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Effect of provenance on the survival of *Picea abies* trees on the IPTNS-IUFRO 1964/68 site in Krynica (Poland)

Abstract: In connection with the decline of spruce stands on the Krynica plots of IPTNS-IUFRO 1964/68, observed in the last decade and attributed to the so-called spiral disease, an attempt was made to determine whether the current health condition of trees is influenced by genotype (provenance). As shown by preliminary observations, the spruces differed in the degree of survival depending on provenance. The inventories of died or broken trees to be removed during the sanitary cutting, made in the years 2000, 2003, 2004 and 2008, yielded also information about the number of spruces that remained in the blocks of the experiment for each provenance and provenance region by Krutzsch (1968). Analysis of variance showed that genotype (provenance) has a statistically significant effect on the survival of trees. In the years 1999–2008, spruces from region 21 (Bohemian Forest) displayed the poorest survival rate in the conditions of the Beskid Sądecki Mts., while those from region 80 (Eastern Siberia) survived best.

Additional key words: Norway spruce, inventory, survival, genotype, spiral disease

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Introduction

Due to the wide range of distribution, Norway spruce (*Picea abies* (L.) Karst.), one of the main forest-forming species in Europe, displays a high intraspecific variability resulting from its adaptation to various habitats through multigenerational natural selection. This variability has been investigated using a number of methods, among them by analysing partial populations of spruce on comparative plots. Such an analysis makes it possible to determine the genetic variability of parental stands and provides a basis for selection programmes. The most important provenance tests with Norway spruce include the international inventory experiments IUFRO 1938, IUFRO 1964/68, and IUFRO 1972. Their results have been published in numerous papers and monographs (Tyszkiewicz 1966; Giertych 1977, 1984, 1998; Schmidt-Vogt 1977; Barzdajn 1996; Matras 2006).

One of the most significant provenance experiments with Norway spruce in Poland is the IUFRO 1964/68 test established by S. Bałut in Krynica. The test covers 1096 provenances from the whole range of this species. The IUFRO experiment forms a part of the worldwide selection programme "Inventory Provenance Test with Norway Spruce" started in 1959 by O. Langlet. The experiment was replicated on 20 research plots in 13 European countries and in Canada. The detailed description of the experiment and the characteristics of the provenances were presented by Bałut and Sabor (2001, 2002).

The observations made during the last decade on the comparative plots (blocks) of the experiment revealed an increased occurrence of deadwood and some signs of the general weakening of single spruce trees or groups of trees from different provenances. The degree of defoliation tended to increase, the trees had dried tops and resin exudates; such symptoms were by many authors called a spiral disease syndrome (Barszcz and Małek 2006; Mańka 2006). Phytopathological analyses carried out by Żółciak and Oszako (2003) and Żółciak et al. (2009) showed the occurrence of pathogenic fungi, among them *Amillaria* ssp., *Heterobasidion* ssp. and *Phytophthora* ssp. The appearance of deadwood coincided with the start of thinning which was planned to take place when the spruce trees on the experimental plots reached an age of 30 years.

Massive windbreaks that appeared in the snowy winter of 1998/99 made it necessary to remove in summer 1999 as many as 933 trees from blocks 02, 06 and 10 located in the Wojkowa Forest Range. At the turn of March 2000, repeated windbreaks caused damage to the same blocks. The losses were greatest in block 02 where 505 trees were blown down by the wind. In winter 2000/2001, further snow- and windbreaks enlarged the windward gap in blocks 02 and 06. In July 2001, spruces on the Wojkowa plots suffered from hurricane-force winds, and as a consequence, 40 m^3 of wood had to be removed in August. Currently, of the three blocks situated in the Wojkowa Forest Range two have disappeared and only one (block 06) has retained 50% of trees.

