001, 2002, 2004; Matras et al. 1996, 2006; Matras and Janson 1998).

The seeds of 20 Norway spruce provenances were also sent to 21 research centres in Europe and Canada. The Forest Research Institute in Warsaw as an initiator of the experiment has been in touch with the institutions which had declared their willingness to participate in the experiment and had set up their experimental plots; the Institute has also been collecting data about the established plots. Altogether, 43 experimental plots were established representing 3 to 20 Polish spruce provenances (Kocięcki 1980b).

Data collection and evaluation

The growth of spruce trees on the experimental plots was assessed periodically. In the initial period (trees up to 10 years of age), the measurements included height; later on (age 10–25 years), diameter at breast height (DBH); and finally, the diameters of all the trees and the cross-sections of model trees (selected on a DBH basis and felled), which provided a basis for calculating the volume per plot or per hectare. Besides, additional measurements and observations were carried out on the plots based on individual research programmes. All information about the plots collected by the Forest Research Institute was used to create a database of the growth and development of Polish provenances of spruce for the whole experiment.

The data from all plots were sent to the institutions participating in the experiment, and the results were published successively (Kocięcki 1980b; Kocięcki et al. 1990; Matras 1993), or reported at scientific conferences. More recently, the aggregated results of the experiment were presented at the IUFRO S.2.02.11 Symposium "Norway Spruce Provenances and Breeding" held in 1997 in Stara Lesna, Slovakia.

To compare the results from all the plots of the IUFRO 1972 experiment, the data were expressed in the units of standard deviation relative to the average obtained from the plots. Adopting such a procedure was necessary because individual plots were established at different times and the measurements were taken at different times after planting.

Statistical analysis was performed using a two-way analysis of variance (ANOVA).

Results

Polish plots

The comparative plantation in Knyszyn belongs to the most representative experimental plots of the IUFRO 1972 series in Poland. Table 2 shows the results of measurements and observations made on the Knyszyn plot on 30-year-old trees, presented in the form of averages for height, DBH, volume of an individual tree, volume per hectare, stem straightness, crown length, and vitality for each provenance.

Statistical analysis demonstrated that the values of the growth and quality characteristics significantly differed between the provenances (Table 3).

The mean height of trees on the Knyszyn plot ranged between 15.7 m for the Wigry provenance and 8.6 m for the Kartuzy provenance (Table 2), which indicates that the variation in this characteristic is very high (45.2%). A wide variation (25.0%) was also observed for DBH; its mean values in Knyszyn ranged from 14.4 cm for Wigry to 10.8 cm for Kartuzy. The DBH differences between the provenances cannot readily be associated with their belonging to one or another subrange of spruce distribution: both relatively slow- and fast-growing provenances were found either in the northeastern or southern subrange (e.g. the fast-growing provenances included Zwierzyniec Białowieski 1, Nowe Ramuki, Borki and Zwierzyniec Białowieski 2 from the Northeast, and Istebna Bukowiec, Istebna Zapowiedź and Zwierzyniec Lubelski from the South of Poland).

Table 3. Statistical analysis of variability in growth characteristics of Norway spruce provenances in IUFRO 1972 experiment

Experimental plots	Characteristic	Degrees of freedom	Sum of squares	Mean square	F-value	p
Knyszyn	DBH	21	5706.779	271.751	3.04727	0.00035
	Height	21	86.370	4.113	3.71244	0.00003
	Volume of single tree in m^3	21	0.01013702	0.000482715	3.132812	0.00025
	Stand volume in $m^3\ ha^{-1}$	21	146.668	6.98419	2.24713	0.00729
Poland mean	Height	19	38.0282	2.001483	2.310818	0.00242
General mean (whole experiment)	Mean height, DBH or volume in standard deviation units	19	162.9012	8.573746	12.62402	0.00000

The variability in the mean volume of an individual tree was high (Nowe Ramuki – 0.187 m^3, Witów – 0.085 m^3; Table 2). As for mean diameter, provenances from the northeastern natural range of spruce performed best, followed by Wigry and Zwierzyniec Białowieski. Poorer positions were occupied by southern provenances: Istebna Bukowiec, Istebna Zapowiedź, Zwierzyniec Lubelski and Rycerka Praszywka 950 m.

Largest differences between the provenances (at age 30 years) on the Knyszyn plot were found in productivity (volume per hectare). The difference between the best provenance (Istebna Bukowiec – 270.56 $m^3\ ha^{-1}$) and the worst one (Witów – 120.50 $m^3\ ha^{-1}$) amounted to 159.06 $m^3\ ha^{-1}$. Among the highly productive provenances were also other southern provenances: Wisła (264.6 $m^3\ ha^{-1}$), Istebna Zapowiedź (246.6 $m^3\ ha^{-1}$), Rycerka Zwardoń (226.4 $m^3\ ha^{-1}$), Zwierzyniec Lubelski (259.08 $m^3\ ha^{-1}$) and Bliżyn (243.45 $m^3\ ha^{-1}$), and only two provenances from the northeastern subrange: Borki (253.09 $m^3\ ha^{-1}$) and Zwierzyniec Białowieski 2 (233.58 $m^3\ ha^{-1}$). The growth of the Borki provenance from the Northeast and the Międzygórze, Rycerka Praszywka 750 m, and Orawa provenances from the South was moderate. Apart from Witów, such provenances as Kartuzy (151.98 $m^3\ ha^{-1}$), Wigry and Zwierzyniec Białowieski (181.30 $m^3\ ha^{-1}$) exhibited very poor growth (Table 2). The variability in growth on the Knyszyn plot continues to increase in successive years of measurement (Matras et al. 1996).

The differences in the quality characteristics of the provenances tested on the plot in Knyszyn were not substantial and did not show any relation to their origin in different subranges. The variability in the growth dynamics among the provenances tended to increase in successive measurement periods. Of course, the biggest changes were observed within the first 5 years after planting, however, even today no provenances display stable growth, perhaps except Witów and Kartuzy which belonged to the poorest growing provenances from the very beginning of the experiment.

An increasing trend in the values of growth characteristics in successive periods was observed for the Istebna Bukowiec, Bliżyn, Zwierzyniec Białowieski 1 and Rycerka Praszywka 950 m provenances, while a decreasing trend was visible for Wigry, Tarnawa, Przerwanki, Zwierzyniec Lubelski, Bliżyn and Borki.

