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Influence of provenance transfer on the growth and survival of *Picea abies* provenances

Abstract: Two provenance experiments with Norway spruce in Slovakia were used to reveal trends in the behaviour of provenances after their transfer. Regressions between the average height and survival of provenances and the differences between the geographic and selected climatic characteristics of the place of origin and provenance plots were significant for most of the characteristics tested. Data from the experiment with Polish and Slovak provenances from 1972 indicated that transfer into warmer regions with a longer vegetation period results in improved height growth and survival, with the exception of survival at initial stages. The experiment from 1964 with a broader altitudinal range of provenance plots, but with unadjusted latest measurements at individual plots available, revealed the best height growth of Slovak Norway spruce provenances after their transfer to sites with the mean annual temperature approximately 1°C higher and with the vegetation period 12 days longer than at places of origin. Transfer into lower altitudes, a warmer climate and a longer vegetation period improved survival. In both experiments, transfer to areas with increased rainfall had a negative effect on growth, which is probably associated with the fact that provenances are not able to exploit additional precipitation for the growth in areas with a colder climate and a shorter vegetation period.

Additional key words: breeding, global warming, adaptation

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Introduction

Provenance experiments were primarily aimed at identifying the best-producing populations for reforestation but they have been shown as a material suitable for many various purposes other than one originally intended, such as constructing yield tables and growth models, studies on evolution, reproductive biology and taxonomy, wood and timber properties, etc. (Lindgren and Person 1995). As provenance experiments are planted simultaneously at several different locations, they provide information on the adaptability of forest trees to diverse environmental conditions, and their long-lasting nature allows predictions of the global changes effects on forest trees (Beuker 1994a, b; Schmidtling 1994; Liesebach 2002).

There are two provenance experiments with Norway spruce established in Slovakia. The first, established in 1968, includes 50 provenances from the IUFRO 1964/68 test planted on 3 plots, and additional 18 Slovak provenances planted on 5 provenance plots, covering the altitudinal range from 400 to 1250 m. The other experiment is a part of the IUFRO 1972 test and besides 20 Polish provenances it includes 10 Slovak provenances and 1 Moravian provenance on 5 experimental plots from 330 m in Central Slovakia to 950 m altitude in Northern Slovakia. The most comprehensive study of the 1964/68 experiment was published by Holubčík (1980). Later, the evaluations of both experiments were done by Šimiak (1985, 1993) and Šimiak and

Lafférs (1988), and the evaluation of IUFRO 1972 was performed by Pacalaj et al. (2002).

The aim of this study is to use data on the growth and survival of some Norway spruce provenances from Slovak provenance plots to reveal trends in their behaviour after transfer, and possibly to predict provenance response to environmental changes.

Material and methods

Data from 10 trial plots of Norway spruce provenances in Slovakia were used in the study (Table 1). Five plots of IUFRO 1972 have been planted in a random complete block design with 4 blocks, each block with 5 × 5 individuals per provenance at a spacing 2 × 2 m. No thinning was applied until the last measurement at the age of 27 years. A similar experimental design was used on five plots of 1964 experiment, but 7 × 7 individuals were planted in each block. From the experiment of 1964, only 15 Slovak provenances were used in the regression analysis. For technical reasons, measurements on the plots of 1964 experiment were not done in the same growing seasons, so the data are slightly distorted in this respect.

Climatic data for Slovak provenances and provenance plots were obtained from the climatic model of the Slovak Republic which was constructed at the Forest Research Institute in Zvolen. For Polish and Moravian provenances, climatic data were obtained from climatic atlases of the respective countries.