Although the extent of damage done to the blocks located in compartment 14 of the Kopciowa Forest Range (No. 01, 03, 04, 05, 07, 08, 09 and 11) was smaller, they also suffered from the gradual dieback of spruces that manifested itself in intense self-thinning, resin exudates, and a high defoliation index. Due to the annual removal of damaged or dead trees from all the IUFRO 1964/68 experimental plots in Krynica, the number of live spruces steadily decreases, which presents a serious threat to the representativeness of the entire experiment (Fig. 1).

The research into the survival of Norway spruce plantations has so far concentrated mostly on trees in the juvenile phases of growth to determine the effect that the selection of forest reproduction material has on the success of the established plantations (Barzdajn 1996; Krupski et al. 1996). Only few studies (Bałut et al. 1991b), however, investigated the significance of the effect of genotype (expressed by the selection of provenance) on the resistance to fungal diseases, in this number *Heterobasidion* ssp., *Armillaria* ssp., etc.

The present work attempts at evaluating the survival of spruce trees on the IUFRO 1964/68 experimental plots in Krynica, and at determining the significance of the provenance (genotype) effect on the general resistance of spruce. The methods used to protect the endangered provenance gene resources in the experiment are also discussed. The specific aims of the work are to determine the dynamics of spruce losses on the IUFRO 1964/68 experimental site; to establish the effect of genotype (provenance) on the survival of plantations; to identify the provenance regions by Krutzsch (1968) with highest and lowest survival; and to suggest the possible causes of the decreasing resistance of stands on the site.

Methods

The IUFRO 1964/68 experiment covers 1096 provenances of Norway spruce from the whole distribution range of the species, including 91 provenances from Poland. With respect to the region of occurrence of a given partial population, the provenances were divided by Krutzsch (1968) into 95 regional groups. In spring 1968, the 4-year-old experimental material was planted in 11 one-hectare blocks, each comprising 99

Fig. 1. Effects of windbreaks and general weakening of spruces on IPTNS-IUFRO 1964/68 plots in Krynica (Wojkowa Forest Range): a – block 10, b – block 06

provenances. Each provenance is represented by 25 trees on average, planted at a spacing of 2 × 2 m. One of the experimental plots is located in the Beskid Sądecki Mts. (southern Poland) in the area of the Krynica Experimental Forest Station of the Krakow University of Agriculture. Blocks 02, 06 and 10 lie in compartment 165 in the Wojkowa Forest Range, and blocks 01, 03, 04, 05, 07, 08, 09 and 11 are situated in compartment 14 in the Kopciowa Forest Range (Fig. 2). The experimental site is located at an altitude of 705–795 m, and is influenced by a mountainous climate of moderately warm and moderately cold belts; the soils are mostly gleyed brown soils developed from the Carpathian flysch formations (Bałut and Sabor 2001).

The research covered the spruce stands in the Kopciowa blocks; those lying in the Wojkowa Forest Range (destroyed by winds in the years 1991–2001) were not investigated. In the years 2000, 2003, 2004 and 2008, an inventory was made of the dead and broken trees to be removed by sanitary cutting. The number of spruces lost in the years 2000–2008 was compared with the number of living trees growing on the plot in 1999. This provided a basis for determining the provenance (genetic) variability, with the division of provenances according to the geographical regions by Krutzsch (1968) being considered.

