Prediction of knot diameter in *Picea abies* (L.) Karst

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Knot diameters were measured in 60 trees of *Picea abies* (L.) Karst. from three different site indexes in southeastern Norway. Ten branch whors were sampled from each tree, and diameters of all the knots were measured at the radial stem plane. Knot diameter was evaluated as mean diameter of the two thickest knots in each sample whorl. The whorl with the maximum value in each tree was on average located at 30% of tree height at G11, 40% at G17 and 60% at G23. The vertical location was related to the position of the crown base, and single tree models for predicting the position and the value were constructed. Knot diameter in the butt log, i.e. in the lower 30% of tree height, was related to annual ring width and site index, and to diameter at breast height and site index.

1 Introduction

The quality of Nordic softwood timber has commonly been regarded as superior to that of central European timber. This is attributed to the fact that the current softwood timber stock in temperate Europe usually grows more rapidly and is more heavily branched and crooked than in northern Europe (Verkasalo and Leban 1996). Softwood timber in Norway is traditionally grown on low productive sites and timber from these forests is characterised by straight stems, low taper, narrow annual rings, large wood density and a high level of strength properties. During the past few decades silviculture of *Picea abies* in Norway has gradually changed from selective cutting, followed by natural regeneration to clear cutting and planting. This change has been motivated by the financial gain obtained by earlier realisation of money invested in planting and by more efficient harvest methods.

The forest area with *Picea abies* has increased. Most of the new areas are either in western Norway or on abandoned agricultural land. What is common to these new areas is that the soil is often more fertile than the traditional forest land. An increasing part of Norwegian *Picea abies* timber delivered to the sawmills is produced by this new kind of forestry on fertile land. An increasingly variable wood quality is observed. Due to the increasing demand for high quality softwood timber, it has become necessary to place more emphasis on wood quality both in silviculture and in the utilisation of wood.

Normally there is large variation in growth among trees in a stand of Norway spruce. This is on one hand due to genetic differences between trees and on the other hand to local variation in growth conditions. This variation in growth is correlated with large variation in wood properties. Earlier studies have shown large tree-to-tree variability in wood properties within stands at fertile sites (Haibø 1991). This makes stand models insufficient, and single-tree models, taking measurable properties on each single tree into account, are required. Such models are useful for the quality assessment of forest resources and for predicting the effect of silvicultural treatments on wood quality.

Knots are one of the main defects in softwood timber. According to Nordic grading rules for structural timber (Anonymous 1997), the knot size is of main importance, since large knots are associated with large grain distortions, which in turn reduce the strength of the wood (Kollmann and Côté 1968).

Knots are occluded branches. The diameter of a knot at a radial distance from the pith is determined by radial

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growth rate of the branch while it is alive and by the lifespan of the branch. In a study of *Pinus resinosa* ait. Forward and Nolan (1961a, b) found that in the upper part of the tree, where the crown was not severely shaded, both longitudinal and radial growth patterns of the branches were similar to that of the stem. In the lower part of the crown where shading was more severe, the growth of the branches was heavily suppressed. This implies that a relationship between the size of the knots and the radial growth of the stem during the period in which the knots were formed can be expected.

Stem and branch growth are both affected by stand density. In a stand with low density, trees will develop longer and thicker branches compared to trees in a more densely spaced stand (Grah 1961; Braastad 1979; Abetz and Unfried 1983; Handler 1988; Johansson 1992; Petersen and Spellmann 1993; Deleuze et al. 1996). Within even-aged stands of *Picea abies* branch diameter in the lower part of a stem is related to diameter at breast height (Braastad 1979; Moltesen et al. 1985; Johansson 1992).