The data of the assessments in 2004–2005 (not adjusted to the same age for all of the plots) for the 1964 experiment, and the data of 1978, 1981, 1986, 1996 and 1999 for the IUFRO 1972 trial were subjected to regression analysis. The significance of both linear and quadratic regressions was tested. Mean height (H), breast height diameter (d.b.h.; D) and survival (P) were dependent variables, and the differences in geographical coordinates and/or climatic characteristics between the experimental plots and the places of origin were taken as independent variables. The geographic variables were longitude (LONG), latitude (LAT) and altitude (ALT), and the climatic variables for both experiments were mean annual temperature (T_Y), mean temperature of July (T_JUL), annual precipitation (P_Y), precipitation from April to September (P_VEG), and the number of days with temperature above 5°C (VEG). For the 1964 experiment, also differences in the mean temperature and precipitation during the vegetation period (April to September), and the number of days with temperature above 0°C and 10°C were used.

Results

Experiment 1964

Regression analysis revealed that the survival of Slovak provenances from the 1964 experiment is higher when provenances are transferred southward, to lower altitudes, into warmer regions with a longer vegetation period, but mortality increases at localities with lower precipitation (Table 4). As regards height growth, the results are summarised in Table 5. According to these, Slovak provenances grow best at lo-

Table 1. Basic data on Norway spruce provenance trial plots

Experiment 1972	Biely Váh Klobušová	Zákamenné Paráč	Bujakovo Kráľova hoľa	Stráže near Zvolen	Slovenská Ľupča Kmeťová
Longitude E.G.	20°20’	19°14’	19°42’	19°07’	19°13’
Latitude N.E.	48°59’	49°27’	48°50’	48°35’	48°40’
Altitude (m)	950	790	700	335	510
Aspect	Northwest	Northeast	Plain	West	East
Mean annual temperature (°C)	4.7	4.6	6.2	7.9	7.1
Precipitation (mm)	824	1049	800	720	862
Vegetation period (days)	178	180	200	223	210
Experiment 1964/68	Zakamenné Mútne	Biely Váh Luxová	Beňuš Zelenô	Beňuš Bujakovo	Veľký Lom Lešť
Longitude E.G.	19°17’	19°56’	19°47’	19°42’	19°19’
Latitude N.E.	49°31’	49°02’	48°49’	48°50’	48°19’
Altitude (m)	1480	1020	760	610	480
Aspect	South	Southeast	Northwest	East	Plain
Mean annual temperature (°C)	1.7	4.3	5.5	6.2	7.7
Precipitation (mm)	1386	889	917	800	726
Vegetation period (days)	132	171	191	200	219

calities that are 202 m lower than their place of origin and 0.3 degree of latitude to the south of it. The best heights can be reached when the material is transferred into regions with July temperature 1.3°C higher, mean annual temperature 0.9°C higher, and temperature during the vegetation period 1.2°C higher than that of the place of origin. An increase in the number of days with temperature above 0°C by 8.4 days, with temperature above 5°C by 9.5 days, and above 10°C by 19.9 days resulted in best heights. Surprisingly, the best heights of provenances could be reached when transferred to locations with July precipitation 22.8 mm lower, precipitation in period April–September 108.5 mm lower, and annual precipitation 120.5 mm lower than at the place of origin. The paradox that provenances grow better at drier locations is probably associated with the fact that spruce can use higher temperature and longer vegetation periods for growth.

The data on d.b.h., summarised in Table 6, showed different trends. According to regression equations, maximum values of d.b.h. would be obtained on plots with shorter vegetation periods by 3.6 to 7.8 days and with almost no changes in temperature, as shown in the last column of Table 6.

Experiment 1972

Significant regressions for height and breast height diameter in the 1972 experiment are presented in Table 7. The only significant regression in 1978 was the regression for height and difference in altitude. This regression indicates that the best height growth of

Table 2. Geographic coordinates and climatic characteristics of provenances in IUFRO 1972 Norway spruce provenance trial

