JOURNAL OF FOREST SCIENCE, *48*, 2002 (1): 16–26

Effect of site altitude on the growth and survival of Norway spruce (*Picea abies* L.) provenances on the Slovak plots of IUFRO experiment 1972

M. PACALAJ[1], R. LONGAUER[1], D. KRAJMEROVÁ[1], D. GÖMÖRY[2]

[1]*Forest Research Institute, Zvolen, Slovak Republic*
[2]*Technical University, Faculty of Forestry, Zvolen, Slovak Republic*

ABSTRACT: The growth, survival, damage and provenance × environment interactions of 30 provenances of Norway spruce (*Picea abies* L.) from Poland, Slovakia and the Czech Republic, were analyzed at the age of 26 years. Significant effects of altitude and site quality but no geographic trends were dectected in the series of 5 provenance plots. Correlation of growth and survival appeared to be insignificant at individual plots and their series. The highest differentiation among provenances was revealed on the plots at the minimum and maximum altitudes (350 and 950 m). Several Slovak (Western-Carpathian) provenances proved to grow significantly better than the average at nearly all plots, and also exhibited insignificant provenance × site interaction. Indigenous provenances from the southern part of the Western Carpathians showed higher adaptability to sites in lower altitudes with longer vegetation but seasonal water deficiency.

Keywords: provenance research; Norway spruce; IUFRO experiment 1972; growth; survival; provenance × environment interactions

Norway spruce (*Picea abies* L.) belongs to forest tree species with the largest natural range. It includes the boreal and hemiboreal zone of North-eastern Europe, and also all higher Alpine, Carpathian, Hercynian and Dinaric-Balkan ranges. Relatively many genetic differences are found especially between the Boreal and mountain Central and Southeastern European provenances of Norway spruce (LAGERCRANTZ, RYMAN 1990; VAN DE SYPE 2001; SPERISEN et al. 2001). Morphological and physiological variations are also observed within the mountain spruce populations in the Alpine, Carpathian and Balkan mountains. They include differences in the crown shape and branching, growth dynamics (HOLUBČÍK 1971; HOLZER, NATHER 1974) as well as clinal variations in the size of cones and shape of cone scales (HOLUBČÍK 1968).

It may be a result of adaptation to contrasting sites, and it can also reflect different phylogeny of local populations because SCHMIDT-VOGT (1977) and many other authors assume that, besides Central Russia, Norway spruce occurred also in several smaller and isolated refuge areas southwards the Alps and Carpathians during the last glacial period.

Several international provenance experiments are focused on the genetic aspects of phenotypic variations of Norway spruce. The oldest one – IUFRO series 1938–1939 – includes 51 provenances planted on 27 plots in 14 countries. In the summary of obtained results, GIERTYCH (1978, 1984) drew conclusions about high adaptability especially of Romanian, Polish, Ukrainian, Latvian, Lithuanian and Belorussian provenances which perform well on almost all plots of the series. They grow poorly only on plots situated northwards of their place of origin. Most of the other provenances, especially those from Finland and Norway, perform satisfactorily only on plots whose site quality is comparable with their place of origin (GIERTYCH 1984). The IUFRO experiment 1964/68, which includes 1,100 provenances of Norway spruce planted on 20 plots in 13 countries, provides similar information. In southern Sweden and eastern Norway, Central-European and particularly Western Carpathian provenances belong to the best performing ones. In addition to the growth, they are tolerant to late frosts. Romanian provenances are mentioned among the best ones on the Danish plot where no late frosts occur (DIETRICHSON 1979). Provenances from North-eastern Poland, Belarus and Baltic states perform well in northern Sweden and Finland. Ukrainian and South-Polish provenances are mentioned among the best ones in Scotland (LINES 1979). Romanian and Ukrainian provenances grow well also in Austria – alike the Western-Carpathian and Bohemian ones (GÜNZL

1979). The IUFRO experiment 1964/68 proves a high genetic value of the Western-Carpathian Norway spruce from the Western Carpathians and also its phylogenetic similarity with its Hercynian provenances.

Two sets of international provenance plots with Norway spruce established by Holubčík are present in Slovakia. Their design allows to study the adaptability and fitness of Norway spruce in a wide range of sites. The older experiment 1964/68 includes 50 provenances on 7 plots planted at altitudes from 400 m in Central Slovakia to 1,250 m in Northern Slovakia. A major part of provenances were obtained from the IUFRO experiment 1964/68. Its earlier evaluations proved a superior growth and survival of Norway spruce from the Carpathians, especially if compared with the provenances from the Alps and South-Eastern Europe (HOLUBČÍK 1982; ŠIMIAK 1985).

The second set of Slovak provenance plots belongs to the IUFRO experiment 1972. This experiment follows after the IUFRO experiment 1964–65, where many Polish provenances revealed excellent growth and high ecological plasticity. The Experiment 1972 includes 4 plots in Poland, 2 in the Czech Republic, 5 in Slovakia, 4 in Germany, 3 in Finland, 6 in Canada, one in Belgium, France, Norway and Austria. The Slovak plots were planted in an altitudinal gradient between 330 m in Central Slovakia and 950 m in Northern Slovakia (HOLUBČÍK 1980b, 1984). These plots were measured at the age of 10 years for the last time (ŠIMIAK 1985). The joint regression analysis revealed significant provenance × environment interactions there (PAULE 1986). In compliance with the expectations, provenances from Poland and particularly those from the Western Beskydy Mts. revealed superior vigour and adaptability.

MATERIAL AND METHODS

Five plots with 20 provenances from Poland, 10 from Slovakia and 1 from the Czech Republic were planted in a random block design with 4 blocks, each block with 5 × 5 individuals per provenance at a spacing of 2 × 2 m. The plots were established in a vertical gradient in order to study Norway spruce adaptability to various sites and to make a comparison of Polish and Slovak provenances. No thinning was applied until the last measurement at the age of 26 years. Out of the total number of provenances, 17 were planted on all 5 plots while the remaining 13 only on 4 provenance plots. One provenance present on 2 plots was omitted from summary evaluation.

