Stem and wood quality assessment in national forest inventories

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Introduction
The first national forest inventory (NFI) of Flanders (Northern Belgium) was carried out in the period 1997-1999, measuring 3074 concentric circle plots in forested areas on a regular 0.5x1km sample grid. Since quality timber is an important forest resource, the inventory also included a tree quality assessment, assigning a quality class to each of four equal-volume stem sections of living sample trees with DBH larger than 7cm. Quality classes range from ‘A’ (straight stem section, no branches, low taper, fine bark, round cross-section, DBH at least 48cm) to ‘D’ (stem section with heavy branches or curved, forked, with damage of any type), with ‘B’ and ‘C’ defining intermediate quality requirements (Waterinckx & Roelandt 2001). The used methodology for tree quality assessment used in the Flemish NFI was inspired by similar designs in Austria, the Slovak republic and France (e.g. Schieler & Hauk 2001). Although the resulting tree quality statistics are among the most detailed available in Europe, they did not respond to stakeholders expectations and hence remained largely unused. This stresses the need for a thorough methodological revision of tree quality assessment before the start of the second NFI. The evaluation process involved three consecutive steps, which are briefly presented in this paper: (1) defining the policy questions underlying the data need from NFI, (2) evaluating the used methods for tree quality assessment in view of these policy questions and (3) proposing a framework for tree quality assessment in the second NFI, based on lessons learned from first NFI.

Post-hoc definition of policy needs
NFI is an inventory and monitoring instrument for policy and management, so the information should be gathered in function of specific needs and (inter)national reporting obligations. Only when the NFI is designed to test specific hypotheses that are relevant to policy and management questions, will it be successful (Noss 1990). Policy questions concerning tree quality had however not been clearly defined prior to the first NFI. In the course of 2007 and 2008 several meetings and interviews were organised with the forest administration and various stakeholders of the forest-wood chain (from forest management to wood industries) to discuss the need for tree quality assessment in the Flemish NFI (Wouters et al. 2008, Wieland et al. 2008). From these discussions, three main policy questions (PQ) could be distinguished for which tree quality assessment is thought to be a necessary input.

1. A first PQ concerns the feasibility of implementing new wood selling strategies in Flanders. Most timber in Flanders is sold as standing trees, often with trees of different dimensions and qualities in one lot. This system fits the historical Flemish context of small-scale forestry for bulk production, but makes it difficult to market high-quality timber. The NFI should provide the necessary resource inventory for an economic feasibility study on alternative methods.
2. A second PQ is about meeting future industry needs. Many wood processing industries fear the continuous supply of sufficient resources that meet their specific quality requirements. The
NFI should provide the basis for 20-30-year projections of wood availability for different industries, through the input of current age-class distributions (projected under different scenarios of land use change and management) and the relation between age and stem quality.

3. A final PQ focuses on the development of empirical models of wood quality as a function of environmental characteristics and stand structure. On the one hand such models could serve to deduce guidelines on site selection and management for specific wood quality targets. On the other hand policy makers could evaluate the possible impacts on wood quality of policies aiming at large scale forest structural changes (such as forest conversion). The NFI, with its vast network of sample plots, should provide the input for the development of solid models.

**Evaluation of stem quality assessment in the first NFI in view of the policy needs**

**PQ1: resource inventory for feasibility study on high-quality timber marketing.** Two main problems are observed, both linked to the use of quality classes:

- Classes (‘A’ to ‘D’) are poorly defined: (i) There is no differentiation between species, making the DBH threshold for A-class very difficult to reach for e.g. pine stands. (ii) The vague definition of some criteria (e.g. branchiness) has lead to an observable bias between inventory teams. (iii) Important quality criteria are not included in the class definition, such as occluded branches or any indicator of internal wood quality. (iv) Definitions of quality requirements differ substantially between countries.
- Classes are difficult to interpret in terms of wood quality and use: (i) They cannot be interpreted as a quality scale, since stem sections being ranked as ‘B’ or even ‘C’ might actually contain an excellent part of sufficient dimensions that meets all the criteria of ‘A’. (ii) They cannot be interpreted as a quality typology for the industry, since class definitions generally don’t correspond to quality needs for specific purposes (e.g. A-class will not necessarily meet all requirements for veneer production).