Prov. No.	Provenance	Country	Altitude (m)	Latitude	Longitude	Mean temperature (°C)		Mean precipitation (mm)		Vegetation period (days)
						annual	July	annual	veg. period	
1	Zwierzyniec Pogorzelec	PL	160	52°48’	23°47’	6.9	17.3	575	420	213
2	Zwierzyniec Krzyże	PL	180	52°42’	23°46’	6.7	17.3	575	420	213
3	Wigry	PL	170	54°03’	23°03’	6.3	16.6	595	425	203
4	Przerwanki	PL	180	54°10’	22°05’	6.7	16.6	585	420	204
5	Borki	PL	180	54°06’	22°04’	6.7	16.6	585	420	204
6	Nove Ramuki	PL	160	53°41’	20°34’	7.15	17.1	635	425	211
7	Międzygórze	PL	580	50°13’	16°45’	6.75	15.5	725	485	206
8	Stronie Śląskie	PL	820	50°14’	16°50’	6.75	15.5	725	485	206
9	Wisła	PL	710	49°38’	18°58’	6.9	15.8	1000	750	188
10	Istebna Bukowiec	PL	630	49°38’	18°53’	7.0	15.8	1000	750	188
11	Istebna Zapowiedź	PL	600	49°34’	18°57’	7.0	15.8	1000	750	188
12	Rycerka Zwardoń	PL	620	49°31’	19°01’	7.0	15.7	925	750	188
13	Rycerka Praszywka 700	PL	700	49°29’	19°00’	6.9	15.7	925	750	188
14	Rycerka Praszywka 950	PL	950	49°29’	19°00’	6.5	15.7	925	800	188
15	Orawa	PL	1050	49°34’	19°33’	6.3	15.8	1050	750	193
16	Witów	PL	1420	49°13’	19°48’	5.5	14.8	1100	800	166
17	Tarnawa	PL	750	49°04’	22°52’	6.5	16.0	850	750	188
18	Zwierzyniec Lubelski	PL	260	50°34’	22°58’	7.3	17.3	575	435	219
19	Bliżyn	PL	310	51°04’	20°41’	7.3	16.7	625	440	212
20	Kartuzy	PL	200	54°23’	18°08’	7.45	17.0	620	415	215
21	Beňuš	SK	925	48°50’	19°56’	4.9	14.3	866	524	186
22	Novoť, Beskydy	SK	870	49°25’	19°07’	4.4	13.9	1137	653	176
23	Stará Voda	SK	700	48°46’	20°42’	5.2	15.0	929	576	188
24	Predajná	SK	900	48°53’	19°41’	4.9	14.4	931	535	173
25	Tatranské Matliare, 1193c	SK	1150	49°10’	20°20’	4.0	13.2	1003	667	170
26	Svinošice, 17b2	CZ	350	49°20’	16°30’	8.0	*	570	360	*
27	Michalová 1, 102m	SK	930	48°47’	19°47’	5.0	14.3	980	578	186
28	Michalová 2, 106a	SK	680	48°43’	19°47’	6.0	15.3	868	522	200
29	Červená Skala	SK	1100	48°50’	20°14’	4.3	13.7	975	581	175
30	Čierny Balog (Krám)	SK	850	48°42’	19°39’	5.5	14.7	923	537	191
31	Lasce (Moštenica)	SK	650	48°48’	19°14’	6.4	16.0	976	518	202

* data not available

Table 3. Geographic coordinates and climatic characteristics of Slovak provenances in 1964 Norway spruce provenance trial

