FORESTRY IDEAS, 2011, vol. 17, No 2 (42)

INVESTIGATION OF DOUGLAS-FIR PROVENANCE TEST IN NORTH-WESTERN BULGARIA AT AGE 20

Krassimira Petkova

Department of Sylviculture, Faculty of Forestry. University of Forestry. 10 Kliment Ohridski Blvd. 1756 Sofia. Bulgaria. E-mail: kpet@abv.bg

UDC 630.232

Received: 05 October 2010
Accepted: 21 November 2011

Abstract

The aim of the study wais to make a comparative analysis of the growth rate of 54 Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) provenances. The provenance test was established in the spring of 1990 with 3-year-old (3+0) seedlings planted in a 2x2 m plot design and two replications. The provenances originated from the North America and were separated into Coastal, Continental and Western Cascade groups. At age 20 growth rate was studied in terms of height and diameter, and stem volume. Coastal provenances demonstrated the best growth parameters, followed by Western Cascade Mountains and continental provenances. The provenances showing fastest growth provenances were Bremerton, of the coastal group, and Darrington, Newhalem and Idanha of the Western Cascade group. These provenances possessed also high resistance to fungal pathogens. Ten continental provenances had the lowest growth rate and productivity and were highly susceptible to the fungal pathogens *Rhabdocline pseudotsugae* and *Phaeocryptopus gaumannii*. Darrington from the Western Cascades in Washington is the recommended provenance for future afforestations with Douglas-fir in Bulgaria.

Key words: adaptation, disease susceptibility, seed sources, tree growth, provenances, *Pseudotsuga menziesii.*

Introduction

Douglas-fir was introduced in Europe in 1827 when the Scottish botanist David Douglas imported seeds of this tree species into England and Scotland. A century later Douglas-fir had already been introduced in almost all European countries. The rapid growth and wood quality of Douglas-fir attracted the attention of many researchers. The majority of studies focused on its growth and productivity and the role of soil and climatic conditions (Tyler et al. 1995, Dundari et al. 2002, Feliksik and Wilczynski 2004). The choice of appropriate provenances quickly became the main research goal of many European studies (Veen 1951, Ruetz 1981, Ruetz and Foerst 1984, Ruetz 1989, Ballian et al. 2002, Zas et al. 2003, Govedar et al. 2003, Perić et al. 2009). Superior growth of the coastal provenances and these from the western side of the Cascade Mountains in the states of Washington and Oregon have been reported in most studies

(Lally and Thompson 1998, Schultze and Raschka 2002, Rau 2005).

Douglas-fir was introduced in Bulgaria a century ago, but it became widespread only in the late 1950s and during the 1960s. Nowadays, plantations of this species occupy about 6714 ha. In many plantations, the species has demonstrated good adaptability (Petkova 1989, Popov 1991, Grozev et al. 1995). However, in some plantations diseases have been found caused by the fungi *Rhabdocline pseudotsugae* Syd (Rosnev 1978, Rosnev 1983a), *Phomopsis pseudotsugae* Wils (Rosnev 1983b) or *Phaeocryptopus gaumannii* (T. Rohde) Petr. (Rosnev and Petkov 1986, Rosnev 1987). Most plantations are of unknown seed origin, which could be one of the main causes of the emerging problems. Twenty years ago provenance tests of 55 Douglas-fir provenances were established in Bulgaria (Popov 1995, Petkova 1999, Popov and Petkova 2003), and these are a rich source of information on the various provenances' growth rate and ability to adapt to the natural conditions in the country. Earlier measurements of these plantations (at age 8 and 16) have indicated that the coastal provenances and the provenances from the Western Cascade Mountains of the states of Washington and Oregon have the best growth rate (Popov 1995, Popov 2001, Petkova 2004). The diseases found on part of these plantations caused by the fungi *Rhabdocline pseudotsugae* Syd. and *Phaeocryptopus gaumannii* (T. Rohde) Petr. (Georgieva and Rosnev 2008, Georgieva 2009) will contribute to the selection of the most tolerant and adaptive provenances for future afforestations with this valuable tree species in Bulgaria. Additional information on the use of Douglas-fir will be obtained from the new provenance tests established in 2006 with seeds from highly productive stands in Germany, Bulgaria and the USA (Petkova et al. 2008).

The aim of this study was to analyze the growth rate of 54 Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) provenances at age 20.

