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ADAPTATION OF SEEDLING GROWTH TO THE ALTITUDE: A CASE OF THE NORWAY SPRUCE FROM THE POLISH SUDETY MOUNTAINS

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SUMMARY.- Seedlings of five Norway spruce [Picea abies *(L.) Karst.] populations originating from different altitudes in the massif of Snieznik Klodzki in the Sudety Mountains (Poland) were grown in the greenhouse. Height, root length, and weight of: root, shoot, needles and bud, as well as biomass allocation were studied. A good correlation of seedling traits and the altitude of mother stands was found. This indicates a rather good ecological adaptation of these, probably introduced populations. Some ecological and silvicultural aspects of the results are discussed.*

RÉSUMÉ.- Les plantes de cinq populations de l'épicea commun [Picea abies *(L.) Karst.] provenant des différentes altitudes du massif de Snieznik Klodzki dans les Sudètes (une chaîne des montagnes en Pologne) ont été cultivées dans la serre. Leurs paramètres suivants ont été analysés: la hauteur, la longueur des racines, le poids frais et le poids sec des racines, des tiges, des aiguilles, des bourgeons et l'allocation de la biomasse. La haute correlation a été notée entre les paramètres des plantes et l'altitude des stations des arbres ayant été les semenciers des graines. Ce résultat montre une plutôt bonne adaptation écologique de ces populations, probablement introduites dans le massif de Snieznik Klodzki. Les aspects écologiques et les conséquences de l'adaptation de l'épicea commun aux conditions montagneuses pour la sylviculture sont discutés.*

RESUMEN.- Plántulas de cinco poblaciones de abeto rojo [Picea abies *(L.) Karst.] procedentes de diferente altitud en el macizo de Snieznik Klodzki, en los Montes Sudetes, (Polonia) se cultivaron en invernadero. Se han analizado los parámetros siguientes: altura y longitud de las raíces, pesos fresco y seco de raíces, tallos, hojas y yemas, así como la distribución de la biomasa. Como resultado se obtuvo una correlación alta entre los parámetros de las plántulas y la altitud de las estaciones*

donde se colectaron las semillas. Esto indica una adaptación relativamente buena de esas poblaciones, probablemente introducidas. Finalmente se discuten algunos aspectos ecológicos y de silvicultura.

Key-words: *Picea abies*, ecological adaptation, linear and weight seedling parameters, biomass allocation, silviculture, Eastern Sudety Mts.

1. Introduction

Norway spruce belongs to the most important species in the European forestry. In Poland it is on second place, but in the more mountainous countries of Central Europe it is a tree number one. In the mountainous environment the question of adaptation of Norway spruce to the altitude is essential (HOLZER, 1979, 1981, 1993). In the past however, due to a trade in seeds of unknown origin an artificial migration of Norway spruce took place (BOUVAREL, 1974, SCHMIDT-VOGT, 1975). In Poland the problem of foreign origin of spruce stands is important first of all in the Sudety Mountains, because the import of unidentified seed material was here especially common (ZOLL, 1958; PERINA & SAMEK, 1958; MDRZYNSKI, 1989, 1993). In the opinion of many foresters the introduced (altitudinally unadapted) spruce populations suffer much more than the local ones from snow, wind, insects, fungi and other abiotic and biotic factors (HOLZER, 1981, MYCZKOWSKI, 1967, ROHMEDER 1964). Therefore it is necessary to search the origin and ecological adaptation of Norway spruce populations.

The aim of this study is to show the differentiation of growth parameters of Norway spruce seedlings, on the background of the altitude of their mother stands, to may estimate if they are adapted to the sites they occupy nowadays in the massif of Snieznik Klodzki, located in the Eastern Sudety Mountains.

2. Material and methods

The cones of Norway spruce were collected in the Eastern Sudety Mountains from 10 mother trees per population in the autumn of 1987. The altitude of mother trees was measured by means of an aneroid altimeter (MODRZYNSKI, 1989). Seeds were preserved in the temperature of about +2° C. For this study five populations from the massif of Snieznik Klodzki were chosen. The altitude, exposure and age of these populations are given in Table 1.

