Attempts in identifying the origin of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) stands in Germany

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Introduction

Douglas-fir is the most important introduced species in Germany. According to the forest inventory from 1986 to 1990, which included only the old Federal States, the area amounts to 119 520 ha (=1.6 %). However, the area varies considerably between the Federal States. Rhineland-Palatinate is the state richest in Douglas-fir; there, the species covers about 38 139 ha (=5.1%) of the forest area (Anonymous A.N., *loc. cit.* p. 48).

Douglas-fir has been planted in Germany for more than 120 years. Very successful plantations were established between 1881 and 1890. The exact origin has not been documented but it can be assumed that the collection area was the coastal region of Washington and/or northern Oregon. The nurseryman John Booth was notably very active in seed procurement. It is reported that the Prussian forest administration received 700 kg of Douglas-fir seed (Schwappach 1901). However, plantations established after 1891 frequently showed problems, and it was assumed that, at least partly, a different seed stock has been imported than in the decades before. In order to throw light into these problems the first provenance experiments were established in 1910 and 1912. Further provenance experiments followed in the ensuing decades (for a general view of German experiments see Schober, 1973). However, results from provenance experiments shall be mentioned here only as far as necessary to understand the reasons why several Federal States in Germany are at present interested in identifying the origin of their Douglas-fir stands. The provenance experiments showed that in most cases provenances from the coast range and western slopes of the Cascade Mountains have proved to be the best with regard to adaptation and quality, whereas those from the interior part of the distribution range frequently show high mortality and damage, indicating mal-adaptation.

For stands established between the two World Wars, seed stock of provenances both from the coastal and the interior race has been imported. These stands are now about 70 or 80 years old and could serve as seed collection stands. The imports continued after World War II, whereby a large amount came from interior sources, such as the Shushwap Lake region (British Columbia). According to a statistic of the Bavarian forest administration, about one third of Douglas-fir seed imported between 1965 and 1971 originated from interior provenances.

Damage symptoms became visible in the 1960s which frequently could not be associated with the impacts of damaging agents. In particular, the severe loss of needles was conspicuous. However, detailed observations revealed for example attack of the needles by the ascomycetous fungus *Rhabdocline pseudotsugae* H. Sydow (see Figure 1). Stephan (1973) described considerable differences between provenances in the susceptibility to this needle cast fungus in field experiments with ten to twelve year old trees. Whereas in 1972 not only the coastal, but also the northern interior provenances showed no infection, the situation changed in 1973–1974. In these years the degree of infection generally increased in the interior provenances; however, some of the northern ones still showed no or low infection.

Attacks by *Phaeocryptopus gaeumannii* (Rohde) Petrak, the second dangerous needle cast fungus of Douglas-fir, had not yet been detected in provenance field experiments between 1960 and 1980. Damages became more apparent from the 1980s onwards when stands had reached the second age class, i.e. they were between 20 and 40 years old. Symptoms in attacked stands are needle discolouration and yellowing, thin crowns as a result of needle cast, distorted growth characters, bark necrosis and resin flow.

Figure 1. Douglas-fir needles infected by *Rhabdocline pseudotsugae*. The light grey spots are naturally yellow to orange and in the final stage show a rust-like colour (Photo: B.R. Stephan)

As one possible reason to explain the damages the 'manganese toxicity theory' had been formulated (Schöne 1997), which concludes that a surplus of manganese in the soil contributes to an excess of manganese content in the needles, resulting in a deficiency in phosphorus and magnesium uptake. Indeed, trees showing high damage symptoms had higher manganese levels in the needles. However, this theory could not be verified in all cases. Fertilization experiments did not result in more damaged trees and sound stands or trees were also found on soils with a high manganese content. Thus, ensuing studies focused more on a genetic background, namely on the question of seed origin.