Main attention was paid to summary evaluation of the height and diameter growth (volume production) as well as damage and survival of provenances at the age of 26 years. Height growth was considered a primary production parameter with regard to the following considerations:

– At the age of 26 years, trees are at the pole stage with still low standing volume;
– Mean height is the most common parameter in the assessment of yield quality;
– Diameter, and also the volume, may be influenced by tree density (uneven survival or thinning) and show much higher individual variations than tree heights.

A three-factorial ANOVA model was applied to investigate differences between plots, provenances, blocks, and their interactions. Duncan's paired multiple-range test was applied to rank provenances according to the height, diameter and volume. Division into the superior, average and inferior ones refers to their classification into statistically homogeneous groups delineated by means of this test.

Table 1. Provenance plots belonging to IUFRO 1972 Norway spruce experiment in Slovakia

Plot	All provenances represented				Incomplete set
	Biely Váh, Klobušová	Zákamenné, Paráč	Kráľova hoľa, Bujakovo	Stráže pri Zvolene	Slovenská Ľupča, Kmeťová
Longitude and latitude	20°20′ E.G.	19°14′ E.G.	19°42′ E.G.	19°07′ E.G.	19°13′ E.G.
	48°59′ N.E.	49°27′ N.E.	48°50′ N.E.	48°35′ N.E.	48°40′ N.E.
Forest vegetation zone and association	5 – *Fageto abietum* vst	4 – *Fagetum abietino-piceosum*	4 – *Fageto-abietum* nst	2 – *Fageto-Quercetum*	3–4 *Fagetum typicum* nst.
Altitude	950	790	700	335	510
Aspect	Northwest	Northeast	Plain	West	East
Inclination	30%	10–20%	15%	25–30%	10%
Parent rock	limestone	mesotrophic flysch series	crystalline schist	andesite, tuff conglomerates	calcareous sandy conglomerates
Average temperature	5.1°C	5.5°C	6.5°C	8.1°C	6–7°C
Precipitation	850 mm	1,114 mm	800 mm	714 mm	750 mm
Size	1.45 ha rectangle	1.4 ha rectangle	1.2 ha rectangle	1.4 ha rectangle	0.81 ha square
Number of blocks	4	4	4	4	4
Number of provenances	31	30	30	31	19

Table 2. Provenances included in the Slovak plots of the IUFRO 1972 experiment (* – basic set of Polish provenances of the IUFRO experiment 1972)

Provenance area	Provenance	Code	Geographic region or mountain system	Latitude	Longitude	Altitude	Provenance plot
Northeast	Zwierżyniec*	1	Białowieża	52°48′	23°47′	160	1,2,3,4,5
Poland	Zwierżyniec*	2	Białowieża	52°42′	23°46′	180	1,2,3,4
	Wigry*	3	Biebrzanska kotl.	54°03′	23°03′	170	1,2,3,4
	Przerwanki*	4	Pojez. Suwalskie	54°10′	22°05′	180	1,2,3,4
	Borki*	5	Pojez. Suwalskie	54°06′	22°04′	180	1,2,3,4
	Nowe Ramuki*	6	Pojez. Olstynskie	53°41′	20°34′	160	1,2,3,4,5/2
	Kartuzy*	20	Pojez. Kaszubskie	54°23′	18°08′	200	1,2,3,4/2
Bohemian	Miedzygórze*	7	Kralický Sněžník Mt.	50°13′	16°45′	580	1,2,3,4,5
Quadrangle	Stronie Śląskie*	8	Góry Złote	50°14′	16°50′	820	1,2,3,4,5
	Svinošice	26	Czech-M. Highlands	49°20′	16°30′	350	1,2,3,4,5/2
Eastern	Zwierżyn. Lubelski*	18	Roztocze	50°34′	22°58′	260	1,2,3,4
Poland	Bliżyn*	19	Holy Cross Mts.	51°04′	20°41′	310	1,2,3,4,5
Western	Wisla*	9	Beskyd Slaski Mts.	49°38′	18°58′	710	1,2,3,4
Beskydy	Istebna-Bukowiec*	10	Beskyd Slaski Mts.	49°34′	18°53′	630	1,2,3,4
	Istebna-Zapowiedz*	11	Beskyd Slaski Mts.	49°32′	18°57′	630	1,2,3,4
	Rycerka *	12	Beskyd Slaski Mts.	49°31′	19°01′	620	1,2,3,4
	Rycerka *	13	Beskyd Slaski Mts.	49°29′	19°00′	700	1,2,3,4
	Rycerka *	14	Beskyd Slaski Mts.	49°29′	19°00′	950	1,2,3,4
	Orawa*	15	Babia Mt.	49°34′	19°33′	1,000	1,2,3,4,5/2
	Novoť	22	Slovak Beskydy Mts.	49°25′	19°07′	870	1,2,3,4,5/2
Eastern Beskydy	Tarnawa	17	Eastern Beskydy Mts.	49°04′	22°52′	750	1,2,3,4,5
Tatras	Wytow *	16	Western Tatras	49°13′	19°48′	1,420	1,2,3,4,5
	Tatranské Matliare	25	High Tatras	49°10′	20°20′	1,150	1,2,3,4,5/2
Central-	Lazce-Moštenica	31	Veľká Fatra Mts.	48°48′	19°14′	650	1,5
Western	Predajná	24	Low Tatras	48°53′	19°41′	900	1,2,3,4
Slovakia	Červená Skala	29	Low Tatras	49°50′	20°14′	1,100	1,2,3,4,5
Central-	Beňuš	21	Slovak Ore Mts.	48°50′	19°56′	925	1,2,3,4,5
Eastern	Michalová	28	Slovak Ore Mts.	48°43′	19°46′	680	1,2,3,4,5
Slovakia	Michalová	27	Slovak Ore Mts.	48°47′	19°47′	930	1,2,3,4,5
	Čierny Balog Krám	30	Slovak Ore Mts.	48°42′	19°39′	850	1,2,3,4,5
	Stará Voda	23	Slovak Ore Mts.	48°46′	20°42′	700	1,2,3,4

Codes of provenance plots: 1 – Biely Váh, 2 – Zákamenné, 3 – Kráľova hoľa, 4 – Stráže pri Zvolene, 5 – Slovenská Ľupča. If a provenance was planted in less than 4 block at a plot, the figure behind slash indicates respective number of blocks where it is present

Spearman's rank variation coefficient test was used to assess correlations between survival, damage and the growth parameters.