No	Mean altitude of 10 mother trees [m asl]	Exposure (Junghans 1967) [kcal $cm^{-2}year^{-1}$]	Age at cone harvest year [year]
1	666	135	100
2	798	90	95
3	929	81	90
4	1052	134	135
5	1162	81	150

Table 1. Location and age of the investigated populations.
Situación y edad de las poblaciones investigadas.

Environmental conditions of the Eastern Sudety Mountains are under strong influence of the altitude. The soils in the lower mountain range are mostly of braun —those in the upper mountain range—, mostly of podsole-type. The climatic conditions are for Norway spruce close to optimal on the bottom (about 700 m asl) and get rapidly worse and worse with the increase of altitude (NEBE, 1968; MODRZYNSKI, 1989). The timberline is located here at about 1300 m a.s.l. and Norway spruce is the main species making it.

The seeds were sown in April 1995 into a mixture of sand and perlit at a ratio 3:1. After 5 weeks the seedlings were transplanted to pots of 12 cm in diameter, filled with a mixture of pit soil, forest soil and sand at a ratio 5 : 3 : 2. The plants were grown in the greenhouse, at a temperature of about 25°C. Germination capacity of the 5 populations did show a decrease in connection with altitude. For the highest population it was 30, and for the lowest –90%.

After the end of growing season the height of seedlings was measured and the length of shoots and roots as well as the biomass of needles, shoots and roots of one-year-old seedlings was analysed. For that purpose 24 plants per population were used. Both fresh and dry weight was studied for comparison and mutual checking of results. Dry weight was obtained after drying in the oven at 105° C for 24 hours.

Pearson's coefficients of correlation to estimate linear regression between the measured parameters and the mean altitudes of 10 mother trees (representing the populations) were calculated using the STATISTICA programme version 5.0.

3. Results

There is a strong linear relationship between the mean height of seedlings and the altitude of mother trees (Figure 1, Table 2). Length of root does not correlate with the altitude of mother stands, but the root/shoot ratio does (Table 2).

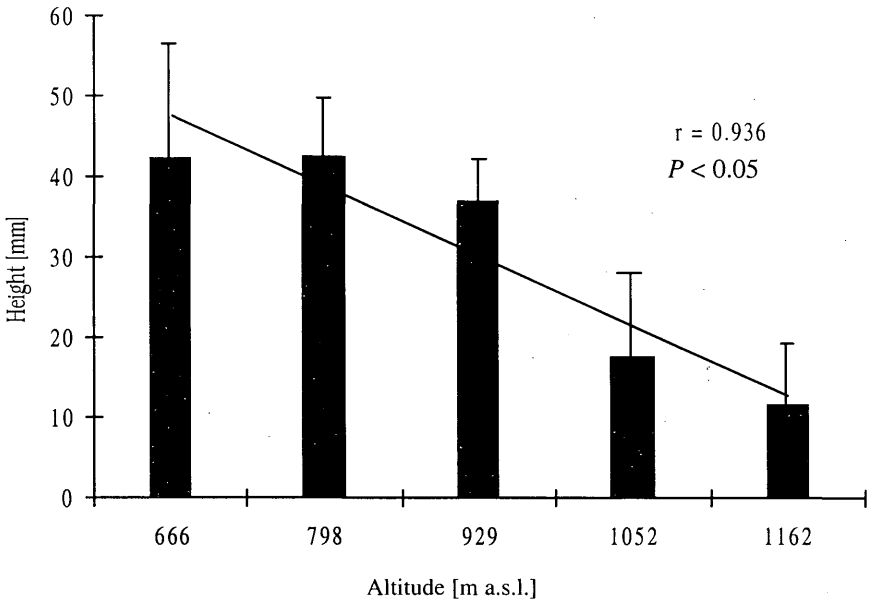

Figure 1. Mean heigts of one year old seedlings being a progeny of five Norway spruce stands located at different altitudes at the massif of Snieznik Klodzki in the Sudety Mountains. Vertical bars represent ± SD (n = 50).
Altura media de las plántulas de un año cuyas semillas proceden de cinco parcelas de abeto rojo situadas en el macizo de Snieznik Klodzki, en los Montes Sudetes, a diferentes altitudes. Las barras verticales representan ± SD (n = 50).