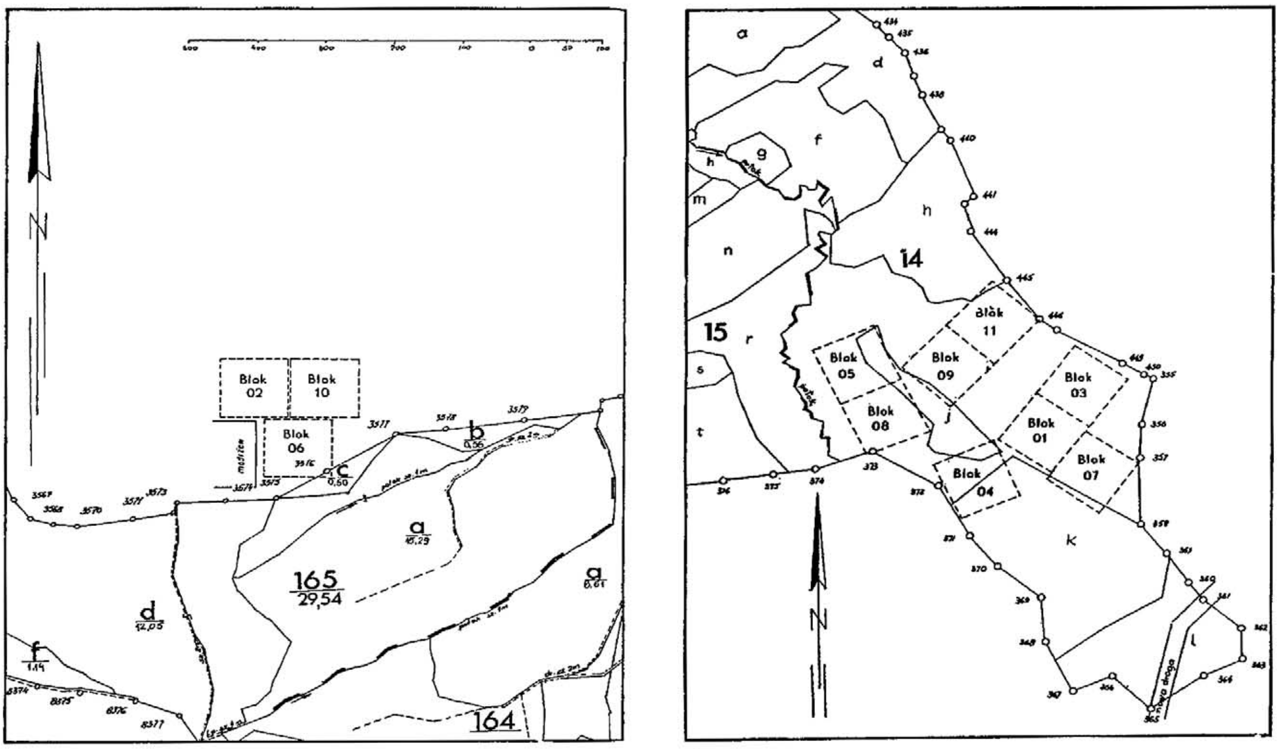
Statistical analyses were carried out using Statistica 8.0 software (StatSoft Inc. 2006). The populations exhibiting highest or lowest survival rate under the conditions of the Beskid Sądecki Mts. were identified by Fisher's test. The provenances in which the mean number of trees lost in the period 2000–2008 was smaller than the mean for the whole spruce population studied were considered to be more viable and better adapted to the local site conditions.

Results

An assessment of the viability of spruces (Fig. 3) showed no statistical differences in the number of lost trees between the experimental blocks in individual years, with the exception of the year 2008 when those differences were fairly high. On all the experimental plots, the process of self-thinning was intensified in 2003. Block 05, with 829 trees lost, was damaged most severely, block 04, with 472 dead trees, suffered the smallest damage.

Analysis of variance revealed significant differences in the number of dead spruces between the study years (Table 1). The largest number of lost trees, 2099 in total, found in 2003, was over three times higher than the number of trees lost in 2004.

A significant difference in the number of lost trees appears when comparing the Krutzsch (1968) regions (Table 1). By arranging those in the order of the mean number of trees lost in the years 2000–2008, two groups of populations with different survival were distinguished. The first group comprised provenances in which the number of lost trees exceeded the mean obtained for the whole collection. These were German



a b

Fig. 2. Distribution of blocks on IPTNS-IUFRO 1964/68 plots in Krynica: a – Wojkowa Forest Range (compartment 165, blocks 02, 06 and 10), b – Kopciowa Forest Range (compartment 14, blocks 01, 03, 04, 05, 07, 08, 09 and 11)