The provenance × environment interactions were tested by means of the regression analysis of FINLAY and WILKINSON (1963), which was based on the mean height of each provenance and height bonity at individual plots calculated as a lumped mean of all provenances.

RESULTS

Significant differences between plots were detected in the mean height and diameter. The mean height followed altitudinal gradient with maximum on Stráže plot in the lowest altitude (330 m). Maximum mean diameter was detected on plots Kráľova hoľa and Paráč situated at the lower natural altitudinal limit of Norway spruce in the Western Carpathians (700–800 m). Also the highest mean volume was detected on Kráľova hoľa plot. The biggest differentiation among provenances depicted in the variation coefficients of mean height, diameter and volume was observed on the plots in extreme altitudes – Stráže 330 m and Biely Váh 950 m. The highest variation in the mean volume was revealed in the most productive plot Kráľova hoľa, however. Special attention has therefore to be paid to the selection of appropriate planting stock of Norway

Table 3. Mean heights and diameters on 4 plots with all 30 provenances

Plot and altitude	No. of individuals	Mean height (m)	Standard deviation (%)	Mean diameter	Standard deviation (%)
Stráže, 335 m	2,315	**13.79**	14.9	12.89	22.45
Kráľova hoľa, 700 m	2,263	12.94	11.6	**14.56**	22.31
Zákamenné, 790 m	2,265	11.42	14.6	13.16	24.31
Biely Váh, 950 m	1,666	9.90	16.3	12.53	25.73

spruce for establishment of stands outside but also inside its natural range.

In addition to the effects of plot and provenance, significant heterogeneity was revealed between the blocks on each of the plots. Provenance × block interactions were also significant, too.

HEIGHT, DIAMETER AND VOLUME GROWTH

The analysis of variance confirmed statistically significant ($P > 99\%$) differences in the heights and diameters of provenances although the proportion of total variance attributable to this effect is relatively low (1.65 and 2.16%). As expected, the smallest residual variance was observed in the height growth.

The results of Duncan's multiple-range tests for height, diameter and volume growth across 4 complete provenance plots are presented in Tables 6, 7 and 8. Information about the mean height of provenances on each of the plots where the height of provenances is represented by the percentage of its grand mean on the respective plot is provided in Fig. 1.

In the height growth, the provenances Stará Voda 700 m, Predajná 900 m, Beňuš 925 m and Novoť 870 m from Slovakia were found superior. They are followed by Wisla 710 m and Rycerka 620 m from the Polish Western Beskydy. The cluster of inferior provenances includes Rycerka 900 m, allochthonous Nowe Ramuki from northern Poland and high-altitude provenance Wytow 1,420 m from the Western Tatras. As shown in Fig. 1, the growth of provenances varies apparently between the plots situated at different altitudes.

Compared to the height growth, the ranking of provenances according to diameter and volume production is somewhat different. But changes in the classes of superior, average and inferior provenances are rather exceptional. Due to the good diameter growth, Rycerka 620 m, Istebna-Zapowiedź and Istebna-Buk were classified into the category of superior provenances while Orawa, 1,000 m and Rycerka 900 m belonged to the average ones. Relatively low heights of the latter two provenances compared to their diameter seem to be fixed genetically as a result of adaptation to high altitudes with more wind, snow and rime. On the contrary, poorer diameter growth ranked the lowland provenances Zwierzyniec and Miedzygorze 580 m from the Polish Sudetes into the category of inferior provenances.

INTERACTION PROVENANCE × ENVIRONMENT

The interactions analysed by the regression analysis based on mean heights are summarised in Table 4. These interactions were significant in the majority of provenances. All three expected situations were present:

1. A negative correlation between the mean height of provenance and height bonities at individual plots, indicating that the provenance in question grows better on less favorable sites, was detected in the provenances from higher altitudes: Červená Skala 1,100 m, Rycerka 950 m, Michalová 930 m, Stronie Slaskie 820 m, and also Stará Voda 700 m from northern slopes of the Slovak Ore Mountains. Several lowland provenances from Eastern and Northern Poland belong to this group as well.

Table 4. Summary results of variance analysis across 4 plots with all 30 provenances

Factor*	Degrees of freedom	Mean square		
		height	diameter	volume
Model	131	167.65356	86.33377	0.030485
Provenance	29	53.79163	21.140017	0.02607181
Plot	3	75,763.34672	1,664.381301	0.76692105
Plot (provenance)	87	14.28982	99.812371	0.00541465
Block (plot)	12	155.78369	131.903284	0.03880127
R square	Model	0.450	0.119	0.175