Material and Methods

The Douglas-fir provenance test is located on the lower northern slopes of the Western Balkan Mountain and is one of 4 field trials established with the aim of studying the adaptability of this species to different climates of Bulgaria. The trial was established on flat terrain facing East, at an altitude of 600 m, latitude of 43°14' N and longitude of 23°09'E. The soil is Orthic luvisol (FAO), mixed sandy and clay, slightly stony, and very deep. The habitat is medium rich to rich. The climate in the region is temperate with an average annual temperature of 10.2°C and annual precipitation of 1004 mm. The duration of the vegetation period is about 6 to 6.5 months.

The provenance test was established in the spring of 1990 with 3-year-old seedlings (3+0), which were planted in a 2x2 m plot design in two replications. Forty to forty-eight seedlings were planted on each plot. The experimental area was prepared by ploughing and the Douglas-fir seedlings were planted with an earth auger. Due to unfavourable environmental conditions in the northern part of the provenance test (waterlogging and swamping) some of the individuals in the second replication died, leaving just 23 provenances in the experiment.

The 54 provenances studied originate from natural stands of Douglas-fir in North America (Fig. 1), and were classified into three groups: continental (26), Western Cascade Mountain (22) and coastal (6) provenances. The continental group includes 21 Oregon provenances, 3 Washington provenances, 1 Montana provenance and 1 New Mexico provenance.

The following indices were determined when the trees reached the age of 20: average diameter at breast height (DBH), average height and stem volume. The average diameter (DBH) for each provenance and replication was determined after measuring the diameters of all trees on the plot. It was calculated according to the Formula 1:

$$D = \sqrt{\frac{4G}{\pi N}} \text{ [cm]}, \qquad (1)$$

where: $G = \Sigma n_i.g_i$ [m^2] is the total basal area of the trees in the provenance, n_i is the number of trees in the respective diameter class, g_i [m^2] is the basal area in the respective diameter class, N is the number of trees in the provenance.

The average height (H) of each provenance was calculated as the arithmetic mean of the heights of 15–25 individual trees, distributed into diameter classes.

The stem volume was calculated according to the Formula 2:

$$V = G.HF \text{ [m}^3\text{]}, \qquad (2)$$

where: G [m^2] is the total basal area of trees in the provenance; HF is the height form factor for *Abies alba* Mill., as presented in table 3 (Poryazov et al. 2004).

Statistical parameters (arithmetic mean, standard deviation and standard error) were assessed for the analyzed height and diameter at breast height per provenance. The differences among provenances were tested by analysis of variance (ANOVA). Since a lot of individuals in the second replication had been lost due to unfavorable environmental conditions, the design of the experiment did not allow testing a full factorial model. Instead, two analyses of variance were done on the height. In the case where the provenances were represented by two replications (23 provenances), the analysis considered the effects of groups, replications and provenances, and in the other case, the analysis considered only the effects of groups and provenances (54 provenances). This inconvenience did not affect testing the effect of the main factors, but rather the interactions among them.

The model for ANOVA (Formula 3) was:

$$Y_{ijkl} = \mu + G_i + P_j + R_k + e_{ijkl}, \qquad (3)$$

where: Y_{ijkl} is the value of the l^{-th} individual of the j^{-th} provenance of the i^{-th} group measured in the k^{-th} replication; μ is the overall mean; G_i is the effect of the i^{-th} group (i = 1, 2, 3); P_j is the effect of j^{-th} provenance (j = 1, 2, ..., 54); R_k is the fixed effect of the k^{-th} replication (k = 1.2); e_{ijkl} is residual error.

To assess the health status of trees of the individual provenances (Georgieva 2009) the degree of crown defoliation was determined according to the European methods for environmental monitoring of forest ecosystems (Eichhorn et al. 2007). Phytopathological surveys were carried out to identify the fungal diseases *Rhabdocline pseudotsugae* and *Phaeocryptopus gaumannii*.

