# Provenance Variation of Wood Density in Grand Fir (Abies grandis Lindley): An Indirect Assessment Using the Pilodyn

FORESTRY

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## ABSTRACT

Assessment of wood density using indirect method with the pilodyn was carried out on 33 provenences of grand fir (Abies grandis) grown at two Sites-Wark and Drummond Hill in Britain. Initial evaluation to determine the need for multiple readings on individual trees produced repeatability value of 0.74 suggesting that a single measurement will suffice. A two-way nested ANOVA model on provenance variation indicated highly significant differences between provenances and sites. The site with a high potential for growth, Drummond Hill, produced wood of relatively lower density than Wark. This suggested that site characteristics may be a limitation on the production of high density wood in grand fir. However, the provenances 12002 and 12042 have comparatively higher wood density irrespective of the site on which they are grown.

Keywords: Wood density, pilodyn, grand fir, provenance.

## INTRODUCTION

Provenance is the ultimate natural origin of a seedlot or the geographic source of seed, plant material or plants from a specific geographic source [1, 2]. The objective of provenance testing in forestry is to locate provenances that will yield seed to produce well adapted and productive forests [3]. Forest productivity may be defined in terms of the density of wood produced. In solid wood products, the strength properties are generally positively correlated with wood density. Similarly, pulp yields and quality are related to this trait. Thus the assessment of wood density assumes greater importance in the search for suitable provenances.

The conventional methods of assessing wood density through the extraction of increment cores or the use of x-ray scanning techniques, though highly accurate are time consuming, expensive and do not facilitate the rapid screening of the density of a large number of genotypes in a provenance trial. A method that is relatively less accurate but allows the rapid determination of wood density in the field is the use of the pilodyn. This is a hand-held instrument that measures wood density indirectly in the outer rings of standing trees. It injects a spring-loaded striker pin into the tree. The depth of pin penetration in millimetres which is inversely proportional to the outerwood density is read off a calibrated scale on the body of the instrument (Fig. 1).

The accuracy of the pilodyn as an instrument for the assessment of wood density has been established [4, 5]. Outerwood density measured by the pilodyn significantly correlates with outerwood density measured by conventional wood density determination methods in many species. For instance, in Pinus radiata, Pinus taeda and Picea glauca the following significant correlation have been reported: -0.96, -0.81 and -0.83 respectively [4,5,6]. Similarly a high correlation has been reported between pilodyn measurements and whole tree density in Pinus elliotii and Picea sitchensis [7, 8]. The number of pilodyn measurements that need to be taken in order to improve upon the accuracy of pilodyn wood density estimates appear to depend on the species. While single measurements per tree may be sufficient for some species, multiple measurements may be needed in others [5,6,7,9]. Therefore in the use of the pilodyn to assess wood density for any particular species, it may be necessary initially to determine the need for taking multiple readings.

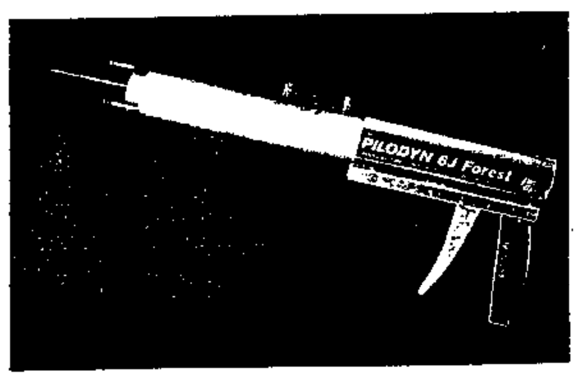


Figure 1. The pilodyn: showing the body of the instrument and the pin

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Table 1: Details of grand fir (A. grandis) provenances