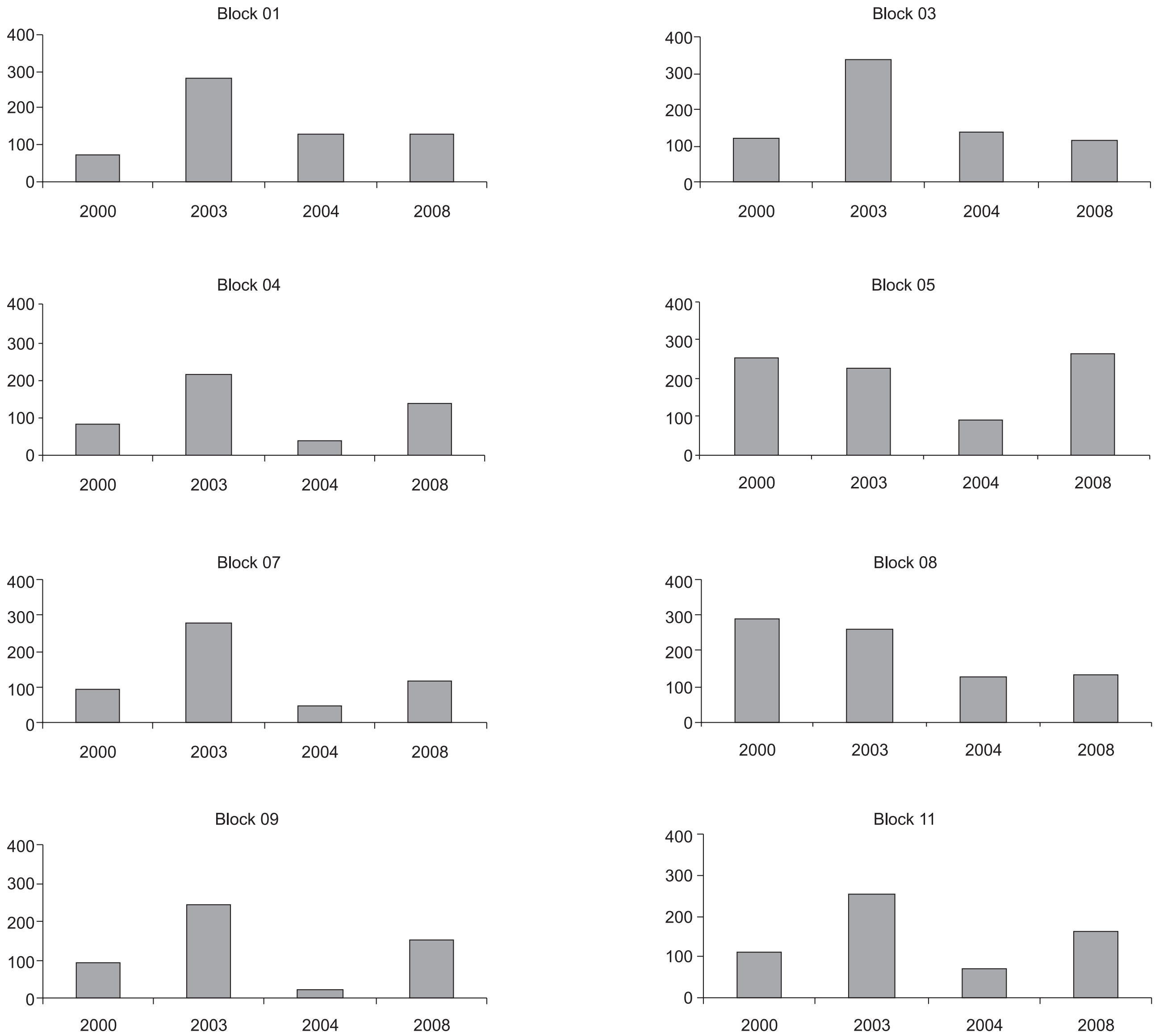


Fig. 3. Number of trees lost in blocks of IPTNS-IUFRO 1964/68 plots in Krynica (Kopciowa Forest Range) over 2000–2008