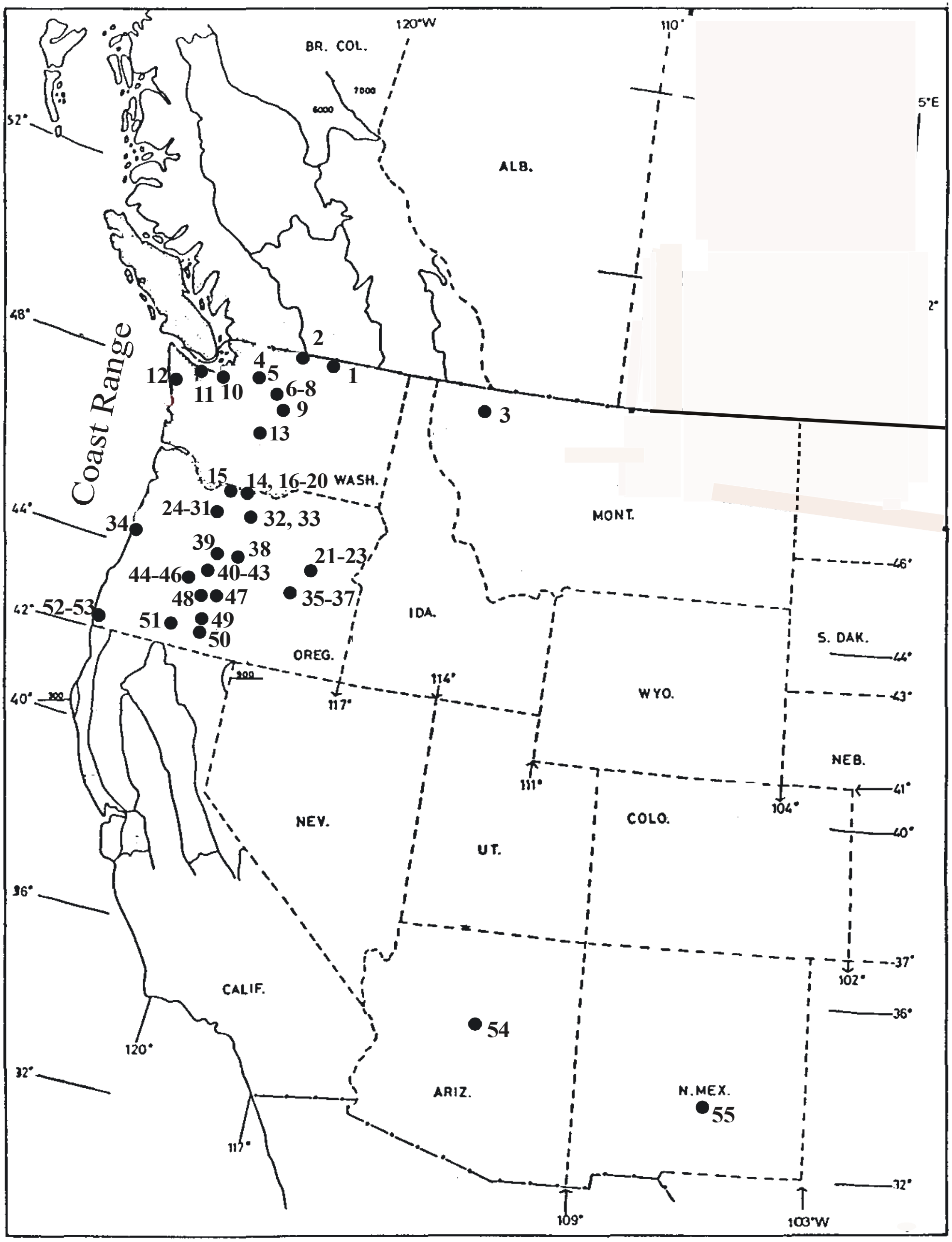

Fig. 1. Geographical location of Douglas-fir provenances (Georgieva 2009).

For each provenance, the coefficient of susceptibility to these pathogens was determined according of Chumakov`s formula No 4 (1974):

$$K = \frac{\sum (Q_n x P_n)}{N}, \qquad (4)$$

where: K is the coefficient of susceptibility; Q_n is the degree of crown defoliation (from 0 to 4); P_n is the number of trees by respective degree; N is the total number of the investigated trees.

Depending on the value of the coefficient of susceptibility (K), provenances were categorized as:

– resistant – with coefficient of susceptibility from 0 to 1;

– less susceptible – with coefficient of susceptibility from 1 to 2;

– medium susceptible – with coefficient of susceptibility from 2 to 3;

– very susceptible – with coefficient of susceptibility from 3 to 4.

Results and Discussion

The overall mean height at age 20 was 10.4 m, ranging from 4.7 to 13.3 m depending on the provenance. Coastal provenances had reached the greatest height, followed by Western Cascade and continental provenances. Western Cascade provenance 7 (Darrington) and coastal provenances 10 and 11 (Bremerton) (Fig. 2) demonstrated particularly rapid height growth. These provenances were also found to be the most rapidly growing in previous studies of the same provenance test (Iliev and Petkova 1995, Petkova 1999, Petkova 2004).