*All factors for all variables statistically significant at $P > 99\%$

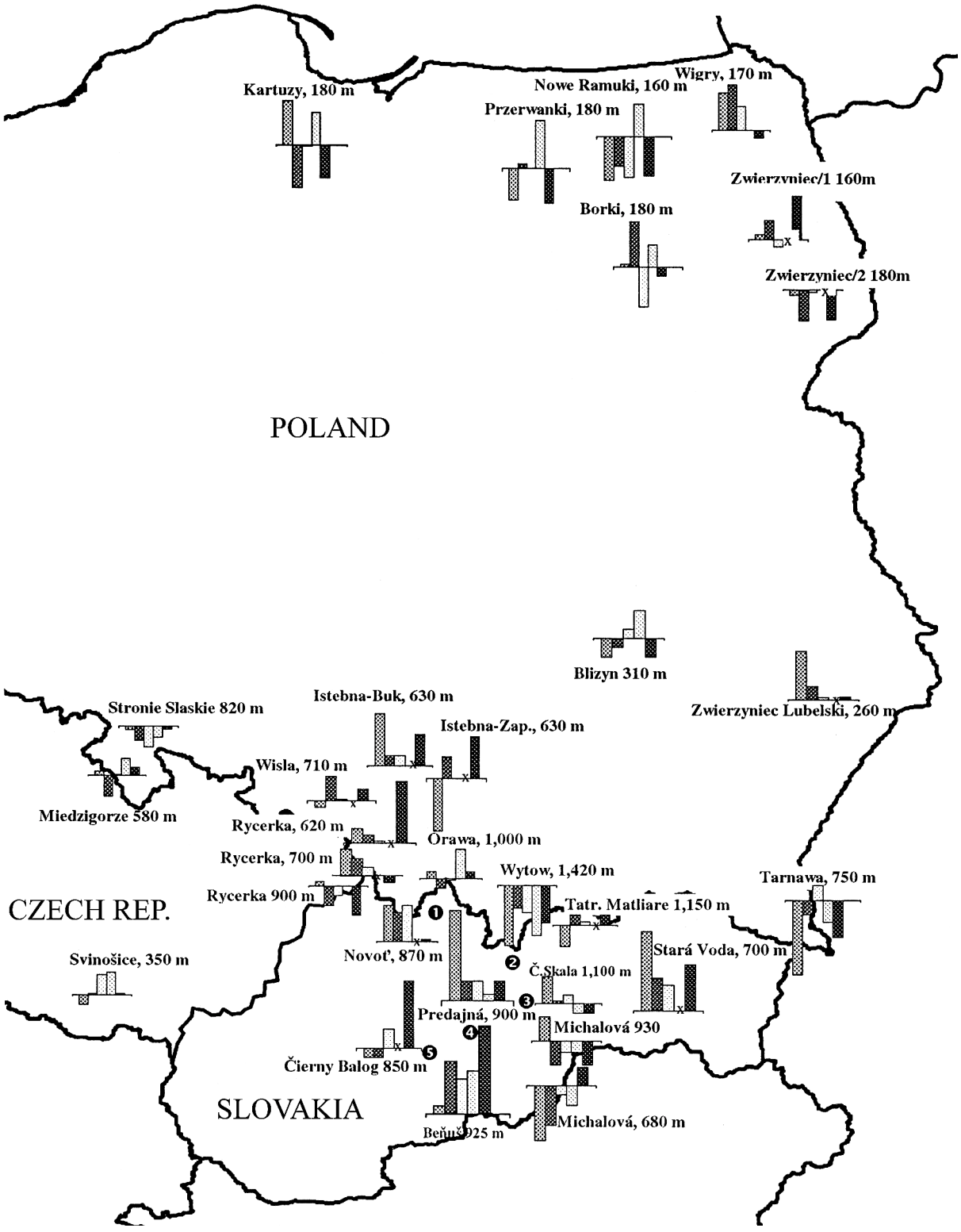

Fig. 1. Heights of provenances as a percentage of mean heights on individual provenance plots. Provenance plots are ranked according to their altitude: 1. Biely Váh 950 m >> 2. Zákamenné, 790 m >> 3. Kráľova hoľa, 700 m >> 4. Slovenská Ľupča, 510 m >> 5. Stráže, 335 m. Symbols ❶ ❷ ❸ ❹ ❺ indicate location of provenance plots. Symbol "x" in a bar chart indicates the absence of a provenance on incomplete plot Slovenská Ľupča

Table 5. Variance components across 4 provenance plots with all 30 provenances

	Variance components (%)		
	height	diameter	volume
Provenance	1.65	2.16	2.32
Plot	38.20	6.36	11.39
Plot (provenance)	2.11	0.81	1.26
Block (plot)	4.99	1.92	2.64
Error	53.05	88.78	82.39

2. A positive correlation indicating that the provenance adapts itself better to more productive sites with higher height class appeared to be typical of especially provenances from lower altitudes or southern part of the natural range of Norway spruce in the Western Carpathians. Provenances belonging to this group utilise longer vegetation and better soil more effectively, and tolerate occasional water deficits. But Rycerka 700 m from the Polish Western Beskydy and Stará Voda 700 m from the Slovak Ore Mts. seem to be exception of this trend.
3. There was no relationship between the mean height and site quality in the provenances Novoť 870 m, Predajná 900 m and Wytow 1,420 m. They are so called generalists. The above-average growth of the Slovak provenances Novoť and Predajná on a broad scale of

Table 6. Duncan's multiple range test for mean heights of provenances ($\alpha = 0.05$) and provenance × environment interactions across all provenance plots. The signs + and – indicate negative or positive values of regression coefficient

No.	Provenance	*N*	Duncan's grouping							Mean height	*Sx*%	Interaction prov. × environment	
23	Stará Voda	291				*A*				12.91	17.4	–	*
24	Predajná	234		*B*		*A*				12.78	18.1	insignificant	
21	Beňuš	311		*B*		*A*				12.76	21.8	+	**
22	Novoť	261		*B*		*C*				12.53	18.1	insignificant	
18	Zwierź. Lubelski	309		*B*		*C*		*D*		12.48	16.9	–	**
9	Wisla	291		*B*	*E*	*C*		*D*		12.46	18.4	+	**
12	Rycerka, 620 m	269		*B*	*E*	*C*		*D*		12.44	20.2	+	*
13	Červená Skala	285		*F*	*E*	*C*		*D*		12.39	18.4	–	**
3	Wigry	297		*F*	*E*	*C*		*D*		12.39	18.2	–	**
11	Istebna-Zap.	297		*F*	*E*	*C*		*D*		12.39	22.1	+	*
26	Svinošice	319		*F*	*E*	*C*		*D*		12.37	19.3	+	**
13	Rycerka, 700 m	270		*F*	*E*	*C*		*D*		12.35	17.6	–	**
30	Čierny Balog	302	*G*	*F*	*E*	*C*		*D*		12.32	21.1	+	**
10	Istebna-Bukow.	248	*G*	*F*	*E*	*C*		*D*		12.31	18.3	+	**
1	Zwierźyniec/1	318	*G*	*F*	*E*	*C*		*D*	*H*	12.26	20.0	+	*
25	Tatran. Matliare	282	*G*	*F*	*E*	*C*	*I*	*D*	*H*	12.21	19.2	+	**
							Mean						
28	Michalová, 930 m	306	*G*	*F*	*E*	*J*	*I*	*D*	*H*	12.13	17.8	–	**
19	Bliźyn	270	*G*	*F*	*E*	*J*	*I*	*K*	*H*	12.10	18.5	–	**
20	Kartuzy	351	*G*	*F*		*J*	*I*	*K*	*H*	12.08	17.1	–	*
4	Przerwanki	241	*G*	*F*		*J*	*I*	*K*	*H*	12.05	16.8	–	*
5	Borki	293	*G*	*F*		*J*	*I*	*K*	*H*	12.04	18.4	–	*
27	Michalová, 680 m	290	*G*			*J*	*I*	*K*	*H*	11.97	23.5	+	**
8	Stronie Slaskie	299				*J*	*I*	*K*	*H*	11.92	19.5	–	**
17	Tarnawa	287				*J*	*I*	*K*	*H*	11.91	22.1	+	**
2	Zwierźyniec/2	321	*L*			*J*		*K*		11.88	18.4	–	**
7	Miedzygorźe	270	*L*			*J*		*K*		11.83	20.9	+	**
15	Orava	229	*L*			*J*		*K*		11.81	19.5	–	*
14	Rycerka, 900 m	329	*L*					*K*		11.75	17.8	–	*
6	Nowe Ramuki	246	*L*							11.54	21.2	–	*
16	Wytow-Tatras	203					*M*			10.30	25.9	insignificant	