The growth of spruce on the other IUFRO 1972 experimental plots in Poland depended clearly on the environmental conditions existing on these plots (Table 4).

The location of the plot affected the growth of spruce provenances, which manifested itself in the position they reached on individual plots in the ranking based on the characteristics studied (Table 4). The mean ranks, which reflected the mean growth

Table 4. Ranking of Norway spruce provenances on experimental plots in Poland

	Provenance	Experimental plots				Mean	Rank dispersion (max – min)
		Knyszyn	Siemianice	Kórnik	Głuchów		
11	Zwierzyniec-Pogorzelce	16	5	19	15	13.73	14
12	Zwierzyniec-Krzyże	8	10	18	1	9.25	17
13	Wigry	18	14	2		11.33	16
14	Przerwanki	14	8	10		10.66	6
15	Borki	5	13	13	9	10.00	8
16	Nowe Ramuki	15	19	14	10	14.50	9
18	Międzygórze	2	3	8	11	6.00	9
19	Stronie Śląskie	11	6	6	13	9.00	7
10	Wisła	3	12	3	5	5.75	9
11	Istebna-Bukowiec	1	1	5	2	2.25	4
12	Istebna-Zapowiedź	6	2	9	8	6.25	7
13	Rycerka-Zwardoń	10	4	15	7	9.00	11
14	Rycerka-Praszywka 700 m	9	9	4	6	7.00	5
15	Rycerka-Praszywka 950 m	13	15	17	16	15.25	4
16	Orawa	12	7	11	14	11.00	5
17	Witów	19	20	20		19.66	1
18	Tarnawa	13	18	12	3	11.50	15
19	Zwierzyniec Lubelski	4	17	1	4	6.50	16
20	Bliżyn	7	11	16		11.33	9
21	Kartuzy	17	16	7	12	13.00	10

performance of the provenances on all the plots, provided a basis for classifying them into distinct groups. The first group comprised provenances exhibiting the best growth, i.e. the highest mean ranks on the four plots, such as Istebna Bukowiec (mean rank 2.25), Wisła (5.75), Międzygórze (6.00), Istebna Zapowiedź (6.25) and Zwierzyniec Lubelski (6.50). Rycerka Praszywka 700 m (mean rank 7.00), Rycerka Zwardoń (9.00), Stronie Śląskie (9.00) and Zwierzyniec Białowieski 2 (9.25) formed a group of well-growing provenances. The largest group included moderately- or poorly-growing provenances: Borki (mean rank 10.00), Przerwanki (10.66), Wigry and Bliżyn (11.33), Tarnawa (11.50), Kartuzy (13.00), Zwierzyniec Białowieski 1 (13.73), Nowe Ramuki (14.50) and Rycerka Praszywka 950 m (15.25). The Witów provenance clearly differed from all the other provenances tested in the experiment: it ranked last on all four plots (Table 4).

Plasticity was defined as being adversely related to the dispersion of ranks a provenance achieved on four experimental plots. The dispersion, i.e. the maximum difference between the ranks obtained on the plots, was very high: 17 positions in the ranking (Zwierzyniec Białowieski 2). Among the 20 provenances tested, also Wigry, Zwierzyniec Lubelski, Tarnawa and Zwierzyniec Białowieski 1 showed high rank differences (16 to 14 positions). The dispersion was smallest for Istebna Bukowiec and Rycerka Praszywka 950 m (4), Orawa and Rycerka Praszywka 700 m (5), and Przerwanki (6), suggesting that the latter provenances have a greater adaptability to various environmental conditions, i.e. are more plastic. Witów held the last position on all plots.

The above simplified classification indicates that there is no relationship between the provenance's plasticity and growth. As a rule, the spruce provenances with moderate growth appeared to be more plastic. The only exception was Istebna Bukowiec which showed both superior growth and high plasticity. The provenances with moderate or low plasticity may perform well under specific environmental conditions, e.g. the Zwierzyniec Białowieski 2 provenance exhibited good growth in Głuchów and Knyszyn but performed poorly on all other plots. Such provenances as Nowe Ramuki, Wigry and Zwierzyniec Białowieski 1 grew well only on one experimental plot.

Foreign plots

The results of measurements of spruce growth characteristics on foreign plots established within the framework of the IUFRO 1972 experiment are shown in Table 5. The provenances were evaluated on the basis of the mean values of the characteristics, expressed in standard deviation units.

At experiment level, the differences in the values of growth characteristics between the provenances were broad (within 6.0991 standard deviation units), with the values ranging between +2.6762 and –3.4229. At provenance level, the differences were largest for Kartuzy (values from +1.9181 to –2.756), and smallest for Rycerka Zwardoń (values from +1.437 to –0.755). All provenances tested in the experiment showed both negative and positive values of the characteristics, except for Witów which consistently exhibited negative values. Due to such wide differences in the performance of provenances on individual plots it is impossible to properly evaluate the results.

Growth of Norway spruce provenances in the IUFRO 1972 experiment

The Norway spruce provenances on the Polish plots were grouped according to the mean values of the growth characteristics expressed in standard deviation units (Fig. 2, Table 5). The following groups were distinguished:

- Group I (above 1.0): Istebna Bukowiec,
- Group II (1.0 to 0.5): Międzygórze, Wisła, Zwierzyniec Lubelski,
- Group III (0.5 to 0.0): Zwierzyniec Białowieski 2, Borki, Stronie Śląskie, Istebna Zapowiedź, Rycerka Zwardoń, Rycerka Praszywka 700 m, Bliżyn,
- Group IV (–0.5 to 0.0): Wigry, Przerwanki, Orawa, Tarnawa, Kartuzy,
- Group V (–1.0 to –0.5): Zwierzyniec Białowieski 1, Nowe Ramuki, Rycerka Praszywka 950 m,
- Group VI (below –1.0): Witów.

The performance of spruce provenances on the Slovak plots differed to some extent from their performance on the plots in Poland (Fig. 3). Istebna Bukowiec was also classified into the group of best provenances (group I), but group II consisted only of the provenances from the southern subrange: Rycerka Praszywka 700 m, Rycerka Zwardoń, Międzygórze and Istebna Zapowiedź. The Wisła, Orawa, Zwierzyniec Lubelski, Bliżyn and Kartuzy provenances belonged to group III; Stronie Śląskie, Rycerka Praszywka 950 m and Tarnawa, as well as almost all northeastern provenances were in group IV; Nowe Ramuki and Witów were classified into the group of poorest provenances (group VI); while group V was non-existent.

