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Assessment of the height growth of *Picea abies* as related to the geographical regions of Krutzsch (IPTNS-IUFRO 1964/68, years 1969–1988)

Abstract: The juvenile height growth of Norway spruce (*Picea abies* (L.) Karst.) was studied in 1095 spruce provenances included in the IUFRO inventory provenance test of 1964/68. Trees growing on the experimental site established in Krynica in the Beskid Sądecki Mts. (Carpathians) were measured at ca. 3-year intervals in the period 1969–1988, from the age of 6 years (i.e. 2 years of planting) to 25 years. The variability of tree height in this spruce population was assessed on the basis of the means expressed in units of standard deviation, calculated for each provenance and each geographical region of Krutzsch in successive years of measurement. Using the standardised units made it possible to characterise the dynamics of spruce growth in provenances from 95 geographical regions representing the whole European range of the species. The effects of geographical region, tree age and their interaction on the variability of height growth within this range were estimated using multi-way analysis of variance with replicated measurements. The regions showing similar spruce growth trends were grouped by using hierarchical cluster analysis. The results on the juvenile dynamics of height growth showed that spruce provenances from various geographical regions of Krutzsch differ significantly in their genetic reactivity. Based on this, several groups of regions were identified: (1) regions with average or weak but stable spruce growth characterised by no significant effects of age or genotype × age interaction in the whole measuring period, or regions with height growth improving with age; (2) regions of spruce provenances constituting a selection elite, with very good height growth in the whole measuring period or in its later part, characterised by no G × A interaction; (3) regions with varied genetic reactivity of height growth dynamics in the juvenile period, and regions of Scandinavian populations with poorest height growth in the whole measuring period. The studies proved that spruce provenances from the regions of Štiavnické Pohorie, Low Tatras (Slovakia), Masurian Lakeland, Augustów Lakeland, Podlasie, Silesian Beskid Mts., Beskid Żywiecki Mts. (Poland), Jutland (Denmark), Bihor Mts., Transylvania, and Eastern Carpathians (Romania) have a high selection value.

Additional key words: Norway spruce, provenance, genetic reactivity, selection value

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Introduction

The 1964/68 IUFRO inventory provenance trial with Norway spruce (IPTNS-IUFRO 1964/68) is the largest provenance experiment with this species in the world. The experiment initiated by Prof. O. Langlet from Sweden covers a collection of progenies from 1095 partial populations of spruce, representing the whole range of the species. Seeds gathered since 1962 were used to produce seedlings which at the age of 4 years were planted in the spring of 1968 in 20 test areas in 13 European countries and in Canada. Each location has 11 blocks where 100 randomly selected provenances, each represented by 25 seedlings on average, are tested on one-seedling plots in a split-plot system (Elandt 1964; Jayaraman 1999). Therefore, each block with its 2500 seedlings represents the entire variability of spruce from its European range. The intraspecific genetic variability in this trial is assessed according to the inventory test of Wright (1976).

The history of the trial was described by M. Giertych in the Introduction to the work by Bałut and Sabor (2001). The most important results of the first 20-year period were presented at the IUFRO Congress in Biri, Norway (Krutzsch 1973), and discussed in several papers (Krutzsch 1974, 1992). The results from the Polish trial area were published in the works of Bałut and Sabor (2001, 2002).

Methods

The spruce provenances included in IPTNS-IUFRO 1964/68 are represented by four types of progeny collections. The respective types are composed of:
1) a single tree,
2) a group of minimum 10 trees in a stand,
3) a group of progenies of 10 trees in a stand,
4) a group of trees in a population from a wider area of species occurrence.

The provenances are grouped into geographical regions according to Krutzsch (1968). The regions differ in the number of provenances (see Table 3). Each provenance is represented by 25 trees on average, randomly distributed between 11 blocks constituting even-aged comparative plantations.

The conditions of the trial are described in detail in another work (Bałut and Sabor 2001).

The present study analyses the data on spruce height as measured during 1969–1988 in all the provenances tested within the IPTNS-IUFRO 1964/68 trial in the test area of the Experimental Forest Station in Krynica. The height variability in this spruce collection is assessed on the basis of the mean height of trees from each provenance, expressed in the units of standard deviation in individual blocks. The detailed results on the height of spruces were reported by Bałut and Sabor (2002) and presented abroad (Sabor 2006).

For each provenance (i) in each block (j) in a given year (k), a mean (x_{ijk}) was calculated from the measured heights of seedlings. Then, from the values obtained, a mean (x_{jk}) and a standard deviation (s_{jk}) in a block were computed for individual years of measurement. The mean heights (x_{ijk}) were converted into the units of standard deviation (z_{ijk}) according to the formula:

$$z_{ijk} = (x_{ijk} - x_{jk})/s_{jk} \qquad (1)$$

where:
$j = 1, .. , 11$ – block number,
$i = 0, ..., p_j$ – provenance number in block j,
p_j – number of provenances in block j,
k – year of measurement (1969, 1972, 1975, 1978, 1983 and 1988),
x_{ijk} – mean height of seedlings in provenance i in block j in year k,
x_{jk} – mean height of seedlings in block j in year k (calculated from the values of x_{ijk}),
s_{jk} – standard deviation of seedling height in block j in year k.

Based on the values of z_{ijk}, one can draw conclusions about the breeding value of a provenance:
– when $z_{ijk} > 0$, then the provenance i in block j in year k has a positive breeding value,
– when $z_{ijk} < 0$, then the provenance i in block j in year k has a negative breeding value.

The values of z_{ijk} were employed for assessing the growth dynamics of Norway spruce in each provenance, block, and year. By using the conversion into the units of standard deviation (1), it was possible to compare spruce growth in different blocks and at different age of trees. The results provided the basic data for characterising the growth dynamics of spruce from the provenances representing the geographical regions of Krutzsch. Since region 96 (Canada) was represented by a single provenance, this was omitted from the analysis.

The effect of geographical region, seedling age and the interaction of both on the dynamics of growth of spruce from the whole range of occurrence was determined using multi-way analysis of variance with replicated measurements. The relevant model is as follows:

$$z_{ijk} = \mu + R_i + (e_{ij}) + Y_k + (R \times Y)_{ik} + (e_{ijk}) \qquad (2)$$

where:
z_{ijk} – seedling height expressed in the units of standard deviation in blocks for geographical region i, provenance and block j, and year of measurement k,
$i - 1, ..., n$ (n – number of geographical regions),
$k - 1, ..., b$ (b – number of years of measurement),
μ – general mean,
R_i – effect of geographical region i,
e_{ij} – effect of the error of estimation of the standardised height in provenance and block j in region i,
Y_k – effect of year of measurement k,
$(R \times Y)_{ik}$ – effect of the interaction between region i and year k,
e_{ijk} – effect of the error of estimation of the standardised height in provenance and block j in region i and year k.

Hierarchical cluster analysis (Sieczko 2003) was used to group the geographical regions according to the growth trends of spruce. The Euclidean distance between any two regions, L_n and L_m, was calculated from the formula:

$$d(L_n, L_m) = \sqrt{\sum_{k=1}^{b} (z_{nk} - z_{mk})^2} \qquad (3)$$

where:

b – number of years of measurement,

z_{ij} – mean height in region i and year k.

As a result, a matrix of distances between the geographical regions was obtained:

$$D = \begin{bmatrix} d(L_1, L_1) & \cdot & d(L_1, L_c) \\ \cdot & \cdot & \cdot \\ d(L_c, L_1) & \cdot & d(L_c, L_c) \end{bmatrix} \qquad (4)$$

where:

$d(L_n, L_m)$ – distance between regions L_n and L_m,

c – number of regions.

The hierarchical grouping of the regions was done using a method of single linkage (nearest neighbour). Each region was treated as a one-element cluster. Similar regions were joined into clusters, and then the closest (most similar) ones were clustered again. The results were presented in the form of a dendrogram.

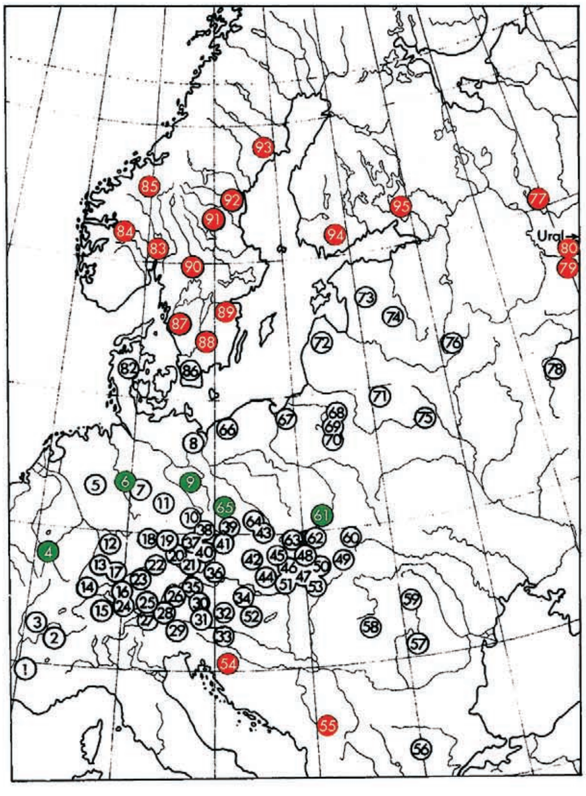
The computations were made using STATISTICA software.

Results and discussion

As shown by variance analysis, the variability of the standardised height of spruce in the years 1969–1988 in provenances representing 95 geographical regions of Krutzsch (1974), i.e. the whole European range of the species (Figs. 1 to 3), was significantly ($p < 0.001$) affected by region, tree age (year of measurement) and the interaction between the two factors (Table 1).

As a result of cluster analysis (with all the distances between geographical regions greater than 0.5 excluded), two large groups of regions displaying similar dynamics of spruce growth were identified (Fig. 4). Besides them there were several smaller such groups and a number of single regions differing from the others in growth dynamics and G × A reactivity. The composition of the groups is shown in Table 2 and their genetic reactivity is depicted in Figs. 5 to 13.