populations (07 – Harz Mts. 2; 11 – Thuringerwald; 12 – Odenwald; 13 – Schwarzwald; 14 – Breisgau; 16 – Swabian Upland; 17 – Swabian Jurassic; 18 – Franconian Jurassic; 21 – Bohemian Forest; 22, 23, 24 – Swabian Bavarian Upland; 25 – Bavarian Alps; 26 – East Alps); most Austrian provenances (27 – Tyrol; 28 – Tyrol Salzburg; 30 – Niedrige Tauern; 31 – Carinthia-Styria (N–E); 34 – Styria (E); 36 – Bohemian Upland, Lower Austria); most Czech provenances (37 – West Bohemia; 41 – Bohemia; 42 – South Bohemia; 43, 45 – Moravia); most Polish provenances (48 – Tatras; 63 – Beskid Śląski, Beskid Żywiecki; 64 – Klodzko Valley; 65 – Silesian Lowland, Great Poland Lowland; 66 – West-Pomeranian Lakeland); and single Swiss provenances (15 – West (Lepontine Alps), Slovak provenances (47 – Nizke Tatry), Bulgarian provenances (56 – Rhodope Mts.), Romanian provenances (56 – East Carpathians), and Swedish provenances (90 – central Sweden). 61.1% of the regions were included in the group of fairly good survival with the average

Table 1. Analysis of variance for number of spruce trees lost over 2000–2008. IPTNS-IUFRO 1964/68 in Krynica

Effect	Sum of squares	Degrees of freedom	Mean square	F
Free term	68931.38	1	68931.38	975.1916*
Provenance region of Krutzsch	55995.62	94	595.70	8.4275*
Years	11309.84	3	3769.95	53.3345*
Error	19933.16	282	70.68	–

* significant at 0.05 level

number of lost trees in the provenance below the mean for the whole population studied. These were the provenances from Baltic republics, Nordic countries, north-central Russia, and northeastern Poland. The distribution of the regions with varied survival is shown in Fig. 4. The division of provenances into uniform groups, made by Fisher's test, allowed identification of the populations that significantly differed from the remaining ones in the number of lost trees. In the research period, provenances from region 80 – western Siberia (Russia) performed the best in the Beskid Sądecki Mts. conditions, while those from region 21 – Bohemian Forest (Czech Republic, Germany) exhibited the poorest survival.

Over the years 2000–2008, the number of live trees without disease symptoms in the experimental blocks 01, 03, 04, 05, 07, 08, 09 and 11 (Kopciowa Forest Range) decreased from 11 853 to 6769. This downward trend is depicted in Fig. 5. During the research period, the mean annual number of lost trees was 565, i.e. 4.7% of all the live spruces.

Because of the fact that the experimental material was threatened due to repeated windbreaks in the Wojkowa Forest Range (blocks 02, 06 and 10) and intensified self-thinning in the Kopciowa Forest Range (blocks 01, 03, 04, 05, 07, 08, 09 and 11), a programme was developed to protect the gene resources of the IUFRO 1964/68 experiment in Krynica by establishing a conservation archive of the endangered provenances. Grafting started in 2000 made it possible to create such an archive at the Krynica Experimental Forest Station in 2007. Currently, 1333 grafts of spruce from provenances representing 73 Krutzsch regions and coming from the wind-damaged collec-