Both fresh and dry weight of whole seedlings, their roots, shoots and needles decrease with the increasing altitude of seed collection. All these relations are significant (Table 2). Only the weight of buds (both fresh and dry) does not correlate with the altitude of origin.

The biomass allocation to buds, needles, shoots and roots (related to whole seedlings) is presented in Figure 2 (fresh weight) and Figure 3 (dry weight). In the case of dry weight, the correlation of all these ratios with the altitude of mother stands is significant. In the case of fresh weight only two of them (shoot/whole seedling and needles/whole seedling) show a significant correlation with this altitude.

Parameters	*Pearson's coeficients of correlation "r"*	*Number of pairs of measurements "N"***	*Probability "P"*
Length			
Length of shoot (seedling height)	**0.94***	**5**	**P < 0.05**
Length of root	0.21	120	P = 0.053
Root / shoot	**0.60**	**120**	**P < 0.001**
Fresh weight			
Whole seedlings	**0.60**	**120**	**P < 0.001**
Roots	**0.30**	**120**	**P = 0.004**
Shoots	**0.74**	**120**	**P < 0.001**
Needles	**0.80**	**120**	**P < 0.001**
Buds	0.17	120	P = 0.115
Root/ whole seeddling	0.20	120	P = 0.078
Shoot / whole seeddling	**0.38**	**120**	**P < 0.001**
Needles / whole seedling	**0.71**	**120**	**P < 0.001**
Bud/whole seedling	0.17	120	P = 0.121
Dry weight			
Whole seedlings	**0.66**	**120**	**P < 0.001**
Roots	**0.34**	**120**	**P = 0.001**
Shoots	**0.66**	**120**	**P < 0.001**
Needles	**0.80**	**120**	**P < 0.001**
Buds	0.04	120	P = 0.743
Root/ whole seeddling	**0.40**	**120**	**P < 0.001**
Shoot / whole seeddling	**0.38**	**120**	**P < 0.001**
Needles / whole seedling	**0.56**	**120**	**P < 0.001**
Bud/whole seedling	**0.60**	**120**	**P < 0.001**

* Marked correlations are significant at P < 0.05.

** In case of seedlings height the mean population height and the altitude make a pair of measurements; in all other cases a pair is made by the parameters of each measured seedling and the altitude.

Table 2. Correlation between the measured parameters of seedlings and the altitude of mother trees.

Correlación entre los parámetros analizados en las plántulas y la altitud de las localidades de procedencia.

4. Discussion

The results obtained in this study for the length and weight parameters as well as for the allocation of biomass in the Norway spruce seedlings grown from seeds collected in different altitudes in the Eastern Sudety Mountains (massif of Snieznik Klodzki), are in a good accordance with the results of previous investigations performed in natural spruce forests. HOLZER (1967, 1993) and SCHMIDT-VOGT (1977) report on strong correlation of seedling height, as well as fresh weight of whole seedling, shoot (with needles) and root with the altitude of mother stands.

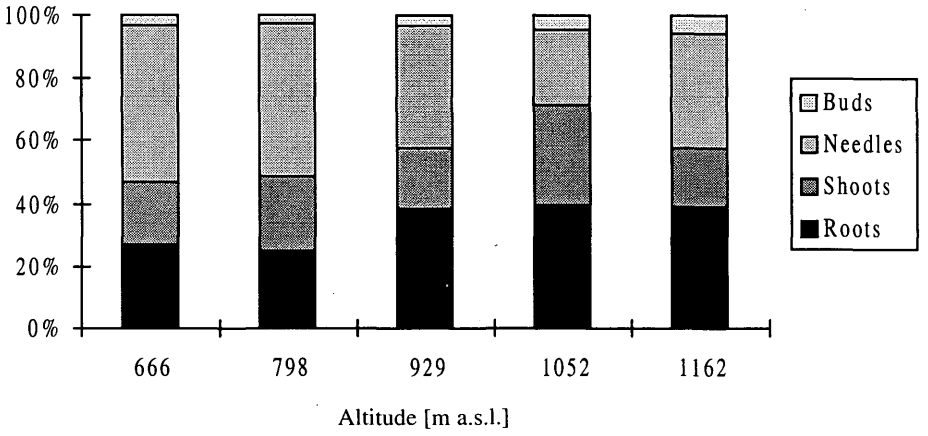

Figure 2. Allocation of fresh biomass to buds, needles, shoots and roots of one year old seedlings being a progeny of five Norway spruce stands located at different altitudes at the massif of Snieznik Klodzki in the Sudety Mountains.
Distribución de la biomasa fresca entre las yemas, hojas, brotes y raíces de las plántulas de un año nacidas de las semillas procedentes de cinco parcelas de abeto rojo situadas a diferentes altitudes en Snieznik Klodzki, Montes Sudetes.