* and ** indicate that the coefficients of regression differ from 1 with probability $P > 95\%$ and $P > 99\%$

sites, ranks them to most valuable provenances of the whole experiment.

SURVIVAL AND DAMAGE

No thinning until the age of 26 years allowed to compare the survival rate of provenances. It ranged between 51 and 88% (Table 6). Statistically significant differences were observed between plots and provenances. The survival did not show any trend with regard to the geographic origin of provenances. High survival was typical, however, of many lowland provenances from northern Poland while the lowest one was observed in the timberline provenance Wytow. No correlation was found between the survival rate and mean height of provenances. The highest correlation coefficient (0.31) was calculated for the plot Kráľova hoľa with the highest volume production.

Visual damage was divided into 2 categories: 1. percentage of trees damaged by deer barking and 2. percentage of trees damaged by wind, rime and heavy snow. The proportion of damaged individuals across all plots was 37%, ranging from 4% in Stráž at the altitude of 330 m to 54% in Biely Váh at the highest altitude of 950 m (Table 8). Deer barking, the dominant damage, is positively correlated with the height growth ($R^2 = 0.81$) and volume production. Such correlation can be explained by its absence in poorly growing provenances with dense branching and slow stem clearing. The damage caused by abiotic factors including snow, wind and rime is positively correlated with the plot altitude.

Table 7. Duncan's multiple range test of mean diameters ($\alpha = 0.05$) across all provenance plots

Provenance	Duncan's grouping						Mean diameter	Standard deviation (%)
23 SK3 Stará Voda				*A*			14.40	24.3
24 SK2 Predajná				*A*			14.35	25.2
10 PLK Istebna-Buk.		*B*		*A*			14.29	24.3
13 PLK Rycerka, 700 m		*B*		*A*	*C*		14.06	24.2
22 SK5 Novoť		*B*	*D*	*A*	*C*		13.92	20.6
21 SK3 Beňuš		*B*	*D*	*A*	*C*		13.88	25.6
12 PLK Rycerka, 620 m	*E*	*B*	*D*	*A*	*C*		13.83	22.6
9 PLK Wisla	*E*	*B*	*D*	*F*	*C*		13.71	24.1
11 PLK Istebna-Zap.	*E*		*D*	*F*	*C*		13.67	28.6
7 PLH Miedzygorze	*E*	*G*	*D*	*F*	*C*		13.61	25.6
20 PLN Kartuzy	*E*	*G*	*D*	*F*	*C*		13.49	22.5
18 PLS Zwierz. Lubelski	*E*	*G*	*D*	*F*	*C*	*H*	13.46	21.9
15 PLK Orawa	*E*	*G*	*D*	*F*		*H*	13.35	26.1
			Mean					
19 PLS Blizyn	*E*	*G*		*F*	*I*	*H*	13.25	23.6
26 CZH Svinošice	*E*	*G*		*F*	*I*	*H*	13.25	23.9
29 SK2 Červená Skala	*E*	*G*		*F*	*I*	*H*	13.21	25.3
8 PLH Stronie Slaskie	*E*	*G*		*F*	*I*	*H*	13.20	25.1
30 SK3 Čierny Balog		*G*		*F*	*I*	*H*	13.18	26.3
14 PLK Rycerka, 950 m		*G*		*F*	*I*	*H*	13.17	22.9
5 PLN Borki		*G*		*F*	*I*	*H*	13.14	22.9
3 PLN Wigry		*G*		*F*	*I*	*H*	13.11	24.6
4 PLN Przerwanki		*G*		*F*	*I*	*H*	13.07	23.4
1 PLN Zwierzyniec/1		*G*		*F*	*I*	*H*	13.07	22.0
28 SK3 Michalová, 680 m		*G*		*F*	*I*	*H*	13.06	24.0
25 SK1 Tatran. Matliare		*G*			*I*	*H*	13.00	24.7
17 PLK Tarnawa		*G*			*I*	*H*	12.97	28.5
27 SK3 Michalová, 930 m				*J*	*I*	*H*	12.83	27.7
2 PLN Zwierzyniec/2				*J*	*I*		12.64	23.6
6 PLN Nowe Ramuki				*J*			12.30	27.3
16 PLK Wytow-Tatras					*K*		11.21	33.1