Group 1 includes 26 spruce provenance regions with the mean standardised height of trees exceeding zero in the whole measuring period. Spruces from the provenances representing these regions do not exhibit a significant effect of G × A interaction in the juvenile phase of life. Because of that they constitute a good source population for the selection of forest re-

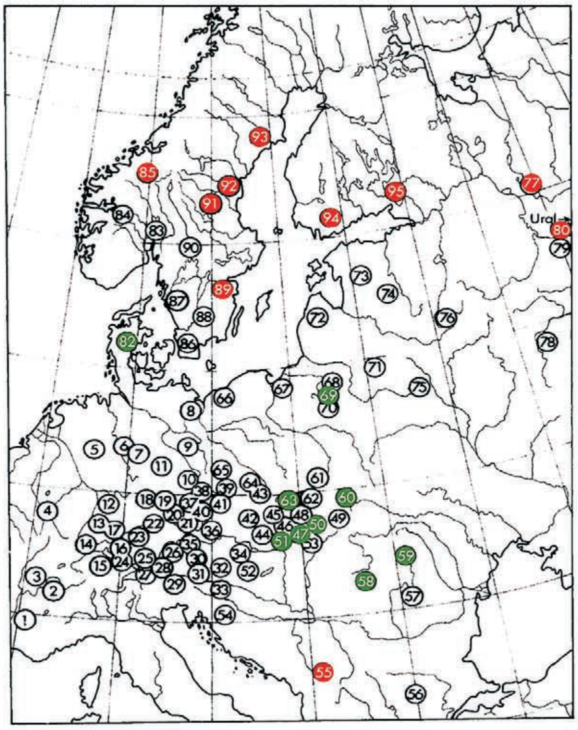


● $\bar{H}_{1969} \le \bar{x} - 1S$ ● $\bar{H}_{1969} \ge \bar{x} + 1S$

No	Provenance	1969
1	Massif Central, Dauphine; France	0.86
2	West Alps: France	-0.58
3	Jura; France	-0.07
4	Ardennes, Vosges, Eifel; Belgium, France, Germany	1.04
5	Rheinisches Schiefergebirge, Hessian, Foothills; Germany	0.59
6	Harz Mts 1; Germany	1.30
7	Harz Mts 2 (Westerhof); Germany	0.52
8	Mecklenburg Lakeland, Schwerin, Rostock; Germany	0.18
9	Lausitz; Germany	1.18
10	Erzgebirge; Czech Republic	0.11
11	Thuringerwald; Germany	0.09
12	Odenwald; Germany	0.76
13	Schwarzwald (Baden-Wurttemberg); Germany	0.26
14	Breisgau; Germany	-0.28
15	West (Lepontine) Alps; Switzerland	-0.51
16	Swabian Upland (Wurttemberg); Germany	0.19
17	Swabian Jura; Germany	0.49
18	Franconian Jury; Germany	0.93
19	Franconia, Upper Palatinate; Germany	0.83
20	Bavarian Forest; Germany	-0.11
21	Bohemian Forest; Czech Republik, Germany	-0.10
22	Swabian-BavarianUpland (Bavaria) 1; Germany	0.92
23	Swabian-BavarianUpland (Swabia) 2; Germany	0.67
24	Swabian-BavarianUpland (Swabia) 3; Germany	0.04
25	Bavarian Alps; Germany	-0.28
26	East Alps; Germany	0.15
27	Tyrol; Austria	-0.15
28	Tyrol-Salzburg; Austria	0.17
29	East Alps; Italy	-0.27
30	Niedrige Tauern, Styria; Austria	0.20
31	Carinthia-Styria; Austria	0.07
32	Styria (N-E) 1; Austria	0.11
33	Styria (S-E) 2; Austria	0.49
34	Styria (E) 3; Austria	-0.10
35	Upper Austria; Austria	0.12
36	Bohemian Upland, Lower Austria; Czech Republic, Austria	0.69
37	West Bohemia; Czech Republic	0.63
38	Central Bohemia; Czech Republic	0.42
39	Sudetes (Krkonose, Tafelgebirge); Czech Republic	-0.03
40	South Bohemia; Czech Republic	0.73
41	Bohemia; Czech Republic	0.53
42	South Bohemia, Moravia; Czech Republic	0.41
43	Moravia 1; Czech Republic	0.74
44	Moravia 2; Czech Republic	0.40
45	Moravia 3; Czech Republic	0.20
46	Velka Fatra, Mala Fatra, Slovakia	0.85
47	Nizke Tatry; Slovakia	0.19
48	Tatras; Slovakia, Poland	-0.62

No	Provenance	1969
49	East Slovakia (Spis); Slovakia	0.44
50	Slovenske Rudohorie; Slovakia	0.19
51	Stiavnicke Pohorie; Slovakia	0.73
52	West Hungary; Hungary	0.14
53	North Hungary; Hungary	-0.81
54	Dalmatia; Croatia	-1.01
55	Montenegro; Yugoslavia	-1.44
56	Rhodope Mts; Bulgaria	-0.75
57	Southern Carpathians, Transylvanian Upland; Romania	-0.66
58	Bihor Mts,Transylvanian; Romania	0.12
59	East Carpathians; Romania	-0.12
60	East Beskids (Tarnawa); Poland	0.21
61	Little Poland Upland; Poland	1.16
62	Babia Góra, Beskid Sądecki; Poland	0.25
63	Beskid Śląski, Beskid Żywiecki;Poland	-0.10
64	Kłodzko Valley; Poland	0.59
65	Silesian Lowland, Great poland Lowland; Poland	1.31
66	West-Pomeranian Lakeland; Poland	0.46
67	East-Pomeranian Lakeland, Warmia, Masuria; Poland	0.24
68	Masurian Lakeland; Poland	0.29
69	Augustów Lakeland, Podlasie; Poland	0.49
70	Białowieża Primeval Forerst; Poland	-0.14
71	Vilnius Lakeland, Belarus Lakeland; Lithuania, Belarus	-0.13
72	Latvia, Estonia, 1	-0.70
73	Latvia, Estonia, 2	-0.54
74	Latvia, Estonia, 3	-0.69
75	Belarus	-0.25
76	East Russia (Valdai Hills); Russia	-0.91
77	Russia 1	-1.78
78	Russia 2 (Central Russian Upland, Smolensk-Moscow Heights)	-0.55
79	Udmurtsk (Upper Kama Upland); Russia	-1.52
80	West Siberia; Russia	-1.63
81	Knusk; Russia	0.23
82	Jutland,(Denmark)	0.32
83	Bogstad (Ostland); Norway	-1.18
84	S-E Norway; Norway	-1.67
85	Central Norway; Norway	-2.13
86	Scania; Sweden	-0.68
87	Gotland; Smaland (S-E Sweden); Sweden	-1.18
88	Gotland; Sweden	-1.42
89	Sondermanland (S-E Sweden); Sweden	-1.53
90	Central Sweden; Sweden	-1.47
91	Norrland; Sweden	-1.72
92	Madelpad; Angermanland; Sweden	-2.26
93	S-E Sweden Cost; Sweden	-2.38
94	South Finland; Finland	-1.35
95	Karelian; Finland; Russia	-1.99
96	Hudson, Ontario; Canada	0.20

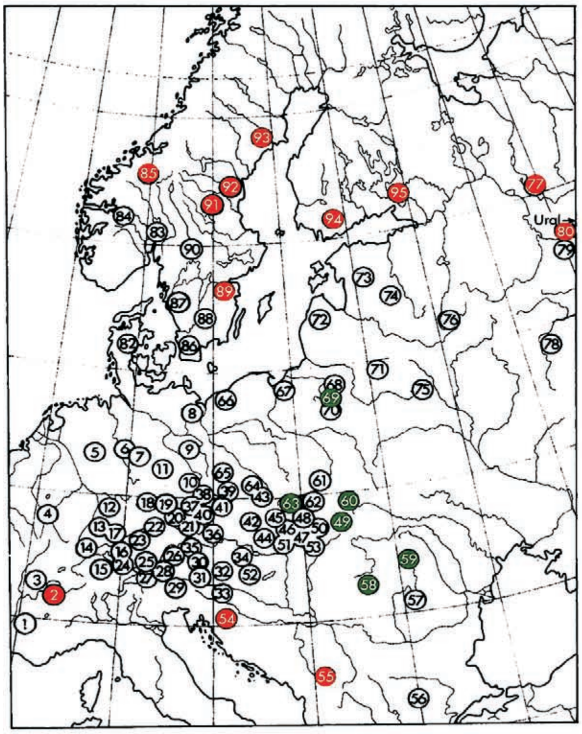
Fig. 1. Location of geographical regions of Krutzsch (1 to 95) after Schmidt-Vogt (1977), and mean height of trees (given in units of standard deviation from block mean) in Norway spruce provenances tested under IPTNS-IUFRO 1964/68. Krynica 1969, tree age 6 years