The results for spruce provenances obtained on German plots (Fig. 4) were in between those received in Poland and Slovakia. Despite the relatively large number of plots (10), the differences among the provenances were smaller. As in Slovakia, the provenances from the northeastern subrange generally exhibited poor grow in Germany, too (group IV and V). The Istebna Bukowiec provenance on German plots was not as clearly superior as it was on the Polish and

Table 5. Growth of Norway spruce provenances in IUFRO 1972 experiment – mean height [*], DBH [**] or volume [***] in standard deviation units

Experimental plots	Tree age	Provenances																			Mean	Unit	SD
		1	2	3	4	5	6	8	9	10	11	12	13	14	15	16	17	18	19	20	21			
Poland																							
Knyszyn [***]	30	–0,8458	0,3670	–1,8288	–0,5361	0,8196	–0,6269	1,2067	0.1408	1.0873	1.2248	0.6697	0.2013	0.2637	0.1074	0.1136	–2.2563	–0.1364	0.9585	0.5959	–1.5260	217.8	m^3 ha^{-1}	43.11
Kórnik [**]	30	–1,5287	–0,9321	1,3795	–0,2610	–0,4101	–0,4847	0,5593	0.6338	1.3795	0.6338	0.0373	–0.4847	1.3049	–0.6338	–0.2610	–2.2743	–0.2610	1.4541	–0.4847	0.6338	15.8	cm	1.34
Siemianice [**]	30	0,6192	–0,0159	–0,3334	0,1429	–0,0159	–1,7623	0,9367	0.6192	0.3016	1.4130	1.4130	1.0955	–0.0159	–0.6509	0.6192	–2.3973	–1.2860	–0.3334	0.3016	–0.6509	11.6	cm	0.63
Głuchów [***]	30	–1,1747	2,4818			–0,2371	–0,4247	–0,4247	–0.7059	0.6067	1.3567	–0.1434	0.1379	0.3254	–1.8310	–0.8934		0.7004	0.6067	0.0441	–0.4247	16.5	cm	1.07
Mean	–0,7325	0,4752	–0,2609	–0,2181	0,0391	–0,8246	0,5695	0.1720	0.8438	1.1571	0.4941	0.2375	0.4695	–0.7521	–0.1054	–2.3093	–0.2458	0.6715	0.1143	–0.4919			
Slovakia																							
Velka Straz [**]	26	–0.1254	–0.8504	–0.4766	–0.9855	0.0345	–1.7527	1.1345	0.5715	0.9584	1.3765	1.0416	1.4370	0.6342	–0.5273	0.2917	–2.2086	–0.8504	0.1869	0.0043	0.1058	127.71	mm	9.25
Bujakovo [**]	26	–0.3562	–0.7400	–0.1996	1.2392	–1.2143	–1.4400	0.8813	0.3394	–0.2024	1.6890	0.9675	–0.1622	0.4673	0.1856	1.2995	–2.4547	0.2589	–0,5531	–0.2413	0.2359	145.90	mm	6.96
Parac [**]	26	–0.1832	–0.2742	0.0326	–0.2742	0.0798	–0.8963	–0.2152	–0.9418	0.7879	0.7947	0.7576	0.5924	2.6762	–0.6772	–0.5153	–2.5806	0.4322	0.4018	0.0259	–0.0230	131.53	mm	5.93
Klobasova [**]	26	0.1692	–0.5727	0.3880	–0.2220	0.3742	–0.4736	0.3622	–0.0221	0.3742	0.8257	–0.7889	0.6724	0.7585	0.7482	0.1132	–3.4229	–1.2413	0.8662	0.1580	0.9334	122.79	mm	11.61
Kostelec 7 D [*]	12	0.0220							–0.1180		0.7280	0.6180		0.5370	0.2870	0.9850	–2.5880	1.1030	0.2790	0.4930		427.00	cm	58.08
Kostelec 9 B [*]	12		1.7030	0.2550					–0.8150					–0.3200		0.3200	–1.8560	–0.0580	0.7790	0.3570		354.00	cm	48.64
Mean	–0.0947	–0.1469	–0.0001	–0.0606	–0.1814	–1.1406	0.5407	–0.1643	0.4795	1.0828	0.5191	0.6349	0.7922	0.0033	0.4157	–2.5185	–0.0593	0.3266	0.1328	0.3130			
Germ																							
Beberbeck [***]	23	0.0583	0.0888	–0.0186	0.9239	–0.5755	–0.3867	–0.0155	–0.7112	1.8121	0.9936	0.4646	–0.0132	0.6911		–0.7661	–2.9487	–0.5571	0.2250		0.7352	123.83	m^3 ha^{-1}	22.25
Wanfried [***]	23	–1.3278	0.1167	–0.9875	–0.8575	–0.9767	–0.5430	0.8476	–0.4711	0.4923	1.5078	0.4534	0.6061	0.0478		0.2904	–1.9767	0.1586	1.9362		0.6834	132.99	m^3 ha^{-1}	16.69
Seelzerthurm [***]	23	–1.4677	–0.4166	–1.5680	0.1298	–1.1264	–0.9162	0.5183	–0.0087	0.6465	1.7313	1.0539	–0.0280	0.1053	0.4072	1.2675	–1.5361	–0.7664	–0.0992	0.5878	1.4857	87.04	m^3 ha^{-1}	17.55
Seesen [***]	23	1.3084			–1.1880	0.7671	–0.9977	–0.2025		–0.7555	0.8796	1.0812	–0.1305			0.3543				–1.7774	0.6610	92.86	m3 ha^{-1}	18.75
Ochsenhausen A [*]	22	0.9509	0.5159	–0.5563	–0.2144	0.2206	–0.9447	–0.5718	–1.1156	–1.6439	–1.5352	1.1996	0.1119	0.7489	–0.1057	1.1996	–1.3798	1.4016	1.5725	–0.1367	0.2828	8.92	m	0.64
Ochsenhausen B [*]	21	0.2791	0.3656	0.8849	0.2791	–0.0022	0.9065	–1.3003	–2.3820	0.7767	0.1926	0.6036	0.1709	–1.2137	–0.4349	–0.9541	–1.5815	0.3656	1.4041	1.1229	0.5171	8.64	m	0.46
Sauerlach A [**]	25	–1.5015	0.5339	0.2249	–1.8958	0.0650	–1.4482	–0.0842	1.4290	0.4913	1.5569	–0.6063	0.6085	0.4380	1.2052	–0.5318	–1.4802	–0.2014	–0.1588	0.3954	0.9601	137.89	mm	9.38
Sauerlach B [**]	25	0.1084	–0.3935	–0.1774	–0.6444	–0.8047	–0.8605	–0.1844	–0.0380	1.5652	2.2413	0.0387	0.6381	0.1990	–0.0171	1.1470	–2.2197	0.1642	0.3663	0.4360	–1.5645	134.55	mm	14.35
Biburg [*]	7	1.3980	2.1060	2.3250	1.3810	0.7670	–0.6060	–0.5220	0.2700	–0.5980	–0.3450	0.6060	1.2470	–0.3200	–0.9600	–0.1350	–0.1850	1.1710	1.5750	0.0840	–0.6230	98.00		11.63
Neureichenau [**]	25	–0.9526	–0.7467		–1.3256	–0.5705		0.5697	1.1025	1.8785	0.2772	0.6140	0.5980	0.3943	0.8840			–0.7002	–1.4865	–1.2146	0.6784	104.41	m^3 ha^{-1}	26.22
Mean	–0.1147	0.2411	0.0159	–0.3412	–0.2236	–0.6441	–0.0945	–0.2139	0.4665	0.7500	0.5508	0.3809	0.1212	0.1398	0.2080	–1.6635	0.1151	0.5927	–0.0628	0.3816			