| Prov. ID | Group | Location | Lat(oN) | Long (oW) | Alt(m) | Number of trees samples |
|---|---|---|---|---|---|---|
| 12001 | 1 | Darrington, Wa | 48 16' | 121 21' | 400 | 25-30 |
| 12002 | 1 | Tulalip, Wa | 48 05' | 122 16' | 30 | 20 |
| 12003 | 1 | Elwha, Wa | 48 04' | 123 38' | 140 | 18 |
| 12004 | 1 | Sequim, Wa | 48 04' | 122 54' | 30 | 20 |
| 12005 | 1 | Louella, Wa | 47 59' | 123 02' | 825 | 25+ |
| 12049 | 1 | Shelton, Wa | 47 11' | 123 07' | 40 | 25 |
| 12051 | 1 | PeEll, Wa | 46 38' | 123 15' | 125 | 20+ |
| 74(7973)5 | 1 | Louella, Wa | 47 55' | 123 05' | 600 | - |
| 12006 | 2 | Leavenworth, Wa | 47 41' | 120 34' | 760 | 20 |
| 12007 | 2 | Leavenworth, Wa | 47 39' | 120 34' | 1200 | 20 |
| 12008 | 2 | Cle Elum, Wa | 47 20' | 120 50' | 825 | 20 |
| 12009 | 2 | Cliffdell, Wa | 46 55' | 121 15' | 945 | 21 |
| 12011 | 2 | Clear Lake, Wa | 46 37' | 121 20' | 945 | 19 |
| 12012 | 2 | Trout Lake, Wa | 46 07' | 121 39' | 945 | 16 |
| 12013 | 2 | Parkdale, Wa | 45 27' | 121 39' | 1040 | 20 |
| 12024 | 3 | Usk, Wa | 48 17' | 117 16' | 650 | 16 |
| 12016 | 4 | Santiam Summit, Ore | 44 26' | 121 52' | 1400 | 19 |
| 12018 | 4 | Bend, Ore | 43 59' | 121 39' | 1500 | 20 |
| 12020 | 4 | Crescent, Ore | 43 28' | 121 57' | 1375 | 30 |
| 12034 | 5 | Dump Creek, Id | 45 50' | 116 01' | 1190 | 7 |
| 12015 | 6 | Sisi Butt, Ore | 44 52' | 121 48' | 975 | 30 |
| 12019 | 6 | Box Canyon, Ore | 43 53' | 122 01' | 1310 | 30 |
| 12021 | 6 | Prospect, Ore | 42 56' | 122 23' | 1160 | 30 |
| 12040 | 7 | Sayward, BC | 50 20' | 125 56' | 25 | 22 |
| 12042 | 7 | Courtney, BC | 49 31' | 124 52' | 45 | 20 |
| 12043 | 7 | Port Alberni, BC | 49 18' | 124 58' | 25 | 22 |
| 12045 | 7 | Nanaimo, BC | 49 03' | 123 46' | 30 | 20 |
| 12047 | 7 | Sooke, BC | 49 22' | 123 47' | 20 | 20 |
| 74(2002) | 7 | Craigvinean, Scot | 50 00' | 125 25' | 0-150 | - |
| 12052 | 8 | Pittsburgh, Ore | 45 56' | 121 10' | 275 | 20 |
| 12053 | 8 | Dallas, Ore | 43 07' | 123 23' | 260 | 12 |
| 12056 | 9 | Norway, Ore | 43 07' | 124 09' | 60 | 20 |
| 12057 | 9 | Gold Beach, Ore | 42 28' | 124 24' | 45 | 21 |

***Legend to Abbreviations:***

*Prov ID - Provenance identification number. BC - British Columbia; Lat - Latitude of provenance origin*
*Scot - Scotland, Long - Longitude of provenance origin; Alt - Altitude of provenance origin;*
*Wa - Washingon; Ore - Oregon; Id - Idaho*

Grand fir (Abies grandis Lindley) is a species whose natural range occurs between latitude $39^{o}$N - $51^{o}$N and longitude $114^{o}$W - $125^{o}$W in north America (Fig. 2). Rangewide provenance trials of the species were initiated by IUFRO (International Union of Forest Research Organizations) in Europe to determine the adaptability and productivity of the species. Grand fir generally has low wood density. Growing in-situ wood density estimate of 445 $kgm^{-3}$ has been reported [10]. As an exotic in Britain the nominal specific gravity was estimated as 0.31 [11]. Because of its generally low wood density, the utilization of provenances with relatively higher wood density will be of importance. Because of the wide geographic range, selection of provenances could take advantage of provenance variation in wood density. The objectives of this paper based on grand fir plantations in Britain are:

1. To assess provenance variation of wood density in grand fir using the pilodyn.
2. To determine the necessity of taking multiple pilodyn readings to improve accuracy

in using the pilodyn to assess wood density in grand fir.