Prov. No.	Provenance	Altitude (m)	Latitude	Longitude	Mean temperature (°C)			Mean precipitation (mm)			No. of days above		
					annual	July	veg. period	annual	July	veg. period	0°C	5°C	10°C
1	Smolnícka Huta 8c1	800	48°46’	20°46’	6.0	15.8	12.2	890	110	545	255	194	131
2	TANAP 219f3	920	49°17’	20°17’	4.5	13.7	10.2	1148	144	770	245	180	105
3	TANAP 514a2	800	49°10’	20°18’	5.5	15.1	11.6	747	106	501	255	193	131
4	TANAP 364d	925	49°14’	20°14’	4.8	14.3	10.8	1032	140	659	250	186	113
5	Habovka 49b	1000	49°15’	19°41’	3.7	12.2	9.0	1199	151	753	233	163	87
6	Habovka 208a	900	49°19’	19°19’	4.3	13.1	9.7	1051	143	691	240	169	98
7	Červená Skala 60c4	1000	48°52’	20°52’	4.5	14.0	10.4	898	100	557	240	178	112
8	Červená Skala 102d	920	48°49’	20°49’	5.0	14.6	11.2	923	106	553	250	191	122
9	Beňuš	700	48°50’	19°50’	5.7	15.3	11.8	852	97	509	258	199	132
10	Čierny Váh 34c	800	48°54’	20°54’	5.5	15.5	11.9	754	105	496	253	190	122
11	Čierny Váh 86b	950	48°54’	20°45’	5.3	15.2	11.6	783	105	510	247	184	118
12	Červená Skala 51c	1000	48°54’	20°12’	4.5	13.9	10.4	906	99	566	237	176	110
13	TANAP	1450	49°11’	20°15’	2.9	11.8	8.4	1154	129	757	224	154	43
14	Poprad	950	48°58’	20°58’	4.7	14.3	10.8	729	90	453	244	184	115
15	Liptovský Mikuláš	960	49°09’	19°57’	4.6	13.9	10.4	940	124	574	243	179	114

Table 4. Results of regression analyses between survival of provenances and differences in altitude, geographic coordinates, precipitation, and temperature characteristics of provenance plots and places of origin

Regression	P	r^2	Equation
Survival × difference in altitude	0.01	0.288	$y = 50.304 - 0.0183x$
Survival × difference in latitude	0.01	0.338	$y = 48.844 - 17.555x$
Survival × difference in longitude			nonsignificant
Survival × difference in mean temperature of July	0.01	0.336	$y = 49.815 + 2.8399x$
Survival × difference in mean temp. of veg. period	0.01	0.329	$y = 50.074 + 2.8397x$
Survival × difference in mean annual temperature	0.01	0.339	$y = 50.189 + 3.5171x$
Survival × difference in No. of days above 0°C	0.01	0.325	$y = 50.733 + 0.2554x$
Survival × difference in No. of days above 5°C	0.01	0.306	$y = 51.118 + 0.2274x$
Survival × difference in No. of days above 10°C	0.01	0.277	$y = 51.096 + 0.1534x$
Survival × difference in precipitation of July	0.01	0.250	$y = 49.619 - 0.1828x$
Survival × difference in precipitation of veg. period	0.01	0.264	$y = 51.536 - 0.0251x$
Survival × difference in annual precipitation	0.01	0.274	$y = 49.451 - 0.0409x$

Table 5. Results of regression analyses between heights of provenances and differences in altitude, geographic coordinates, precipitation, and temperature characteristics of provenance plots and places of origin

Regression	P	r^2	Equation	x_{max}*
Height × difference in altitude	0.01	0.632	$y = 2001.84 - 30.483x - 0.001x^2$	–202.6
Height × difference in latitude	0.01	0.574	$y = 1987.129 - 544.809x - 1055.379x^2$	–0.3
Height × difference in longitude	0.01	0.167	$y = 2096.9 + 392.95x$	
Height × difference in mean temperature of July	0.01	0.632	$y = 2020.117 + 72.943x - 27.861x^2$	1.3
Height × difference in mean temp. of veg. period	0.01	0.655	$y = 2033.385 + 69.056x - 29.366x^2$	1.2
Height × difference in mean annual temperature	0.01	0.695	$y = 2052.863 + 80.678x - 46.882x^2$	0.9
Height × difference in No. of days above 0°C	0.01	0.730	$y = 2085.123 + 4.73x - 0.281x^2$	8.4
Height × difference in No. of days above 5°C	0.01	0.672	$y = 2054.042 + 3.837x - 0.202x^2$	9.5
Height × difference in No. of days above 10°C	0.01	0.633	$y = 2005.212 + 3.16x - 0.079x^2$	19.9
Height × difference in precipitation of July	0.01	0.557	$y = 1957.916 - 5.274x - 0.116x^2$	–22.8
Height × difference in precipitation of veg. period	0.01	0.537	$y = 1988.354 - 0.414x - 0.002x^2$	–108.5
Height × difference in annual precipitation	0.01	0.510	$y = 1943.15 - 1.196x - 0.005x^2$	–120.5