Table 8. Survival and damage of provenances across all provenance plots

No.	Provenance	Survival (%)	Healthy trees (%)	Damaged trees (%)	
				deer barking	abiotic agents
14	Rycerka, 900 m	82.25	65.96	33.13	0.91
2	Zwierźiniec, 180 m	80.25	58.88	39.25	1.87
26	Swinošice	80.00	65.56	34.17	0.28
1	Zwierźiniec, 160 m	79.50	58.49	40.57	0.94
21	Beňuš	79.00	66.58	32.91	0.51
20	Kartuzy	78.60	70.99	28.75	0.25
27	Michalová, 930 m	77.00	71.95	27.53	0.52
30	Čierny Balog	75.00	65.87	32.80	1.33
3	Wigry	74.25	66.33	30.64	3.03
11	Istebna-Bukowiec	74.25	66.67	32.66	0.67
28	Michalová, 680 m	74.00	74.59	24.32	1.08
8	Stronie Slaskie	73.40	69.48	29.43	1.09
23	Stará Voda	72.75	52.23	47.08	0.69
9	Wisla	72.50	68.28	31.03	0.69
15	Orawa	72.50	60.69	36.90	2.41
29	Červena Skala	72.00	70.56	28.61	0.83
25	Tatranské Matliare	70.50	64.54	35.46	0.00
7	Miedzigorźe	69.00	69.57	29.57	0.87
19	Blizyn	68.40	72.51	26.02	1.46
22	Novoť	68.22	64.17	35.83	0.00
5	Borki	68.00	67.06	32.35	0.59
13	Rycerka, 700 m	67.50	61.11	37.78	1.11
12	Rycerka, 620 m	66.75	59.55	40.07	0.75
17	Tarnava	66.00	73.64	24.55	1.82
6	Nove Ramuki	64.67	73.20	22.34	4.47
4	Przerwanki	64.40	78.88	18.94	2.17
18	Zwierźyniec Lubelski	62.00	56.77	42.58	0.65
10	Istebna-Zapovied	61.75	58.70	40.08	1.21
24	Predajná	58.44	58.94	40.30	0.76
16	Wytow	54.00	76.67	22.22	1.11

DISCUSSION AND CONCLUSIONS

The Slovak provenance plots belonging to the IUFRO experiment 1972 cover a broad scope of forest sites where Norway spruce is grown as a commercial species. Although the provenances included in the experiment do not represent all parts of the natural range of Norway spruce in Slovakia and Poland, each major provenance region is represented by several provenances.

Significant effects of the site, differentiation of provenances, and interactions between provenances and site quality, were proved by the variance analysis. All plots also showed a heterogeneity among blocks. The residual error, the highest from among the variance components, originates especially from the individual variance within provenances.

From the methodological point of view, mean heights were considered as the primary parameter of provenances with regard to the relatively low age of experimental plantations. Mean height depends only little on tree densities and shows smaller variation than diameter growth. These properties make it suitable also for routine assessments of yield quality of forest stands.

In the summary evaluation of the IUFRO 1972 experiment, MATRAS (1993) concluded about a superior growth especially of the provenance Zwierzyniec Lubelski, growing well on most European plots. It was surpassed only by the lowland provenance Borki in Finland and Canada. The provenances Wytow 1,450 m, Rycerka 950 m, Orawa 1,000 m and Stronie Slaskie 820 m lag behind the average, on the other hand. The lowland provenances from northern Poland performed better in Finland and Germany, while those from southern Poland in France and Belgium.

Only a small change over the groups of superior and inferior provenances was encountered on the Slovak provenance plots at the age of 5, 7, 10, 15 and 26 years. After the first measurement, the provenances Wigry, Istebna-Zapo-

wiedz and Zwierzyniec Lubelski were reported as excellent, while Wytow 1,420 m and Nowe Ramuki 160 m were inferior (HOLUBČÍK 1979, 1980a). At the age of 10 years, the group of well performing provenances was enlarged by Zwierzyniec 160 m and 180 m, Rycerka 620 m and Rycerka 700 m (ŠIMIAK, LAFFERS 1988). At the age of 15 years, the best Polish provenances included Zwierzyniec 160 m and 180 m, Rycerka 620 m, Rycerka 700 m and Istebna-Bukowiec.

The majority of Slovak provenances improved their growth at the age of 26 years. Many of them are fully comparable with the best provenances from Poland. In the plots situated in higher altitudes, the best ones are especially those from the Low Tatras and the Slovak part of Western Beskydy. In lower altitudes, they are replaced by provenances from the Low Tatras and Slovak Ore Mts. Provenance Predajná from Low Tatras, Novoť from Western Beskydy, Beňuš and Stará Voda from Slovak Ore Mts., grow very well at each of the plots. Predajná and Novoť revealed, in addition, only insignificant site × environment interaction. These findings correspond well with conclusions of GIERTYCH (1978) about a very good growth of the Western Carpathian provenances in the IUFRO experiment 1964–65. From among 70 Polish provenances which relative height exceeded the mean value of all 14 provenance plots by more than 25% at the age of 9–11 years, more than 20 provenances were from the Western Carpathians. At the age of 15–25 years, the Western Carpathian provenances belonged to the best ones, e.g., in the Swedish (PERSSON, PERSSON 1992), Norwegian (FOTTLAND, SKRØPPA 1989) and Irish (NIEUWENHUIS, ROSTAMI 1993) plots of the IUFRO experiment 1964–65.

The provenance experiments and marker-aided studies do not prove geographic trends but suggest ecotypic variation among the Carpathian and Eastern-Hercynic populations of Norway spruce. It may be contributed by the phylogeny more than assumed by SCHMIDT-VOGT (1977). Contrary to his conclusion about a single South-Carpathian glacial refuge, many studies from the Carpathian region prove refugial populations of Norway spruce also at the foothills of the Eastern Carpathians (POP 1929), Northern Hungary (ZÓLYOMI 1953), Southern Moravia and Slovakia (OPRAVIL 1978; KRIPPEL 1986).

With regard to the growth, survival and provenance × environment interactions, the provenances on the Slovak plots of the IUFRO 1972 experiment can be divided into 3 groups:

– Provenances from higher altitudes of the Western Carpathians and several provenances from Northern and Eastern Poland, which appear to be better adapted to colder and humid sites inside the natural range of Norway spruce.
– Many autochthonous provenances from the lower natural altitudinal limit of Norway spruce in the Slovak Ore Mts. and Western Beskydy Mts. adapt more successfully to warmer sites in lower altitudes with richer soils, on longer vegetation but also seasonal soil desiccation.
– The provenances Novoť 870 m, Predajná 900 m and Stará Voda 700 m, adapt well to a broad scope of sites. Especially the provenance Novoť 870 m proves a high quality of Norway spruce from North-western Slovakia, which is fully comparable with far better recognised provenances from the Polish part of the Western Beskydy Mts.