# MATERIALS AND METHODS

## Experimental Materials

The experimental material consists of thirty-three provenances of grand fir. Thirty-two of these were sampled from the range of the species, while one provenance is a land race that has undergone a generation of adaptation in Britain. The sampling methodology used in the collection of provenances has been discussed [12]. The details of the provenances with their locations of latitude, longitude, altitude and number of trees sampled are presented in Table 1. The provenances are classified into nine groups which are based on the major vegetational zones within the range of the species [13].

## Experimental Sites

The provenance trials of grand fir were established on twelve sites in Britain (Fig.3). This study covers two of these sites namely Wark and Drummond Hill, both of which are experimental sites of the British Forestry Commission. The sites were chosen because of the differences in soils, site exposure and the growth per-

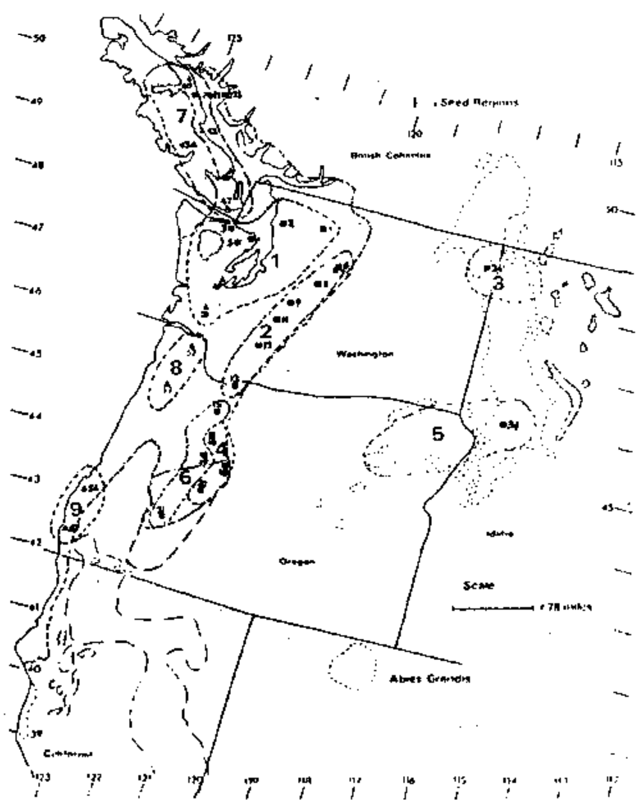

Fig. 2: Map showing the locations of grand fir (A.grandis) Provenance groups within the range of the species.
N.B.: Provenance identification number (PROV ID) prefix 120 - omitted from the map.

formance of grand fir from earlier assessments [14]. The site conditions are summarized in Table 2.

## Experimental Layout

The provenances were planted in 1979 and were laid out in three randomised blocks on each site using seedlings of the experimental material presented in Table 1. Within a block each provenance is represented by 25(5 x 5) trees at a spacing of 2 metres in a square plot.

Table 2: Details of two experimental site with grand fir provenances trials.

| Detail | Site: Wark | Site: Drum |
|---|---|---|
| Grid reference | NY 799786 | NN 713408 |
| Latitude | 55° 1[illegible]N | 56° 54'N |
| Altitude (m) | 201 | 200 |
| Longitude | 02° 34'W | 04° 10'W |
| Rainfall (mm/yr) | 1016 | 1270 |
| Soil Type | Peaty gley | Surface water gley |
| General Topography | Even sloping ground with slight undulations | Concave sloping ground with slightly sloping terraces |
| Length of growing season (days) | 176 | 176 |
| Exposure | Moderate | Sheltered. |
| Vegetation | Mainly *Molinia caerulea* with patches of *Juncus* species and other minor species | Various species of grasses, *Carex sp., Juncus sp., Pteridium sp., Hieraciu sp., Campanula rotundiflora, Ranunculus sp. and Stellaria sp* |

# DATA COLLECTION

To meet the objectives of this paper two sets of data were collected. Firstly, eighty trees on provenance plots boundaries were randomly selected. On each of these a 6 Joule pilodyn with a 2.5mm needle was used to make two opposite readings at breast height. Readings were made to the nearest 0.5mm.