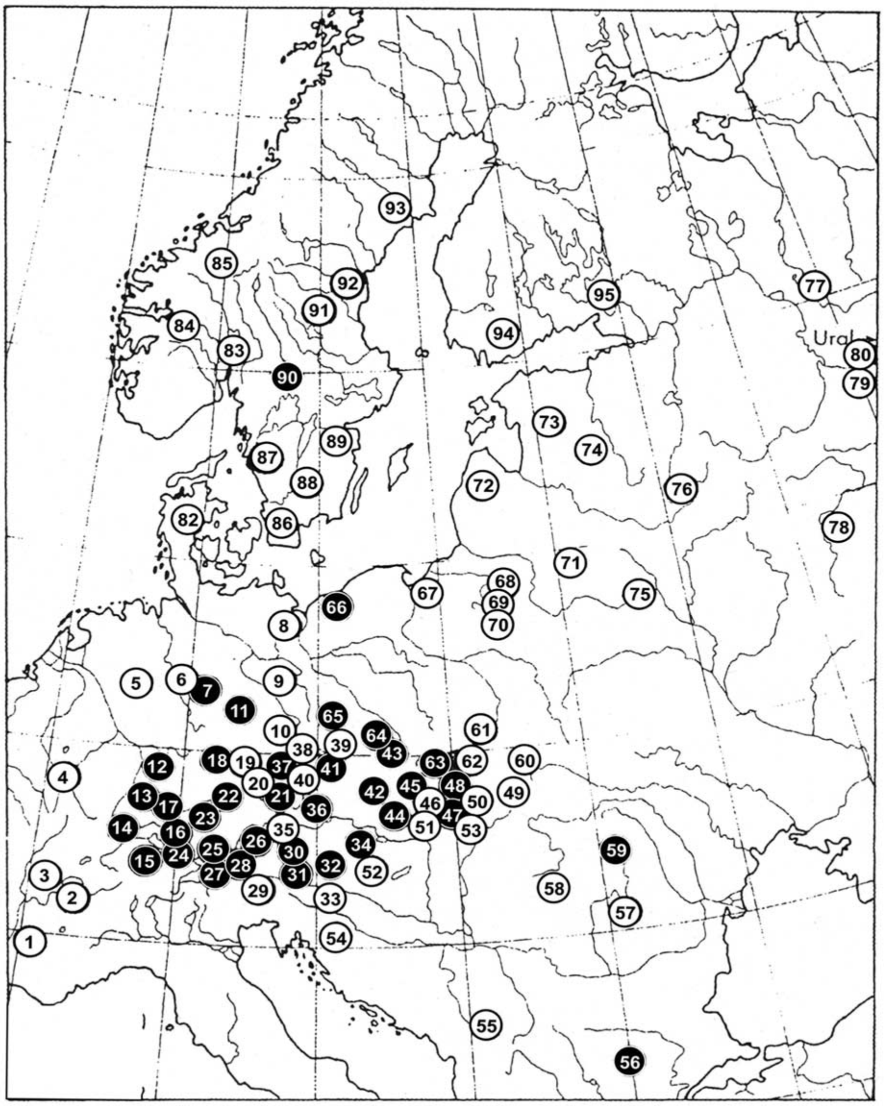


Fig. 4. Location of provenances exhibiting good or poor survival on IPTNS-IUFRO 1964/68 plots in Krynica (Krutzsch 1968, modified)

○ provenances with good survival (mean number of lost trees exceeds the mean for the whole population)

● provenances with poor survival (mean number of lost trees is smaller than the mean for the whole population)

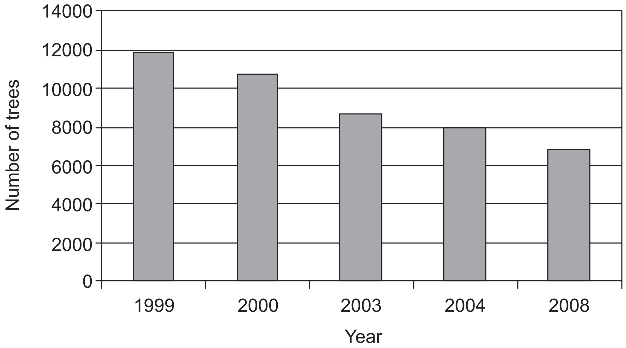


Fig. 5. Inventory of live spruce trees in blocks of IPTNS-IUFRO 1964/68 plots in Krynica (Kopciowa Forest Range) over 1999–2008

tions of blocks 02, 06 and 10 have been planted there (Fig. 6a, Table 2). The grafting programme is being continued. Successively, the archive will be enlarged by including collections of grafts from the remaining provenances of the experiment, especially from the Kopciowa blocks. Besides of launching the gene resources conservation programme, attempts were made to control root pathogens using the biological preparation Rotstop (Fig. 6b).