References

DIETRICHSON J., 1979. Norway spruce provenance trials in Nordic countries. Proc. of the IUFRO joint meeting of working parties on Norway spruce provenances and Norway spruce breeding. Lower Saxony Forest Research Institute, Echerode, Germany: 3–14.

FINLAY K.W., WILKINSON G.N., 1963. The analysis of adaptation of provenances in a plant-breeding programme. Austr. J. Agric. Res., *14*: 742–754.

FOTTLAND J., SKRØPPA T., 1989. The IUFRO 1964/68 provenance experiment with Norway spruce (*Picea abies*) in Norway. Variation in mortality and height growth. Meddelelser fra Norsk Institutt for Skogforskning Communications of the Norwegian Forest Research Institute*, 43*(1): 1–30.

GIERTYCH M., 1978. Plastyczność polskich ras świerka (*Picea abies* /L./ Karst.) w świetle międzynarodowego doświadczenia IUFRO z lat 1964–68. Arboretum Kornickie, *23*: 185–206.

GIERTYCH M., 1984. Report on the IUFRO 1938 and 1939 provenance experiments on Norway spruce (*Picea abies* /L./ Karst.). Kórnik, Polish Academy of Sciences: 179.

GÜNZL L., 1979. International IUFRO Norway spruce provenance experiments of 1938 and 1964/68 and additional Austrian provenance experiments. Proc. of the IUFRO joint meeting of working parties on Norway spruce provenances and Norway spruce breeding. Lower Saxony Forest Research Institute, Echerode, Germany: 51–56.

HOLUBČÍK M., 1968. Otázky premenlivosti a proveniencie smreka obyčajného (*Picea abies* Karst.) z hľadiska produkcie. In: Zvyšovanie prírastku lesov. Zvolen, VÚLH: 213–237.

HOLUBČÍK M., 1971. Dimensions of cones of Norway spruce (*Picea abies* Karst.) in Slovakia. Acta Inst. For. Zvolen., *XIII*: 77–119.

HOLUBČÍK M., 1979. Juvenilný rast poľských a domácich proveniencií smreka (*Picea abies* Karst.). Lesn. Čas., *25*: 255–270.

HOLUBČÍK M., 1980a. Vplyv prostredia na výškový rast domácich a poľských proveniencií smreka obyčajného (*Picea abies* Karst.). Folia Dendrol., *7*: 5–35.

HOLUBČÍK M., 1980b. Provenienčný výskum smreka obyčajného (*Picea abies* L.) a jeho využitie v praxi. Lesn. Štúd., *33*. Bratislava, Príroda: 94.

HOLUBČÍK M., 1982. Vzrast a kvalita proveniencií smreka obyčajného (*Picea abies* KARST.) v jeho optime na Slovensku. Folia Dendrol., *9*: 15–43.

HOLUBČÍK M., 1984. Wachstum und Qualität von Provenienzen der Gemeinen Fichte (*Picea abies* KARST.) in trockeneren und wärmeren Regionen der Slowakei. Folia Dendrol., *11*: 263–287.

HOLZER K., NATHER J., 1974. Die Identifizierung von Fortlichem Vermehrungsgut. In: 100 Jahre Forstliche Bundesversuchsanstalt Wien. Forstliche Bundesversuchsanstalt Wien: 13–42.

KRIPPEL E., 1986. Postglaciálny vývoj vegetácie Slovenska. Bratislava, Veda: 307.

LAGERCRANTZ U., RYMAN N., 1990. Genetic structure of Norway spruce (*Picea abies*). Evolution, *44*(1): 38–53.

LINES R., 1979. Results of the IUFRO 1964/68 experiments with *Picea abies* in Scotland after 11 years. Proc. of the IUFRO joint meeting of working parties on Norway spruce provenances and Norway spruce breeding. Lower Saxony Forest Research Institute, Escherode, Germany: 41–50.

MATRAS J., 1993. Growth of Norway spruce in IUFRO 1972 experiment. Norway spruce provenances and breeding. Proc. of the IUFRO S 2.2.11 symposium Latvia 1993. Riga 1993: 100–104.

NIEUWENHUIS M., ROSTAMI T., 1993. The IUFRO Norway spruce provenance trial in Ireland – an update. Norway spruce provenances and breeding. Proc. of the IUFRO S 2.2.11 symposium Latvia 1993. Riga 1993: 113–118.

OPRAVIL E., 1978. Smrk (*Picea* DIETR.) v československém kvartéru. Čas. Slez. Muz., Serie C, *27*(2): 97–123.

PAULE L., 1986. Strategy of choice of Norway spruce provenances for high altitudes. In: Franz Kempe Symposium, Umea: 33–55.

PERSSON B., PERSSON A., 1992. Survival, growth and quality of Norway spruce (*Picea abies* (L.) Karst.) provenances at the three Swedish sites of the IUFRO 1964/68 provenance experiment. Sveriges Lantbruksuniversitet Skogsvetenskapliga fakulten Garpenberg Department of Forest Yield Research. Report No. 29: 67.

POP E., 1929. Pollenanalyse einiger Moore der Ostkarpaten (Dorna-Lucina). Bull. Grad. bot. si. al. Muz. bot. de la Univ. diu Cluj, *9*: 3–4.

SCHMIDT-VOGT H., 1977. Die Fichte. Hamburg, Paul Parey Verlag: 647.

ŠIMIAK M., 1985. Hodnotenie provenienčných pokusov smreka 1964/68 vo veku 20 rokov, IUFRO 1972 vo veku 10 rokov. [Záverečná správa.] Zvolen, VÚLH: 117.

ŠIMIAK M., LAFFERS A., 1988. Hodnotenie proveniencií smreka a jedle. [Záverečná správa.] Zvolen, VÚLH: 105.

SPERISEN C., BÜCHLER U., MÁTYÁS G., 2001. Genetic variation of mitochondrial DNA reveals subdivision of Norway spruce (*Picea abies* (L.) Karst.). Proc. of the IUFRO Norway Spruce Symposium: Norway Spruce Provenances and Breeding. Slovakia, Stará Lesná 1997. Zvolen, Arbora Publishers (in print).