● $\bar{H}_{1978} \leq \bar{x} - 1S$ ● $\bar{H}_{1978} \geq \bar{x} + 1S$

No	Provenance	1978
1	Massif Central, Dauphine; France	-0.70
2	West Alps: France	-0.78
3	Jura; France	-0.48
4	Ardennes, Vosges, Eifel; Belgium, France, Germany	0.64
5	Rheinisches Schiefergebirge, Hessian, Foothills; Germany	-0.06
6	Harz Mts 1; Germany	0.16
7	Harz Mts 2 (Westerhof); Germany	0.16
8	Mecklenburg Lakeland, Schwerin, Rostock; Germany	-0.57
9	Lausitz; Germany	0.04
10	Erzgebirge; Czech Republic	0.57
11	Thuringerwald; Germany	-0.09
12	Odenwald; Germany	0.17
13	Schwarzwald (Baden-Wurttemberg); Germany	-0.36
14	Breisgau; Germany	-0.74
15	West (Lepontine) Alps; Switzerland	-0.77
16	Swabian Upland (Wurttemberg); Germany	-0.27
17	Swabian Jura; Germany	-0.26
18	Franconian Jury; Germany	0.22
19	Franconia, Upper Palatinate; Germany	0.66
20	Bavarian Forest; Germany	-0.15
21	Bohemian Forest; Czech Republik, Germany	-0.35
22	Swabian-BavarianUpland (Bavaria) 1; Germany	-0.24
23	Swabian-BavarianUpland (Swabia) 2; Germany	-0.19
24	Swabian-BavarianUpland (Swabia) 3; Germany	-0.26
25	Bavarian Alps; Germany	-0.20
26	East Alps; Germany	0.02
27	Tyrol; Austria	-0.64
28	Tyrol-Salzburg; Austria	-0.19
29	East Alps; Italy	-0.30
30	Niedrige Tauern, Styria; Austria	-0.08
31	Carinthia-Styria; Austria	-0.09
32	Styria (N-E) 1; Austria	-0.01
33	Styria (S-E) 2; Austria	0.39
34	Styria (E) 3; Austria	-0.39
35	Upper Austria; Austria	-0.49
36	Bohemian Upland, Lower Austria; Czech Republic, Austria	0.40
37	West Bohemia; Czech Republic	0.29
38	Central Bohemia; Czech Republic	0.37
39	Sudetes (Krkonose, Tafelgebirge); Czech Republic	0.70
40	South Bohemia; Czech Republic	0.59
41	Bohemia; Czech Republic	0.73
42	South Bohemia, Moravia; Czech Republic	0.29
43	Moravia 1; Czech Republic	0.63
44	Moravia 2; Czech Republic	0.31
45	Moravia 3; Czech Republic	0.55
46	Velka Fatra, Mala Fatra, Slovakia	0.41
47	Nizke Tatry; Slovakia	1.04
48	Tatras; Slovakia, Poland	0.57
49	East Slovakia (Spis); Slovakia	0.90
50	Slovenske Rudohorie; Slovakia	1.14
51	Stiavnicke Pohorie; Slovakia	1.36
52	West Hungary; Hungary	0.68
53	North Hungary; Hungary	0.47
54	Dalmatia; Croatia	-0.60
55	Montenegro; Yugoslavia	-1.38
56	Rhodope Mts; Bulgaria	-0.55
57	Southern Carpathians, Transylvanian Upland; Romania	-0.86
58	Bihor Mts,Transylvanian; Romania	1.27
59	East Carpathians; Romania	1.20
60	East Beskids (Tarnawa); Poland	1.50
61	Little Poland Upland; Poland	0.75
62	Babia Góra, Beskid Sądecki; Poland	-0.07
63	Beskid Śląski, Beskid Żywiecki;Poland	1.19
64	Kłodzko Valley; Poland	0.03
65	Silesian Lowland, Great poland Lowland; Poland	0.67
66	West-Pomeranian Lakeland; Poland	0.48
67	East-Pomeranian Lakeland, Warmia, Masuria; Poland	0.44
68	Masurian Lakeland; Poland	0.87
69	Augustów Lakeland, Podlasie; Poland	1.20
70	Białowieża Primeval Forerst; Poland	0.69
71	Vilnius Lakeland, Belarus Lakeland; Lithuania, Belarus	0.59
72	Latvia, Estonia, 1	0.11
73	Latvia, Estonia, 2	-0.17
74	Latvia, Estonia, 3	0.21
75	Belarus	0.88
76	East Russia (Valdai Hills); Russia	-0.05
77	Russia 1	-1.29
78	Russia 2 (Central Russian Upland, Smolensk-Moscow Heights)	-0.32
79	Udmurtsk (Upper Kama Upland); Russia	-0.86
80	West Siberia; Russia	-1.74
81	Knusk; Russia	0.83
82	Jutland,(Denmark)	1.12
83	Bogstad (Ostland); Norway	-0.41
84	S-E Norway; Norway	-0.57
85	Central Norway; Norway	-1.70
86	Scania; Sweden	0.15
87	Gotland, Smaland (S-E Sweden); Sweden	-0.57
88	Gotland; Sweden	-0.65
89	Sondermanland (S-E Sweden); Sweden	-1.21
90	Central Sweden; Sweden	-0.70
91	Norrland; Sweden	-1.88
92	Madelpad, Angermanland; Sweden	-1.73
93	S-E Sweden Cost; Sweden	-2.62
94	South Finland; Finland	-1.17
95	Karelian; Finland, Russia	-1.74
96	Hudson, Ontario; Canada	1.97

Fig. 2. Location of geographical regions of Krutzsch (1 to 95) after Schmidt-Vogt (1977), and mean height of trees (given in units of standard deviation from block mean) in Norway spruce provenances tested under IPTNS-IUFRO 1964/68. Krynica 1978, tree age 15 years



● $\bar{H}_{1988} \leq \bar{x} - 1S$ ● $\bar{H}_{1988} \geq \bar{x} + 1S$

No	Provenance	1988
1	Massif Central, Dauphine; France	-0.88
2	West Alps; France	-1.08
3	Jura; France	-0.81
4	Ardennes, Vosges, Eifel; Belgium, France, Germany	0.81
5	Rheinisches Schiefergebirge, Hessian, Foothills; Germany	0.27
6	Harz Mts 1; Germany	0.60
7	Harz Mts 2 (Westerhof); Germany	0.50
8	Mecklenburg Lakeland, Schwerin, Rostock; Germany	-0.12
9	Lausitz; Germany	0.06
10	Erzgebirge; Czech Republic	0.52
11	Thuringerwald; Germany	0.08
12	Odenwald; Germany	0.34
13	Schwarzwald (Baden-Wurttemberg); Germany	-0.30
14	Breisgau; Germany	-0.81
15	West (Lepontine) Alps; Switzerland	-0.88
16	Swabian Upland (Wurttemberg); Germany	-0.18
17	Swabian Jura; Germany	-0.18
18	Franconian Jury; Germany	0.40
19	Franconia, Upper Palatinate; Germany	0.63
20	Bavarian Forest; Germany	0.22
21	Bohemian Forest; Czech Republik, Germany	-0.47
22	Swabian-BavarianUpland (Bavaria) 1; Germany	-0.15
23	Swabian-BavarianUpland (Swabia) 2; Germany	-0.08
24	Swabian-BavarianUpland (Swabia) 3; Germany	-0.11
25	Bavarian Alps; Germany	-0.34
26	East Alps; Germany	0.00
27	Tyrol; Austria	-0.73
28	Tyrol-Salzburg; Austria	-0.08
29	East Alps; Italy	-0.24
30	Niedrige Tauern, Styria; Austria	-0.10
31	Carinthia-Styria; Austria	-0.06
32	Styria (N-E) 1; Austria	0.04
33	Styria (S-E) 2; Austria	0.33
34	Styria (E) 3; Austria	-0.09
35	Upper Austria; Austria	-0.53
36	Bohemian Upland, Lower Austria; Czech Republic, Austria	0.45
37	West Bohemia; Czech Republic	0.62
38	Central Bohemia; Czech Republic	0.30
39	Sudetes (Krkonose, Tafelgebirge); Czech Republic	0.70
40	South Bohemia; Czech Republic	0.36
41	Bohemia; Czech Republic	0.63
42	South Bohemia, Moravia; Czech Republic	0.40
43	Moravia 1; Czech Republic	0.72
44	Moravia 2; Czech Republic	0.53
45	Moravia 3; Czech Republic	0.67
46	Velka Fatra, Mala Fatra, Slovakia	0.65
47	Nizke Tatry; Slovakia	0.96
48	Tatras; Slovakia, Poland	0.51
49	East Slovakia (Spis); Slovakia	1.11
50	Slovenske Rudohorie; Slovakia	0.92
51	Stiavnicke Pohorie; Slovakia	0.99
52	West Hungary; Hungary	0.75
53	North Hungary; Hungary	0.13
54	Dalmatia; Croatia	-1.01
55	Montenegro; Yugoslavia	-1.83
56	Rhodope Mts; Bulgaria	-0.79
57	Southern Carpathians, Transylvanian Upland; Romania	-0.60
58	Bihor Mts,Transylvanian; Romania	1.04
59	East Carpathians; Romania	1.34
60	East Beskids (Tarnawa); Poland	1.33
61	Little Poland Upland; Poland	0.29
62	Babia Góra, Beskid Sądecki; Poland	0.54
63	Beskid Śląski, Beskid Żywiecki;Poland	1.11
64	Kłodzko Valley; Poland	0.26
65	Silesian Lowland, Great poland Lowland; Poland	0.70
66	West-Pomeranian Lakeland; Poland	0.72
67	East-Pomeranian Lakeland, Warmia, Masuria; Poland	0.47
68	Masurian Lakeland; Poland	0.80
69	Augustów Lakeland, Podlasie; Poland	1.12
70	Białowieża Primeval Forerst; Poland	0.35
71	Vilnius Lakeland, Belarus Lakeland; Lithuania, Belarus	0.40
72	Latvia, Estonia, 1	0.19
73	Latvia, Estonia, 2	-0.26
74	Latvia, Estonia, 3	0.32
75	Belarus	0.31
76	East Russia (Valdai Hills); Russia	-0.36
77	Russia 1	-1.58
78	Russia 2 (Central Russian Upland, Smolensk-Moscow Heights)	-0.45
79	Udmurtsk (Upper Kama Upland); Russia	-1.64
80	West Siberia; Russia	-2.67
81	Knusk; Russia	0.55
82	Jutland,(Denmark)	0.74
83	Bogstad (Ostland); Norway	-0.61
84	S-E Norway; Norway	-0.81
85	Central Norway; Norway	-2.12
86	Scania; Sweden	0.34
87	Gotland, Smaland (S-E Sweden); Sweden	-0.55
88	Gotland; Sweden	-0.36
89	Sondermanland (S-E Sweden); Sweden	-1.36
90	Central Sweden; Sweden	-0.61
91	Norrland; Sweden	-2.28
92	Madelpad, Angermanland; Sweden	-2.31
93	S-E Sweden Cost; Sweden	-3.12
94	South Finland; Finland	-1.72
95	Karelian; Finland, Russia	-2.07
96	Hudson, Ontario; Canada	1.17

Fig. 3. Location of geographical regions of Krutzsch (1 to 95) after Schmidt-Vogt (1977), and mean height of trees (given in units of standard deviation from block mean) in Norway spruce provenances tested under IPTNS-IUFRO 1964/68. Krynica 1988, tree age 25 years

Table 1. Results of analysis of variance used for assessing growth dynamics of Norway spruce according to geographical regions of Krutzsch

Source of variation	Sum of squares	Degrees of freedom	Mean sum of squares	F	p
Region (R)	2733.1	94	29.08	11.75	0.001
Error	2484.8	1004	2.47	–	–
Age – Year (Y)	5.4	5	1.09	4.52	0.001
R × Y	444.6	470	0.95	3.93	0.001
Error	1209.1	5020	0.24	–	–

production material. Such a material will exploit the full genetic variability of spruce from its whole range to meet the needs of forest regeneration plantations in the Carpathian site conditions (Fig. 5).