Discussion

As one of the largest international inventory tests, the IUFRO 1964/68 experiment gives the possibility to compare survival at a level of partial populations representing the genetic variability of the spruce species in its whole range of occurrence.

The study of the survival of trees in eight blocks of the experiment indicates that Norway spruce exhibits genetic variability in the resistance to biotic and abiotic factors under the conditions of the Beskid Sądecki Mts.

The finding that genotype has a significant effect on the observed variability was confirmed by Żółciak et al. (2009) who showed a significant relationship between the provenance region and the number of infested trees. Other authors also reported that the natural resistance to the spiral disease syndrome has a hereditary basis (Sierota 2001).

The provenances of spruce from the NE range of its distribution, Baltic republics, NE Russia, and high-mountain sites exhibited better survival. These are progeny populations of parental stands growing in a climate similar to that found on the Krynica experimental site located in the Beskid Sądecki Mts. at an altitude of about 700 m. This fact seems to confirm the adaptation of trees to such conditions through multigenerational natural selection. Due to the greater incompatibility with the site, the remaining genotypes are in a worse condition, which makes them more susceptible to fungal infections, insect attack, and abiotic factors (windbreaks), resulting from the high G × E interaction effect (Sabor 2000). Earlier studies on the average height in Norway spruce provenances (Bałut et al. 1991a) demonstrated that the best results of the reproduction of spruce in mountain regions are achieved if the provenances of parental stands come from altitudes similar to those at which the plantation is located.

The other factors contributing to the self-thinning of spruce trees on the experimental site were abiotic (drought), biotic (fungi, insects, deer), and anthropogenic (man). As follows from the research, all of them

Fig. 6. Gene resources protection programme for Norway spruce: a – conservation archive of endangered provenances, b – control of root pathogens

Table 2. Conservation archive of IPTNS-IUFRO 1964/68 in Krynica. Number of grafts representing provenance regions of Krutzsch (1968) – state of 2007

Provenance region of Krutzsch	Block 02	Block 06	Block 10
02 West Alps FR		21	1
03 Jura FR		3	
04 Ardeny GR/FR	1		
05 Rheinisches Schiefergebirge GR	3		6
06 Harz Mts 1 GR		1	2
07 Harz Mts 2 GR		25	
08 Meclenburg GR		4	4
11 Thuringerwald GR		20	1
13 Schwarzwald GR		1	
14 Breisgau GR		13	4
15 West Alps SW	5	9	5
16 Swabian Upland GR		6	2
17 Swabian Jura GR	7	17	15
19 Franconia Palatinate GR		15	6
20 Bavarian Forest GR	1		
21 Bohemian Forest CZ	4	39	18
22 Swabian-Bavaria 1 GR	14	12	2
23 Swabian-Bavaria 2 GR		33	12
24 Swabian-Bavaria 3 GR		21	
25 Bavarian Alps GR	3		
26 East Alps GR	2	32	16
27 Tyrol AU	3	5	
28 Tyrol-Salzburg AU		23	4
29 Est Alps IT			5
30 Tauen AU		14	6
31 Carinthia-Styria AU		11	4
32 Styria 1 AU		75	31
33 Styria 2 AU			1
34 Styria 3 AU		7	1
36 Bohemian Upland CZ/AU	6	3	6
38 Central Bohemia CZ		23	3
39 Sudetes CZ		8	
40 South Bohemia CZ		16	6
41 Bohemia CZ	5		6
42 South Bohemia, Moravia CZ		13	6
43 Moravia 1 CZ		10	
44 Moravia 2 CZ			3
45 Moravia 3 CZ	1	26	28
47 Nizke Tatry SK	1	29	4
48 Tatras SK		17	1
49 East Slovakia SK			1
50 Slovnicke Rudohorie SK	8		1
52 West Hungary		15	
53 North Hungary			6
55 Montenegro		11	
56 Rhodope Bulgaria		9	
57 Transylvanian Upland RM		15	3
58 Bihor RM	6	11	
59 East Carpathians RM		17	7
61 Little Poland		13	
63 Beskid Śląski PL		20	9
65 Silesian Lowland PL		4	
66 West-Pomeranian PL			17
67 Warmia, Masuria PL		39	
68 Masurian Lakeland PL	2		1
69 Augustów Podlasie PL		20	
71 Belarus Lakeland LI		19	
72 Latvia, Estonia 1		28	
73 Latvia, Estonia 2		19	
74 Latvia, Estonia 3	3		
75 Belarus		26	
76 East Russia			15
78 Russia 2		10	
81 Knusk, Russia		21	
82 Jutland DN		20	
83 Bogstad NR	7	10	
85 Central Norway		10	
87 Gotland SW		6	
90 Central Sweden	4	30	
91 Norrland SW		17	
93 SE Sweden		10	
94 South Finland		19	
96 Hudson, Ontario, Canada			7
Total	54	480	176