Experimental plots	Tree age	Provenances																				Mean	Unit	SD
		1	2	3	4	5	6	8	9	10	11	12	13	14	15	16	17	18	19	20	21			
Finland																								
Algo [*]	12	0.3220				0.4540	0.1240	–0.2460	–0.0910	0.1500		–0.0690	–0.2700	0.0790	–0.1840	–0.2910	0.1980	0.1910	–0.0640	–0.0860	–0.2270	299.00	cm	125.23
Haavisto [**]	8	0.2340	0.2800		0.2050	0.8250	0.1200	–0.2160	0.1310	0.0280	–0.7010	–0.3820	0.0280	–0.4960	–0.6830	–1.0300	–0.7680	0.2730	0.2800	1.7030	0.2620	38.00	cm	10.73
Karttipera [**]	7	1.3320	1.2470	0.7370	–0.7080	–0.5100	1.7570	0.3830	–1.3040	0.4110	–0.5380	–0.9630	0.5100	1.7570	–0.8220	–0.0990	–1.4310	–0.4820	0.5380	–1.0200	–0.6380	44.00	cm	3.11
Mean	0.6293	0.7635	0.7370	–0.2515	0.2563	0.6670	–0.0263	–0.4213	0.1963	–0.6195	–0.4713	0.0893	0.4467	–0.5630	–0.4733	–0.6670	–0.0060	0.2513	0.1990	–0.2010				
Belgium																								
Hives [***]	22	–1.4169	–0.3126	–0.7249		–0.7132	–0.3018	0.0015	–0.0480	1.2658	1.0563	1.7599	0.5548	0.4224		0.1849	–2.3005	–0.3584	–0.0720		1.0027	173.38	$m^3\ ha^{-1}$	35.12
France																								
Champenoux [**]	17	–0.7440	–0.6230	–0.7940	–0.8570	–1.5010	–0.1660	–0.0290	0.1190	1.9270	0.5410	0.5370	0.2250	0.5530	1.1580	–0.3920	–2.4030	–0.0490	1.2560	0.8730	0.3690	73.16	mm	8.15
Norway																								
As [*]	8	0.4790	0.5650	–1.0610	1.0780	–0.2050	–0.4620	–0.2910	–0.9750	–1.0610	0.9930	0.7360	1.1640	0.2220	0.7360	0.2220	–2.6870	–0.1200	1.4200	–0.0340		243.40	cm	11.69
Croatia																								
Zelendvor [?]	7	–0.6090	1.3980				–0.6780	–0.3480	–1.2420	0.3430	2.2420	0.1660	0.0060	0.0420		–0.6780	–1.1700	1.1040			–0.5750	38.89	cm	3.61
Mean in Europe	–0.1905	0.2455	–0.1250	–0.2186	–0.1857	–0.5527	0.1100	–0.2167	0.5209	0.8454	0.4564	0.3806	0.3962	–0.0861	0.0716	–1.9128	0.0098	0.5335	0.0951	0.1373				
Canada																								
Vercheres [*]	18	1.2730	1.1740		0.1610	1.2770	0.3590	0.3390	–0.5420	–0.3520	0.9240	1.0750	–0.7550	–0.2290	–0.7960	–0.6000	–2.7470	0.2440	0.3650	–0.0220	–1.1490	461.34	cm	55.58
Lotbiniere [*]	20	0.2869	0.6061			1.4383	0.7758	–0.5144	–1.9014	–0.6679	0.1940	0.3987	–0.0659	–0.7891	–1.4072	–0.9264		1.3387	1.6511	0.1698	–0.5871	752.19	cm	74.26
Il. Madelleine [*]	18	0.7950	0.4300		0.3260	0.0840	–1.5950	–0.7890	–0.6510	0.7410	–1.3790	0.4590	–0.3400	1.1740	–0.3770	0.9990	–0.7930	–0.0150	0.8080	–1.7950	1.9180	223.17	cm	24.05
La Patrie [*]	13	0.6440	0.9990			–0.3800	0.3950	–1.6440	0.7130	0.8190	0.6160	–0.2830	0.2560	0.2790	–0.2000	–0.9890		0.8240	0.7130	–0.0070	–2.7560	208.70	cm	21.67
Valcartier [*]	15	0.0279	–0.0857	–1.2893	0.0539	1.5755	0.3913	–0.2608	–0.5139	–0.5561	–0.6696	0.8422	0.5405	0.4529	–0.8221	–0.0500	–2.5903	0.5438	2.1335	0.3848	–0.1084	217.04	cm	30.82
Mean	0.6054	0.6247	–1.2893	0.1803	0.7990	0.0652	–0.5738	–0.5791	–0.0032	–0.0629	0.4984	–0.0729	0.1776	–0.7205	–0.3133	–2.0434	0.5871	1.1341	–0.2539	–0.5365				
General mean	–0.0621	0.3108	–0.1804	–0.1687	–0.0159	–0.4461	–0.0040	–0.2751	0.4335	0.6940	0.4631	0.3051	0.3609	–0.2081	0.0095	–1.9273	0.1029	0.6336	0.0328	0.0211				

See Fig. 1 for provenance names

Slovak plots, while the Zwierzyniec Lubelski and Zwierzyniec Białowieski 2 provenances in Germany and Poland were comparable in growth (group II and III).