Group 2 comprises 21 spruce provenance regions for which the mean standardised height of trees assumed negative values in the whole period of measurement (Fig. 6). Spruces originating from these regions form an inappropriate source population for the selection of forest reproduction material.

Spruces from the five provenance regions forming group 3 showed negative values of mean standardised height in the entire period. The values were much lower than in group 2, suggesting that those spruces constitute a population highly unsuitable for selection purposes (Fig. 7).

Spruces from the five regions composing group 4 had average values of mean standardised height in the whole period. Although these values increased with tree age (from a very low level in 1969), they still remained below zero, making the population unsuitable for selection (Fig. 8).

Group 5 consists of four regions with the mean standardised height above zero. Its values increased in the years 1969–-1975 and then remained high. Not showing a significant effect of G × A interaction in the juvenile period, spruces from these provenance regions constitute a most suitable source population for the needs of the selection of forest reproduction material, making it possible to use the entire genetic variability of spruce from its whole range for the needs of forest regeneration plantations in the site conditions of the Carpathian Mts. (Fig. 9).

Group 6 forms another set of regions with provenances highly suitable for selection purposes. The mean standardised heights of spruces from these four provenance regions exceeded zero in the whole measuring period. The spruces did not exhibit a significant effect of G × A interaction in the juvenile period, so they form a population fully exploiting the genetic

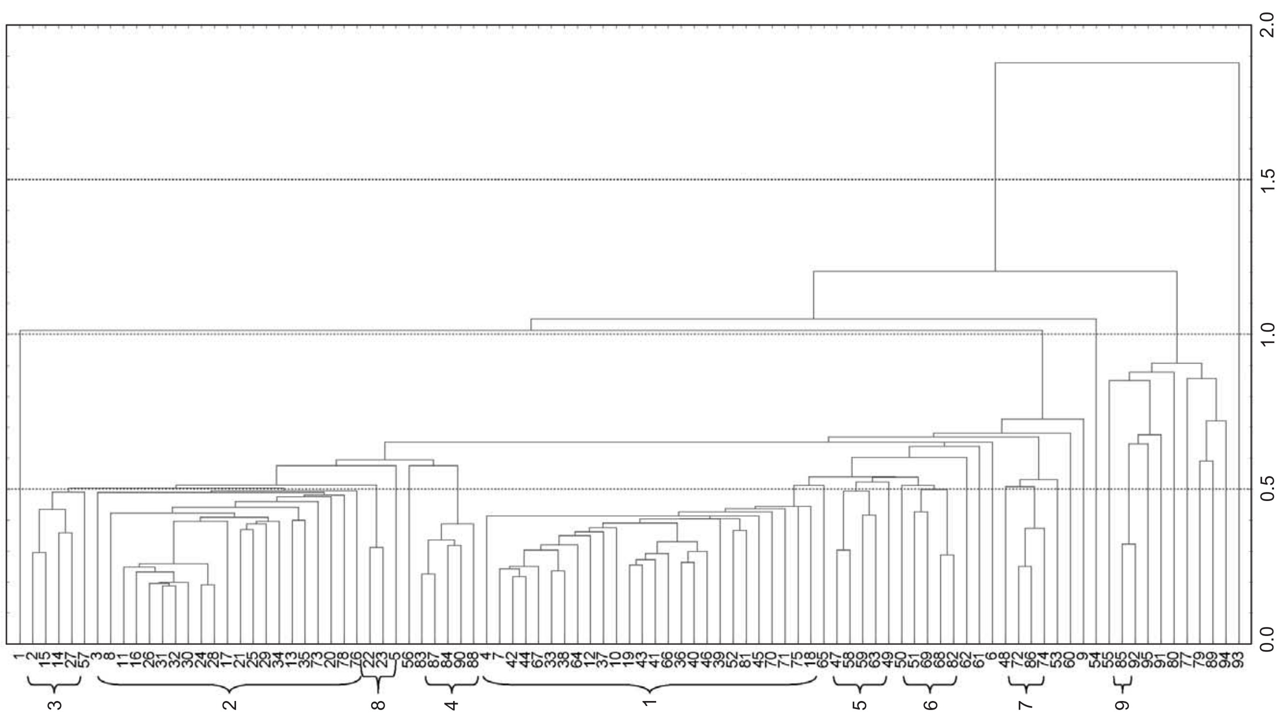


Fig. 4. Dendrogram for geographical regions of Krutzsch. Regions are grouped according to similar height growth dynamics of spruce trees in years 1969–1988; 1, ..., 9 – numbering of groups

Table 2. Growth dynamics of Norway spruce from provenances representing geographical regions of Krutzsch (years 1969–1988)

No. acc. to Krutzsch	Geographical region	No. of prove-nances	Mean height of trees expressed in units of standard deviation						Group acc. to dendro-gram from Fig. 4
			1969	1972	1975	1978	1983	1988	
4	Ardennes, Vosges, Eifel; Belgium, France, Germany	5	1.04	0.77	0.77	0.64	1.04	0.81	1
7	Harz Mts 2 (Westerhof); Germany	12	0.52	0.38	0.30	0.16	0.37	0.50	1
10	Erzgebirge; Czech Republic	11	0.11	0.09	0.53	0.57	0.42	0.52	1
12	Odenwald; Germany	7	0.76	0.28	0.14	0.17	0.02	0.34	1
18	Franconian Jury; Germany	11	0.93	0.68	0.56	0.22	0.23	0.40	1
19	Franconia, Upper Palatinate; Germany	11	0.83	0.79	0.70	0.66	0.74	0.63	1
33	Styria (S–E) 2; Austria	7	0.49	0.69	0.42	0.39	0.4	0.33	1
36	Bohemian Upland, Lower Austria; Czech Republic, Austria	17	0.69	0.74	0.70	0.40	0.51	0.45	1
37	West Bohemia; Czech Republic	12	0.63	0.63	0.16	0.29	0.38	0.62	1
38	Central Bohemia; Czech Republic	8	0.42	0.53	0.31	0.37	0.28	0.30	1
39	Sudetes (Krkonose, Tafelgebirge); Czech Republic	7	–0.03	0.5	0.69	0.70	0.40	0.70	1
40	South Bohemia; Czech Republic	9	0.73	0.72	0.56	0.59	0.58	0.36	1
41	Bohemia; Czech Republic	19	0.53	0.76	0.84	0.73	0.64	0.63	1
42	South Bohemia, Moravia; Czech Republic	25	0.41	0.27	0.21	0.29	0.30	0.40	1
43	Moravia 1; Czech Republic	10	0.74	0.81	0.81	0.63	0.56	0.72	1
44	Moravia 2; Czech Republic	11	0.40	0.35	0.36	0.31	0.25	0.53	1
45	Moravia 3; Czech Republic	24	0.20	0.43	0.51	0.55	0.69	0.67	1
46	Velka Fatra, Mala Fatra, Slovakia	5	0.85	063	0.71	0.41	0.60	0.65	1
52	West Hungary; Hungary	7	0.14	0.79	0.77	0.68	0.66	0.75	1
64	Kłodzko Valley; Poland	9	0.59	0.31	0.29	0.03	0.23	0.26	1
66	West-Pomeranian Lakeland; Poland	17	0.46	0.67	0.89	0.48	0.69	0.72	1
67	East-Pomeranian Lakeland, Warmia, Masuria; Poland	8	0.24	0.39	0.41	0.44	0.36	0.47	1
70	Białowieża Primeval Forerst; Poland	7	–0.14	–0.07	0.74	0.69	0.43	0.35	1
71	Vilnius Lakeland, Belarus Lakeland; Lithuania, Belarus	9	–0.13	0.56	0.74	0.59	0.56	0.4	1
75	Belarus	6	–0.25	0.24	0.93	0.88	0.56	0.31	1
81	Knusk; Russia	3	0.23	0.54	0.81	0.83	0.72	0.55	1
3	Jura; France	5	–0.07	–0.18	–0.66	–0.48	–0.7	–0.81	2
8	Mecklenburg Lakeland, Schwerin, Rostock; Germany	12	0.18	–0.42	–0.63	–0.57	–0.21	–0.12	2
11	Thuringerwald; Germany	9	0.09	–0.05	–0.25	–0.09	0.18	0.08	2
13	Schwarzwald (Baden-Wurttemberg); Germany	19	0.26	–0.17	–0.64	–0.36	–0.45	–0.30	2
16	Swabian Upland (Wurttemberg); Germany	15	0.19	–0,08	–0,16	–0,27	–0.11	–0.18	2
17	Swabian Jura; Germany	28	0.49	–0.04	–0.27	–0.26	–0.34	–0.18	2
20	Bavarian Forest; Germany	7	–0.11	–0.50	–0.31	–0.15	–0.04	0.22	2
21	Bohemian Forest; Czech Republik, Germany	58	–0.10	–0.22	–0.31	–0.35	–0.41	–0.47	2
24	Swabian-Bavarian Upland (Swabia) 3; Germany	13	0.04	–0.29	–0.42	–0.26	–0.18	–0.11	2
25	Bavarian Alps; Germany	14	–0.28	–0.33	–0.37	–0.20	–0.19	–0.34	2
26	East Alps; Germany	26	0.15	0.03	0.07	0.02	–0.06	0	2
28	Tyrol-Salzburg; Austria	21	0.17	–0.16	–0.40	–0.19	–0.19	–0.08	2
29	East Alps; Italy	5	–0.27	–0.07	–0.61	–0.30	–0.26	–0.24	2
30	Niedrige Tauern, Styria; Austria	24	0.20	–0.05	–0.25	–0.08	–0.06	–0.10	2
31	Carinthia-Styria; Austria	24	0.07	–0.05	–0.1	–0.09	–0.03	–0.06	2
32	Styria (N-E) 1; Austria	49	0.11	0.02	–0.06	–0.01	0.07	0.04	2
34	Styria (E) 3; Austria	12	–0.10	–0.14	–0.70	–0.39	0.02	–0.09	2
35	Upper Austria; Austria	3	0.12	–0.43	–0.60	–0.49	–0.45	–0.53	2
73	Latvia, Estonia, 2	5	–0.54	0.01	–0.23	–0.17	–0.17	–0.26	2