Stephan (1998) assessed the number of fungal fruit bodies of *Phaeocryptopus gaeumannii* on needles of 22-year-old trees in four consecutive years (1987 to 1990) on 31 provenances of the International Union of Forest Research Organizations (IUFRO) collection. The heaviest attack showed provenances from the interior part of British Columbia. Southern interior provenances were generally less attacked, and coastal provenances showed an intermediate degree of infection. Interestingly, the annual loss of needles did not correspond with the annual number of fruit bodies on the retained needles.

Silvicultural background

Several reasons have led to Germany's present interest in checking its stands and determining their probable region of origin:

- For about the past three decades, natural regeneration techniques have increasingly been applied in silviculture. As a consequence, less seed is needed, imports have decreased and the use of European Douglas-fir stands as seed source has gained importance.
- The majority of the original stands (old natural growth) in the Pacific Northwest, especially below 500 m a.s.l. has been cut. Therefore, the possibilities to collect in suitable stands are considerably reduced.
- The American tree seed certification scheme did and does not sufficiently fulfil European requirements and standards (Anonymous 1966, Fletcher *et al.* 1991). A national register comprising selected seed stands does not exist. For about 25 years, trade was carried out according to the OECD Scheme (OECD 1974) and only seed of the category 'source identified' was imported. However, Germany has experienced that sometimes interior provenances might have been declared falsely as coastal ones.

- Several older Douglas-fir stands in Germany might have been integrated into the national register of approved seed stands before damage became evident. However, in the meantime sanitary status may have changed making a check necessary.
- Finally, several older stands of proper origin have proved to be outstanding in provenance experiments (landrace development).

Forest administrations do not want further unsuitable material to be propagated. Additionally, many stands planted after World War II have now achieved an age of 40 or more years and can therefore be approved and registered as seed stands. Consequently, several Federal States of Germany, e.g. Rhineland-Palatinate, Northrhine-Westphalia, Thuringia and Hesse are investigating numerous Douglas-fir stands both with regard to their silvicultural suitability as well as to their affiliation either to the variety *Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii* (coastal race) or the variety *P. menziesii* var. *glauca* (Beiss.) Franco (interior race). This is done by using biochemical–genetic methods and by assessing phenotypic characters.

Isozyme studies

First results on range-wide patterns of allozyme variation in Douglas-fir have been published by Li and Adams (1989). They found different variation patterns for the coastal and the interior variety, and as well as for the northern and the southern part of the interior variety. In Austria and Germany, results from investigations on the variation of isozyme gene markers were published by Klumpp (1995) and Hoffmann and Geburek (1995). Due to the increasingly visible damage, comparative studies between damaged and healthy stands were also carried out in Germany (Leinemann 1996, 1998). The investigations are still going on in the Federal States of Rhineland-Palatinate (Leinemann and Maurer 1999), Northrine-Westphalia and Thuringia (Maurer *et al.* 2003; Schmitt *et al.* 2003).

In order to verify the differences between the coastal and the interior Douglas-fir races, eight provenances of each from the IUFRO collection were used as reference populations and analysed using isozyme techniques. The result was that at the gene locus 6-PGDH-A, the allele A3 occurs with high frequency in the coastal variety and low frequency in the interior variety (90% vs. 30%), whereas the reverse (4% vs. 60%) is valid for allele A6 (Figure 2) (Leinemann 1997). Variation ranges are not overlapping; therefore, the method is well suited to discriminate between the two varieties. Other isozyme loci, like ACO, also showed different allele frequencies but will not be further considered here.