In Finland, the spruce provenances performed somewhat different. The provenances from the north-eastern range, except for Przerwanki, were the best (group I). Of southern provenances, only Wisła,

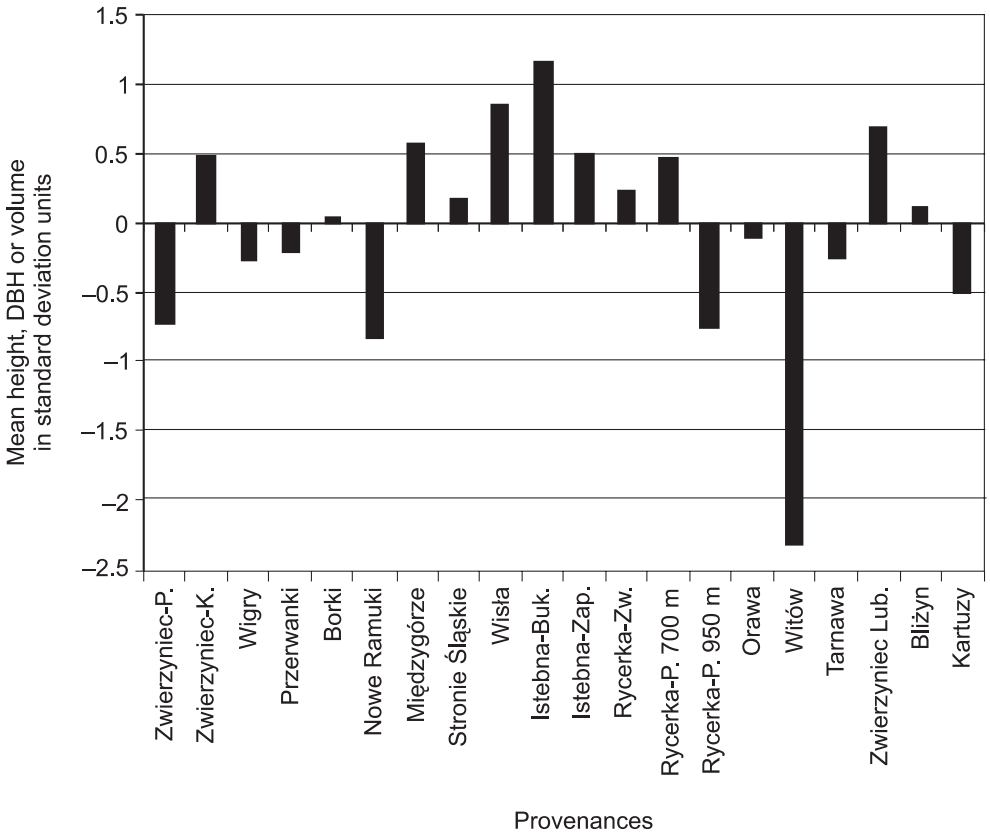

Fig. 2. Growth of Norway spruce provenances in IUFRO 1972 experiment – mean for Polish plots

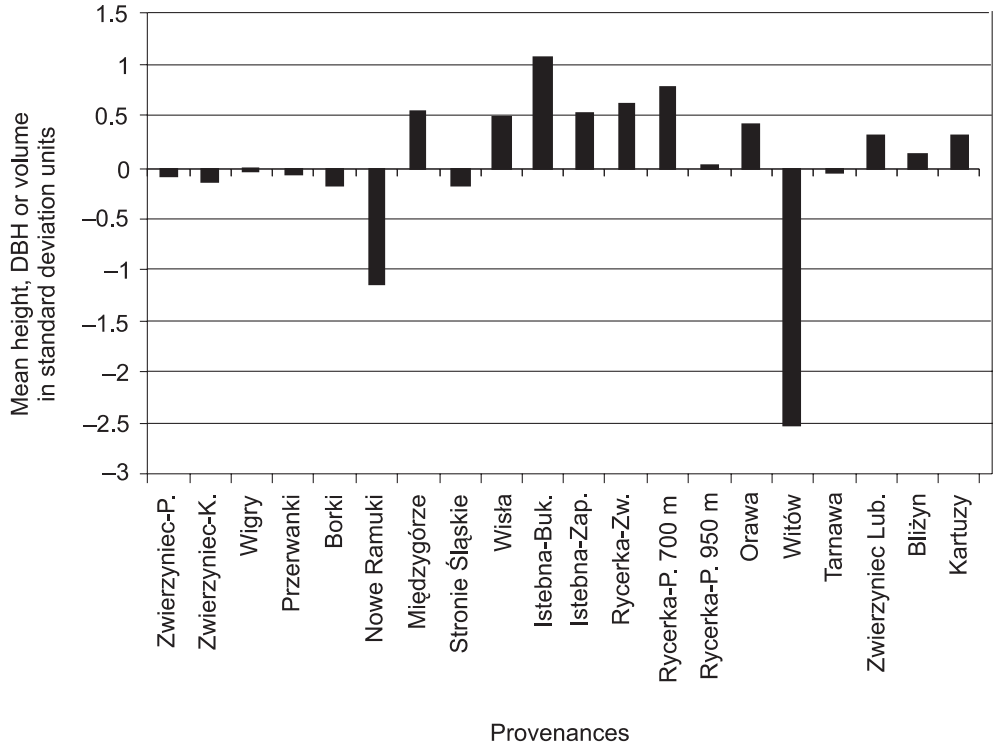

Fig. 3. Growth of Norway spruce provenances in IUFRO 1972 experiment – mean for Slovak plots

Rycerka Zwardoń, Rycerka Praszywka 700 m, Zwierzyniec Lubelski and Bliżyn were classified into group II, while Istebna Bukowiec and Rycerka Praszywka 950 m performed poorly (group IV), similar to Witów (Fig. 5).