76	East Russia (Valdai Hills); Russia	5	–0.91	–0.55	0	–0.05	–0.51	–0.36	2
78	Russia 2 (Central Russian Upland, Smolensk–Moscow Heights)	7	–0.55	–0.45	–0.15	–0.32	–0.45	–0.45	2
2	West Alps: France	13	–0.58	–0.77	–0.91	–0.78	–0.97	–1.08	3
14	Breisgau; Germany	16	–0.28	–0.72	–0.94	–0.74	–0.51	–0.81	3
15	West (Lepontine) Alps; Switzerland	18	–0.51	–0.69	–1.05	–0.77	–0.85	–0.88	3
27	Tyrol; Austria	16	–0.15	–0.56	–0.93	–0.64	–0.77	–0.73	3
57	Southern Carpathians, Transylvanian Upland; Romania	5	–0.66	–1.04	–1.02	–0.86	–0.78	–0.60	3
83	Bogstad (Ostland); Norway	10	–1.18	–0.70	–0.59	–0.41	–0.34	–0.61	4
84	S-E Norway; Norway	5	–1.67	–0.61	–0.66	–0.57	–0.58	–0.81	4
87	Gotland, Smaland (S-E Sweden); Sweden	9	–1.18	–0.70	–0.65	–0.57	–0.48	–0.55	4
88	Gotland; Sweden	8	–1.42	–0.82	–0.76	–0.65	–0.34	–0.36	4
90	Central Sweden; Sweden	18	–1,47	–0,66	–0,61	–0,70	–0,56	–0,61	4
47	Nizke Tatry; Slovakia	23	0.19	0.45	1.07	1.04	0.92	0.96	5
58	Bihor Mts,Transylvanian; Romania	6	0.12	0.31	1.09	1.27	1.01	1.04	5
59	East Carpathians; Romania	25	–0.12	0.41	1.54	1.20	1.33	1.34	5
63	Beskid Śląski, Beskid Żywiecki; Poland	15	–0.10	0.62	1.32	1.19	1.19	1.11	5
51	Stiavnicke Pohorie; Slovakia	2	0.73	0.84	1.40	1.36	0.99	0.99	6
68	Masurian Lakeland; Poland	7	0.29	0.98	1.24	0.87	0.82	0.80	6
69	Augustów Lakeland, Podlasie; Poland	8	0.49	0.95	1.22	1.20	1.18	1.12	6
82	Jutland,(Denmark)	5	0.32	0.99	1.18	1.12	0.93	0.74	6
72	Latvia, Estonia, 1	8	–0.7	–0.12	0.18	0.11	0.42	0.19	7
74	Latvia, Estonia, 3	8	–0.69	0.07	0.30	0.21	0.17	0.32	7
86	Scania; Sweden	7	–0.68	–0.28	0.19	0.15	0.53	0.34	7
22	Swabian-Bavarian Upland (Bavaria) 1; Germany	31	0.92	0.33	–0.07	–0.24	–0.14	–0.15	8
23	Swabian-Bavarian Upland (Swabia) 2; Germany	35	0.67	0.36	–0.23	–0.19	–0.11	–0.08	8
85	Central Norway; Norway	5	–2.13	–1.65	–1.74	–1.7	–1.94	–2.12	9
92	Madelpad, Angermanland; Sweden	9	–2.26	–1.81	–1.88	–1.73	–2.02	–2.31	9
93	S-E Sweden Cost; Sweden	6	–238	–2.64	–2.85	–2.62	–2.67	–3.12	10
94	South Finland; Finland	6	–135	–0.88	–1.34	–1.17	–1.29	–1.72	11
89	Sondermanland (S-E Sweden); Sweden	4	–1.53	–1.22	–1.4	–1.21	–0.74	–1.36	12
79	Udmurtsk (Upper Kama Upland); Russia	4	–1.52	–1.37	–1.12	–0.86	–0.97	–1.64	13
77	Russia 1	5	–1.78	–1.78	–0.85	–1.29	–1.46	–1.58	14
80	West Siberia; Russia	3	–1.63	–1.5	–1.37	–1.74	–2.18	–2.67	15
91	Norrland; Sweden	9	–1.72	–1.91	–2.08	–1.88	–1.71	–2.28	16
95	Karelian; Finland, Russia	4	–199	–1.29	–1.30	–1.74	–1.69	–2.07	17
55	Montenegro; Yugoslavia	3	–1.44	–1.69	–1.52	–1.38	–1.88	–1.83	18
54	Dalmatia; Croatia	2	–1.01	0.21	–0.90	–0.6	–0.84	–1.01	19
9	Lausitz; Germany	2	1.18	1.19	0.49	0.04	0.45	0.06	21
1	Massif Central, Dauphine; France	5	0.86	0.05	–0.54	–0.70	–0.92	–0.88	22
60	East Beskids (Tarnawa); Poland	4	0.21	1.01	1.65	1.50	1.44	1.33	23
53	North Hungary; Hungary	4	–0.81	–0.25	0.63	0.47	0.38	0.13	24
48	Tatras; Slovakia, Poland	25	–0.62	–0.17	0.34	0.57	0.43	0.51	25
6	Harz Mts 1; Germany	7	1.30	0.74	0.08	0.16	0.16	0.60	26
61	Little Poland Upland; Poland	5	1.16	1.18	0.70	0.75	0.29	0.29	27
62	Babia Góra, Beskid Sądecki; Poland	6	0.25	0	–0.02	–0.07	0.56	0.54	28
50	Slovenske Rudohorie; Slovakia	7	0.19	1.05	1.29	1.14	0.42	0.92	29
49	East Slovakia (Spis); Slovakia	3	0.44	0.79	0.88	0.90	0.79	1.11	30
65	Silesian Lowland, Great poland Lowland; Poland	10	1.31	0.94	0.81	0.67	0.66	0.70	31
5	Rheinisches Schiefergebirge, Hessian, Foothills; Germany	9	0.59	–0.26	–0.32	–0.06	0.15	0.27	32
56	Rhodope Mts; Bulgaria	16	–0.75	–0.96	–0.59	–0.55	–0.63	–0.79	33

4 – Ardennes, Vosges, Eifel; Belgium, France, Germany
7 – Harz Mts 2 (Westerhof); Germany
10 – Erzgebirge; Czech Republic
12 – Odenwald; Germany
18 – Franconian Jury; Germany
19 – Franconia, Upper Palatinate; Germany
33 – Styria (S – E) 2; Austria
36 – Bohemian Upland, Lower Austria; Czech Republic, Austria
37 – West Bohemia; Czech Republic
38 – Central Bohemia; Czech Republic
39 – Sudetes (Krkonose, Tafelgebirge); Czech Republic
40 – South Bohemia; Czech Republic
41 – Bohemia; Czech Republic
42 – South Bohemia, Moravia; Czech Republic
43 – Moravia 1; Czech Republic
44 – Moravia 2; Czech Republic
45 – Moravia 3; Czech Republic
46 – Velka Fatra, Mala Fatra, Slovakia
52 – West Hungary; Hungary
64 – Kłodzko Valley; Poland
66 – West - Pomeranian Lakeland; Poland
67 – East-Pomeranian Lakeland, Warmia, Masuria; Poland
70 – Białowieża Primeval Forerst; Poland
71 – Vilnius Lakeland, Belarus Lakeland; Lithuania, Belarus
75 – Belarus
81 – Knusk; Russia

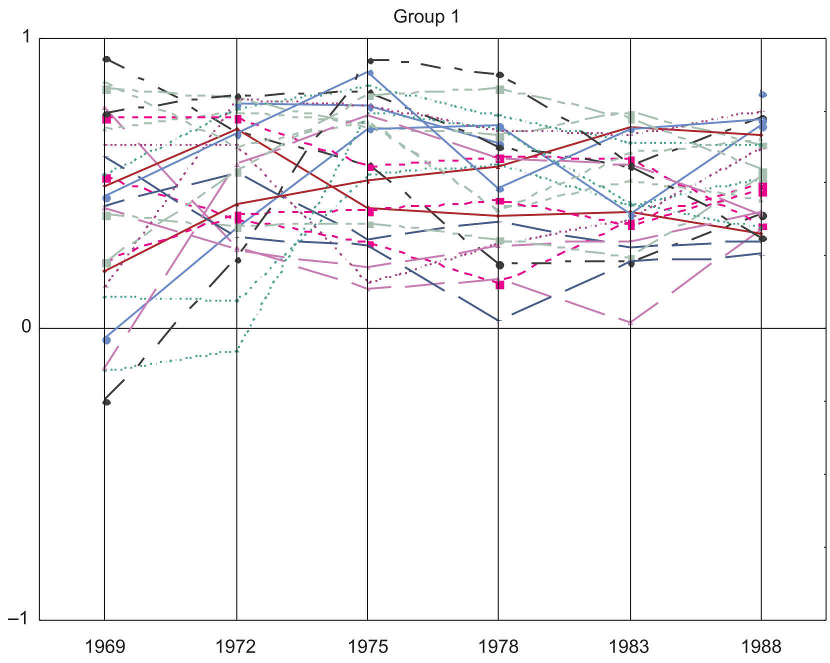


Fig. 5. Group 1 of Krutzsch regions: mean standardised height of spruce trees in years 1969–1988. Good height growth, no effect of G × A interaction