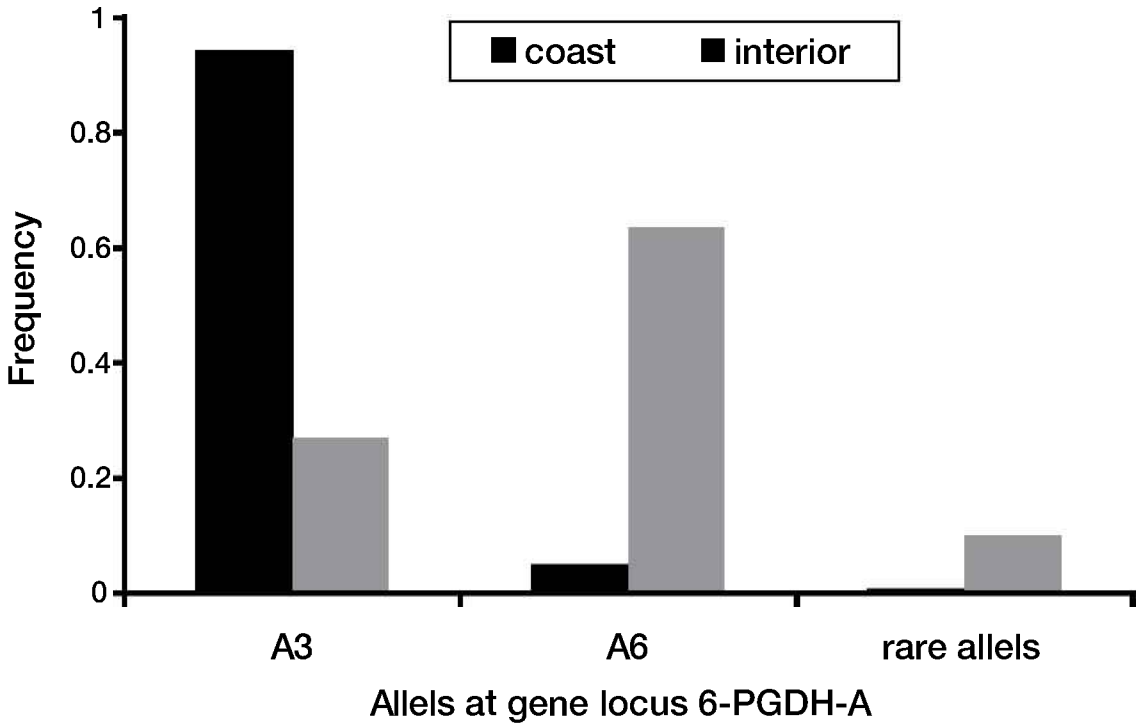

Figure 2. Mean frequencies of the alleles A3, A6 and rare alleles for the enzyme gene locus 6-PGDH-A for the coastal and interior race derived from 16 IUFRO provenances which served as reference populations (after Leinemann and Maurer 1999).

Two examples may illustrate the situation. The genetic profile of a stand with heavy damage symptoms (Dreis in Rhineland-Palatinate) shows high conformity to that of the reference profile of the interior variety (Figure 3). Consequently it can easily be associated with the interior race. However, in the past seed might have been mixed or some cultures with failed patches might have been completed by replanting with different provenances. Thus, a mixture of races might have resulted, as is assumed for the stand Mayen in Rhineland-Palatinate because it shows an intermediate profile. In this case the proportions belonging to the coastal and interior race, respectively, may be calculated by a formula developed by Bernstein (for details see Leinemann and Maurer, 1999). In the case of a mixed stand of good quality, Northrhine-Westphalia has decided to approve it as seed stand if at least 80 % of the trees belong to the coastal variety.