In Canada, the performance of lowland spruce provenances from the northern range was similar to

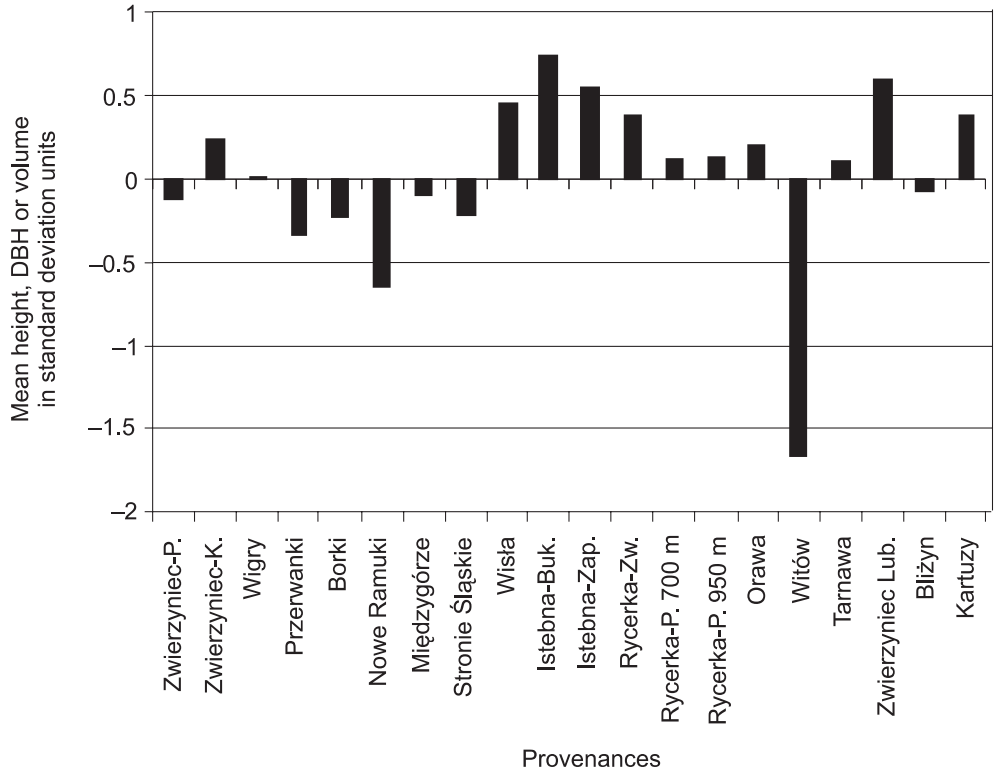

Fig. 4. Growth of Norway spruce provenances in IUFRO 1972 experiment – mean for German plots

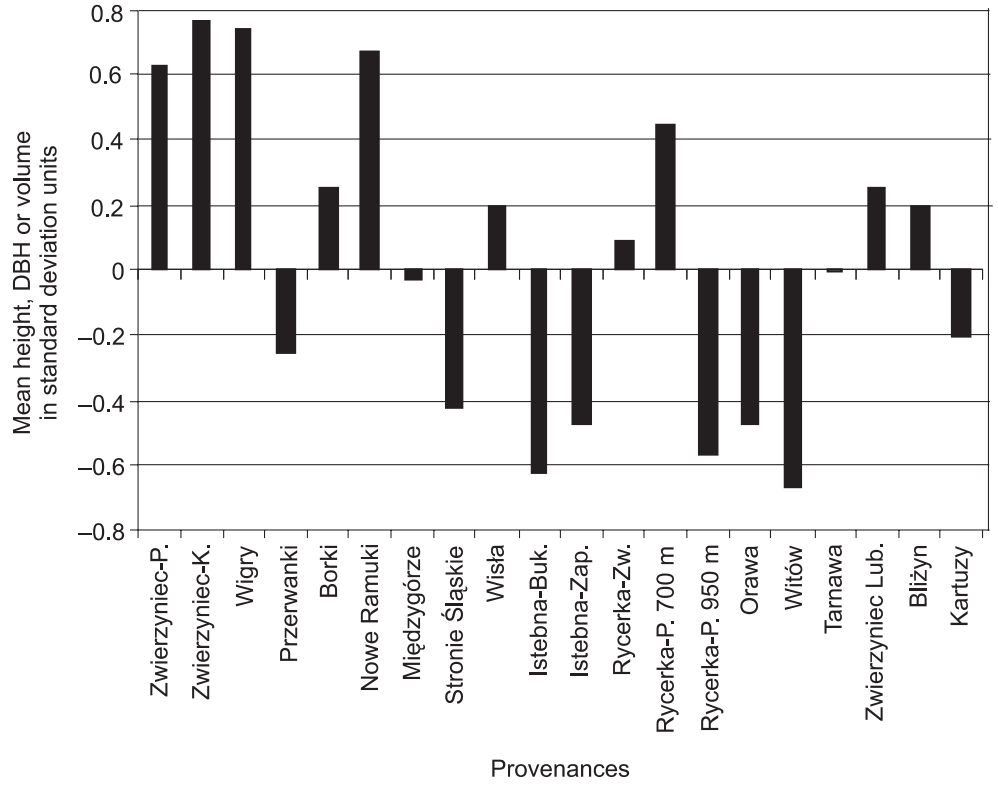

Fig. 5. Growth of Norway spruce provenances in IUFRO 1972 experiment – mean for Finnish plots

that in Finland: they were classified into the groups of best provenances (I or II) with the values of growth characteristics always above zero (Fig. 6). Of southern provenances, only Zwierzyniec Lubelski and Tarnawa were included in group I. The Silesian Beskid Mts. provenances exhibited rather average growth and were classified into group II or III, while the growth of the Sudeten provenances and those of Rycerka Praszywka 950 m and Kartuzy was very poor (group IV).

Based on the average results for Europe and the whole experiment (Fig. 7, 8), the grouping of the provenances assumed the following form:

– Group I (above 1.0): no provenances,
– Group II (1.0 to 0.5): Istebna Bukowiec, Zwierzyniec Lubelski,
– Group III (0.5 to 0.0): Wisła, Istebna Zapowiedź, Zwierzyniec Białowieski 2, Rycerka Praszywka 700 m, Rycerka Zwardoń, Tarnawa, Bliżyn,
– Group IV (–0.5 to 0.0): Międzygórze, Kartuzy, Wigry, Zwierzyniec Białowieski 1, Orawa, Przerwanki, Borki, Rycerka Praszywka 950 m, Nowe Ramuki, Stronie Śląskie,
– Group V (–1.0 to –0.5): no provenances,
– Group VI (below –1.0): Witów.