3 – Jura; France
8 – Mecklenburg Lakeland, Schwerin, Rostock; Germany
11 – Thuringerwald; Germany
13 – Schwarzwald (Baden-Wurttemberg); Germany
16 – Swabian Upland (Wurttemberg); Germany
17 – Swabian Jura; Germany
20 – Bavarian Forest; Germany
21 – Bohemian Forest; Czech Republik, Germany
24 – Swabian-Bavarian Upland (Swabia) 3; Germany
25 – Bavarian Alps; Germany
26 – East Alps; Germany
28 – Tyrol-Salzburg; Austria
29 – East Alps; Italy
30 – Niedrige Tauern, Styria; Austria
31 – Carinthia-Styria; Austria
32 – Styria (N-E) 1; Austria
34 – Styria (E) 3; Austria
35 – Upper Austria; Austria
73 – Latvia, Estonia, 2
76 – East Russia (Valdai Hills); Russia
78 – Russia 2 (Central Russian Upland, Smolensk-Moscow Heights)

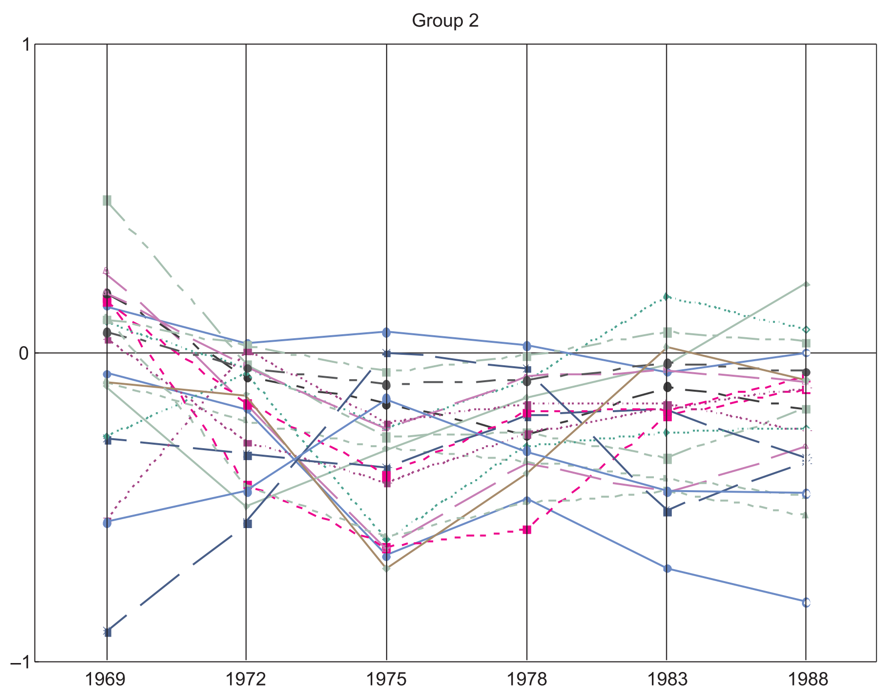


Fig. 6. Group 2 of Krutzsch regions: mean standardised height of spruce trees in years 1969–1988. No effect of G × A interaction

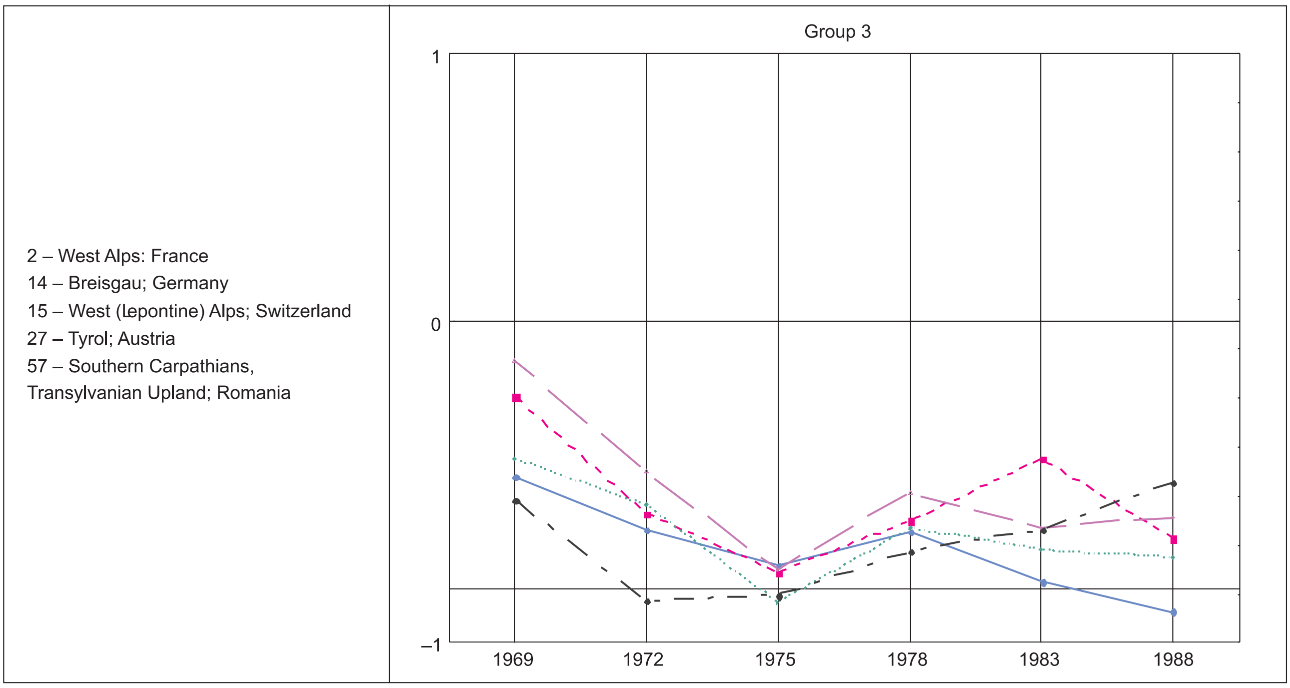


Fig. 7. Group 3 of Krutzsch regions: mean standardised height of spruce trees in years 1969–1988. Poor height growth, no significant effect of G × A interaction

variability of the species from its whole range, especially in the later period of breeding (Fig. 10).

Group 7 comprises three geographical regions of spruce provenances whose mean standardised height was below zero in the early years (1969 and 1972), while from 1975 it remained slightly above zero. Spruces from these regions do not exhibit a significant effect of G × A interaction and are not very suitable as a source population for the selection of forest reproduction material, especially in the initial period of breeding (Fig. 11).

In the two provenance regions forming group 8, the mean standardised height exceeded zero in 1969 and 1972, but from the year 1975 it assumed negative values. Spruces originating from these regions are not well suited for the selection of reproduction material, particularly in the later period of breeding (Fig. 12).

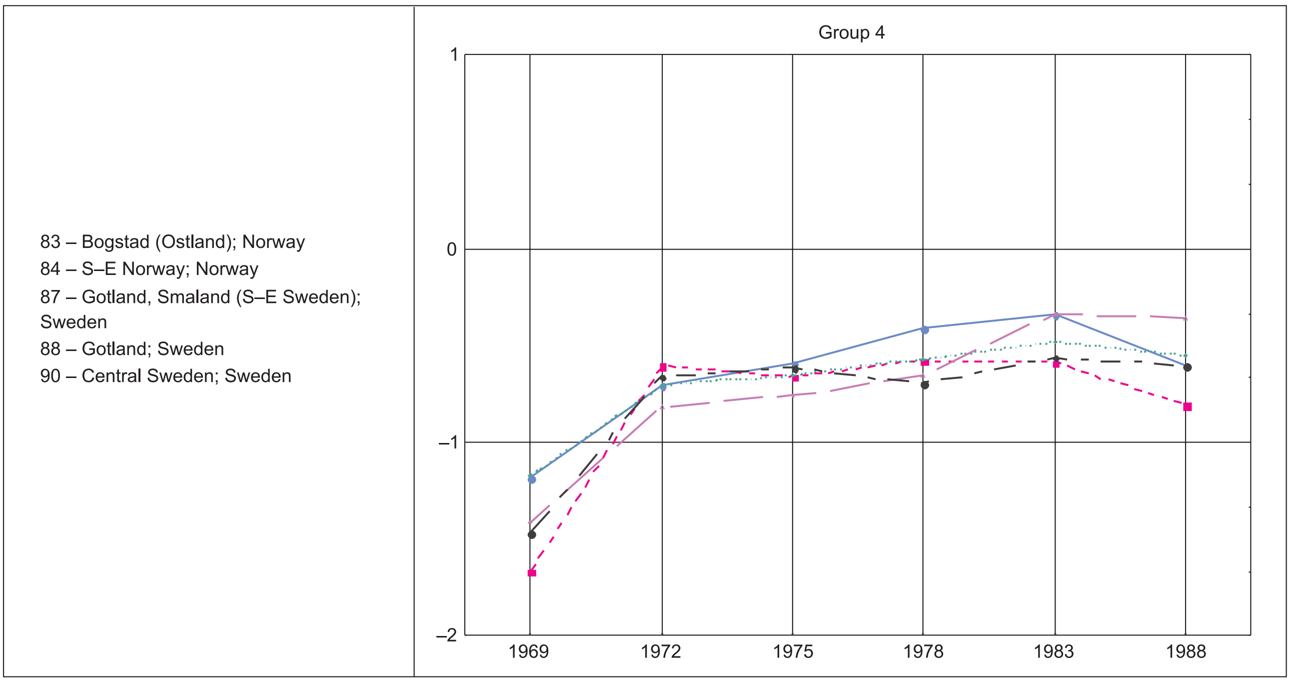


Fig. 8. Group 4 of Krutzsch regions: mean standardised height of spruce trees in years 1969–1988. Very poor height growth, no significant effect of G × A interaction