The slowest height growth was registered in the case of 10 continental provenances: 1 (Greenwood) and 2 (Keremeos), Washington, 3 (Whitefish), Montana, 21, 22, 23 (Bates), 35, 36, 37 (Canyon City), Eastern Oregon and 55 (Alamogordo), New Mexico. These provenances were evaluated as very susceptible to fungal pathogens *Rhabdocline pseudotsugae* and *Phaeocryptopus gaeumanii*, causing needle cast (Georgieva 2009). Diseases were detected on trees at age 17 and were observed until the trees reached age 20.

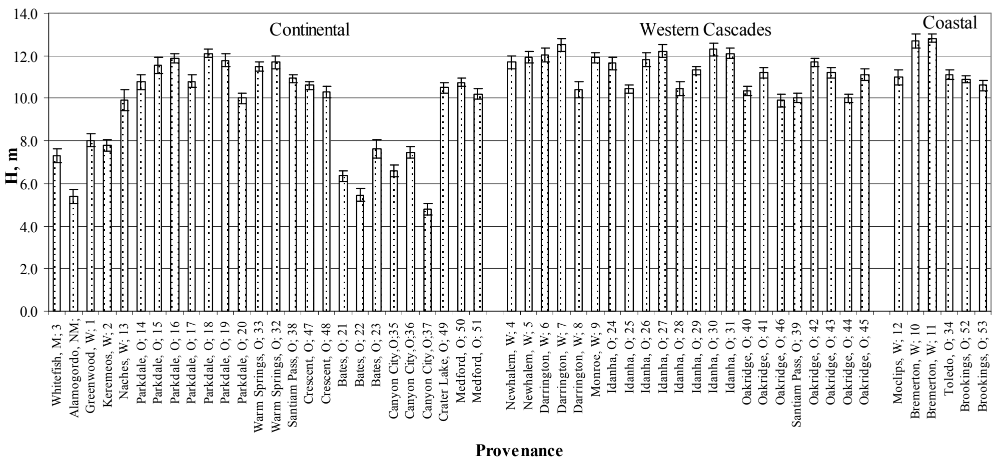

Fig. 2. Averrage height of 20-year-old Douglas-fir provenances planted at 1990 in Bulgaria.

Over the four years of observation, a decline was witnessed in the health status of this provenance group as the coefficient of susceptibility increased from 2.0 to 2.9. The main reason for the poor health status of these provenances was the combined development of the two fungi, *Rhabdocline pseudotsugae* and *Phaeocryptopus gaeumanii*. Most other provenances were attacked to a varying extent by *Phaeocryptopus gaeumanii* only (Georgieva 2009).

Results from studies of other provenance tests in Bulgaria using the same provenances (Popov 1995, Popov 2001) showed that the Washington coastal provenances (Bremerton and Moclips) and some of the Washington and Oregon Western Cascade provenances (Newhalem, Darrington, Monroe, Idanha, Oakridge) kept the best growth rate. These provenances were also characterized by very good growth in the provenance test subject to this investigation (Fig. 2), and in addition, they demonstrated very good resistance. The coefficient of susceptibility of provenances 7 (Darrington) and 43 (Oakridge) for the whole four-year observation period was 0.0. The other provenances were less affected by *Ph. gaeumanii* and were therefore categorized as less susceptible, with K = 0.2–1.6 (Georgieva 2009).

In testing the differences in height among provenance groups, when only 23 provenances were considered (the provenances being presented in 2 replications), the group effect proved not statistically significant ($p = 0.078$), however, it was statistically significant when all 54 provenances were included in the analysis ($p = 0.004$). The provenance effect was highly significant in both cases ($p < 0.001$). Replication effects were not significant (Table 1).

The average diameter of the provenance test at age 20 was 11.8 cm. With respect to this index, the highest values were again recorded on coastal provenances, followed by Western Cascade and con-

Table 1. ANOVA for the height.