Secondly, a single underbark pilodyn measurement was made on the inner 9(3 x 3) trees of each provenance plot. The measurements were made in April 1992.

# STATISTICAL ANALYSIS

For each provenance plot the mean pilodyn penetration value was calculated and subsequently used in further analyses. To determine the necessity of making multiple pilodyn measurements in grand fir, the repeatability as represented by the intraclass correlation of the measurements made on the eighty trees was calculated. A high intraclass correlation (r _ 0.5) would imply that multiple readings are not necessary [15]. The intraclass correlation is derived from the relationship:

$r = A^2 / A^2 + B^2$ [15] where

$r$ = intraclass correlation

$A^2$ = between trees variance

$B^2$ = within tree variance

where $A^2 = B^2 + 2 A^2$, the coefficient of the between tree variance component arising from the fact that two readings were taken on each tree [15].

To extract the variance components, the analyses of variance model shown below was used to analyse the data.

$Y_{ij} = m + A_i + E_{ij}$ [16] where

$Y_{ij}$ = the $j^{th}$ item of the $i^{th}$ pilodyn penetration value group.

$m$ = the parametric mean.

$A_i$ = the random contribution of the $i^{th}$ pilodyn penetration value group, and

$E_{ij}$ = the error term of the $j^{th}$ item of the $i^{th}$ pilodyn penetration value group.

The pilodyn measurements made on the provenances were analysed using a nested ANOVA model shown below. The hierarchic arrangement for the provenances were Population/Group/Provenance. Where population consisted of all the provenances in a block, and nested within this population were a number of provenance groups and subsequently nested in the groups were individual provenances. The model which is a two-way mixed model facilitates the examination of the contribution of the levels of the hierarchy as well as the interaction with site.

$Y_{ijklm} = u + a_i + b_{ij} + c_{ijk} + d_{ijkl} + (ac)_{ijkl} + (ad)_{ijkl} + e_{ijklm}$

where:

$Y_{ijklm}$ = $m^{th}$ item of the $l^{th}$ provenance in the $k^{th}$ group of the $j^{th}$ block of the $i^{th}$ site. [16].

$u$ = the parametric mean of the population.

$a_i$ = fixed treatment effect of the $i^{th}$ site.

$b_{ij}$ = random treatment effect in the $j^{th}$ block of the $i^{th}$ site.

$c_{ijk}$ = fixed treatment effect of the $k^{th}$ group in the $j^{th}$ block of the $i^{th}$ site.

$d_{ijkl}$ = random treatment effect of the $l^{th}$ provenance of the $k^{th}$ group in the $j^{th}$ block of the $i^{th}$ site.