From the comparison of fresh and dry weight parameters performed in our study one can see that the latter gives better correlation of biomass allocation to root and bud. Biomass alloçation as an indirect trait (a ratio) turns to be a useful characteristic of Norway spruce altitudinal ecotype - similarly to length and weight parameters as well as the bud-set index, recommended by HOLZER (1975, 1993) and MODRZYNSKI (1989,1995). The latter obtained for 18 populations originating from different altitudes in the Karkonosze Mountains (the highest range of the Sudety Mountains) results, which correspond to those, described above.

The results obtained in our study lead to the conclusion that the Norway spruce populations in the massif of Snieznik Klodzki show nowadays clear signs of good ecological adaptation, despite of possible foreign origin. This may be explained as follows:

1. Those from the imported populations, which were totally unadapted to the new mountain site, were destroyed by the factors of the harsh environment.
2. Some of the introduced populations could survive and reach the reproduction age.
3. In such populations the best-adapted trees participated mostly in the seed production.

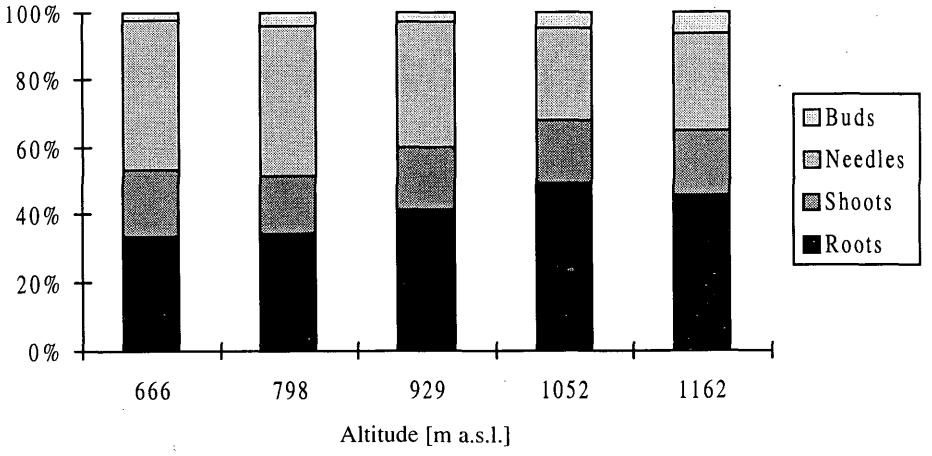

Figure 3. Allocation of dry biomass to buds, needles, shoots and roots of one year old seedlings being a progeny of five Norway spruce stands located at different altitudes at the massif of Snieznik Klodzki in the Sudety Mountains.
Distribución de la biomasa seca entre las yemas, hojas, brotes y raíces de las plántulas de un año nacidas de las semillas procedentes de cinco parcelas de abeto rojo situadas a diferentes altitudes en Snieznik Klodzki, Montes Sudetes.

4. Those trees were pollinated rather by the vigorous pollen of the native populations, than by their own pollen.
5. Norway spruce as evolutionary young and genetically extremely polimorphic species may undergo a very effective selection.

Independently from how we would try to explain the results, we can state that the progeny of five Norway spruce populations tested in our study show features of good adaptation to the sites (elevations) on which they mother trees grow today. Consequently, from the silvicultural point of view they can be treated as native ones. It means that the spruce stands in the massif of Snieznik Klodzki should be regenerated by selfsowing and their seed sources can be used for artificial regeneration.

Numerous Norway spruce-provenance experiments and breeding programs (GIERTYCH, 1976, 1978, 1979, 1985; KRUTSCH, 1992) search for trees and populations which are optimal for the silviculture, but it seems that the local spruce populations are still the most appropriate for the silviculture in the mountainous area.

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