*point where the equation reaches maximum

Table 6. Results of regression analyses between d.b.h. of provenances and differences in altitude, geographic coordinates, precipitation, and temperature characteristics of provenance plots and places of origin

Regression	P	r^2	Equation	x_{max}*
D.b.h. × difference in altitude	0.01	0.444	$y = 202.295 + 0.002x - 0.00007x^2$	16.1
D.b.h. × difference in latitude	0.05	0.316	$y = 202.209 - 8.992x - 59.65x^2$	–0.1
D.b.h. × difference in longitude			nonsignificant	
D.b.h. × difference in mean temp. of July	0.01	0.389	$y = 203.286 - 0.039x - 1.635x^2$	0.0
D.b.h. × difference in mean temp. of veg. period	0.01	0.395	$y = 203.893 - 0.325x - 1.749x^2$	–0.1
D.b.h. × difference in mean annual temperature	0.01	0.433	$y = 205.084 - 0.695x - 2.833x^2$	–0.1
D.b.h. × difference in No. of days above 0°C	0.01	0.398	$y = 206.383 - 0.125x - 0.017x^2$	–3.6
D.b.h. × difference in No. of days above 5°C	0.01	0.366	$y = 203.806 - 0.14x - 0.012x^2$	–5.7
D.b.h. × difference in No. of days above 10°C	0.01	0.419	$y = 200.843 - 0.075x - 0.005x^2$	–7.8
D.b.h. × difference in precipitation of July	0.05	0.144	$y = 199.138 - 0.041x - 0.006x^2$	–3.2
D.b.h. × difference in precipitation of veg. period	0.05	0.189	$y = 207.22 + 0.025x$	
D.b.h. × difference in annual precipitation	0.05	0.209	$y = 208.52 + 0.024x$	

* point where the equation reaches maximum

Table 7. Significant regressions between height (H) and d.b.h. (D) in different years and differences in geographic and climatic characteristics of test plots and places of origin

Dependent variable	Independent variable	P	r^2	Equation	x_{max}*
H81	LAT	0.05	0.0693	$y = 101.0428 - 13.4543x - 2.2163x^2$	–3.04
H86	LAT	0.05	0.0575	$y = 3.4845 - 0.3613x - 0.0599x^2$	–3.01
D86	LAT	0.05	0.0392	$y = 3.8528 - 0.3552x - 0.0619x^2$	–2.87
H81	LONG	0.01	0.0505	$y = 105.8228 - 3.2287x$	
H78	ALT	0.05	0.0470	$y = 36.8345 + 0.0017x - 0.000008x^2$	107.51
H81	ALT	0.01	0.0547	$y = 107.6051 - 0.0161x$	
H86	ALT	0.05	0.1040	$y = 3.7825 - 0.0006x - 0.000001x^2$	–354.55
H99	ALT	0.05	0.1101	$y = 12.1446 - 0.0012x - 0.000001x^2$	–404.19
D86	ALT	0.01	0.1124	$y = 4.176 - 0.0006x - 0.000001x^2$	–281.58
D96	ALT	0.05	0.0560	$y = 11.4425 - 0.0002x - 0.000001x^2$	–80.70
D99	ALT	0.01	0.0926	$y = 13.4231 + 0.0002x - 0.000002x^2$	49.86
H81	T_Y	0.01	0.3645	$y = 109.8497 + 9.8135x$	
H86	T_Y	0.05	0.4139	$y = 3.8384^2 + 0.2957x - 0.0392x^2$	3.78
H99	T_Y	0.01	0.3147	$y = 12.037 + 0.5191x$	
D86	T_Y	0.01	0.3129	$y = 4.0741 + 0.3015x$	
D96	T_Y	0.05	0.0455	$y = 11.3145 + 0.1101x$	
H81	T_JUL	0.01	0.3323	$y = 105.7939 + 8.5457x$	
H86	T_JUL	0.01	0.3763	$y = 3.5979 + 0.2651x$	
H99	T_JUL	0.01	0.3026	$y = 11.829 + 0.4647x$	
D86	T_JUL	0.01	0.3137	$y = 3.9399 + 0.2747x$	
D96	T_JUL	0.05	0.0500	$y = 11.2708 + 0.1049x$	
H81	P_Y	0.05	0.0470	$y = 108.3335 - 0.0274x$	
H86	P_Y	0.05	0.0384	$y = 3.6773 - 0.0007x$	
H99	P_Y	0.05	0.0322	$y = 11.953 - 0.0013x$	
D86	P_Y	0.05	0.0292	$y = 4.0245 - 0.0007x$	
H81	P_VEG	0.05	0.0294	$y = 105.2585 - 0.0302x$	
H86	P_VEG	0.05	0.0538	$y = 3.6788 - 0.0018x - 0.000005x^2$	–169.16
D99	P_VEG	0.05	0.0439	$y = 13.3209 - 0.0008x - 0.000009x^2$	–47.74
H81	VEG	0.01	0.3017	$y = 105.2517 + 0.6623x$	
H86	VEG	0.05	0.3506	$y = 3.6797 + 0.0221x - 0.0002x^2$	56.08
H99	VEG	0.01	0.2997	$y = 11.7943 + 0.0376x$	
D86	VEG	0.05	0.3139	$y = 4.0408 + 0.0238x - 0.0002x^2$	49.51
D96	VEG	0.05	0.0477	$y = 11.2594 + 0.0083x$	
D99	VEG	0.05	0.0355	$y = 13.3098 + 0.005x - 0.0004x^2$	6.24