**PQ2: projections based on quality distribution over age-classes.** Additionally to the problems with classes, a major problem rises by projecting current quality distribution over age-classes into the future. Whereas effects of changing climate and site might operate on larger time scales, the 20-30 year projection horizon might be sufficient to see significant changes in geographic species distributions or stand structure due to current large-scale policy choices (e.g. forest conversion). Tree quality doesn’t simply (and maybe only marginally) depend on age, so the projection of age-classes cannot inform on future quality availability. A better approach would be to develop appropriate models of tree quality, incorporated into a decision support tool. This however leaves the need for NFI to provide input data on the current tree quality, as a basis for future projections.

**PQ3: model development.** A fundamental question is whether the NFI is the most appropriate instrument for this purpose. We are aware of a few tentatives in Europe (confirmed by our own analysis on the Flemish NFI dataset) to predict quality classes as measured in the NFI from stand structural or site information, but in all cases only weak relations were found with high risk of confounding. Not surprisingly, since there is no biological ground for any class definition. The alternative is to develop relations for individual quality indicators. But also here the NFI may not be appropriate, because of the limited assessment of site and structural data, and because of the unfeasibility of the direct measurement of many quality indicators at all sample trees. In our framework we propose rather the opposite way, i.e. developing models for quality indicators on an independent dataset, and using them to predict quality at NFI locations.
From this analysis we draw conclusions regarding tree quality assessment in the second NFI:

a) The concept of classes is appealing for its simplicity and its relation to the silvicultural approach to tree quality, but it fails to give the needed information for answering policy needs. It should be replaced by the individual (direct or indirect) assessment of relevant quality indicators for different industries, including indicators of internal wood quality.

b) Assessed quality indicators should be species specific and clearly defined.

c) The quality assessment should focus on the stem section with best quality. Since for high-quality stems up to 80% of the value can be found in the lower 6m above the stem base (e.g. Baar 2005), and most industries require a minimum dimension of 3m, we propose to focus on the best 3m-section between 0.5 and 6m height.

d) Since age-class related projections are abandoned, the quality inventory in very young stands is no longer necessary. Quality assessment can be limited to trees that reached a species-specific DBH threshold of potential high-quality timber.

e) The quality assessment can be limited to five main species groups: pine, poplar, oak, beech and birch. Together these species represent 85% of total standing stock in Flanders.

A framework for including tree quality assessment in NFI

To implement the conclusions from our evaluation, we developed a decision framework. The rationale is to select appropriate quality indicators, evaluate whether they can be assessed indirectly (development of relations), and if this is not feasible, verify whether they can be assessed accurately and in a cost-efficient way within the second NFI.

1. Select appropriate quality indicators

For each considered species a list of internal (wood) and external (stem) quality indicators should be composed, based on their relevance for the species and for different industries. EU grading rules for round timber can serve as a basis for indicator selection (EN 1316-1 for oak and beech, ENV 1927-2 for pine), and many literature sources provide complementary information (e.g. Hapla & Steinfatt). Attention should be paid to the precise definition of indicators and the compatibility with existing standards.

2. Decide on direct or indirect assessment of selected indicators

The direct assessment of all quality indicators within the NFI, which also include the coring of all sample trees necessary for internal wood quality assessment, would be far too time-consuming and costly. Therefore quality indicators should be assessed indirectly, where possible, through relations with site, stand and tree characteristics.

Many authors have documented the complex and often interacting relations between wood quality on the one hand and silviculture, stand structure, site quality and tree and wood morphology on the other hand (Bergès et al. 2008, Cutter at al. 2004, Knoke 2003, MacDonald & Hubert 2002). Also in Flanders such relations are under development for oak, beech, pine and poplar, with the aim of incorporating them into an individual tree growth model and a decision support tool for sustainable forest management (cf www.simfortree.be). The use of predictive models in the framework of the NFI requires that quality indicators can be predicted based on regional data (e.g. GIS thematic maps, climate), or data that are available or can be easily measured within the NFI sample plots. Partial results for oak in Flanders indicate that good predictive models are found for taper, form factor, branchiness, average rate of growth, growth regularity and latewood-earlywood ratio.
Remaining direct measurement to be considered in the second NFI include independent variables that are not readily available as GIS thematic maps or in the first NFI, as well as quality indicators for which no satisfying models are found. The final decision on their inclusion will depend on the importance that is accorded to the quality indicator under consideration and on the accuracy and cost-efficiency of the corresponding measurements.