The above mentioned studies all consider branch diameter at different height intervals in the lower part of the stem. Branch diameter of *Picea abies* increases upwards in the lower part of the stem (Braastad 1979, Abetz and Unfried 1983; Handler 1988; Colin and Houllier 1991, Bues 1996) and the maximum branch diameter of a tree is found in the lower part of the living crown (Colin and Houllier 1991). Uusvaara (1975) found the thickest branches of *Pinus sylvestris* to be located at 60% of tree height for trees older than 50 years and at 40% of tree height for trees younger than 30 years. Complete vertical profiles of branch diameter have been reported for *Picea abies* (Colin and Houllier 1991) and for *Pseudotsuga menziesii* (Maguire et al. 1994).

Björklund (1997) analysed the vertical variation in knot diameters of *Pinus sylvestris* and divided the stems into four sections; i.e. establishment section, constant growth section, retardation section and crown section. The constant growth section was characterised by a constant level of maximum knot diameter of the whorls. Petersson (1998) found that the mean of the maximum knot diameter of the whorls in this section could be predicted from annual ring width and latitude.

The aims of this study are: i) to describe the vertical variation in knot diameter within trees and to locate the position of the whorl with the thickest knots in the tree, ii) to find single tree predictors of this position and its value and iii) to find single tree predictors of the knot diameter below the lowest living branch where the knots have reached their maximal size.

### 2 Materials and methods

The study was based on 60 trees from 6 sites in south-eastern Norway. The site indexes, defined as dominant height at 40 years age (Tveite 1971), were G11, G17 and G23. There were two replicates of each site index. One of the sites at G17 had a slope, while the others were nearly level. The two sites with site index G23 had been planted while the origins of the other sites were unknown. Most probably they were naturally regenerated. Based on stand records, sample trees were selected from stands which had not been thinned since large variation in breast height diameter was desired. The two stands at G11 might have been subject to selective cuttings which used to be a common practice.

Within each stand the diameter at breast height of 100 trees within a concentrated area was recorded. The trees were divided into five classes according to diameter at breast height, with an equal number of trees in each group. Then two trees were chosen at random within each group. This gave a total of 60 sampled trees, 10 from each site. The recorded whole tree measurements were diameter at breast height over bark (DBH), total height (H), height to the lowest living branch (HLLB) and height to the base of the living crown (HBLC), defined as the lowest whorl with at least 3/4 of the branches still alive. Age and annual ring widths were measured from increment cores at breast height. All the parameters used in the study are defined in Table 1, and mean, standard deviation, minimum and maximum values of the whole tree, attributes of the sample trees, are given separately for each site in Table 2.

From each tree 10 branch whorls were sampled. The lowest one as close to the stump as possible, then the one closest to each 10% of the total height upwards. All the knots in the sample whorls were measured using the method proposed by Koehler (1936). The knots were split in the centre in the radial stem plane, using an ordinary band saw. Knot diameter was measured with 1 mm accuracy at normal angle to the knot axis just inside the bark for sound knots and at the border between sound and dead knots for dead knots (Fig. 1). This border was defined

| Table 1. Notation and definition of the variables used in the paper |
|--------------------------------|-------------------|
| Variable | Definition |
| **Tree-level variables** | |
| DBH | Diameter at breast height over bark (cm) |
| H | Total height (m) |
| AGE | Age at breast height (years) |
| HBLC | Height to the base of the living crown; i.e. where at least 3/4 of the branches are alive (m) |
| HLLB | Height to the lowest living branch (m) |
| CLBLC | H-HBLC (m) |
| CLLLB | H-HLLB (m) |
| CRBLC | CLBLC/H (proportion of H) |
| CRLLB | CLLLB/H (proportion of H) |
| ZRLC | Relative distance from top of the tree (proportion of CLBLC) |
| ZRLBLC | Relative distance from top of the tree (proportion of CLLLB) |
| a-b | Mean annual ring width of the annual ring interval a-b at breast height (mm); a and b denotes annual ring number from the pith (mm) |
| Max(2Maxkdw) | Maximum value of 2Maxkdw in each tree (mm) |
| **Whorl-level variables** | |
| 2Maxkdw | Mean diameter of the two thickest knots in a whorl (mm) |