* point where the equation reaches maximum

Table 8. Significant regressions between survival (P) in different years and differences in geographic and climatic characteristics of test plots and places of origin

Dependent variable	Independent variable	P	r^2	Equation	x_{min}*
P78	LONG	0.05	0.0329	$y = 91.9128 - 0.1806x + 0.3188x^2$	–0.28
P81	LONG	0.05	0.0614	$y = 77.6198 - 0.4399x + 0.5409x^2$	0.41
P86	LONG	0.05	0.0569	$y = 67.7953 - 0.3901x + 0.6237x^2$	0.31
P96	LONG	0.05	0.1004	$y = 59.3395 - 0.7242x + 0.7687x^2$	0.47
P78	ALT	0.05	0.0389	$y = 93.0911 + 0.0044x$	
P78	T_Y	0.01	0.0802	$y = 92.7423 - 1.4875x$	
P81	T_Y	0.05	0.0290	$y = 80.3326 + 1.4361x$	
P86	T_Y	0.01	0.0631	$y = 71.0301 + 2.4412x$	
P96	T_Y	0.01	0.0845	$y = 64.5116 + 2.7436x$	
P99	T_Y	0.01	0.0602	$y = 64.8574 + 2.3761x$	
P78	T_JUL	0.01	0.1086	$y = 93.1543 - 1.5935x$	
P86	T_JUL	0.05	0.0410	$y = 69.7408 + 1.7966x$	
P96	T_JUL	0.05	0.0546	$y = 63.0365 + 1.981x$	
P99	T_JUL	0.05	0.0460	$y = 63.5832 + 1.8818x$	
P78	P_Y	0.01	0.1179	$y = 92.735 + 0.014x$	
P81	P_Y	0.01	0.0639	$y = 79.6163 + 0.0166x$	
P78	P_VEG	0.01	0.1118	$y = 94.5949 + 0.019x$	
P81	P_VEG	0.01	0.0569	$y = 81.7586 + 0.0218x$	
P78	VEG	0.01	0.2021	$y = 95.2036 - 0.1102x - 0.0038x^2$	x_{max}** = –14.5
P96	VEG	0.05	0.0529	$y = 62.8227 + 0.1579x$	
P99	VEG	0.05	0.0326	$y = 63.5183 + 0.1289x$	

*point where the equation reaches minimum
**point where the equation reaches maximum

provenances at this stage was obtained when they were transferred to altitudes about 107 m higher (this is due to the fact that lowland Polish provenances showed excellent growth at nursery stage and this supremacy remained after the first years of plantations). Height and d.b.h. in other years show mostly a quadratic relationship with the difference in altitude, with maximums reached for altitude increase between –404 m for height in 1999 and 50 m for d.b.h. in 1996. Similarly, maximum height in 1981 and 1986 and maximum d.b.h. in 1986 were obtained for transfer approximately 3 degrees southward.