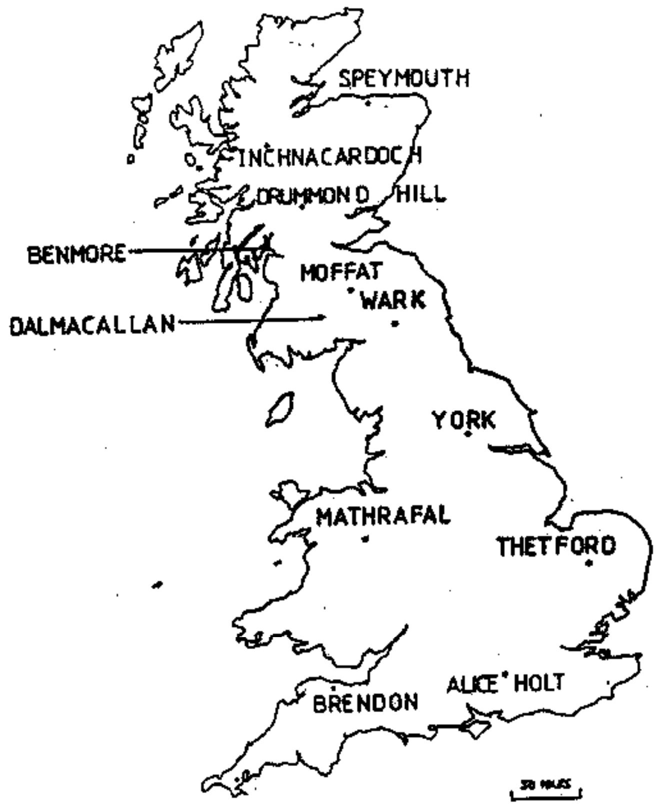


Fig. 3: Map showing Wark and Drummond Hill and 10 other sites on which the grand fir (Abies grandis) provenance experiments have been planted.

Table 3. Results of ANOVA for pilodyn penetration 80 grand fir trees

| Source of Variation | DF | SS | MS |
|---|---|---|---|
| Tree | 79 | 878.736 | 11.12 |
| Residual | 80 | 135.357 | 1.69 |
| Total | 159 | 1014.093 | |

$(ac)_{ijk}$ = interaction between the $i^{th}$ site and the $k^{th}$ group in the $j^{th}$ block.

$(ad)_{ijkl}$ = interaction between the $i^{th}$ site and $l^{th}$ provenance of the $k^{th}$ group in the $j^{th}$ block.

$e_{ijklm}$ = error term of the $m^{th}$ item of the $l^{th}$ provenance of the $k^{th}$ group in the $j^{th}$ block of the $i^{th}$ site.

## RESULTS

The results of the ANOVA for the extraction of variance components to calculate the intraclass correlation is presented in Table 3. The intraclass correlation (r) is thus calculated as:

$$r = 4.7155/4.7155 + 1.692 = 0.736$$

The results of the ANOVA examining variation between provenance groups and sites is presented in Table 4. The usual ANOVA table has two additional variance component percentage (V€%) columns which refer to the percentage variance explained by the indicated source of variation.

The results indicate highly significant differences between provenances, blocks within sites and sites. The interaction term partitioned into site, provenance group interaction and site, provenance within group interaction is not significant. The means of the pilodyn values for the provenances are presented in Table 5.

## DISCUSSION AND CONCLUSION

The high repeatability value of 0.74 as measured by the intraclass correlation suggests that multiple pilodyn measurements for the indirect assessment of wood density in grand fir (A. grandis) is not necessary. A single reading will provide reasonably accurate estimate. This finding is in agreement with work done on Pinus elliotii [7]. As a rule needle penetration readings varied within 1mm of each other which agrees with work done on Pinus taeda [9].

The pilodyn values range from 15.49mm - 19.47mm at Wark and 15.63 - 19.57mm at Drummond Hill. On both sites provenances 12042 and 12051 had the lowest and highest pilodyn values respectively. It therefore appears that 12042 is a provenance with an inherently higher wood density while 12051 had a lower wood density. A millimetre difference in pilodyn measurements may represent a large difference in wood density. For example in Pinus radiata, 1mm difference in pilodyn measurements is reported to represent a difference of $20kg/m^3$ in wood density [4]. Generally, pilodyn values are higher at Drummond Hill than at Wark. Grand fir has a higher growth performance at Drummond Hill [14], suggesting that faster growth rates appear to result in the production of low density wood. This is in agreement with an observation that faster growth in the species tend to result in wood of lower density [17].