made an increasing impact on the survival of spruce in the period 2000–2008.

According to the report on the condition of forests in Poland (PGL 2004), the total precipitation of 2003, the year in which the percentage of spruce trees lost on the IUFRO experimental plots in Krynica was highest, amounted to 362.2 mm and was lower than the mean for the preceding years (430.7 mm). Drought is one of the factors determining the condition of spruce stands in Krynica (Żółciak and Oszako 2002). The evidence is, for example, the dead bark of roots found in trees not attacked by pathogens, and the marked decrease in increment observed since 1999. Having a flat root system, Norway spruce is susceptible to water deficits and requires considerable amount of moisture. Some studies (Giertych 1987; Burczyk and Giertych 1988), however, did not fully confirm the correlation between genotype and level of precipitation. It seems therefore that water deficit constitutes only one of the factors that contribute to the weakening of spruce stands.

The results of this research also indicate that provenances from the regions where the probability of occurrence of late-flushing provenances is statistically significant lost a smaller number of trees (Sabor 1984). This suggests that such partial populations were less damaged by late frosts than the others, so their physiological condition was better.

Bark tapping by *Cervidae* may also be counted among the factors contributing to the weakening of stands. The injuries done to the bark constitute a gateway to infections which lead to a further decline of trees. Research into the damage caused by deer to the experimental spruce stands in Krynica, however, did not found any relationship between provenance and tapping intensity (M. Kobak, MSc. thesis, AR Kraków 2008).

To sum up, the studies to date have not unequivocally shown that the genotypic effect is the only cause of the differences in tree survival between various provenance regions. However, the results of 1999–2008 indicate that genotype significantly affects the observed variability. Therefore, further research is needed to clarify this issue. Considering the current threats to the existence of the spruce stands tested in the IUFRO 1964/68 experiment, it seems that the only way to preserve the gene resources of this population is by establishing conservation archives. Such a plan has already been launched.

Conclusions

1. In the years 1999–2008, the symptoms of the disorder known as a spiral (complex) disease syndrome steadily worsened in the blocks of the IUFRO 1964/68 experiment in Krynica. As a result, in the years 2000–2008 it became necessary to remove 5084 trees (42.9% of the total number of spruces growing on the plots in 1999) by sanitary cutting and selective thinning.
2. Genotype (provenance; provenance region) was found to have a significant effect on the number of lost trees. In the period 1999–2008, relatively high survival rate was exhibited by provenances from Baltic republics, Nordic countries, north-central Russia, and northeastern Poland. Spruces from region 80 – western Siberia (Russia) proved to be most viable in the mountain conditions of Beskid Sądecki, and those from region 21 – Bohemian Forest (Czech Republic, Germany) were poorest in this respect.
3. In order to conserve the fullest possible collection of the threatened spruce provenances, a programme has been set up which currently protects 44 provenances. Every year, further endangered trees are successively grafted. The conservation archive established in 2007 in Krynica includes 1333 grafts. Attempts are also made to control the pathogenic root fungi using the biological preparation Rotstop.

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