Source of variation	DF	Mean squares	F-ratio	P-value
I. Number of provenances = 23				
Group effect				
Group	2	175.8	11.805	0.078
Replication	1	6.15	0.495	0.545
Provenance effect				
Provenance	23	72.224	23.166	<0.001
Replication	1	0.151	0.05	0.825
II. Number of provenances = 54				
Group effect				
Group	2	345.057	266.752	0.004
Replication	1	24.254	11.478	0.008
Provenance effect				
Provenance	53	78.136	20.529	<0.001
Replication	1	0.085	0.029	0.866

tinental provenances. The biggest average diameter was measured on Western Cascade provenance 7 (Darrington), 14.3 cm, and the smallest one, on continental provenance 37 (Canyon City), 4.7 cm. Testing the group, provenance and replication effect on diameter growth proved all effects as statistically significant (Table 2).

Table 2. ANOVA for diameter.

Source of variation	DF	Mean squares	F-ratio	P-value
Group effect				
Group	2	470.8	37.663	<0.001
Replication	1	996.2	79.45	<0.001
Provenance effect				
Provenance	53	181.9	7.11	<0.001
Replication	1	747.4	34.95	<0.001

For the entire provenance test, the average value of stem volume was 138.4 $m^3.ha^{-1}$. The highest stem volume was calculated for provenance 15 (Parkdale) – 223.2 $m^3.ha^{-1}$ and the lowest, for provenance 37 (Canyon City), only 4.5 $m^3.ha^{-1}$. The following provenances deserve particular attention, too: 5 (Newhalem), 6 and 7 (Darrington), 24 and 30 (Idanha) of the Western Cascade group and coastal provenances 10 and 11 (Bremerton). Their stem volume exceeded 200 $m^3.ha^{-1}$, which confirms the great potential and viability of these Douglas-fir provenances. The Darrington provenance has been reported as high-performing in the region of Sarajevo (Bosnia and Herzegovina) with a stem volume of 235 $m^3.ha^{-1}$ at age 37 (Ballian et al. 1999). In the Western Balkan Mountain, this provenance manifested better its growth potential since as early as age 20 its stem volume was 211 $m^3.ha^{-1}$, which is comparable to the volume achieved by the same provenance at almost double that age in Bosnia and Herzegovina. Along with its high performance, the Darrington provenance in the provenance test in this study was characterized by the highest resistance to the fungal pathogens *Rhabdocline pseudotsugae*, and *Phaeocryptopus gaeumanii*, as its coefficient of susceptibility for the entire four-year observation period was K=0.0 (Georgieva 2009). In the Western Balkan this provenance manifested itself in full growth potential, since at the age 20 its stem volume was 211 $m^3.ha^{-1}$, which is two times greater comparable to the same provenance at two times greater age in Bosnia and Herzegovina. Along with its high performance the provenance Darrington was characterized by the highest resistance to fungal pathogens *Rhabdocline pseudotsugae* and *Phaeocryptopus gaeumanii*, proven by the coefficient of susceptibility for the entire four-year observation period K=0.0 (Georgieva 2009).

The Darrington provenance was defined as very well growing by Günzl (1984), based on measurements and observations in multiple provenance tests in Austria. According to Rau (2005) Douglas-fir provenances of the Western Cascade were also characterised as particularly fast-growing in Hesse (Germany). Based on studies of 7 experimental Douglas-fir plantations in Germany, Kleinschmit et al. (1979) reported that Washington coastal provenances were the best according to a number of indicators.

Conclusions

1. The best growth parameters (height, diameter and stem volume) were found in the group of coastal provenances, followed by the Western Cascade group and the continental group.

2. The most rapidly growing provenances were the Washington coastal provenances (Bremerton), and the Darrington, Newhalem and Idanha provenances of the Western Cascades in Washington and Oregon. These provenances were characterized by high resistance to the fungal pathogens *Rhabdocline pseudotsugae* and *Phaeocryptopus gaeumanii*. For future afforestations with Douglas-fir in Bulgaria, Darrington provenances can be recommended as they combine rapid growth and high productivity with resistance to the fungal diseases.

3. The test revealed statistically significant effects of groups, provenances and replications with regard to growth in diameter and statistically significant differences between groups and provenances for growth in height.

4. The slowest growth and the lowest productivity were found in the continental provenances 1 (Greenwood) and 2 (Keremeos) of Washington, 3 (Whitefish) of Montana, 21, 22, 23 (Bates), 35, 36, 37 (Canyon City) of eastern Oregon and 55 (Alamogordo) of New Mexico, which also proved very susceptible to *Rhabdocline pseudotsugae* and *Phaeocryptopus gaeumanii* and should be excluded from future afforestations with Douglas-fir in Bulgaria.

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