VAN DE SYPE H., 2001. Geographic structure of adaptive traits in the IUFRO 1964/68 experiment. Proc. of the IUFRO Norway Spruce Symposium: Norway Spruce Provenances and Breeding. Slovakia, Stará Lesná 1997. Zvolen, Arbora Publishers (in print).

ZÓLYOMI B., 1953. Die Entwicklungsgeschichte der Vegetation Ungarns seit dem letzten Interglazial. Acta Biol. Acad. Sci. Hungaricae, *4*: 367–430.

Received 16 July 2001

Vplyv nadmorskej výšky stanovišťa na rast proveniencií smreka obyčajného (*Picea abies* L.) na slovenských plochách experimentu IUFRO 1972

M. PACALAJ[1], R. LONGAUER[1], D. KRAJMEROVÁ[1], D. GÖMÖRY[2]

[1]*Lesnícky výskumný ústav, Zvolen, Slovenská republika*

[2]*Technická univerzita, Lesnícka fakulta, Zvolen, Slovenská republika*

ABSTRAKT: V práci sa hodnotí rast, prežívanie a interakcia proveniencia × prostredie 30 poľských, slovenských a českých proveniencií smreka obyčajného (*Picea abies* L.) vo veku 26 rokov. Na sérii piatich plôch sa zistil významný vplyv nadmorskej výšky a kvality stanovišťa. Nepotvrdila sa však korelácia medzi rastom a geografickým pôvodom proveniencií. Najvyššia diferenciácia proveniencií sa zistila na plochách v najnižšej a najvyššej nadmorskej výške (350 a 950 m n.m.). Niekoľko slovenských proveniencií sa vyznačovalo nadpriemerným rastom a nevýznamnou interakciou proveniencia × prostredie. Na plochách v nižších nadmorských výškach sa dlhšiemu vegetačnému obdobiu a sezónnemu vlahovému deficitu veľmi dobre prispôsobilo viacero autochtónnych proveniencií z južnej časti areálu smreka v Západných Karpatoch.

Kľúčové slová: provenienčný výskum; smrek obyčajný; pokus IUFRO 1972; rast; prežívanie; interakcie proveniencia × prostredie

Smrek obyčajný (*Picea abies* L.) patrí k drevinám s najväčším areálom. Veľká rozmanitosť podmienok, v ktorých sa prirodzene vyskytuje, viedla najmä v horských oblastiach k vytvoreniu fyziologicky a morfologicky diferencovaných populácií.

Hlavným cieľom medzinárodného provenienčného pokusu IUFRO 1972 je hodnotenie adaptability poľských proveniencií smreka. Na piatich slovenských plochách pokusu sa rast 20 poľských proveniencií porovnáva s deviatimi slovenskými a jednou provenienciou z Česko-

moravskej vrchoviny. Umiestnenie plôch do nadmorskej výšky od 330 m po 950 m umožňuje vyhodnotiť adaptabilitu týchto proveniencií v širokom spektre stanovištných podmienok. Plochy boli založené v blokovej schéme po 5 × 5 sadeníc na provenienciu, spone 2 × 2 m a štvornásobnom opakovaní. Do veku 26 rokov na nich nebol uskutočnený prebierkový zásah.

V práci je vyhodnotený rast, prežívanie a poškodenie proveniencií. Pri výškovom raste sa regresnou analýzou založenou na porovnaní priemerných výšok proveniencií a výškovej bonity každej z plôch vyhodnotili aj interakcie proveniencia × prostredie.

Pri hodnotení série plôch sa nepreukázala štatisticky významná korelácia medzi výškovým rastom a prežívaním, resp. geografickým pôvodom proveniencií. Najvyššia medziprovenienčná a vnútroprovenienčná diferenciácia sa zistila na plochách v najväčšej a najmenšej nadmorskej výške. Tento jav jednoznačne nabáda k opatrnosti pri výbere reprodukčného materiálu smreka na extrémnejších typoch stanovíšť.

Z poľských proveniencií rastom vynikli pahorkatinné, resp. nížinné proveniencie Zwierzyniec Lubelski 260 m n. m., Wigry 170 m n. m., no len niektoré západobeskydské proveniencie. Vo veku 26 rokov väčšina proveniencií zo Slovenska zlepšila svoj rast v porovnaní s predošlými hodnoteniami. Poľským sa buď vyrovnávajú, alebo ich prevyšujú. Na provenienčnej ploche v najväčšej nadmorskej výške sa nadpriemerným rastom vyznačovala proveniencia Stará Voda 700 m n. m. zo Slovenského rudohoria, Novoť 870 m n. m. zo Západných Beskýd a dve proveniencie z vyšších polôh Nízkych Tatier (Predajná 900 m a Červená Skala 1 100 m). V nižších polohách to boli opäť Stará Voda a Novoť. Okrem nich Čierny Balog 850 m n. m. a Beňuš 925 m n. m. zo Slovenského rudohoria.

Proveniencie lepšie prispôsobené stanovištiam s chladnejšou a vlhkejšou klímou pochádzajú spravidla z vyšších nadmorských výšok Západných Beskýd a Nízkych Tatier. Okrem toho sem patria niektoré proveniencie z východného a severovýchodného Poľska. Proveniencie, ktoré na nižšie položených plochách dokážu využiť lepšie stanovištné podmienky a znášať prípadný vlahový deficit, pochádzajú najmä zo spodnej hranice a južnej časti prirodzeného areálu smreka v Západných Karpatoch. Výborný a vyrovnaný rast slovenských proveniencií Novoť 870 m, Predajná 900 m a Stará Voda 700 m potvrdil kvalitu slovenských proveniencií v porovnaní s najlepšími poľskými provenienciami.

Corresponding author:

Ing. ROMAN LONGAUER, CSc., Lesnícky výskumný ústav, T. G. Masaryka 22, 960 92 Zvolen, Slovenská republika
tel.: + 421 45 531 43 27, fax: + 421 45 532 18 83, e-mail: roman.longauer@fris.sk