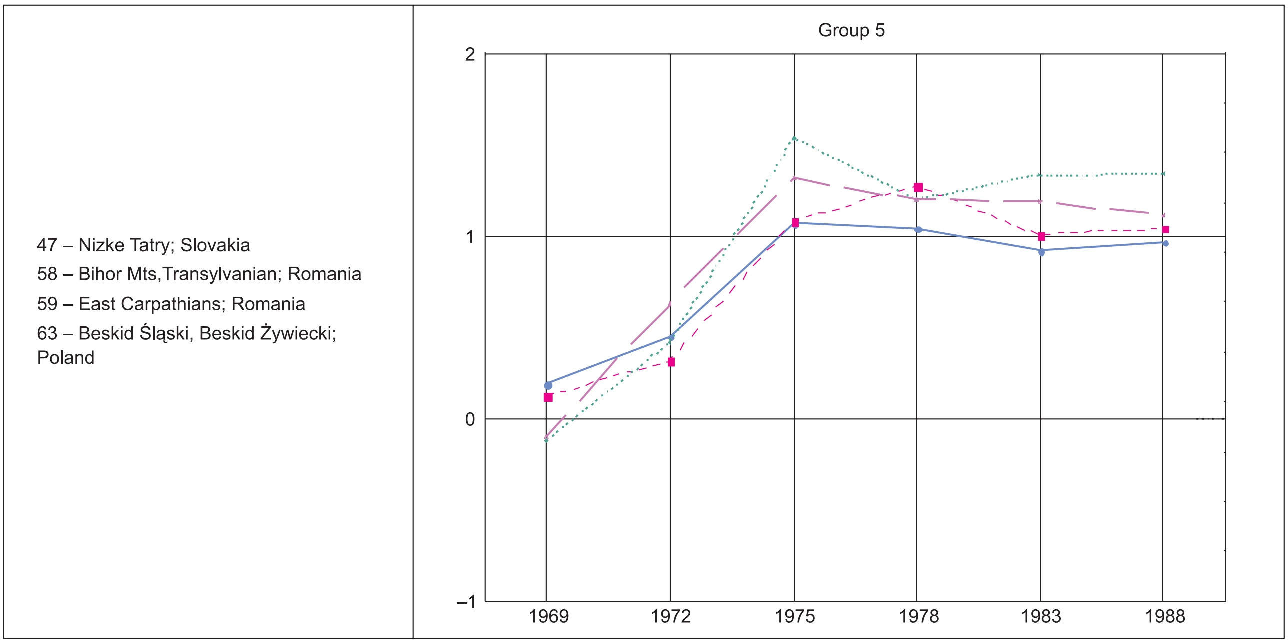


Fig. 9. Group 5 of Krutzsch regions: mean standardised height of spruce trees in years 1969–1988. Significant effect of G × A interaction

Spruces from the two provenance regions forming group 9 had the mean standardised height below zero in the whole study period and did not show any significant effect of G × A interaction in the juvenile period. They are very ill-suited for selection purposes (Fig. 13).

Cluster analysis (with the distances exceeding 3 excluded) demonstrated that the growth reactivity of spruce varied greatly between 1969 and 1972, and was stable from 1975 to 1988 (Fig. 14).

Looking at the location of the spruce groups identified in this study it can be seen that these populations exhibit significant geographical variability (Fig. 15).

The genetic effect exhibited by spruce provenances at a level of the geographical regions of Krutzsch and the effect of the genotype × plantation age interaction under the conditions of the Beskid Sądecki Mts. in the Polish part of the Western Carpathians were found to be significant. As indicated by the stable adaptation reactivity of provenances from groups 5 and 6 of

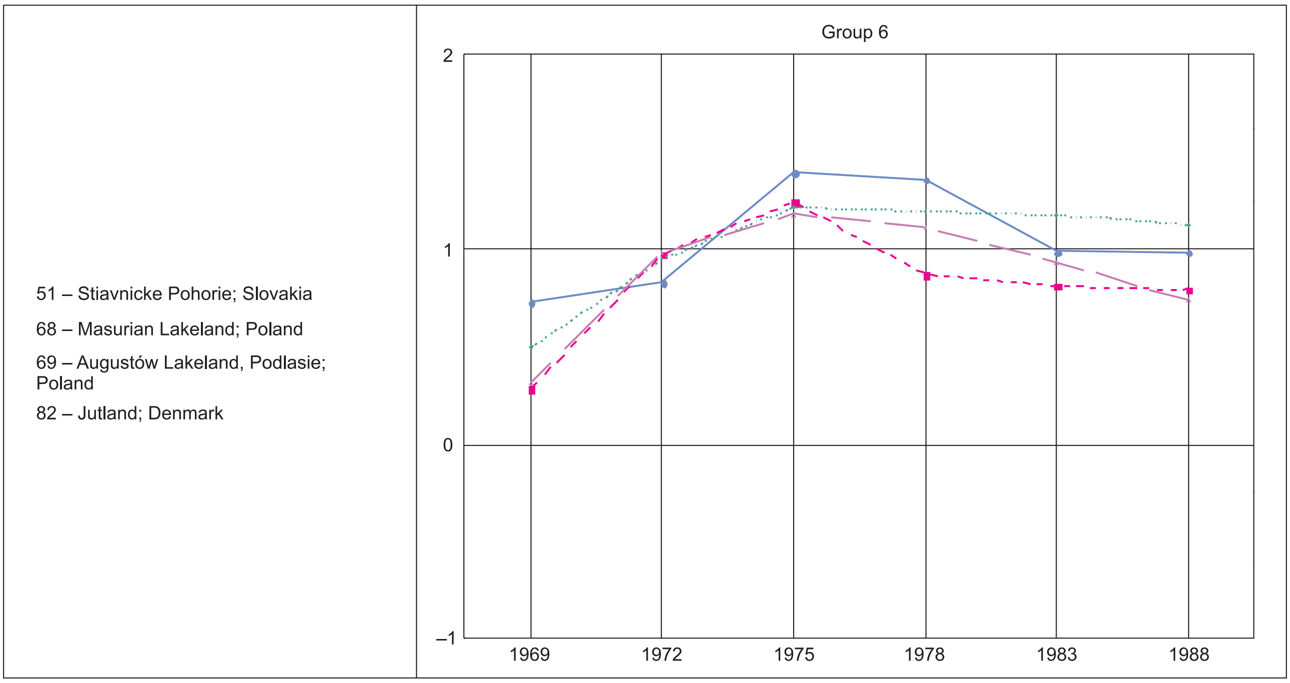


Fig. 10. Group 6 of Krutzsch regions: mean standardised height of spruce trees in years 1969–1988. Varied effect of G × A interaction; mean height increases with age

Fig. 11. Group 7 of Krutzsch regions: mean standardised height of spruce trees in years 1969–1988. Poor height growth, significant effect of G × A interaction; mean height increases with age

Krutzsch regions, which maintained a high growth rate (around 1 standard deviation from the mean for the whole population), as well as by the high values of height for provenances from groups 1 and 7, the spruce from the mountain sites of the Western and Southern Carpathians and that from the NS range of the species have a good genetic quality. The findings presented in this paper correspond with the results of most of the previous assessments of spruce provenances tested under the IUFRO 1964/68 and IUFRO 1972 experiments (Krutzsch 1974; Bałut and Sabor 2001, 2002; Matras 2006; Sabor 2006).

Conclusions

1. The growth dynamics of spruce from the geographical regions of Krutzsch greatly differed both between the regions and the years of measurement, suggesting that it is genetically determined.

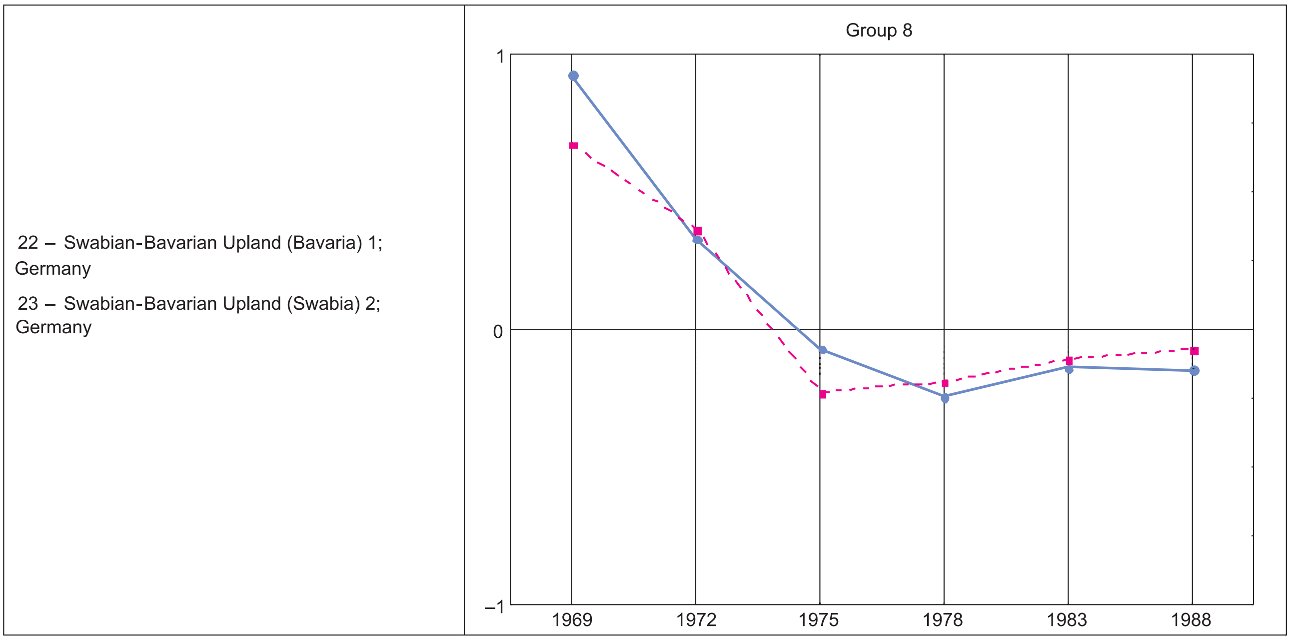


Fig. 12. Group 8 of Krutzsch regions: mean standardised height of spruce trees in years 1969–1988. Poor height growth, significant effect of G × A interaction