3. Accuracy of direct measurements

Tentative model results for Flanders indicated four tree measurements as important independent variables, to be considered for inclusion in the second NFI: height, diameter and angle of the lowest living branch bigger than 2cm, and crown radius. The second NFI in Flanders will be carried out using the FieldMap equipment (integrated laser rangefinder, inclinometer, scope, electronic compass, field computer, GPS, electronic calliper) and software (www.fieldmap.cz).

We tested the FieldMap on its ability to accurately measure branch diameter (remote diameter measurement) branch height (via the diameter measurement or independently from a fixed position), branch angle (function ‘width’ and ‘3D-length’) and crown width (function ‘width’).

All variables were measured on young trees with many small branches between 0.5 and 6m height, by a trained field team. For efficiency reasons all measurements at one branch were done from the same position, only changing position between branches (except for the height measurement from one fixed position, which was done at the end for all branches together). This position was chosen as the best compromise to combine different measurements, with the equipment on a line through the stem base perpendicular to the branch, a distance from the stem of at least 2m and an inclination to the branch base not higher than 50°. For branch height and branch angle also a visual estimate was included besides the FieldMap measurement. Direct measurements of all variables were available after tree felling.

Results indicate that the FieldMap equipment has a tendency to underestimate branch diameter, and increasingly so with height. RMSE averages 4mm, but maximal deviations peak towards 11mm for high and small branches. The accuracy of the measurement is hampered by the difficulty of using high scope zoom factors (above 3x we could not replicate results with different operators). The measurement is time consuming.

Branch height estimates that come with the remote diameter measurement have low accuracy (RMSE 9cm), mainly because of the changing measurement position between branches. Both the height measurement from one fixed position (RMSE 4cm) and the visual estimate on a 6m pole next to the tree (RMSE 5cm) perform better. The visual measurement is superior at lower branch heights, but tends to underestimate height for branches above 2m. Both the fixed position measurement and the visual estimate perform very similar and have equal time needs.

Although easy and quick, branch angle measurements with the ‘width’ function are to be avoided (RMSE 11.4° and deviations up to 24°). The high inaccuracy is due to the sensibility of this measurement to the equipment position (assumes perfect perpendicular position to the branch) and the relative high measurement error on short width measurement. The ‘length’ function (RMSE 6.9°) and the visual estimate (RMSE 6.8°) perform equally well. Since the ‘length’ measurement requires the 6m pole, it is cumbersome or even impossible for too high branches. The visual method is surprisingly accuracy and has a low time need.

Crown widths, finally, are only measurable with the function ‘length’. We reached an average RMSE of 0.20m and a maximal deviation of 0.28m, which are acceptable.
Although FM is not in the first place designed for detailed branch or crown measurements, it is clearly possible to make such measurements. However, in doing so the equipment is clearly pushed to its limits. In the context of NFI measurement we recommend FieldMap to be used only for diameter measurement of high branches, for branch height measurements (from a fixed position) and for crown width measurements. Quicker methods obtain equal accuracy for branch diameter of low branches (calliper) and branch angle (visual estimate). However, FieldMap accuracies can probably be improved if equipment position is optimised for each individual measurement, making it very suitable for scientific applications. In this context we can mention the high accuracy obtained with the 'length'-function for branch azimuth measurements (RMSE 8.1°), which is very difficultly achieved with alternative methods.

4. Cost-efficiency of direct measurements
We estimated the cost-efficiency of the proposed quality assessment method for oak in Flanders through the estimation of time needs (as a proxy for labour costs). Based on the first NFI, we estimate a total of 2014 oak trees for quality assessment (DBH threshold of 25cm). Basic quality assessment on all trees, including description of damage, dead branches and sweep, is estimated at 4 minutes per tree. Medium quality assessment on 90% of the trees (assumed to meet certain basic quality criteria), including measurement of branchiness, spiral grain and some site characteristics, is estimated at 9 minutes per tree. Top quality assessment on 20% of the trees, including measurements of crown widths and some high-quality requirements, is estimated at 4 minutes per tree. This results in an average time need of 12.9 minutes per tree. Considering that oak is only one of the five main species for quality assessment, and that time needs for other species will be similar, the total time need for quality assessment in the second NFI would reach 77.4% of that in the first NFI (in which quality was assessed for 55972 trees, with an average of 3 minutes per tree). Further time economy can be reached by omitting certain measurements, increasing the DBH threshold, or measuring only a sample of trees that reach the DBH threshold. We conclude that the proposed method of quality assessment is feasible.

Literature cited