Unlike in the 1964 experiment, where regressions with the differences in temperature characteristics were quadratic, in the IUFRO 1972 experiment they are mostly linear and indicate that warmer climate has generally a positive effect on the growth of provenances. Also a longer growing season can result in improved growth and even though for heights and d.b.h. in some years relationships are curvilinear, the curves are mostly monotonously growing within the range of our empirical data. As for the 1964 experiment, also in the 1972 experiment transfer to regions with higher mean annual precipitation adversely affected provenance growth. The negative effect of precipitation on growth is not so pronounced in the case of precipitation in the period April–September as some regressions are quadratic which means that within a certain range height or d.b.h. is growing with increasing precipitation.

The regressions between survival and differences in climatic characteristics of experimental plots and places of origin are summarised in Table 8. They show some different trends compared to growth characteristics, especially a negative effect of increased temperature and a positive effect of higher precipitation on survival at early stages of the 1972 experiment. Data from 1986 and later measurements did not reveal significant regressions between survival and differences in either annual precipitation or precipitation in the period April–September, while survival improved with temperature increase and an increase in the length of vegetation period.

Discussion

Using provenance research data from Slovak Norway spruce provenance trials we tried to reveal trends in the reaction of provenances after their transfer. The results of regression analyses for the 1964 experiment showed that the 1°C increase in the mean annual temperature improves the height growth of Norway spruce provenances by about 1.6% (calculated from the equation in Table 5). Pretzsch and Ďurský (2002) on the basis of their simulation programme predicted that the increase in temperature by 1°C would cause an increase in the mean annual volume increment at age 100 years by 5.9%, but the increase by 3°C would reduce the mean annual volume increment by 8.9%. Schmidtling (1994), based on data from the IUFRO Norway spruce 1938 experiment, revealed that the 4°C increase in the mean annual temperature would cause a height loss, as compared to a local source, by 11%. On the other hand, the temperature increase by 4°C on Slovak plots of the 1972 experiment did not tend to reduce productivity. The results differ between various provenance experiments in Slovakia as they include different provenance sets and also different experimental plots covering different ranges of environmental conditions, e.g. the plot with the highest altitude in the 1964 experiment lies at 1480 m, while in the 1972 experiment, it is at 920 m. The results from the 1972 experiment may also be affected by the fact that the climatic characteristics for Polish provenances were assessed with much smaller precision than for Slovak provenances, the data for which were gathered from a very accurate climatic model constructed by the National Forestry Centre – Forest Research Institute in Zvolen.

Beside temperature, also precipitation will play an important role in adaptation to the changing environment. Pretzsch and Ďurský (2002) predicted that productivity can improve especially in mountainous areas with sufficient precipitation but suboptimal radiation. According to the results of the 1972 experiment, precipitation seemed to be crucial for the survival at initial stages after planting as survival was better on plots with higher precipitation and lower temperature. However, at later stages starting at age 10 years, temperature constitutes a more important factor for survival than precipitation. Also according to Persson (1998) and Pretzsch and Ďurský (2002), mortality at early stages is a decisive factor affecting the final species composition. Selection of species and seed sources able to ensure the needed survival rate is essential for successful establishment of plantations.

Our findings support the idea that Norway spruce is a very adaptable species and that even a rather sudden change in environmental conditions, such as provenance transfer over very large distances, does not pose a great problem. However, it is important to monitor provenances over a longer time to reveal reactions to possible extreme events, such as droughts or frost, and their fluctuations.

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