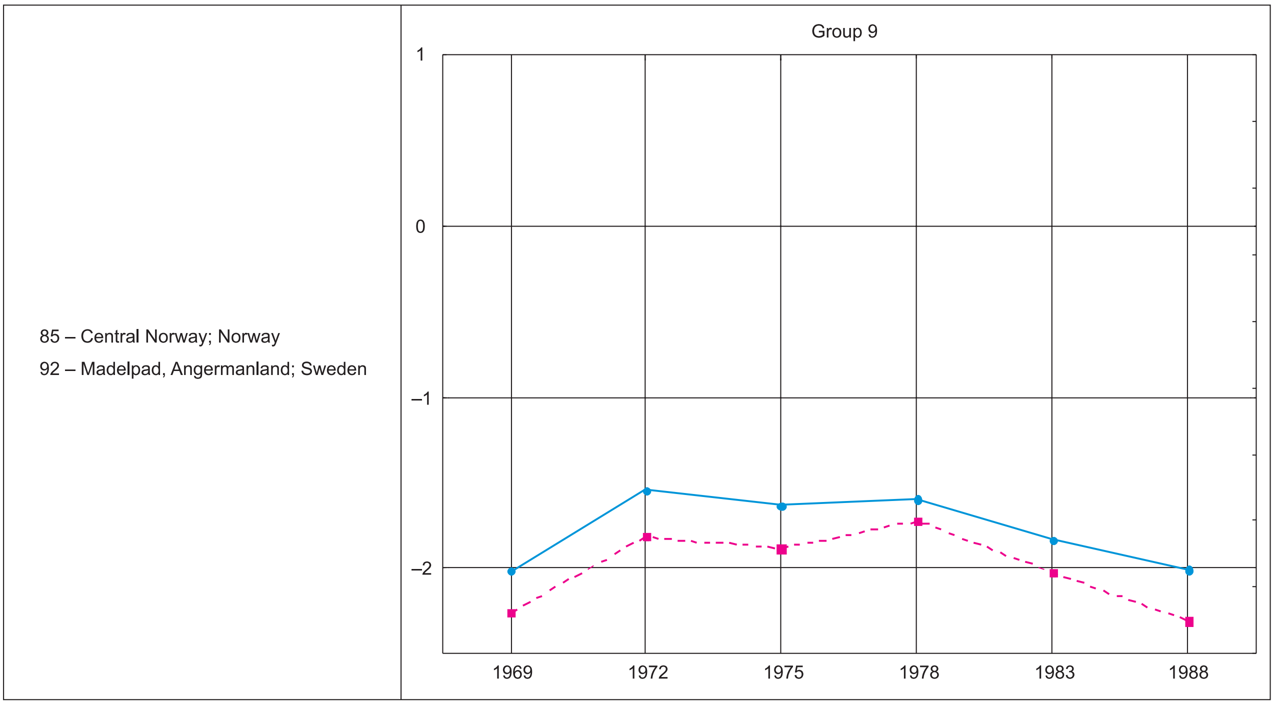


Fig. 13. Group 9 of Krutzsch regions: mean standardised height of spruce trees in years 1969–1988. Very poor height growth, significant effect of G × A interaction

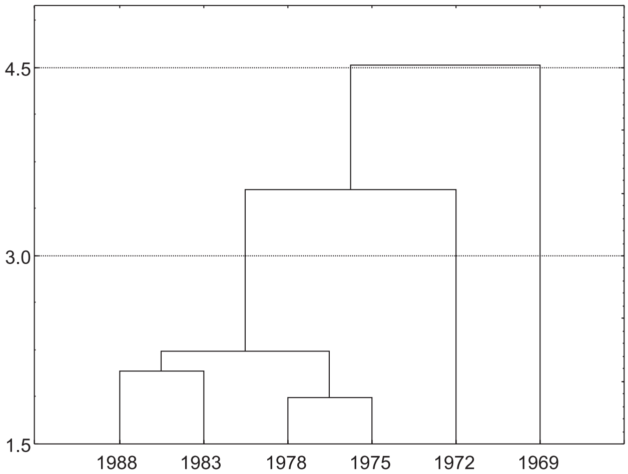


Fig. 14. Dendrogram for years of measurement. Years are grouped according to similar height growth dynamics of spruce trees in years 1969–1988 in whole collection of IPTNS-IUFRO 1964/68 in Krynica

2. The study identified several groups of geographical regions similar in the growth dynamics of spruce in the years 1969 to 1988, i.e. of trees up to 25 years old.
3. The reactivity of spruce differed considerably between 1968 and 1972, but was stable in the later period of breeding (1975–1988), i.e. from the 11th to the 25th year of tree life.
4. In terms of suitability for the selection of forest reproduction material, the best source populations of spruce are those from the provenance regions included in groups 5 and 6, i.e. from Štiavnické Pohorie, Low Tatras (Slovakia), Masurian Lakeland, Augustów Lakeland, Podlasie, Silesian Beskid Mts., Beskid Żywiecki Mts. (Poland), Jutland (Denmark), Bihor Mts., Transylvania, and Eastern Carpathians (Romania).
5. Spruce provenances representing groups 1 and 7, i.e. those from the western and northern ranges of the species, that consistently showed the mean standardised height above zero, can also be taken into account as a source of reproduction material for selection programmes.

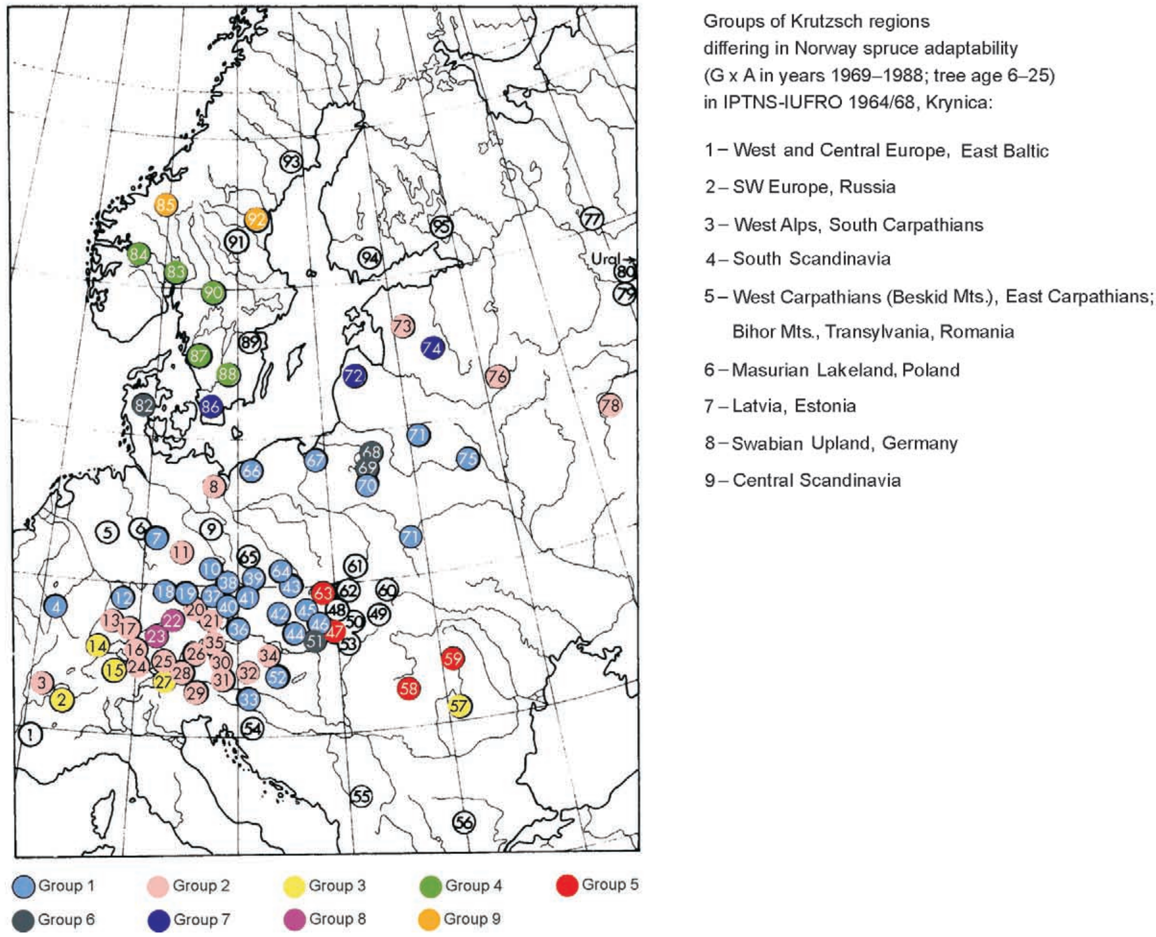


Fig. 15. Map of Europe showing distribution of geographical regions of Krutzsch grouped according to dendrogram from Fig. 4

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