The variability in the values of growth characteristics across the whole experiment was significantly larger than that for Polish plots, but in general it displayed a similar pattern.

Discussion

The Polish provenances of Norway spruce tested in the IUFRO 1972 provenance experiment exhibited a high variability in growth on the plots in Poland. This variability constitutes one-half of the variability found for the whole experiment carried out in Europe and Canada. The differences in the morphological and growth characteristics of Polish spruce provenances have already been shown in many investigations (Holst 1963; G¸hrn 1966; Fober and Giertych 1971; Lines 1974; Giertych 1976, 1987a, b, 1991; Holubčik 1979; Holzer 1981; Giertych and Królikowski 1982; Roulund et al. 1986; Barzdajn 1995, 1996a, b; Rau et al. 1998). This can be attributed to the Poland's specific conditions, glaciation periods, spruce migration from various refuges, and formation of three different subranges of spruce in Poland, separated by so-called spruceless belts, i.e. the Central Poland and Carpathian disjunctions (Kocięcki 1980b).

The variability in growth characteristics among the provenances on Polish plots allowed their division into a number of groups differing in response to environmental conditions. It was found that the groups of provenances exhibiting similar growth were comparable only in single cases to the groups of provenances with similar plasticity.

The variability in growth characteristics (DBH, height, volume) among Norway spruce provenances

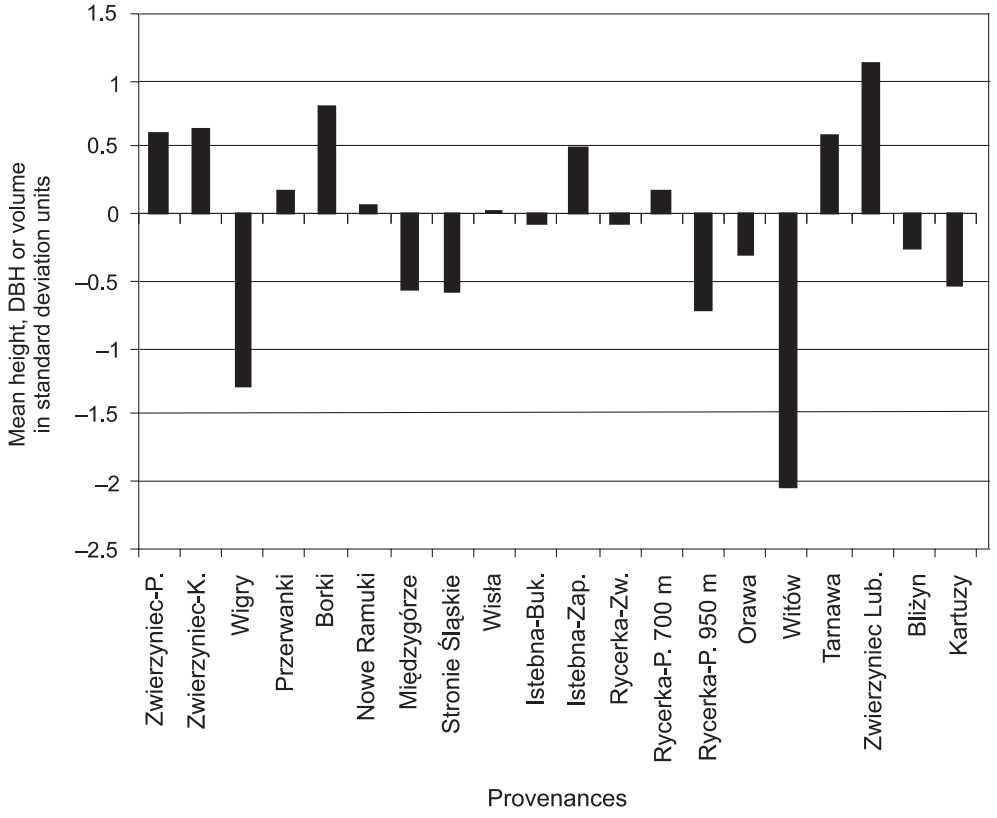

Fig. 6. Growth of Norway spruce provenances in IUFRO 1972 experiment – mean for Canadian plots

across the whole experiment was high (within 6.099 standard deviation units), and no significant changes were found compared to the previous period (6.183). At provenance level, the variability was also high: between 4.674 for Kartuzy and 2.1920 for Rycerka Zwardoń, suggesting differences in the growth of provenances between the plots.

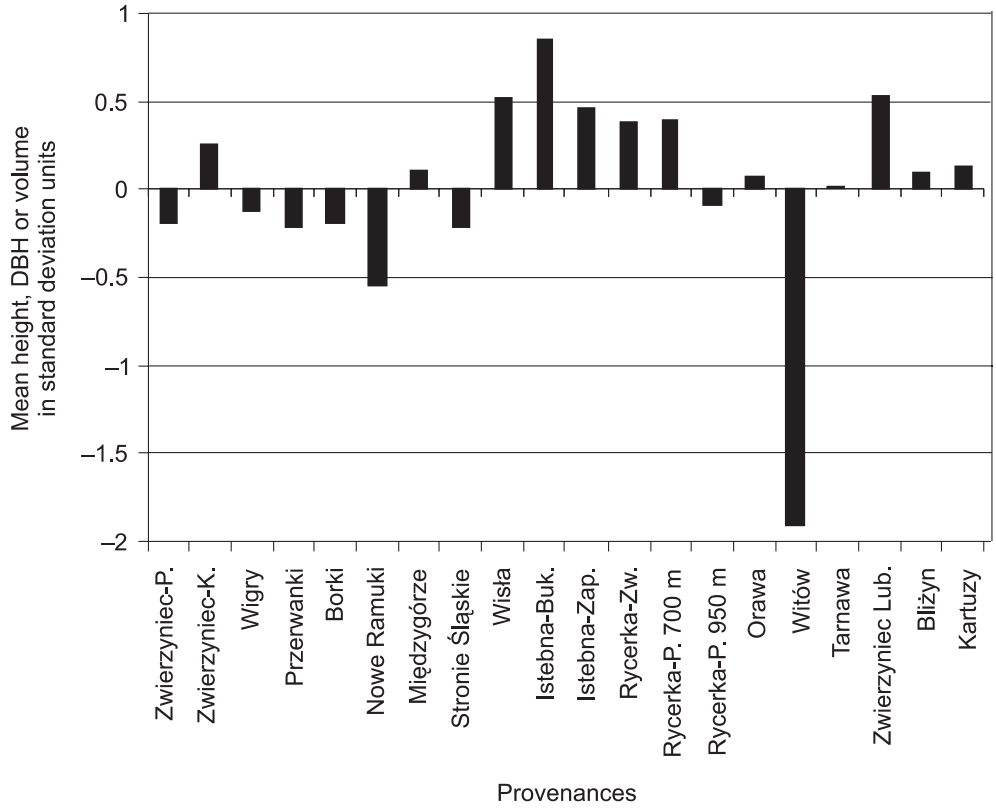

Fig. 7. Growth of Norway spruce provenances in IUFRO 1972 experiment – mean for European plots