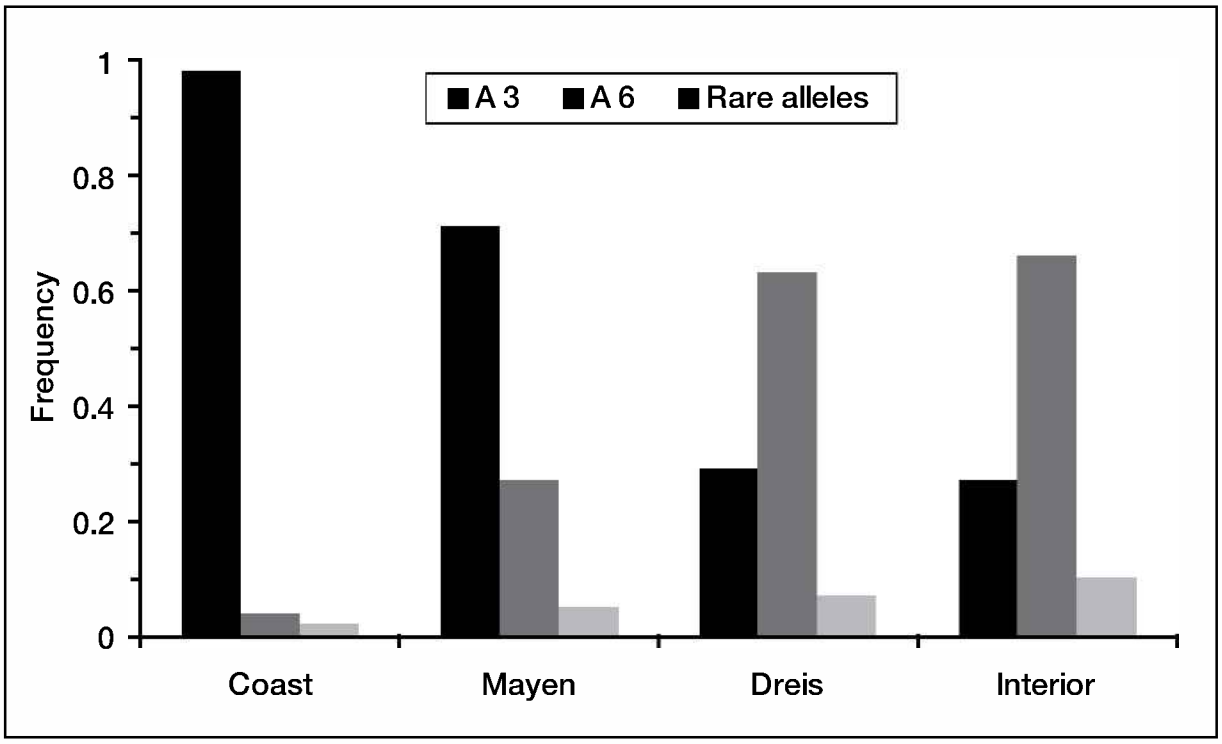

Figure 3. Genetic profiles of the coastal (left-hand columns) and interior race (right-hand columns) and two German Douglas-fir stands with regard to the 6-PGDH-A gene locus. The genetic structure of the ill stand Dreis conforms to that of the interior reference population. The genetic structure of the stand Mayen indicates a mixture of both races (after Leinemann and Maurer 1999).

Morphological characters for judging silvicultural suitability

The Federal State of Hesse based the valuation of silvicultural suitability of stands (for further propagation) on morphological traits. Rau (2002) described eight criteria which indicate mal-adaptation of a provenance:

- Needle discolouration
- Heavy needle cast (only one to two age groups on the branches)
- Heavy branchiness (extraordinary, many and notably thick branches in relation to stem diameter and growing space)
- Bad stem form (extraordinarily high proportion of trees with remarkable bends)
- Bark remarkably fissured and coarse, often grey and connected, with swellings and coarse branches
- Resin flow on the stem up into the crown which is not caused by artificial pruning
- Early and heavy fructification
- High losses after the establishment phase, even on sites well suited for Douglas-fir.

Figures 4–8 show examples of desired and undesired characters of Douglas-fir trees. Note that these examples cannot be considered in all cases to be representative for the provenance mentioned.

Figure 4. Douglas-fir stem with fine bark (IUFRO no. 1001, Stoner, BC) (Photo: E. Burchard).

Figure 5. Stem with undesired characters: bends, bumps and coarse, fissured bark (IUFRO no. 1031, Gold River, BC) (Photo: E. Burchard).