The results however tends to disagree with a suggestion that slower growing provenances may yield wood of high density [14]. Provenances in groups 4 and 6 are for example, slow growing, but the pilodyn values are relatively higher, particularly at Drummond Hill. To the

**Table 4: Results of ANOVA for pilodyn penetration in 33 provenances of grand fir.**

| Source of | DF | SS | MS | VR | SIG | VIC(%) | VC(%) |
|---|---|---|---|---|---|---|---|
| Bock | 4 | 32.42 | 8.11 | 7.05 | 0.01 | 15.17 | 16.83 |
| Group | 9 | 50.96 | 5.66 | 1.32 | ns | 10.59 | |
| Group Provenance | 23 | 98.33 | 4.28 | 3.72 | 0.01 | 8.0 | |
| Prov. | 32 | 149.28 | 4.67 | 4.06 | 0.01 | - | 9.68 |
| Site | 1 | 31.53 | 31.53 | 27.42 | 0.01 | 58.98 | 65.43 |
| Site *Grp¹ | 9 | 12.99 | 1.44 | 1.25 | ns | 2.70 | 3.00 |
| Site * (Grp (Prov.)¹ | 23 | 29.72 | 1.29 | 1.12 | ns | 2.42 | 2.68 |
| Plot | 128 | 146.75 | 1.15 | | | 2.14 | 2.38 |
| Total | 197 | 402.71 | | | | 100 | 100 |

1 Grp = Group    Prov = Provenance

**Table 5: Mean Pilodyn Measurements (mm) of 33 Grand Fir Provenances at Wark and Drummond Hill**

| Prov. ID | Group | Site | |
|---|---|---|---|
| | | Wark | Drummond Hill |
| 12001 | 1 | 16.07 | 17.96 |
| 12002 | 1 | 16.22 | 16.44 |
| 12003 | 1 | 17.30 | 18.15 |
| 12004 | 1 | 16.23 | 17.77 |
| 12005 | 1 | 17.13 | 16.67 |
| 12049 | 1 | 16.63 | 18.66 |
| 12051 | 1 | 19.47 | 19.57 |
| 74(7973)5 | 1 | 17.53 | 18.69 |
| Mean | | 17.07 | 17.99 |
| 12006 | 2 | 16.54 | 16.24 |
| 12007 | 2 | 17.52 | 17.11 |
| 12008 | 2 | 16.52 | 16.43 |
| 12009 | 2 | 16.44 | 16.87 |
| 12011 | 2 | 16.07 | 18.00 |
| 12012 | 2 | 16.68 | 18.81 |
| 12013 | 2 | 16.10 | 17.55 |
| Mean | | 16.55 | 17.29 |
| 12024 | 3 | 17.45 | 17.43 |
| 12016 | 4 | 16.64 | 16.72 |
| 12018 | 4 | 18.20 | 18.81 |
| 12020 | 4 | 17.14 | 17.47 |
| Mean | | 17.36 | 17.67 |
| 12034 | 5 | 17.88 | 17.94 |
| 12015 | 6 | 18.29 | 19.20 |
| 12019 | 6 | 16.66 | 18.79 |
| 12021 | 6 | 16.96 | 19.37 |
| Mean | | 17.31 | 19.12 |
| 12040 | 7 | 18.13 | 18.1[illegible] |
| 12042 | 7 | 14.55 | 1[illegible].63 |
| 12043 | 7 | 16.83 | 17.38 |
| 12045 | 7 | 15.96 | 16.22 |
| 12047 | 7 | 16.87 | 17.24 |
| Mean | | 16.38 | 16.92 |
| 12052 | 8 | 18.30 | 18.34 |
| 12053 | 8 | 16.61 | 18.03 |
| Mean | | 17.45 | 18.18 |
| 12056 | 9 | 15.49 | 17.21 |
| 12057 | 9 | 15.69 | 17.42 |
| Mean | | 15.59 | 17.32 |
| 74(2002) | 10 | 16.22 | 17.74 |

contrary provenances 12002 and 12042 are faster growing provenances with lower pilodyn values and hence apparently high wood density. Thus selection should be based on growth performance and inherent ability of provenances to produce high density wood.

The study has indicated that multiple reading on individual trees are not necessary in using the pilodyn to rapidly evaluate wood density in grand fir. There is variability in the pilodyn values of grand fir provenances, suggesting that there is variation in wood density at the provenance level. Growing the species on a site with high potential for growth will result in the production of low density wood, however, some provenances will have high wood density irrespective of the site on which they are grown.

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