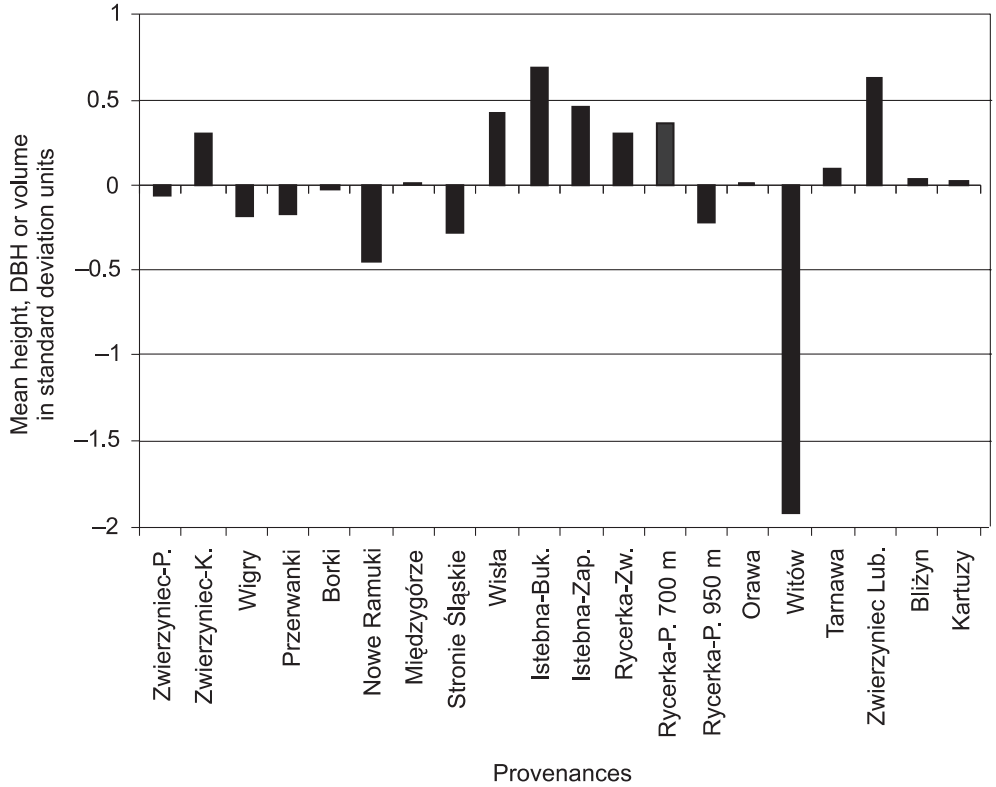

Fig. 8. Growth of Norway spruce provenances in IUFRO 1972 experiment – general mean

According to the values of growth characteristics expressed in standard deviation units (assuming 0.5 SDU intervals) the provenances were classified into five major groups. The leading group comprises the best-performing provenances: Istebna Bukowiec and Zwierzyniec Lubelski. These provenances have exceptional breeding value for the whole area in which the evaluation was carried out. The second group consists of good-quality provenances such as Wisła, Istebna Zapowiedź, Zwierzyniec Białowieski 2, Rycerka Praszywka 700 m, Rycerka Zwardoń, Tarnawa and Bliżyn, which, however, do not ensure appropriate economic results in all conditions. The next two groups are composed of the Międzygórze, Kartuzy, Wigry, Zwierzyniec Białowieski 1, Orawa, Przerwanki, Borki, Rycerka Praszywka 950 m, Nowe Ramuki and Stronie Śląskie provenances with growth below average, which should not be broadly used without further detailed studies. The last group comprises just one provenance, Witów; it is recommended that this mountain provenance should not be grown in lowland conditions.

To sum up, the research results concerning the provenance variability of Norway spruce in Poland, presented in this paper, quite thoroughly describe the growth of these provenances in the juvenile phase of development and their adaptability to various environmental conditions, however, they do not fully reflect the real growth potential of individual provenances. The spruce stands representing the individual provenances are dynamically changing with time, as indicated by the differences in provenance performance in successive measurement periods. The decisions made on the basis of these results may bear a considerable error, and therefore any guidelines for practice may only be treated as suggestions on the possibility of using individual spruce provenances on a commercial scale.

Conclusions

1. The variability in growth characteristics among the Polish spruce provenances tested in the IUFRO 1972 provenance experiment is very high (within 6.099 standard deviation units), and in fact, it has not changed in successive measurement periods.
2. The performance of the provenances depended largely on environmental conditions. Therefore, it is impossible to single out any "universal" provenance which would be adaptable to the whole variety of conditions that may occur in the cultivation of spruce.
3. The Istebna Bukowiec and Zwierzyniec Lubelski provenances, showing very good growth and high plasticity, have a very high breeding value and thus should be recommended for a wider use in reforestation.
4. The Wisła, Istebna Zapowiedź, Zwierzyniec Białowieski 2, Rycerka Praszywka 700 m, Rycerka Zwardoń, Tarnawa and Bliżyn provenances, exhibiting good growth and fairly high plasticity, can be used on a larger scale for the needs of seed production in their regions of origin and, to some extent, in seed regions with comparable environmental conditions.
5. The growth of the Witów, Stronie Śląskie, Rycerka Praszywka 950 m and Międzygórze provenances was rather poor, therefore the collection of seeds from these provenances should be largely limited.
6. As suggested by the growth variability between the provenances in the juvenile phase, those making selection decisions on the basis of short-period research results may be at risk of committing serious errors (e.g. choosing provenances that grow well only in the juvenile phase to be used on a wide scale, or completely rejecting those that in this early phase tend to grow slowly).

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