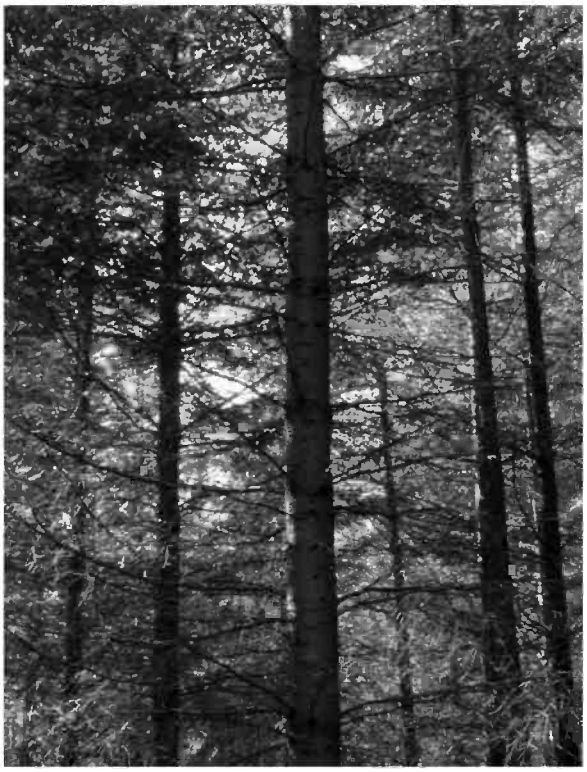

Figure 6. Douglas-fir originating from the Olympic Peninsula with fine branching in the forest district of Gahrenberg (Photo: Hessen-Forst, Forsteinrichtung, Information, Versuchswesen).

Figure 7. Heavy branching (IUFRO no. 1047, Concrete, WA) (Photo: E. Burchard).

Figure 8. Douglas-fir trees with good (left, IUFRO no. 1005, Williams Lake, BC) and bad (right, IUFRO no. 1018, Salmon Arm, BC) stem forms (Photo: E. Burchard).

Results

In Germany, the minimum legal requirements for a Douglas-fir stand to be approved as seed stand are, among others, an area of at least 0.25 ha, comprising at least 40 trees and an age of 40 years. Despite these requirements, most of the stands checked were larger than the minimum area. If smaller stands were included (as in Thuringia), and if they were identified as being of coastal origin, the intention was to select trees for seed orchards in these reduced populations. Hesse carried out its field inspections in stands larger than one hectare and included plantations younger than 40 years. Results of the study are summarized in Table 1.

Table 1. Studied Douglas-fir stands: summary data

Federal State	Criteria (area, age)	No. seed stands†	No. other stands‡	Area (ha)§	Interior origin¶
Rhineland-Palatinate	>0.25 ha, >40 years	38	17	~ 500	9%
Northrhine-Westphalia	>0.25 ha, >40 years, >50 trees/ha	91	39	~ 220	27%
Thuringia	–	23	12	20	16%
Hesse	>1 ha, >20 years	–	Total no. 555	~1200	115 stands

† Number of seed stands checked
‡ Number of other populations included
§ Total area of checked stands
¶ Percentage/number identified as populations of interior origin
– = no data available

Conclusions

Due to their excellent performance, numerous old European Douglas-fir stands can be considered as a very valuable genetic resource and should therefore be used for seed collections or for natural regeneration,

as long as their population size is in accordance with legal regulations. However, many stands have also been established using unsuitable provenances, mainly from the interior distribution range of the species. Damages which have not been registered at young ages may become serious at more advanced ages. Forest administrations attempt to avoid natural regeneration of these unsuited stands as well as their use as seed collection stands. In addition to the visual assessment of stands with regard to their performance and health, isozyme analyses have proved to be a valuable tool to discriminate between coastal and interior races. For pure stands, affiliation to one of the races is no problem. In the case of racial mixtures the proportions of trees belonging either to the coastal or interior race, can be estimated. An affiliation of individual trees to a race is not possible. Nevertheless, it must also be mentioned that in years favourable for the development of needle cast fungi, infections have also been observed in stands belonging to the coastal race. However, as a rule these stands recover in the ensuing years.

In recent years, several hundred stands have been checked with regard to their silvicultural suitability and their race affiliation. In this way, Germany is increasingly using genetic resources of Douglas-fir of approved value.

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